New and improved demonstrations, each illustrating a single scientific paper

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http://hdl.handle.net/2144/4838

Boston University
NEW AND IMPROVED DEMONSTRATIONS,
EACH ILLUSTRATING A SINGLE SCIENTIFIC PRINCIPLE

A Group Project

In partial fulfillment of requirements for
the degree of Master of Education
1950
Service Paper Approved by

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ACKNOWLEDGEMENT

The group wishes to express its sincere appreciation to Dr. John Gammons Read for his interest and advice in preparing this paper.
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CHAPTER I

INTRODUCTION

Statement of the problem. The purpose of this study is to design new and improved demonstrations, each illustrating a scientific principle as presented in the research of Edgar W. Martin¹ and Harold E. Wise².

SELECTION OF THE PROBLEM

Source. The committee reporting on science education in America for the Forty-sixth Yearbook³ asserted, "There is great need for a development of an adequate series of demonstrations to be used in classes for building up very scientific understandings of particular science concepts, principles and applications". This suggestion was presented to a seminar in science teaching conducted by Dr. John G. Read at the Boston University School of Education

¹Edgar W. Martin. A Determination of the Principles of the Biological Sciences of Importance for General Education, Doctoral Dissertation, University of Michigan, 1944

²Harold E. Wise. A Determination of the Relative Importance of Principles of Physical Science for General Education, Doctoral Dissertation, University of Michigan, 1941

and was adopted as the objective of this study.

Justification. Concomitant with the development of principles as goals of science instruction has been the development of the lecture-demonstration method of presentation which, by research evidence, has proved to be best suited for the heterogeneous secondary school classes. Concerning the economy of the lecture-demonstration technique as compared to the two pupil laboratory method, Anibell\textsuperscript{1} reports a saving of up to 90%.

Knox\textsuperscript{2} asserts that, for purposes of providing knowledge for both immediate and permanent retention, and for purposes of providing technique or handling new problems, the demonstration method is much to be preferred to the laboratory method in the case of average superior pupils. On the other hand, W. W. Carpenter's\textsuperscript{3} research led him to conclude that dull pupils profit more by the demonstration method than from individual laboratory work.


\textsuperscript{3}W. W. Carpenter. "A Study of the Comparison of Different Methods of Laboratory Practice on the Basis of Results Obtained on Tests of Certain Classes in High School Chemistry", \textit{Journal of Chemical Education}, Vol. 3, July 1926, pp. 798-805
Cunningham\(^1\), in conducting an analysis of the research relating to the merits of the lecture-demonstration method as compared with the laboratory method of science instruction, offers the following suggestions concerning the demonstration method:

1. The demonstration method is recommended when the learning involved in connection with the exercises is complicated and difficult.

2. The demonstration method is superior to the laboratory method when ordinary written information tests are to be used in evaluating the results.

3. When the laboratory apparatus is sufficiently large to be visible at a distance, the demonstration method may be used to advantage.

4. If the apparatus is of such nature that the pupils may err in determining and interpreting the results, the demonstration method will be the superior method of presentation.

5. General ability in scientific thinking is so complicated that either method can probably be used to advantage in its development.

Efron\(^1\) corroborates these advantages of the demonstration method and asserts further that inexpensive and improvised apparatus is not only an economic necessity in the small high school, but that it is in harmony with the best points of view in science teaching.

Supplementary to these preceding advantages, Potthoff\(^2\) states that all of the arguments usually advanced in favor of visual aids may be employed for the use of demonstrations in science teaching. The use of realia, the concrete, when illustrating the unfamiliar, of itself provides an experiential basis for learning, whether the learning be remembering facts, understanding processes, or seeing how motor skills are executed.

**Scope.** The experiments and demonstrations contained in this study are for use in the junior and senior high school, and they are based on biological and physical principles. The principles used in the field of biology were the major principles compiled by Martin\(^3\) in a doctorate study. The following is Martin's criteria for a

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\(^3\) op. cit.
principle. For a statement to be a principle:

1. It must be a comprehensive generalization which resumes the widest possible range of facts within the domain of facts with which it is directly concerned. The facts resumed in the generalization must denote
   a. objects and/or events and the relations between them, and
   b. properties.

2. It must be scientifically true. To satisfy this criterion, it must be
   a. Verifiable; i.e., it must be stated so that it suggests, either directly or indirectly, a definite operation of observation or experiment whereby its true value can be tested or verified.
   b. Consistent with the body of accepted scientific knowledge and except for a few limiting or singular exceptions, with all the data relevant to it.

In the field of physical science, the principles used in the study were those determined by Wise\(^1\) in his study. In his study a principle is defined in terms of this cri-

\(^{1}\)op. cit.
teria:

1. To be a principle, a statement must be a comprehensive generalization describing some fundamental process, constant mode of behavior, or property relating to natural phenomena.

2. It must be true without exception within limitations specifically stated.

3. It must be capable of illustration.

4. It must not be a definition.

Criteria for demonstrations. This criteria was determined by the members of a seminar, composed of graduate students majoring in science education. The criteria was approved by Dr. Read, adviser on the thesis and director of the seminar. Following is the criteria for a demonstration:

1. It must demonstrate a principle.

2. It should work and be as infallible as possible.

3. Apparatus should be on a large scale.

4. It should be simple and speedy.

5. It should be of easily available and inexpensive materials.
RESEARCH PROCEDURE

Each of the principles, as stated by Martin\(^1\) and Wise\(^2\), was copied on 5 by 8 inch cards and classified according to topics. The individual principles were then thoroughly scanned by members of the group working on this project for familiarization purposes and for any possible clues that would suggest themselves for the setting up of demonstrations.

Books, magazines, personal suggestions, and any other suitable materials and writings were used as sources for ideas to construct the demonstrations of the principles. Each demonstration was prepared with the simplest possible and most readily available materials. When each demonstration was in its complete form, it was copied by a professional draftsman and subsequent photo-off-set reproductions are included to illustrate the apparatus.

To accompany each demonstration, there was included a description of the equipment, the materials used, and the manner in which they were used. Where it was necessary, suggestions were made as to the best sources for obtaining the materials required to construct the demonstrations. However, few, if any, of the demonstrations required the

\(^{1}\text{op. cit.}\)
\(^{2}\text{op. cit.}\)
use of materials that were not readily available.

Finally, listed applications of the principle in the environment were made.
CHAPTER II

GROWTH OF PRINCIPLES AS A GOAL OF SCIENCE EDUCATION

The principle as a goal of science teaching was first stressed by Downing\(^1\) in 1925. Downing asserted that scientific problem-solving progressed in three stages: (1) the accumulation of facts, (2) discovery of apparent relation and sequence of these facts reduced to principles, (3) the discovery of the approximate causes that are amenable to these laws, or generalizations.

The research in the field of science principles has centered around three universities under the aegis of the following men: Elliot R. Downing at the University of Chicago, S. Ralph Powers at Columbia University, and the University of Michigan's Francis Curtis.

In 1927, Craig\(^2\), in developing a course of study for the Horace Mann School, examined textbooks, courses of study, syllabi, and handbooks for objectives, content, and time allotment to determine a tentative list of objectives

\(^1\)Elliot R. Downing. Teaching Science In The Schools, University of Chicago Press, 1925, p. 33

\(^2\)Gerald S. Craig. Certain Techniques Used in Developing A Course of Study in Science for the Horace Mann Elementary School, Teachers College Contributions to Education, No. 276, Teachers College, Columbia University, New York, 1927
for an elementary science course. Among the forty-five objectives secured, some were stated as principles which conformed with his criteria; e.g., "certain objectives that are selected for elementary school science should conform to those facts, principles, generalizations and hypotheses of science which are essential to the interpretation of the natural phenomena which challenge children".

Downing directed a study by Heineman\(^1\) in which a principle was defined as a statement of relationship between two or more facts, usually causal in nature. In this study, twenty general science books published between 1915 and 1927 were examined, and a total of ninety-three principles were found. However, no author of a textbook gave first consideration to the study of principles and little unanimity was evidenced among the authors as to which science principles are of the greatest importance at the general science level in schools.

In 1931, Wilbur\(^2\) used the following criteria for the determination of principles in his study. A principle is a comprehensive generalization which:

\(^1\)Ailsie Heineman. "A Study of General Science Textbooks", General Science Monthly, XII, November 1928, pp. 11-23

\(^2\)Oliver B. Wilbur. A Study of the Principles of Science Contained in General Science Textbooks Published Since the Beginning of the Year 1924, Unpublished Masters Thesis, University of Michigan, 1931
1. Is stated positively and definitely.
2. Is true with but rare exceptions within the limitations set up by the statement.
3. Clearly states or implies a dynamic process or interaction.
4. Is demonstrable experimentally.
5. Is clearly not a part of a larger principle.
6. Is not merely a definition or a description.
7. Has wide application in the natural environment, and is not ruled out by any of the preceding criteria.

Fourteen ninth grade general science textbooks were analyzed and statements which satisfied the criteria were selected. These principles were submitted to specialists in biology, chemistry, geology and physics for validation in terms of criteria and revision of inaccuracies of statement. One hundred and seventy principles were submitted to ten teachers of general science who were asked to classify the principles as "necessary, desirable, or undesirable in a general science course". Five principles regarded as necessary by all the instructors were found in fewer than four of the fourteen textbooks examined.

The publication of the Thirty-First Yearbook of the
National Society for the Study of Education\textsuperscript{1} provided the first nationally recognized program for the development of the science curriculum around principles and generalizations of the natural sciences.

Powers\textsuperscript{2}, writing for the committee of the Yearbook, asserts:

"These principles and generalizations are functional in that they furnish a background for intelligent response to stimuli that occur in common unspecialized experience. The understanding of principles and generalizations comes from the association of ideas that are developed from experiences. These understandings are the products of the activities of the school if the ideas from which they come are products of classroom activities."

Curtis directed Robertson's\textsuperscript{3} study in 1934 to determine the important principles of science suitable to serve as goals of instruction in the elementary grades of the public school. This study yielded a list of one hundred and thirteen principles.

In 1935 Pruit\textsuperscript{4} made a study "to determine the con-


\textsuperscript{2} Ibid. p. 43


cepts and generalizations in the field of chemistry which are of most distinctive value to man in interpreting his environment. This study yielded one hundred and thirty-five principles.

Arnold conducted an investigation "to select major generalizations from the field of geology which may be of interest to liberally educated persons." The results of this study, along with the lists of principles secured by Pruit and Robertson, were used by Wise as the basis for a tentative list of principles of physical science which are most important for general education.

In this study Wise defined a principle as follows:

1. To be a principle, a statement must be a comprehensive generalization describing some fundamental process, constant mode of behavior, a property relating to natural phenomenon.

2. It must be true without exception within limitations specifically stated.

3. It must be capable of illustration.

4. It must not be a definition.


\[2\] op. cit.
This tentative list of principles was submitted to a jury of two for evaluation in terms of the criteria. A total of 272 principles was accepted as satisfying the standards. This list of principles was evaluated on the basis of its applicability to the interpretation of situations frequently encountered in everyday activities. In addition, eleven textbooks of physical science were analyzed for applications of these principles and a total of 3,403 were obtained. The final list of Wise's principles has been accepted as the physical science framework for this study, and demonstrations teaching these principles are presented in this paper.

A study was conducted by Martin in 1944 to determine the principles of the biological sciences of most importance for general education. The following criteria was used for the determination of biological principles.

For a statement to be a principle,

1. It must be a comprehensive generalization which resumes the widest possible range of facts within the domain of facts with which it is directly concerned. The facts resumed in the generalization must denote

   a. objects and/or events and the relations

\[\text{\textsuperscript{1}} \text{op. cit.}\]
between them, and
b. properties.

2. It must be scientifically true. To satisfy this criterion, it must be
a. Verifiable; i.e., it must be stated so that it suggests, whether directly or indirectly, a definite operation of observation or experiment whereby its true value can be tested or verified.

b. Consistent with the body of accepted scientific knowledge and except for a few limiting or singular exceptions, with all the data relevant to it.

Five research studies, six textbooks, and a survey series of the biological sciences were analyzed to determine an initial list of biological generalizations. These were submitted to three specialists in science teaching for evaluation in terms of two criteria: (1) Is the statement a generalization or the biological sciences? (2) Is it a principle?

Those statements which satisfied both criteria were organized into a list of "major principles", and those which satisfied only the first criterion were compiled as "minor principles". The final list of major principles contained three hundred items.
These "major principles" have been accepted as the source principles to be incorporated in the biological demonstrations contained in this study.

SUMMARY

Since Downing first promulgated the idea that the true teaching of science depended upon the understanding of science principles, many studies have been conducted in the effort to compile an adequate list of principles. The most complete lists of principles were presented by Martin (biological sciences) and Wise (physical sciences) in 1944 and 1941 respectively. There have been no attempts made to develop demonstrations devoted solely to the presenting of principles in a functional manner.
GRADUATIONS MADE WITH MARKING PENCIL

PLANT

OPEN TUBING

RUBBER STOPPER

NUTRIENT LIQUID

TEST TUBE
I. **PRINCIPLE:**

Water is essential to all living things because protoplasmic activity is dependent upon an adequate water supply.

II. **DESCRIPTION OF APPARATUS:**

Material needed: Large test tube, two-hole rubber stopper, glass tubing, plant, marking pencil, and water or nutrient solution.

Construction: The rubber stopper is slit on one side as far as the hole. The plant is then inserted, through this slit, into the hole of the stopper. A small piece of glass tubing is inserted into the other hole. The test tube can then be marked with the china pencil or by pasting a calibrated strip of paper on the tube. The test tube is then filled to three-quarters full with water or the nutrient solution, and the stopper fitted tightly. The roots of the plant should be well immersed in the liquid.

III. **PROCEDURE:**

Sequence of Steps: The demonstration is set up in an appropriate location and the amount of liquid absorbed by the roots can be measured at regular time intervals. By using the nutrient solution instead of water the plant may be kept in a vigorous condition for a longer period of time.

Suggested Teacher Presentation: This demonstration will be most effective if used at the time when the students are studying plant nutrition. The students should have an understanding of osmosis and of
the substances plants take out of the soil in water solution. This experiment can be given to students as a project toward extra credits.

IV. APPLICATIONS:

1. Use of trees as a flood control measure.

Project Devised By Norman H. Sasseuille

Boston University School of Education, 1950

Adviser, Dr. John G. Read
THERMOMETER

TWO-HOLE STOPPER

FLASK

MIXTURE, BROWN SUGAR, WATER, YEAST

GLASS TUBING

TEST TUBE

LIME WATER
I. **PRINCIPLE:**

Aerobic decomposition (fermentation) is accomplished at ordinary temperatures by the intervention of special enzymes. Dissimilation occurs in the absence of oxygen - its final products are carbon dioxide and alcohol, and free energy is released.

II. **DESCRIPTION OF APPARATUS:**

A. Materials needed:
   1. 250 ml flask (2)
   2. Glass tubing
   3. Two-hole stoppers (4)
   4. Thermometers (2)
   5. Brown sugar, yeast, water
   6. Test tubes (2)
   7. Fresh lime water

B. Construction:

   1. Apparatus set up as shown in diagram

III. **DEMONSTRATION PROCEDURE:**

A. Sequence of Steps:
   1. Experimental - 1/2 yeast cake dissolved in warm water is added to the brown sugar
   2. Control - warm water is added to the brown sugar
B. Necessary Explanations:
   1. Experimental - The production of carbon dioxide is detected by the lime water precipitating. The production of alcohol is detected by the odor.
   2. No results are recorded for the control.

C. Suggested Teacher Applications:
   1. May be used to demonstrate the production of grain alcohols, the production of sauerkraut, the production of bread.

Project Devised By Aldas Ridgley, Jr.

Boston University School of Education, 1950

Adviser, Dr. John G. Read
I. **PRINCIPLE:**

Every influence exercised by micro-organisms upon man and his environment, whether beneficial or detrimental, is the result of a chemical change in the substance from which they secure their nutrition or by a chemical product synthesized from them.

II. **DESCRIPTION OF APPARATUS:**

A. **Materials needed:**
   1. Test tube
   2. Cotton plug
   3. Incubator
   4. Universal indicator
   5. Sample of raw milk

III. **DEMONSTRATION:**

A. **Sequence of Steps:**
   1. Dilute 5 cc of skimmed raw milk with 5 cc of distilled water.

   2. Place in sterile test tube and add sufficient indicator to show a neutral ph.

   3. Incubate at 37 degrees C. and observe a change to an acid ph.

B. **Necessary Explanations:**
   1. The micro-organisms, present in all milk, feed on the milk and cause the production of an acid.
C. Suggested Teacher Applications:

1. The demonstration may be used in the study of milk, bacteria, or nutrition.

IV. APPLICATIONS:

A. Cider industry
B. Dairy industry
C. Leather industry
D. Drug industry

Project Devised By Aldas Ridgley, Jr.

Boston University School of Education, 1950

Adviser, Dr. John G. Read
**PRINCIPLE**

Enzymes, vitamins and hormones are chemical regulators (stimulators and suppressors) of the reactions that occur in living organisms.

**I. DESCRIPTION OF APPARATUS:**

1. Two or more culture dishes or other suitable vessels.
2. Blotter paper cut to fit the bottoms of above vessels.
3. One or two Petri dishes with covers.
4. Agar Agar, one gram in powder form.
5. Fifty cubic centimeters of water to prepare Agar medium.
6. Oat seeds.

**Additional equipment for Other Demonstrations:**

1. Two or more plant pots with soil, or hydroponics equipment for growing seedlings.
2. Vitamin B₁ (Thiamine Chloride), in tablet or crystalline form.
3. Indolebutyric acid or Merck and Company's "Hormodin."
4. Small amount of seeds as Marigold, Zinnia, Tomato, Radish, etc.

**Construction:** The oat seeds are germinated on the well moistened blotters which have been placed at the bottoms of the vessels. It is well to keep each of the containers covered until the seeds have germinated to retain the moisture.
The Agar medium is prepared by mixing the Agar powder and water and bringing the mixture to a boil slowly. This is then poured on the Petri dish to make a gelatinous film about one-eighth of an inch thick. About twenty-five cubic centimeters of the medium are sufficient for each standard 100 mm. Petri dish. The cover of each dish is replaced and the medium allowed to solidify.

II. PROCEDURE:

Sequence of Steps: The oat seeds are germinated in one of the vessels, and about two days later a second set of seeds are germinated in another vessel. When the growing coleoptiles are one inch or so in length, the tips are cut off and placed on the Agar gelatin. The growth substance, auxin, diffuses out onto the Agar gelatin when the Petri dish is covered and allowed to set until the following day. Then the second set of germinated seeds are similarly decapitated and small blocks of the Agar gelatin are placed preferably on one side of the cut surfaces of the growing coleoptiles. The auxin contained in the Agar gelatin diffuses out and causes elongation of the cells beneath. The growing sheath (coleoptile) should bend in the direction away from the area of cells that have been stimulated by the auxin.

Suggested Teacher Presentation: Plain Agar blocks containing no auxin can be placed on several decapitated oat seedlings and these used as controls. The demonstration described requires somewhat delicate manipulation, but it shows that there is present in the tip of a growing
oat sheath a growth substance that is responsible for some of the seedling's reactions.

III. APPLICATIONS:

The addition of vitamin $B_1$ to plants growing in soil or in soilless equipment (hydroponics) can be used as a demonstration of how this vitamin is able to stimulate the more rapid growth of plants. As controls, the same plants are grown under the same conditions as the treated ones, but no thiamin chloride is added. The normal amount of the necessary nutrients are still added to the growing plants as the addition of vitamin $B_1$ serves as stimulation to growth only.

Indolebutyric acid or Merck and Company's preparation, "Hormodin," can be used as a stimulator of root formation. The latter is sold by many seed stores in powder form. The seeds (oat, etc.) are treated with a pinch of the powder by sprinkling and then transferred onto a well moistened blotter contained in a glass vessel. This is then covered with a glass plate or any suitable material to prevent excess evaporation of water from the container. As a control, untreated seeds are placed on a well moistened blotter and covered and set aside to germinate along with the treated ones. It is more than likely that the treated seeds will germinate much faster than the untreated ones.

Project Devised By Nicholas J. Hnatyk
Boston University School of Education, 1950
Adviser, Dr. John G. Read
FLUIDS

I. PRINCIPLE

Water is essential to all living things because protoplasmic activity is dependent upon an adequate supply of water.

II. DESCRIPTION OF APPARATUS

Materials needed - Battery jar, two sponges, cardboard or wooden partitions, soil, germinated seed, plant, and cardboard box.

Construction - The battery jar is divided into three compartments by use of the cardboard or wood partitions. The center compartment is filled with soil. A plant is placed in this compartment and allowed a few days to adapt itself. A germinated seed is also placed in the center section. The seed is placed against the side of the jar so that it can be seen from the outside. The sponges are placed in the end sections. A small cardboard box, with a small window cut out of one side (2x2 in.), is placed over the center section so that it covers the plant.

III. PROCEDURE

Sequence of steps - After the equipment has been set up, the sponge at one end of the jar is moistened at periodic intervals. In a few days the roots of the germinated seed will grow out in the direction of the wet sponge. The sponge at the other end of
the jar is kept dry and used as a control. When results are notice-
able, the dry sponge can then be wet and the first sponge is allowed
to dry up, and it now acts as the control.

The cardboard box covering the plant is kept in the same
position until the plant shows a tendency to lean toward the opening.
Then the position of the box can be shifted so that the opening is on
another side. No watering of the plant or soil should be done during
the period of the experiment.

Suggested teacher presentation -

This experiment will be most effective if carried on at the time
when students are studying plant nutrition and behavior. The student
should have the knowledge that plants are nourished by the osmotic
process which takes place in the roots. This experiment can be used
as a project for extra credit.

IV. APPLICATIONS

1 - Positive tropism.

2 - Negative tropism.

Project Devised By Norman H. Sasseuille

Boston University School of Education, 1950

Adviser Dr. John G. Read
THERMOMETER

EGG TRAY

COTTON BATTING

COVERS OF BOTH BOXES

Paper towel acts as wick

Egg tray

Glass tubing supports egg tray

Beaker

Water

Thermostat

Plug

Insulation

Light

Inner box lined with tin foil

Power source
1. AIR CELL APPEARS IN CANDLING
2. MARK OUTLINE OF AIR CELL WITH PENCIL
3. CUT INSIDE OF LINE WITH FINE SAW.
4. TAP THE DISC WITH END OF SAW TO CRACK IT INTO SMALL PIECES
5. PRY UP THE SMALL PIECES OF THE DISC
6. CUT THE OUTER MEMBRANE WITH A PAIR OF FINE SCISSORS
7. COVER THE OPENING WITH SCOTCH-TAPE TO REDUCE DESICATION
8. END VIEW OF EGG SHOWING THE DEVELOPING EMBRYO.
GROWTH OF A SINGLE CELL INTO AN ORGANISM

I. PRINCIPLE:

The cell is the unit of structure and function in all organisms."

II. DESCRIPTION OF APPARATUS:

a. Material Needed

(1) List of General Materials

1. An incubator
2. A pencil
3. Inexpensive fine saw
4. Strong light source for candling the eggs
5. Six fertilized chicken's eggs (setting eggs)

The eggs are the single cells that will develop into organisms.

(2) List of Materials Needed to Make an Incubator

1. Two cardboard boxes, one about 9 x 9 x 9 inches and the other about 12 x 12 x 12 inches
2. One extension cord, 12 feet long
3. One bi-metal bar thermostat, adjustable
4. Three feet of electric cord to connect the thermostat
5. Two electric plugs
6. One light socket
7. One 3 watt light bulb and adapter (Christmas tree light, white)
b. Construction

(1) Construction of an Incubator

The quality of the incubator used in conducting this experiment is probably one of the most important factors in dictating the success of the experiment. Incubators may be either purchased or home made. Regardless of whether they are made in the classroom or purchased, the two most important things to consider are: (1) The temperature in the incubator must be constantly maintained between 99 and 103 degrees F. and (2) the air in the incubator must be relatively moist to assure the proper development of the egg. These two factors must be kept in mind when selecting or making an incubator.

The incubator described below is relatively simple and inexpensive to construct. It consists of two cardboard boxes, one placed inside the other. The inner box is separated from the outer box by a layer of insulating material that is about one inch thick. Cotton batting, glass fiber, or any other good insulating material may be used. (Excelsior is not satisfactory.) A 3-way electric light plug may be
placed in the insulation between the outer and inner box. The two outlets that are not used should be covered with scotch tape or in some way sealed to prevent the insulation from getting into the plug and causing a short circuit. Two glass rods may be placed about half way up in the inner box to support the bottom of a candy box that acts as an egg tray. The lower part of the inner box should be lined with tin foil. A beaker of water, a thermostat, and a 3 watt Christmas tree light are then placed in this lower part of the inner box, under the egg tray. A 3 watt Christmas tree light will burn, day and night, for about 28 days. Therefore, every time incubation is started with a new group of eggs, a new light bulb should be installed.

Easy access is gained to the eggs by simply lifting the four covers on each of the cardboard boxes. A thermometer can then be placed through a hole in the top so that the bulb can rest in the egg tray. It is a good plan to cover the top of the outer box with a layer of insulating material, even if it is only newspaper.

If the over-all dimensions of the outer box are 12 x 12 x 12 inches, the egg tray should be large enough to hold at least six eggs.

(2) Cutting a Window in an Egg

Cutting a window in an egg is a moderately delicate operation, but the technique can be easily mastered with a little practice and care. It is suggested that the teacher practice cutting one or two inexpensive
small size or pullet eggs before a more expensive fertilized egg is cut. After this practice a person should be able to cut the window in an egg with success at each attempt.

It is suggested that the teacher follow the steps listed below in cutting the egg.

1. Candle the egg to determine the position and size of the air cell.

The air cell shows up as a dark area at the rounded end of the egg.

2. Make a dotted line, with a pencil, on the shell of the egg that will outline the edges of the air cell.

3. Make short cuts with light strokes of a fine saw all around the egg, just inside the limits of the dotted line. Do not attempt to cut completely through the shell on the first trip around the egg. Continue around the egg several times, cutting a little deeper each time into the original saw marks until the membrane is approached. After the cutting has come this far, proceed with caution.

4. After the small "cap" of shell has been separated from the rest of the shell, tap it lightly with the end of the saw until it is cracked.

5. Carefully lift off the pieces of the shell that have been cracked. This will leave the membrane exposed.

6. Cut the membrane with a small pair of scissors. If the egg is fresh, the air cell may be small, so the scissors must be used carefully. After the membrane has been cut away, an inner
membrane will be left intact. This inner membrane is nearly transparent, and the growth of the embryo can be observed through it.

7. A piece of scotch tape may be placed over the opening to prevent moisture from escaping from the egg, or a piece of transparent plastic may be placed over the hole and held in place with glue.

The following facts should be kept in mind while doing this experiment:

1. The fertilized egg must be no more than seven days old when incubation is started.

2. Once incubation has started it should not be interrupted.

3. It is perfectly safe to remove the egg from the incubator for several minutes each day for the students to examine. This short interruption of incubation should not hurt the egg in any way.

4. The incubation period will be about twenty-one days in length. If there is any variance it will not be any more than twenty-four hours longer or shorter than the standard twenty-one days.

5. The incubator should be kept between 99 and 103 degrees F. during the entire twenty-one days of incubation.

6. The eggs should be turned over at least twice a day while they are incubating, with the exception of the last three days. They should not be turned during the nineteenth, twentieth, and twenty-first days of incubation.
7. An open dish of water should be kept in the incubator at all times. A paper towel, rolled up, and placed in the water will act as a wick and thereby cause faster evaporation of the water. This is done to keep the air, inside the incubator, moist.

8. The air cell in the egg is large enough to afford satisfactory cutting even at the time it is first laid. It will not grow much larger during the first week after it has been laid, although it will enlarge later.

9. Incubation will usually start in fertilized eggs even though ideal conditions do not exist, but it is unlikely that the egg will develop more than four or five days if the conditions of temperature and moisture are not satisfactory.

10. Care should be taken not to chill the fertilized eggs before they are placed in the incubator.

III. **SUGGESTED TEACHER PRESENTATION:**

   a. **Sequence of Steps:** After the incubator has been set up, six fertilized chicken's eggs should be secured. Cut a window in one of the eggs and then set all six of them in the incubator. The embryo will first be visible about four days after the eggs have started incubation. After eight days of incubation it is possible to hold the egg in front of a strong light and observe the action of the beating heart through the window in the egg.
Allow the class to examine the eggs once each day. This may be done by holding the eggs to a strong light source to candle them. It is possible to watch the development of the embryo through the window in the shell, but much more satisfactory results may be obtained by looking through the window while the egg is being held to the source of a strong light. Candling the egg with the window in it is far more effective than candling an egg that has a complete shell.

b. Necessary Explanation

It is doubtful that the first egg cut will actually live through the entire incubation period and hatch. However, if a new egg is cut about every four days the result will be the same as if the first egg had developed through the entire twenty-one days and hatched. It is also advisable to have several eggs undergoing incubation at the same time for other reasons as well. In the event that one of the eggs should be accidentally broken during the period of incubation the experiment could be carried to a satisfactory conclusion with the remaining eggs. Also, a very small percentage of supposedly fertilized eggs are not fertile. This is very rare, but should be considered.

It is also suggested that this experiment be conducted during mild weather, as the temperature in school rooms is sometimes as low as 35 degrees F. on weekends, and 80 degrees F. or above during some school days. Unless the insulation is perfect in the incubator,
such extremes would affect its temperature and cause the embryos to die, because of the low wattage light bulb.

This experiment has been designed to show that a single cell will divide into the many cells that constitute an organism.

Project Devised By Harold A. Miner

Boston University School of Education, 1950

Adviser, Dr. John G. Read
I. PRINCIPLE:

Digestion accomplishes two things-- it makes food soluble in water, thus enabling the nutrients to pass through membranes, and thereby reach and enter the cells; it reduces complex nutrients (fats, proteins, carbohydrates) to a simple building material which can be rebuilt into whatever living material or structural features are necessary at the place of use.

II. DESCRIPTION OF APPARATUS:

A. Materials needed:

1. Thistle tubes (3)
2. Goldbeaters skins (3)
3. Glass vessels (3)
4. Test tubes (2)
5. Ring stands & clamps (3)
6. Potato starch, pancreatin, baking soda, egg white, Fehling's solution, conc. caustic soda, and copper sulfate, iodine.

B. Construction:

1. Attach goldbeaters skins securely to thistle tubes using rubber bands and suspend in vessels of water as shown in diagram using ring stands and clamps.
III. DEMONSTRATION PROCEDURE:

A. Sequence of Steps:

1. Pour mixture of starch and water into first thistle tube and allow to stand.

2. Pour mixture of starch which has been heated and mixed with pancreatic juice (1 gm pancreatin, 2 gms baking soda, 200 cc water) pour into 2nd tube and allow to stand.

3. Pour cooked egg white into third thistle tube and add pancreatic juice.

4. Water in first vessel is tested for starch with the iodine and for sugar with Fehling's solution, results negative.

5. Water in second vessel is tested the same, results show presence of sugar.

6. Water in third vessel is tested for peptone by adding in a test tube, conc. caustic soda to which a few drops of copper sulfate have been added. Results, a reddish violet color designating the presence of peptone.

B. Necessary Explanations:

1. In first vessel no absorption takes place and no breakdown of complex carbohydrates takes place.

2. The carbohydrates in the second vessel are broken down and absorption takes place through the membrane.
3. In the third vessel complex proteins are broken down and absorption takes place through the membrane.

C. **Suggested Teacher Applications:**

1. May be used to demonstrate the process of digestion.

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Project Devised by Aldas Ridgley, Jr.

Boston University School of Education, 1950

Adviser, Dr. John G. Read
EXPERIMENTAL

SKIMMED MILK

RENEN

PLUG AND
INCUBATE AT 98°F

CONTROL

SKIMMED MILK

PLUG AND
INCUBATE AT 98°F

CURDS

WHEY

AFTER 2 HOURS
OF INCUBATION

AFTER 2 HOURS
OF INCUBATION
I. **PRINCIPLE**

Digestion in plants and animals is carried on by an enzyme or organic catalyst which takes part in and speeds up the chemical reactions but do not undergo any permanent changes themselves.

II. **DESCRIPTION OF APPARATUS**

A. **Materials:**
   1. Sterilized test tubes (2)
   2. Cotton plugs (sterilized, non-absorbent)
   3. Sample of skimmed milk

III. **DEMONSTRATION PROCEDURE**

A. **Sequence of Steps:**
   1. Experimental - about 5 cc of fresh skimmed milk, 5 cc of distilled water, and one rennet tablet are placed in a test tube, and plugged.
   2. Control - about 5 cc of fresh skimmed milk, 5 cc of distilled water are mixed, and plugged.
   3. Both test tubes are incubated at 98 degrees F.

B. **Necessary Explanations**
   1. Within 2 hours milk in experimental tube curdles.
   2. Within 2 hours no change noted in control tube.
C. Suggested Teacher Applications:

1. Demonstration may be used in teaching digestion.

Project Devised By Aldas Ridgley, Jr.

Boston University School of Education, 1950

Adviser, Dr. John G. Read
CONTROL

NUTRIENT WITH NITRATES

WICK

EXPERIMENTAL

NUTRIENT WITH NO NITRATES IN RAIN OR DISTILLED WATER
PRINCIPLE

An animal cannot live without proteins. They are necessary in cell growth and maintenance; so, are necessities in the diets of animals. Plants are able to use carbohydrates and nitrates to build up proteins necessary for growth and maintenance of their cells.

I. DESCRIPTION OF APPARATUS

Material Needed:
1. Four or more culture dishes or similar vessels.
2. Blotter paper.
3. Piece of mosquito netting, not more than one square yard.
4. One quarter to one half a pound of paraffin wax.
5. Four or more plant pots, clay, medium to small size.
6. Pieces of wood and few nails to make stands for plant pots.
7. Wick material, preferably of the glass fiber type, four inch lengths.
8. Coarse sand, gravel, or vermiculite, enough to fill plant pots.
9. Chemicals necessary to prepare nutrient solution, none of which need to be chemically pure. No more than a four ounce quantity of each is necessary even for long periods of use.

Food Solution

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superphosphate</td>
<td>2 teaspoons</td>
</tr>
<tr>
<td>Sodium Nitrate</td>
<td>&quot;</td>
</tr>
<tr>
<td>Magnesium Sulfate</td>
<td>2-1/2 teaspoons</td>
</tr>
</tbody>
</table>
**Stock Solution**

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potassium Chloride</td>
<td>1 teaspoon</td>
</tr>
<tr>
<td>Water</td>
<td>5 gallons</td>
</tr>
<tr>
<td>Boric Acid</td>
<td>1 teaspoon</td>
</tr>
<tr>
<td>Manganese Sulfate</td>
<td>1 &quot;</td>
</tr>
<tr>
<td>Zinc Sulfate</td>
<td>1 &quot;</td>
</tr>
<tr>
<td>Copper Sulfate</td>
<td>1/2 &quot;</td>
</tr>
<tr>
<td>Ferric Chloride</td>
<td>1/4 &quot;</td>
</tr>
<tr>
<td>Water</td>
<td>1/2 gallon</td>
</tr>
</tbody>
</table>

Ammonium sulfate may be added (1/2 teaspoon) to the food solution to increase the nitrogen content. Potassium nitrate may be substituted for the sodium nitrate, potassium sulfate for the potassium chloride, and ferric citrate or ferric sulfate for the ferric chloride.

10. Most of the common seeds, flower or vegetable, can be grown successfully in the hydroponics equipment.

**Alternate Equipment**

Instead of using the wick method of feeding the plants with the nutrient solution, the siphoning method or regular flooding and draining method may be used. Glass tubing, bent to suit the apparatus, plus a quart milk bottle or canning jar are necessary for each siphon set-up. In addition, at least a quart size catch basin is necessary to be placed under each plant pot to collect the excess nutrient solution as it flows down through the bottom hole in the pot. A small piece of glass or plastic should be placed over this hole to prevent the washing down of the sand or gravel in the plant pot.
II. PROCEDURE

Sequence of Steps: Seeds may first be germinated on a well moistened blotter contained in a covered vessel or culture dish. Then they are transferred to the germinating net which has been dipped in melted paraffin wax and the wax cleared from the meshes. The net is taped to a culture dish or other suitable vessel and the vessel filled with the nutrient solution up to the net. Seedlings may be grown in this manner for several weeks if the nutrient is drained and replaced with fresh solution weekly.

For permanent growth, the seedlings are transferred to the plant pot which is filled with well washed sand or gravel. Vermiculite may be used in place of these. A four inch wick, preferably of glass fibers, is inserted through the hole in the bottom of the pot so that it is about one inch up in the pot. A small wooden stand is built with a one inch hole through the top for insertion of the wick. The legs or supports of the stand are of sufficient height (2-1/2 inches for culture dish) to enable any suitable vessel to be inserted beneath it. The plant pot is set on the stand and the wick inserted through the hole. A culture dish or other vessel is filled with the nutrient solution and placed under the stand with the wick immersed in the solution. No other watering or feeding is necessary to supply the growing plants with nutrition. It is well to allow the plants to stand for at least a day before refilling the vessel with solution when it is used up.
The food solution is mixed in a quart or more of water until dissolved and sufficient water added to make five gallons of solution. The food solution may be kept in the original smaller quantity, if large containers are not available, and proportionate amounts of water added as the solution is ready to be used.

The boric acid, manganese sulfate, and zinc sulfate are dissolved first in a quart of water and then the copper sulfate is added. It is preferable, but not necessary, to dissolve the ferric chloride separately to prevent precipitation of the iron, and this may be kept as a second stock solution until ready for use. However, the total amount of water needed to make the stock solution is necessary for each five gallons of food solution, and this is to be added just before use.

If the alternate siphon method of supplying the plants with nutrient is used, a stand should be built of sufficient height to raise the solution above the level of the top of the plant pot. The outflowing end of the glass tubing should be drawn out over a flame to make the opening smaller and thus slow down the flow of the nutrient. This siphoning method enables a continuous flow of plant food from reservoir to the sand or gravel. The solution draining down into the catch basin under the plant pot may be reused if the flooding method is used.
Suggested teacher Presentation: The total elimination of the nitrogen containing compounds in preparing the nutrient solution is used to demonstrate the necessity of nitrates in the plant’s diet. Controls are set up with the use of the complete food formula and grown under similar conditions as the experimental plants that are fed solutions lacking nitrates and nitrogen. A notable symptom of nitrogen deficiency in the plant is the color of the leaves, which turn light-green and yellow. Also, there will be signs of growth retardation in the plant as compared to the properly fed control.

III. APPLICATIONS

The hydroponic method of growing plants is very readily adaptable to many other experiments and demonstrations. By the elimination of certain of the mineral compounds in preparing the nutrient solution, various physiological deficiencies and malfunctions can be demonstrated.

Phosphorus is necessary to the plants in the formation of protein substances, to increase root growth, and for proper cell division. Phosphorus deficiency causes a discoloration of the leaves, which become reddish and then yellow in color.

A small amount of iron is necessary to plants in the formation of chlorophyll. Its deficiency causes the leaves to turn white. In demonstrating effects of iron deficiency, the water used for the preparation of the nutrient should be tested for the presence of iron. This can be
done by adding about an eighth of a teaspoonfull of sodium ferrocyanide to a test tube full of the water. If a blue tinge shows up at once, or after standing a while, iron is present in the water. The demonstration will be more successful when iron free water is used to prepare the nutrient solution.

Although the demonstrations herein are limited to plant life, protein and other dietary requirements by animals may be just as readily demonstrated by varying the diets of white mice, hamsters, or other more readily available animals, if it is so desired.

Project Devised By Nicholas J. Hnatyk

Boston University School of Education, 1950

Adviser, Dr. John G. Read
NERVE CONDUCTION

I. PRINCIPLE:

For any given nerve cell there is a lowest strength of stimulus which will evoke a response. Stimuli of lower strength are said to be below the threshold.

II. APPARATUS:

The same apparatus is used in this demonstration as in the preceding one, except that only one low-powered flame producer is used. Paper matches are suggested.

III. PROCEDURE:

a. Sequence of steps: A "stimulus" is applied to the "nerve cell" in increasing strength by holding a paper match some distance below the guncotton and bringing it slowly closer. Some experimentation will be needed to find the distance where the heat of the flame will not ignite the guncotton. All stimuli below the ignition point are below the threshold of response of the "nerve."

b. Suggested teaching procedure: It is only necessary during the demonstration to explain that the strength of stimulus is being built up by moving the match closer to the guncotton. In fact, in some classes even this may not be necessary. Questioning after the demonstration should bring from the class the necessary ideas with no trouble.

Project Devised By William O. Bellows
Boston University School of Education, 1950
Adviser Dr. John G. Read
NERVE CONDUCTION

I. **PRINCIPLE**

In general, the extent of a response is rather definitely fixed for any given nerve cell. If a cell responds at all, it does so to its full capacity.

II. **APPARATUS:**

a. **Materials:** Cellulose nitrate, either in the form of gun cotton twisted into a rope, or nitrocellulose movie film cut into strips, is the basic material used to represent the nerve cell. (Note: cellulose acetate movie film, which is becoming more common, cannot be used.) Tongs or clamps and two or more types of flame-producing apparatus are the only other materials needed for this demonstration.

b. **Construction:** Guncotton is easily made by treating absorbent cotton with a mixture of nitric and sulphuric acids. One treatment is all that is needed. Guncotton is not dangerous when burning unless it is confined, but it is not advisable to store it. Make as much as is needed a day or two beforehand, so that it will have a chance to dry thoroughly.

III. **PROCEDURE:**

a. **Sequence of steps:** One rope of "nerve cell" is held in the tongs or clamp, and the "stimulus" applied to one end of it. This is repeated with a larger or smaller "stimulus" (the stimuli are...
represented by flames of varying sizes.)

b. Suggested teaching procedure: It is suggested that a few ideas about the shape of nerve cells be given the class before the demonstration, as well as some information about the reaction of a nerve cell to a stimulus, and the travel of an impulse along a nerve fiber. It should not be necessary to quote the principle involved before the principle is demonstrated. The best procedure would be to get a statement of the principle by questioning the class after the demonstration. It will be necessary to explain then that smaller stimuli evoke responses from a smaller number of nerve cells, since this question will almost certainly be raised. It would be best if the students raised this question, but in the event they do not, it must be raised by the teacher.

Project Devised By William O. Bellows

Boston University School of Education, 1950

Adviser Dr. John G. Read
I. PRINCIPLE:

Most cases of fermentation, souring, and putrefaction are brought about by living micro-organisms.

II. DESCRIPTION OF APPARATUS:

A. Materials needed:

1. 250 ml flask (2)
2. Cotton plug
3. Potato

III. DEMONSTRATION:

A. Sequence of Steps:

1. Place in experimental and control flasks sufficient sliced peeled potatoes to cover bottoms and sufficient water to cover potatoes.
2. The experimental flask is boiled almost dry and the sterile cotton plug is inserted before removing from heat.
3. The control flask is boiled almost dry and removed from the heat.
4. Both flasks are allowed to remain at room temperature.

B. Necessary Explanations:

1. The experimental flask shows no change when the control flask exhibits a good growth of saprophytic micro-organisms which feed on the potato and cause putrefaction.
C. Suggested Teacher Applications:

1. The demonstration may be used to show Pasteur's experiments with putrefaction or in a study of the canning and preserving of foodstuffs.

IV. APPLICATIONS:

1. The early methods of raised bread making
2. The ripening and corning of meats
3. The manufacture of vinegar
4. The tanning of hides
5. The pickling industry
6. The dairy industry
7. The tobacco industry
8. Sewage disposal system

Project Devised By Aldas Ridgley, Jr.

Boston University School of Education, 1950

Adviser, Dr. John G. Read
PRINCIPLES

In the presence of sunlight the chloroplasts of chlorophyll-bearing plants convert carbon dioxide and water into intermediate substances, and these into sugar, and that into starch, and liberate oxygen; thus, directly or indirectly, producing practically all the food in the world.

All living cells require oxygen to provide energy or to build new protoplasm.

I. DESCRIPTION OF APPARATUS:

Materials needed:

1. Two screw-top glass Mason jars, quart size or larger.
2. Four pieces of glass tubing, 1/4 inch outside diameter, 8 to 10 inch lengths.
3. Three or four short pieces of rubber tubing, with inside diameter 3/16 of an inch.
4. Three or four pinch-clips, or substitutes therefor.
5. Two pieces of Lucite or Plexiglass, 1/8 inch thick and 3 inches square.
6. Two four ounce, wide mouth bottles.
7. Two two-hole rubber stoppers, one inch or more in diameter at large end.
8. Two small glass containers, one ounce or so in size.
9. About two ounces of soda lime (calcium oxide and sodium hydroxide mixture).
10. One ounce of lime water.
11. Carbon dioxide generator, bottle with two-hole stopper and thistle tube or funnel inserted in one of the holes.
12. Chemicals for producing carbon dioxide as, marble chips plus hydrochloric acid, or sodium bicarbonate plus tartaric acid, or dry ice.
13. Oxygen generator, test tube with one-hole stopper, plus stand for support and a bunsen burner or alcohol lamp.
14. Chemicals for generating oxygen, as potassium chlorate plus manganese dioxide.
15. Growing seedlings of any type.

Construction:

The glass insertion in the screw cap of the Mason jar is removed and the Lucite or Plexiglass cut to fit the metal cap. A round hole is then cut in the plastic to take the rubber stopper snugly. The jar should be so fitted that it can be made air-tight. The glass tubing is bent at right angles as illustrated in the diagram. Connections between the glass tubes are made by use of the short pieces of rubber tubings. The pinch clips are used by applying them over these pieces of rubber tubing.
Mention need not be made of the construction of the carbon
dioxide and oxygen generators, as these may be constructed to meet
the demonstrator's preference.

II. PROCEDURE:

Sequence of Steps: Growing seedlings of approximately equal
size are placed into the two Mason jars, using either hydroponic
nutrient solution or a two inch layer of moist fertile soil on the bottom
of each jar to feed them. In one jar is placed a small container of soda
lime and the jar is tightly closed. The soda lime will absorb the carbon
dioxide that is contained in the jar. At least one piece of glass tubing
should be inserted into this jar, but the open end with the rubber
tubing should be tightly clamped to prevent entrance of carbon dioxide
from the air.

A small container of lime water is placed inside the second Mason
jar along side the growing seedlings and this jar is similarly capped
tightly. The glass tubing is inserted through the rubber stopper and
pinch clips attached at the rubber tubing connectors.

Suggested Teacher Presentation: Carbon dioxide is introduced
into the jar containing the lime water and the pinch clip applied
tightly after procedure is done. Similarly, oxygen may be added,
but this time to both of the jars. After several days, the process
may be repeated again. The jars should be placed in the sunlight and
the seedlings allowed to grow. In a week or two, it should become apparent that the plants growing under the abundance of carbon dioxide grow much faster than those in the jar with none.

To demonstrate the need for oxygen by the plants, place a small lighted candle in one of the jars containing growing seedlings and cap it tightly. The lighted candle should consume most of the oxygen contained in the jar and go out. Oxygen is added to the second jar and this is tightly capped. Both jars are then placed in the sunlight and the plants allowed to grow. Amounts of carbon dioxide should also be added to both jars at frequent intervals, but this should be done with care so as not to introduce any oxygen into the experiment jar. After several days it will become apparent that the plants getting an adequate supply of oxygen continue growth, while those in the second jar do not.

III. APPLICATIONS:

The apparatus used to demonstrate the above principles can also be utilized for the demonstration of the following principle:

Decomposition of the carbon compounds of organisms provides a replenishment of carbon in the atmosphere in the form of carbon dioxide. Thus, carbon is continually subjected to a series of cyclic changes from living to non-living substances.
PHOTOSYNTHESIS CAN NOT TAKE PLACE IF CARBON DIOXIDE IS ABSENT

I. PRINCIPLE

Chlorophyll-bearing plants are adapted for food making.

II. DESCRIPTION OF APPARATUS

Material Needed

1. 2 large cardboard boxes about 18 inches x 18 inches
2. 2 small geranium plants
3. 1 large battery jar
4. 1 small dinner plate, about 8 inches in diameter
5. 1 piece of stiff cardboard
6. 1 2-hole rubber stopper, #4
7. Glass tubing
8. Rubber tubing
9. 1 rotary type exhaust and pressure pump, motor driven
10. 3 8-ounce gas collecting bottles
11. 3 2-hole rubber stoppers, #7
12. Lime water
13. Paraffin wax
14. Beaker of hot water
15. Beaker of warm alcohol, denatured
16. Bunsen burner
17. Iodine test solution
18. Scotch tape
Construction: Take a rectangular piece of cardboard about four inches wide and 18 inches long. Connect the two ends, by means of scotch tape to form a cylinder. The cylinder should be just large enough to fit snugly over the open end of the large battery jar. Pull the cardboard cylinder down over the battery jar until about one-fourth of its length is around the glass. Then firmly attach the cardboard cylinder to the battery jar by means of scotch tape, as is shown in the diagram. Be certain that there are no air leaks between the cardboard cylinder and the battery jar. Cut a round hole through the cardboard cylinder with a sharp knife, just large enough to fit a #4 2-hole rubber stopper. Bend some glass tubing and put it into the stopper as indicated in the diagram, then attach the stopper and tubing to the battery jar. The end of the glass tubing that acts as the air intake should be about one-half inch from the bottom of the battery jar. The end of the glass tubing that acts as the exhaust should be near the stopper.

Cut some more glass tubing to fit the stoppers on the gas collecting bottles. The end of the piece of glass tubing that acts as an intake should be as close to the bottom of the bottle as possible without interfering with the passage of air through the tubing. Connect the glass tubing in the bottle stoppers and the glass tubing in the stopper in the battery jar to both the exhaust and pressure jets of the vacuum pump by means of rubber tubing. A motor driven rotary
exhaust pump is satisfactory. The three gas collecting bottles should be half-ful of clear lime water. To be sure that the system is air-tight, pour melted paraffin wax over the four stoppers. The system is now ready for use.

After the potted plant has been put on the eight-inch plate the battery jar and its attached cardboard collar should be placed over it. Then pour some melted paraffin wax around the edge of the plate to completely seal the jar from the air. The system should be completely air-tight and should resemble the complete diagram.

The following method of making an iodine test solution for this experiment has been found to be quite satisfactory. Dissolve .5 grams of iodine crystals and 1.5 grams of potassium iodide crystals in 25 cc of water. This solution should be diluted at the ratio of 1 cc of solution to 50 cc of distilled water just before it is to be used. Use fresh distilled water, fresh alcohol, and fresh test solution with each batch of leaves that is tested.

III. PROCEDURE

a. Sequence Of Steps: Select two small geranium plants and place them side-by-side on a table. Then place a large cardboard box over each plant so that is completely shielded from all light. Leave the cardboard box over the plants for at least twenty-four hours.
After the plants have been away from the light for twenty-four hours take a leaf from each plant to test for starch and then start the experiment at once. Place one plant under the battery jar as previously described and set the apparatus on a windowsill in the bright sunlight. Set the control plant beside the plant under the battery jar. After it is certain that the system is air-tight start the vacuum pump and let it run for about five minutes. This will start the air circulating through the system. After the pump has been running for five minutes shut it off for two minutes. Then alternate two minute periods of running with two minutes of rest for about four and one half hours. It is not necessary to run the pump for the entire four and one half hours. Both plants should be in bright sunlight during this part of the experiment.

After four and a half hours remove the plant from under the battery jar and take three leaves from each plant. There are now a total of eight leaves to be tested. One from each plant after it had been in the sun for four and one half hours. Mark the leaves so that they can be identified after they have been through the various solutions. Cutting the stems at various lengths is a good method of marking them.

To carry out the test for starch follow the procedure as outlined below: Place the leaves in a beaker of water that is just under boiling temperature. Leave them in the water for
sixty seconds. This will kill the cells. Then place them in hot
denatured alcohol for seven minutes. This will remove the
chlorophyll from the cells and makes the leaf nearly white in
color. The alcohol is highly inflammable and it should be heated
by placing it in hot water; not with a direct flame from a bunsen
burner. After removing the leaves from the alcohol they should
be placed in the diluted iodine test solution for ninety seconds. The
leaves should be removed from the alcohol carefully because they
are quite brittle at that point. The leaves should be placed in
distilled water after they are taken from the test solution to remove
the excess iodine that is on their surfaces. Then spread the leaves
out on paper towels and examine them. The leaves from the control
plant should show areas of dark blue or purple that indicate where
starch has formed. The leaves from the plant that was under the
battery jar may show some starch, but it will be only in very small
amounts. The leaves that were taken from both plants before the
experiment started will not show any starch at all. This proves
conclusively that a plant deprived of carbon dioxide will not
produce starch even if it is in the bright sunlight and has plenty
of water available.

b. Necessary Explanation

It is very important that the entire system should be air-
tight. This will make it possible to pass the same air through the
lime water many times and the removal of carbon dioxide from the air will be far more complete than it otherwise would be.

It is better to use at least three leaves from each plant to test for starch than it is to use only a single leaf. The starch content will vary from leaf to leaf within the same plant, therefore the results can be conclusive only if there are several leaves to judge. The comparison of the starch produced in the two plants should be made by showing all three leaves of one plant beside all three leaves of the other plant.

Another substance that would not require the circulation of air through the system may be substituted for lime water to remove carbon dioxide from the battery jar, but is doubtful that it would be as effective a demonstration from the standpoint of the understanding that is imparted to the student. Soda lime could be used in a sealed jar but there is no visible evidence that it is taking up the carbon dioxide that is in the air, within the sealed container. As the lime water becomes milky the students can see that a change is taking place in the lime water. The circulation of air through the system should remove a larger percentage of carbon dioxide than would be removed by soda-lime in stagnant air.

Project Devised By Harold A. Miner
Boston University School of Education, 1950

Adviser Dr. John G. Read
I. **PRINCIPLE:**

Meiosis or chromosome reduction from the diploid to the haploid number occurs at some stage in all organisms in which sexual processes take place; and when followed by the return to the diploid number of chromosomes at fertilization it keeps the number of chromosomes constant for the species.

II. **DESCRIPTION OF APPARATUS:**

Materials needed: Sandwich case (plastic, 5 & 10 stores), cement, agar-agar or gel, insulated wire, bare copper wire, bare silver-colored wire, and cork.

Construction: The above equipment may be used to make models of the different stages of meiosis and mitosis division. The bare copper wires are attached to two small balls of cork in the form of a spindle. The insulated pieces of wire are then attached to the copper wires perpendicularly. The insulated wire represents the chromosomes. The balls of cork, representing the centrioles, are also used to support the bare silver wires, representing asters. A 2 per cent agar-agar solution or some sort of gel may be used to represent the protoplasm. While the above structure is held in place in the plastic case, the agar or gel is poured into the case. The cover of the case is then put on and sealed with cement.
III. **PROCEDURE:**

Sequence of Steps: Suggested Teacher presentation - These models will be useful during the study of the meiosis and mitosis cell divisions. The student should have the basic knowledge of cell structure and function. These models make very good student projects.

IV. **APPLICATIONS:**

1. Cell division in all plants and animals.

Project Devised By Norman H. Sasseuille

Boston University School of Education, 1950

Adviser, Dr. John G. Read
SELF SEALING STOPPER

RUBBER TUBE

CO

OXYGEN

HYPO NEEDLE

TEST TUBE

VENOUS BLOOD

CAIUM HYDROXIDE
I. PRINCIPLE: The transfer of Oxygen and Carbon Dioxide during respiration takes place because of forces in the blood and in the air.

II. DESCRIPTION OF APPARATUS:
   a. Material needed:
      1. Self-sealing bottle
      2. Hypodermic needle
      3. Rubber tube
      4. Test tube
      5. Ca (OH)2
      6. Venous blood
   b. Construction:
      None.

III. PROCEDURE:
   a. Sequence of Steps: Some venous blood is obtained under oil and placed in the self-sealing bottle. Ca(OH)2 is placed in a test tube and the rubber tube is placed in it. The needle is attached to the open end of the rubber tube, and when ready is plunged into the self-sealing bottle causing a change in color of the blood and Ca(OH)2.
B. Suggested teacher presentation:

This experiment is suggested as an aid in describing respiration in higher forms of animal life. It is probably best suited as a precursor of this study.

IV. APPLICATIONS:

All blood bearing animals.

Project Devised by Anthony Vegelante
Boston University School of Education, 1950

Adviser Dr. John G. Read
THE GILL SYSTEM OF FISHES

I. DESCRIPTION OF APPARATUS

A. Material needed and analogies:
   1. T-tube - represents water canals.
   2. Y-tube - represents blood vessel.
   3. Syringe - represents heart.
   4. Venous blood.
   5. Rubber connectors.
   7. Funnel

B. Construction:

   The T-tube is attached to the funnel which is placed under a faucet. The membrane is attached to the bottom end of the Y-tube, which is then attached to the T-tube by a rubber connector. A self-sealing membrane is attached to the upper open end of the Y-tube and the lower end is closed off with a stopper. The venous blood is collected under oil in the syringe.

II. PROCEDURE:

A. Sequence of steps: The water is turned on and the water is allowed to pass through the side of the funnel into the T-tube. The syringe containing the venous blood is inserted into the self-sealing
GERMINATED PEAS SEEDS
BLOTTER PAPER
CONTAINER WITH NUTRIENT
EXPERIMENTAL

DRY SEEDS
NO SOLUTION
CONTROL
PRINCIPLES

The energy which makes possible the activity of most living things comes at first from the sun and is secured by the organism through the oxidation of foods within its body.

As long as life continues in any organism, energy is being released.

I. DESCRIPTION OF APPARATUS:

Materials needed:

1. Two funnels, one half pint size.

2. Two four ounce, wide mouth bottles, or two small size tumblers or similar containers.

3. Two thermometers, preferably of the glass rod type.

4. Two bell jars, or similar equipment for use as overall covers for the apparatus.

5. Approximately three ounces of pea seeds.

6. Several strips of blotter paper, six or more inches long and cut into 1/4 inch strips.

7. Any suitable container and blotter paper to start the germination of the seeds.

Construction:

Each funnel is placed in the mouth of the bottle or tumbler, which acts as the container for the water or nutrient and as a support for the
funnel. A blotter, six or more inches in length, is cut into 1/4 inch strips and these are inserted in one of the funnels until they come out an inch or so out of the bottom. No blotter strips are necessary for the second, or control, funnel.

II. PROCEDURE:

Sequence of Steps: One half, or less, of the seeds are first germinated on a well moistened blotter in a flat bottomed vessel. As soon as the seeds have germinated, they are transferred into the funnel containing the blotter strips, and water is poured through the seeds and funnel into the supporting vessel. Enough water should be poured so that the ends of the strips of blotter paper are immersed in it. One of the thermometers is then inserted well in the middle of the germinated peas, and the entire apparatus covered with a bell jar or other transparent apparatus to prevent any effects of drafts of air on the thermometer readings.

Similarly, the ungerminated peas are placed in the second funnel, thermometer inserted, and the apparatus covered. No water need be added to this control set-up.

It might be mentioned that the two thermometers should be checked for similarity in readings before use, by placing them together in a container of water for several hours. Any difference in the readings of the two should be noted and this error applied when used for the demonstration.
Suggested Teacher Presentation:

Some of the energy which is released in the respiration of the seedlings takes the form of heat, and this can be measured by the higher temperature readings on the thermometer inserted in the germinated seedlings against the readings of the control set-up.

Project Devised By Nicholas J. Hnatyk

Boston University School of Education, 1950

Adviser, Dr. John G. Read
THE PARTS OF A TYPICAL CELL

I. PRINCIPLE:

Every cell consists essentially of a mass of protoplasm which is usually differentiated into a central portion, the nucleus, and an outer portion, the cytoplasm.

II. DESCRIPTION OF APPARATUS

a. Material Needed

1. Bunsen burner or hot cone electric heater
2. 250 cc beaker
3. Running water or an extra 250 cc beaker of cold water
4. Tripod
5. Asbestos screen
6. Table knife
7. Teaspoon
8. 6 pieces of filter paper or sections of paper towels
9. A chicken's egg. The egg is used because it is a single cell and is large enough to be seen without a microscope.
10. 5 signs about 7'' x 9'', reading:
    - nucleus
    - nuclear membrane
    - cell membrane
    - cell wall
    - cytoplasm
III. PROCEDURE:

   a. Sequence Of Steps:

The pre-test should be given before any part of the demonstration starts. After that has been accomplished select a comparatively fresh chicken's egg and boil it before the class for about 5 minutes. Boiling the water in a 250 cc beaker over a bunsen burner flame is satisfactory. A hot cone type electric heating unit may be used to heat the water if a gas source is not available in the class room.

After hardboiling the egg remove it from the beaker of boiling water and cool it under a stream of cold tap water or place it in a beaker of cold water. If this step is not followed it will be very difficult to handle the egg comfortably during the early part of the experiment.

Take the egg and make a cross sectional cut through the shell, albumen, and yolk. Leave one half of the egg intact and take portions of the other half of the egg to place on the filter papers, or sections of paper toweling, beneath the proper label. The portions to be separated are the shell or cell wall, the cell membrane which is just under the shell, the albumen or cytoplasm, the membrane separating the albumen and yolk, and the yolk or nucleus. The labels cell wall, cell membrane, cytoplasm, nuclear membrane, and nucleus should appear on individual cards large enough to be seen from the
back of the room.

At the completion of this part of the demonstration allow the students to come to the table at the front of the room to examine the half of an egg that is still intact and the five separate parts under their proper labels. After all of the students have had a chance to come to the table take down the labels and give the post-test.

The diagram shows the recommended arrangement of the demonstration table for this experiment.

The entire demonstration, including the pre-test, the boiling of the egg, the dissection of the egg, and the post-test can be given in about 40 minutes, or one class period.

Project Devised By Harold A. Miner

Boston University School of Education, 1950

Adviser Dr. John G. Read
CONSTRUCTION OF INCUBATOR

I. DESCRIPTION OF APPARATUS

A. Materials needed:

1. 12 pieces of scrap lumber approx. 1/4"x1/4"x12"
2. 5 pieces of scrap wall board approx. 12"x12"
3. 5 pieces of aluminum foil
4. 4 pieces used cork insulation approx. 14"x14"x2"
5. 1 piece of board from crate approx. 14"x14"x1/8"
6. 2 pieces of glass 7 1/4x9 1/4 and 10x11
7. 1 Electric light socket
8. 4 feet of rubber covered wire
9. 1 used hot air thermostat, or if not obtainable from a plumbing or heating shop, an ether vapor brooder switch
10. 1 pan approx 11x11x1/4" or a 250 ml glass vessel with glass wool wick.
11. Wire nails and linoleum cement
12. Plaster of Paris

II. PROCEDURE

A. Construction:

1. Cubic frame is constructed of the 1/4x1/4 inch stock, and wall board applied to sides, back, top and bottom.
2. Aluminum foil is placed over the wall board and cork is cemented in place leaving the front and bottom open.

3. The 14x14x1/8 inch board is cemented to the bottom and scrap cork is used to frame the front.

4. Outer glass and inner glass is framed and cemented in place.

5. Socket is situated in lower back portion of incubator and thermostat situated in upper front portion of incubator.

6. Inner surface is protected with a light coat of plaster of Paris and may be painted.

7. Hinges on door are optional.

Project Devised By Aldas Ridgley, Jr.

Boston University School of Education, 1950

Adviser, Dr. John G. Read
RUBBER TUBING
BEAD
FUNNEL CONTAINING NaOH + INK
BEAD
RUBBER TUBE
BEAD
T-TUBE
RUBBER CONNECTOR

FUNNEL CONTAINING PHENOLPHTHALEIN
THE ENDOCRINE SYSTEM

I. DESCRIPTION OF APPARATUS:

A. Materials needed and analogies:

1. Two funnels - representing endocrine gland and activating organs.
2. Two T-tubes - representing blood vessel and openings of gland and organ.
4. Two beads
5. Phenolthalin
6. Rubber connectors

B. Construction:

The long tubes of the T-tubes are attached by a rubber connector. One of the T-tubes is attached by a rubber connector to a faucet. The funnels are attached to the short tubes of the T-tube by rubber connectors containing the beads. The NaOH, colored with ink, is placed in the funnel nearest the faucet and the phenolthalin is placed in the other funnel.

II. PROCEDURE:

A. Sequence of Steps: The water is turned on and is allowed to flow slowly through the T-tubes. The colored NaOH is released and allowed to flow with the water until it meets the released phenol
and a distinct color reaction takes place.

B. Suggested teacher presentation:

This experiment may be shown after a brief explanation before embarking on a study of endocrine glands.

III. APPLICATIONS:

Higher forms of animal life.

Project Devised By Anthony Vegelante

Boston University School of Education, 1950

Adviser Dr. John G. Read
I. **PRINCIPLE:**

The erosion of soil by water from plowed slopes can be minimized by contour plowing or terracing.

II. **APPARATUS:**

a. **Materials:** A model made of cardboard boxes containing two troughs, upper and lower, and earth, as shown in the diagram. A small amount of water is the only other material necessary for this demonstration.

b. **Construction:** A large cardboard carton is cut so that is has a slanting top as shown. A shallow cardboard box which fits this slanting top closely is used to hold the earth, which may be kept from sliding down by gluing cardboard cleats to the bottom of the box. The depth of this box should be about one inch. The upper and lower troughs may be made from a cardboard mailing tube, and these may be made waterproof by impregnating with melted paraffin. Fine earth is packed into the top, on both sides of the cardboard partition, and furrowed with a small hand cultivator or other instrument. The small cardboard combs that are dispensed by machine in some boys' gymnasiums are ideal for this purpose. The depth of the furrows should be about 3/16 inch.
III. **PROCEDURE:**

   a. **Sequence of steps:** Water is slowly poured into the upper trough so that it floods over the lower edge of the trough and runs down over the sloping earth. Then the earth that has been carried down to the lower trough on each side can be exhibited to the class after lifting out the lower trough and draining off the water.

   b. **Suggested teaching procedure:** It is best to prepare the class for the demonstration by emphasizing the importance of good topsoil to our food supply, and by bringing out some facts about the misuse of soil by farmers in this country. It is necessary to explain that the old farming practice consisted of plowing furrows up and down hills. Then the demonstration can be shown with the suggestion perhaps other types of plowing that have been developed will prove more economical of soil. This is all the explanation that is needed. The observations of the class regarding the amount of soil conserved can be clarified by questioning.

IV. **APPLICATIONS:**

   This demonstration applies to the conservation of natural resources, a subject which is receiving more emphasis in classrooms today than in the past. Pupils can easily visualize large-scale contour plowing from the demonstration.

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**Project Devised By William O. Bellows**  
*Boston University School of Education, 1950  
Adviser Dr. John G. Read*
BEFORE

PISTON

BLACK AND WHITE CARAMELS
(ROOM TEMPERATURE)

AFTER
I. PRINCIPLE:

Rocks may be formed by the compacting and cementing of sediments.

II. DESCRIPTION OF APPARATUS:

A. Materials - Several black and white caramels or pieces of modeling clay, a piston or vise or any suitable means to develop pressure.

III. PROCEDURE: Place several caramels beneath the piston. New exert pressure until the caramel starts to extend beyond the edges of the piston. Finally remove the piston and examine the single piece of caramel produced.

Questions: What change took place in regard to the number of caramels? What happened to the shape of the mound of caramels? The resulting mass of caramel is held together by what? What caused this?

IV. APPLICATIONS: Sandstone, certain types of limestone and glacial ice.

Project Devised by Carl Orcutt

Boston University School of Education, 1950

Adviser, Dr. John G. Read
SUPPORT
ELECTRIC CLOCK
COFFEE CAN
SPRINGS
CAN OF CEMENT
CURTAIN ROD
RUBBER CUSHION
HOME MADE SEISMOGRAPH

I. PRINCIPLE:
   Earthquakes are caused by the sudden slippings of earth materials along faults.

II. DESCRIPTION OF APPARATUS:

1. Materials Needed:
   - Wooden framework
   - 4 sponge rubber bath sponges
   - 3 Screen door type coil springs
   - 3 Screw eyes
   - Heavy cement weight
   - Hollow brass curtain rod
   - Knife edged fulcrum
   - Old electric clock
   - One pound metal coffee can
   - One eight inch brass rod ten inches long
   - Light sheet metal support
   - Recording type pen point

Construction:

A light wooden framework as shown in the diagram is built out of soft pine boards to support the weight. Three screw eyes are screwed into the under side of the framework in order to support the springs. The eyes are equilaterally placed.
The weight is suspended from the framework and rubber cushions are placed under each leg of the framework.

A small machine screw is soldered to the metal side of the can so that it is radial to the can. This is known as the pivot screw. A small hole is drilled into one end of the curtain rod so that it will fit over the pivot screw. The knife-edge was built up from an old shelf bracket. This is located about three (3) inches from the pivot.

At the other end of the curtain rod the recording pen is fastened. The pen was acquired from a recording-type barometer using hydroscopic ink.

A regular kinemograph could be used for recording the vibrations, but in this case a substitute was built from an electric clock and a piece of 1/8 inch brass rod was soldered to that part of the mechanism that turns the minute hand. At the other end of the rod an empty 1-lb. coffee can was soldered as shown in the diagram. A light piece of aluminum was used as a support. A piece of paper is fastened to the drum which will make one revolution in an hour.

**Theory of operation:** The most important part of this apparatus is the heavy suspended weight. Since it is supported by springs, cushioned on rubber sponges, and has a high mass, it is unaffected by small vibrations occurring in the vicinity. The pivot point, therefore, is now "a point of reference" that is unaffected by the local vibrations.
The knife edge is resting on a surface that is not protected against vibrations and transmits them to the curtain rod. We now have a curtain rod fixed at one end, and a fulcrum that is sensitive to vibrations. The result is a mechanical amplifier. The amplification depends upon the ratio of the distance between the end of the rod and the pivot and the fulcrum and pivot. The longer the rod, the greater the amplification. One model has been built that uses a compounded lever system. That is, two mechanical amplifiers in series.

The seismograph is designed to be used in buildings where most of the vibrations are in the vertical plane and it is less sensitive to longitudinal vibrations.

**Suggested Teacher Presentation:**

If the seismograph is set up in a building, recordings can be made of trucks and cars driving by, vibrations caused by people walking about, elevators in the building, and of course, actual earthquakes.

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Project Devised By Harold S. Sossen

Boston University School of Education, 1950

Adviser, Dr. John G. Read
I. **PRINCIPLE:**

Most bodies expand on heating and contract on cooling; the amount of change depending on the change in temperature.

II. **DESCRIPTION OF APPARATUS:**

A. **Materials Needed:**

Test tube, one hole rubber stopper, glass tubing, water, small rubber balloon, bunsen burner, clamp, ring stand, dry ice and acetone, or cracked ice and salt water and a small beaker.

III. **PROCEDURE:** Note position of rubber balloon before and after heating.

Part I. Remove the balloon and note its contents.

Questions: What happened to the balloon as the water was heated? What was in the balloon finally? Where did this come from? Why?

Part II. To freeze the water, slowly, add acetone to a layer of small pieces of dry ice in a beaker. Caution must be taken as vigorous bubbling occurs. When the mixture is quiet the test tube of water can be immersed for a short time until ice forms (too long an exposure may break the tube.)

Questions: What happened to the water? Why? Is the volume of water larger or smaller now? What generally happens to the size of bodies when they are heated? What happens to bodies when they are cooled?

IV. **APPLICATIONS:**

Steam engines, hot springs, frozen foods.

When demonstration has been talked over, other items such as eggs, elastics, flowers, frankfurts, mercury, and marshmallows may
size of bodies when they are heated? What happens to bodies when
they are cooled?

IV. APPLICATIONS:

Steam engines, hot springs, frozen foods.

When demonstration has been talked over, other items such as
eggs, elastics, flowers, frankfurts, mercury, and marshmallows may
be frozen and shattered and thus more fully utilize the value of the
freezing mixture. More solids such as cadmium and lead could be
melted and offered as a further enlargement of Part I.

Project Devised By Carl Orcutt

Boston University School of Education, 1950
Adviser, Dr. John G. Read
I. **PRINCIPLE:**

Every pure solid has its own specific melting point.

II. **DESCRIPTION OF APPARATUS:**

A. A cylindrical block of iron with a hole in the center, wide enough to take a bimetallic bar, whose bottom is about 1/2 inch from the bottom of the block; and with an 1/8 inch hole through the center, going to the bottom of the block.

B. A bimetallic bar is inserted in the hole of the block.

III. **PROCEDURE:**

The block of iron with the bimetallic bar is placed on a ring-stand with a Bunsen burner underneath it.

A small amount of:

<table>
<thead>
<tr>
<th>Substance</th>
<th>Melting Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>naphthalene</td>
<td>80° C</td>
</tr>
<tr>
<td>sulfur</td>
<td>113° C</td>
</tr>
<tr>
<td>hydroquinine</td>
<td>170° C</td>
</tr>
<tr>
<td>tin granules</td>
<td>232° C</td>
</tr>
<tr>
<td>sodium hydroxide</td>
<td>318° C</td>
</tr>
<tr>
<td>lead granules</td>
<td>327° C</td>
</tr>
<tr>
<td>zinc granules</td>
<td>419° C</td>
</tr>
</tbody>
</table>

are placed on the iron block and the burner is lighted. The bimetallic bar bends as the temperature increases and solids melt one by one.

*Project Devised by Stephen A Gatzimos
Boston University School of Education, 1950
Adviser: Dr. John G. Read*
FILLING OF SAND OR IRON FILINGS
COMPOUND BAR
PORCELAIN CRUCIBLES
ASBESTOS SCREEN
COFFEE CAN
I. **PRINCIPLE:**

Every pure liquid has its own specific boiling point.

II. **DESCRIPTION OF APPARATUS:**

A. Coffee can filled level full with iron filings or sand.

B. Six small porcelain crucibles are sunk in the iron filings in regular order.

C. A bimetallic bar is inserted upright in the center.

III. **PROCEDURE:**

The apparatus is placed on a ring-stand with a Bunsen burner underneath it. The liquids:

- methyl iodide Boiling point 42° C.
- carbon tetrachloride " " 77° C.
- water " " 100° C.
- glycol " " 197° C.
- glycerine " " 290° C.
- mercury " " 360° C.

are put into the crucibles and the burner is lighted. The bimetallic bar bends as the temperature increases and the liquids boil off one by one.

Project Devised By Stephen A. Gatznios

Boston University School of Education, 1950

Adviser, Dr. John G. Read
HEAT

I. DEMONSTRATION

1. Conduction - Transmission of heat from molecule to molecule

2. Insulation - Prevention of the escape of heat by conduction.

II. DESCRIPTION OF APPARATUS

Materials: Cardboard doll house or garage (5 and 10¢ store), piece of zinc, copper, asbestos, tin-foil, rock wool (hardware store will give you a sample). They should all measure about 5 x 5.

Small birthday candles and an electric bulb in a stand. Scotch tape.

Construction: Scotch tape the various samples to the walls and roof (other types may be added to walls and roof if desired). Fasten a candle to the outside of each wall. Plug in the electric light bulb. The house will probably have to be raised a little on books so the bulb will not touch any of the roof, try to center it so that the heat will be distributed as evenly as possible.

III. PROCEDURE

1. Show class how samples are fastened to the walls and roof

2. Have them make a note of types used

3. Light bulb

4. Watch candles
Which falls first? 2 - 3, etc.? Check to see what kind of material was lining that wall. What materials used will conduct heat? What materials will not? What would you use for insulation in your home?

IV. APPLICATION

Conduction - Copper tea kettles
             Iron pipes
             Copper boilers
             Aluminum pans

Insulation-  Asbestos
             Rock wool)
             Wood)
             Plaster)

Houses

Project Devised By M. F. Coyle

Boston University School of Education, 1950

Adviser Dr. John G. Read
BATTERY JAR WITH COLD WATER

NYLON THREADS

GENERATING FLASK WITH HOT COLORED WATER
HEAT - CONVECTION

I. PRINCIPLE - CONVECTION

Heat is transferred by convection in currents of gases or liquids, the rate of transfer decreasing with an increase in the viscosity of the circulating fluid.

II. DESCRIPTION OF APPARATUS

Materials: large battery jar filled with clean cold water, a generating flask, boiling water, red ink, 2 glass tubes, 2-holed rubber stopper, nylon thread, and cement.

Construction: Glue small pieces of nylon thread to bottom of one glass tube giving it a fringe effect, now insert tubes in stopper making sure one tube goes to within an inch of the bottom of the generating flask. Boil water, fill flask, add a few drops of red ink, insert stopper with glass tubes and immersed in battery jar of cold water.

III. PROCEDURE

1. Boil water and add red ink
2. Fill flask (fill to brim)
3. Insert stopper with glass tubes
4. Immerse in battery jar of cold water
5. Class: Watch the nylon threads closely. Are they moving?

Why? What's happening to the red water? Why does it stay on top?
What pushed it out? Why?

This can be repeated using other liquids showing the difference in the rate of transfer.

IV. APPLICATIONS

1. Hot water system
2. Hot air system
3. Ventilation

Project Devised By M. F. Coyle

Boston University School of Education, 1950

Adviser Dr. John G. Read
CONDUCTION OF HEAT

I. PRINCIPLE:

II. DESCRIPTION OF APPARATUS:

A. Materials Needed:
   1. Wires of different materials - all of same diameter
   2. Bunsen burner or a similar source of heat.
   3. Supports to lay wires on

B. Construction of Apparatus:
   1. Twist together two or more stout wires of the same
diameter such that a short stem of twisted wires and long prongs
are formed. Two wires are best formed in parallel prongs.
   2. Support the arrangement in some manner such that the
twisted ends extend over the burner.

III. PROCEDURE FOR EXPERIMENT:

   After preliminary study of heat, the transmission of heat is
studied. During discussion of transmission of heat, this experiment
can be demonstrated to show heat transmission and also different
rates of heat transmission in different materials. Heat is applied
by means of the bunsen burner to the twisted ends of the wires. After
several minutes, slide a sulphur tipped match along each of the long prongs until ignition. The point of ignition will be farther out in a good conductor, such as copper, than in a relatively poor conductor, such as iron. Thus, the idea of conduction is shown and the different rates of conductivity in different materials.

IV. APPLICATIONS:

A. Insulation

B. Materials used for different jobs.

Project Devised By Robert B. McIntyre

Boston University School of Education, 1950

Adviser, Dr. John G. Read
GLASS CHIMNEY

T-SHAPE PIECE OF CARDBOARD, TIN, ETC. FOR PARTITION

GLASS BEAKER

CANDLE ON BEAKER BOTTOM

H₂O
CONVECTION

I. PRINCIPLE:

Heat is transferred by convection in currents of gases or liquids.

II. DESCRIPTION OF APPARATUS:

A. Materials Needed:
   1. Shallow beaker or tray
   2. Piece of candle
   3. Lamp chimney
   4. Piece of tin - cut in T shape
   5. Water

B. Construction:
   1. Set piece of candle in the shallow beaker or tray
   2. Place lamp chimney over the candle
   3. Pour in sufficient water to seal lower end of chimney - about one half inch
   4. Place T shaped piece of tin in the chimney top so it hangs as a partition dividing the chimney in half

III. PROCEDURE:

Lead up to introduction of experiment by proper discussion of heat and its transmission. Thus experiment may be used to illustrate convection. Light the candle, place chimney over the candle, and seal the base with water. If a source of smoke
such as a cigarette or piece of smouldering paper is held over one edge of the chimney, smoke will pass down one side of the partition and up the other. If the partition is removed, the candle will be extinguished by lack of fresh air or oxygen.

IV. APPLICATIONS:

A. Heating systems.

B. Chimney draft.

Project Devised By Robert B. McIntyre

Boston University School of Education, 1950

Adviser, Dr. John G. Read
THISTLE TUBE

GLASS T

WATER JACKET

1/2" GLASS TUBE - #7 2-HOLE STOPPER

COLD H₂O OUT

RUBBER CONNECTIONS

COLD H₂O IN

STEAM GENERATOR

GLASS TUBING

BUNSEN BURNER
CONVECTION-HOT WATER HEATING SYSTEM

I. PRINCIPLE:

Heat is transferred by convection in currents of gases or liquids.

II. DESCRIPTION OF APPARATUS:

A. Materials Needed:

1. Steam boiler or generator - standard High School equipment
2. Glass tubing - standard tubing all right - larger tubing is better
3. Stoppers and rubber hose
4. Bunsen burner
5. Large tube - tubing above will pass through interior of large tube which will be filled with cold water to serve as radiator.
6. Glass T - same size as tubing used.
7. Old thistle tube - to serve as expansion tank
8. Coffee grains - used grains are best as they have done all the swelling they will
9. Clamps - to shut off system through hose connections
10. Cold water supply - faucet or tap
11. Supports for system - ring stands or constructed supports
B. Construction:

1. Arrange the supports so as to make best use of them

2. Set boiler near one support

3. Place one hole stopper in opening at top of boiler - put piece of glass tubing through stopper flush with bottom surface

4. At upper end of tube, attach glass T by means of rubber hose. Cut short lengths of hose for this purpose.

5. Attach thistle tube at top of T - to serve as expansion tank.

6. Take large glass tube - put in each end, a two hole stopper - through the two stoppers, put a continuous length of glass tubing with extensions remaining on each end - through the other two holes, place short pieces of tubing to serve as inlet and outlet for water - serves as radiator.

7. Attach one end of continuous tubing to the horizontal extension of the glass T.

8. If insufficient extension remains at other end of continuous tube, bend it down. If standard quarter inch tubing is used, bend should not be greater than 45 degrees - larger tubing may approach 90 degrees - small tubing works against convection, due to friction and sharp bends constrict tubing to too great an amount - if sufficient extension is not available, bend separate tube with
two 45 degree bends forming a channel - attach one end to extension of continuous tube.

9. Attach a length of straight tubing, which will connect with bottom of boiler, to the other end of the bent tubing - this completes the circuit of the system.

10. Attach hosing for cold water inlet to radiator to the end of the radiator furthest from boiler - attach hosing for water outlet to end of radiator nearest boiler.

11. Fill boiler and tubing with water - at top of boiler put in one half teaspoon of coffee grains - close system and tighten all connections.

12. Apply heat and check all points for leakage.

III. PROCEDURE:

During discussion of heat, radiation, conduction, and convection will be covered. Many pictures describe the hot water heating system but few students actually can interpret the pictures. Here is an opportunity to actually see such a system in operation. The apparatus should be set up before the class begins. Explain the apparatus briefly to satisfy pupil curiosity. Light burner and apply heat. Then begin lecture on heat. The coffee grains will be carried around the circuit by the currents. If the small tubing is used, the radiator must be
tipped to get more aid from gravity. When the coffee grains are in sight and moving through the circuit, at the first convenience, begin discussing convection and this system. Explain thoroughly how it works.

IV. APPLICATIONS:

A. Household heating system

B. Description of convection

Project Devised By Robert B. McIntyre

Boston University School of Education, 1950

Adviser, Dr. John G. Read
DIFFUSION OF LIGHT

I. PRINCIPLE:

If a beam of light falls on irregular surfaces, the rays of light are scattered in all directions.

II. DESCRIPTION OF APPARATUS:

A. Materials Needed:

1. Battery jar.
2. Black paint or piece of cardboard
3. Source of light which will give good beam

B. Construction of Apparatus:

1. Paint bottom of battery with black paint, leaving a hole in the center about one half inch in diameter.

or

Cut cardboard so it will completely cover bottom of battery jar and cut small hole about one half inch in diameter which, when cardboard is placed against bottom of jar, will be in center of jar bottom.

2. Place light source so that beam of light is directed through the half inch hole at bottom of jar.
III. **PROCEDURE:**

This experiment may be used on the study of reflection and refraction of light. Direct light beam through hole at bottom of jar. Room should be darkened. Little light is in evidence inside of jar other than the beam. Now fill jar with smoke. Entire jar becomes illuminated. Smoke particles reflect and refract the light to and from each other in all directions.

IV. **APPLICATIONS:**

A. Frosted light bulbs.

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Project devised by Robert B. McIntyre

Boston University School of Education, 1950

Adviser, Dr. John G. Read
I. PRINCIPLE:
Construction of images.

II. APPARATUS:
2 similar object (ex. small dog salt shakers), glass plate and stand to hold glass upright.

III. METHOD OF ASSEMBLING:
Set up 2 objects on opposite sides of a glass plate, which is set in supports to maintain plate in an upright position. Sight from one side of glass plate and vary the object on the opposite side until it coincides with the image of the object which is on the same side of glass as the line of sight.

Project Devised By J. J. Knowles
Boston University School of Education, 1950
Adviser, Dr. John G. Read
I. **PRINCIPLE:**

By the law of inverse squares, light varies as the inverse square of the distance from the light source.

II. **APPARATUS:**

Box painted black in the interior. 2 adjustable walls A - B, and a fixed wall C. Walls may have cut out areas as shown or areas painted white. If areas are cut out, fine wires could be criss-crossed to show the unit areas as they should appear on A and B. Adjustable sliders to hold walls A and B, and sealer attached to the upper edges of the box. Incandescent lamp set on a base so that filament is on axis of hole in front end of box.

III. **METHOD OF ASSEMBLING:**

Set light at a standard distance from the box and keep as much stray light as possible from entering open top of box. Push sliders, holding walls, along the top of the box until areas correspond to cut out section of walls and note the measurement shown on scale on top edges of box. If a light meter is available it could be used at various distances in the box and then compared with its reading near the light or at the opening in the front end of the box.

Project Devised By J. J. Knowles

Boston University School of Education, 1950

Adviser, Dr. John G. Read
I. PRINCIPLE:

Diffraction of light rays when passing through different media.

II. APPARATUS:

Box with ground glass top. (ground glass may be made by applying oil and emery to a piece of plain glass and rubbing same with a small piece of flat glass) End of box has a slit to admit light. Top of box has a protractor attached as shown. Adjustable clips on the sides allow one medium to be measured, or the effects of 2 or more media could be shown. The critical angle could also be demonstrated.

III. METHOD OF ASSEMBLING:

Set up on demonstration table and bring a strong light source to slit at end of box. If light source bothers operator the light could be confined except when needed for the slit, or an opaque extension could be put on glass top at the end where the light is to be placed.

Project Devised By J. J. Knowles

Boston University School of Education, 1950

Adviser, Dr. John G. Read
WOOD PAINTED BLACK

MIRROR

SUNLIGHT OR FLASHLIGHT SHINES ON MIRRORS

REFLECTIONS ON CEILING ALL IN LINE
I. **PRINCIPLE:**

If a beam of light falls upon a smooth, regular surface, the rays of light are reflected only in one direction.

II. **DESCRIPTION OF APPARATUS:**

- A flat board, 9 in x 9 in., painted black.
- Five mirror strips, 5 in. x 1/2 in.
- Light beam from electric bulb or sun.

III. **PROCEDURE:**

The mirrors are placed flat and parallel on the board. The mirrors are covered with a cardboard and the light is directed toward the covered mirrors. The cardboard is moved, uncovering one mirror at a time. As the mirrors are uncovered, the light is reflected on the ceiling in regular order.

Project Devised By Stephen A. Gatzmios

Boston University School of Education, 1950
Adviser, Dr. John G. Read
I. PRINCIPLE:

If a beam of light falls upon an irregular surface, the rays of light are scattered in all directions.

II. DESCRIPTION OF APPARATUS:

A flat board, 9 in. x 9 in.; painted black
Five mirror strips, 5 in x 1/2 in.
Four wedges
Light beam from electric bulb or sun.

III. PROCEDURE:

The mirrors are placed on the board with the wedges under all mirrors except the center one, as shown on diagram. The mirrors are covered with a cardboard and the light is directed toward the covered mirrors. The cardboard is moved uncovering one mirror at a time. As the mirrors are uncovered, the light is reflected on the ceiling in a direction different from each mirror.

Project Devised By Stephan A. Gatzimos

Boston University School of Education, 1950
Adviser, Dr. John G. Read
I. **PRINCIPLE**

Pressure in a confined liquid is distributed equally in all directions.

II. **DESCRIPTION OF APPARATUS**

A. Materials:

- 1-gallon round motor oil can
- 1/4 inch glass tubing
- #6 single hole rubber stopper
- 1/4 inch solid rod 1 foot long
- 6 inches of 1/8 inch copper tubing (type used in automobile temperature gauge)
- 1 inch diameter hollow brass tube 6 inches long
- wooden handle for rod

B. Construction:

Cut the glass rod into three 10" sections and flame seal one end of each. Cut the copper tubing into three pieces each 1-1/8" long and make a right angle bend in each. Solder the brass pipe into the hole at the top of the oil can so that it is liquid tight at the joint. Fit the rubber stopper on the 1/4 inch rod so that it will act as a plunger to fit into the brass pipe. Drill 1/8" holes at the top, middle, and bottom of the oil can into which the right angle tubes are soldered. Using "Duco" cement, fasten the three glass rods to the copper tubes as shown in the diagram.
III. SUGGESTED TEACHER PRESENTATION

Fill the can with colored water up to almost the top of the brass pipe. Note the manometer readings on the tree glass tubes. Insert the plunger and press down. Note the amount of rise on each manometer. Are they equal?

IV. APPLICATION

Diving suits

Building underwater tunnels

Submarines

Project Devised By Harold Sossen

Boston University School of Education, 1950

Adviser Dr. John G. Read
OATMEAL BOX

AIR FROM FAN OR VACUUM CLEANER

TRANSPARENT CYLINDER

RED INK

CARDBOARD FUNNEL
LIQUIDS AND GASES

I. PRINCIPLE - BERNOULLI'S

As the velocity of flow through a constricted area increases, the pressure decreases.

II. DESCRIPTION OF APPARATUS

a. Material needed: Large Quaker Oats box, light weight cardboard or heavy paper, small piece of plastic, 2 small glass tubes "U" shaped, red ink, scotch tape, cement and a high speed fan or vacuum sweeper.

b. Construction: Cut cardboard or heavy paper into a cone, be sure to leave an extra 1/8 inch for overlapping. Cut off top and bottom of box and roll plastic into a tube about 3/4 inch in diameter, connect box and tube by means of the cone. Cement and scotch tape securely. Insert the glass "U" tubes containing red ink, one to be placed in the center of the box, the other in the plastic tube, where it joins the cone. Turn the vacuum sweeper on and let the air blow through the Venturi tube.

III. SUGGESTED TEACHER PRESENTATION

1. When the Venturi tube has been constructed and the air moves through it, watch the red ink in each glass tube.

2. Have the class check the levels of the ink before and after the vacuum has been turned on.
Is there difference? Have one of the pupils tell which tube differs and how.

What made the ink rise in a short distance in the second glass tube?

What brought about this decrease in pressure in the smaller (plastic) tube?

Follow up with a demonstration of a flit-gun.

IV. APPLICATIONS

1. Carburetors

2. Flit-gun

3. Atomizer

4. Airplane

Project Devised by M. F. Coyle

Boston University School of Education, 1950

Adviser Dr. John G. Read
THISTLE TUBE

TALL GRADUATED TUBE

LITMUS SOLUTION

CONCENTRATED $\text{H}_2\text{SO}_4$
DIFFUSION OF LIQUIDS

I. PRINCIPLE:

A fluid has a tendency to move from a region of higher pressure to one of lower pressure.

II. DESCRIPTION OF APPARATUS:

A. Material Needed:
   1. Tall jar - graduated tube - or something similar
   2. Long thistle tube
   3. Blue litmus solution - largely water
   4. Concentrated sulfuric acid.

B. Construction of Apparatus: None needed.

III. PROCEDURE:

The diffusion of liquids involves molecular action and this idea should be well covered when the experiment is introduced. The tall jar is filled with water which is colored with blue litmus solution. A small amount of the acid is introduced at the bottom of the jar by means of the long thistle tube. The density of the acid is greater than that of the litmus solution and the acid will thus remain at the bottom, with a well-defined line of separation, for the litmus solution turns red where it is in contact with the acid. If allowed to stand for a while, this line will lose its sharp distinction and the entire blue solution will slowly turn red. By this
means, it can be shown that the acid molecules have made their way through the solution to the top.

IV. APPLICATIONS:

A. Osmosis

B. Miscible liquids

Project Devised By Robert B. McIntyre

Boston University School of Education, 1950

Adviser, Dr. John G. Read
I. **PRINCIPLE:**

A fluid has a tendency to move from a region of higher pressure to one of lower pressure; the greater the difference, the faster the movement.

II. **DESCRIPTION OF APPARATUS:**

A. **Materials Needed:** Rubber tubing, funnels, a "T" tube, clamps, ringstands, glass nozzle or glass from a medicine dropper and water.

III. **PROCEDURE:** Fill the system with water and have the three clamps at "A" "B" and "C" tight before the experiment is started. Then remove successively clamps "C" "B" and "A" noting the effect each time and adding water occasionally so that the system remains full.

A board of some kind should be placed behind the nozzle "C" and as different heights of water are noted, these heights should be marked.

Questions: Why didn't the water come out the nozzle when the "C" clamp was removed? Which side produced the highest fountain? Why? Why didn't the water reach as high as the funnel from which it started? What general conclusion can you make?

IV. **APPLICATIONS:** Artesian wells, fountains and hydrants connected to a standpipe water system.

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Project Devised By Carl Orcutt

Boston University School of Education, 1950

Adviser, Dr. John G. Read
WATER

COVERED
PLASTIC
ROWBOAT

GLASS ROD

WEIGHTS
I. **PRINCIPLE:**

A body immersed or floating in a fluid is buoyed up by a force equal to the weight of the displaced fluid.

II. **DESCRIPTION OF APPARATUS:**

A. **Materials Needed:** Battery jar, pan balance, small plastic row boat, glass tubing, thin cord, water and a set of weights.

B. **Construction:** The left pan and its supports are removed from a balance. In its place a thin cord is tied and the left arm is weighted to compensate for the removal of the pan. In the battery jar a glass tube is wedged so that the effect is similar to that of a single pulley.

III. **PROCEDURE:**

The small plastic row boat is covered with rubber or some other waterproof material and attached to the string at such a length so that it will be held under the surface. The force necessary to accomplish this can then be measured directly by adding weights to the right hand pan. Now, remove the boat and its covering and fill the boat with water and reweigh it.

Questions: How did the two weight measurements compare? In which direction did the force on the boat act in the first set-up? On any floating body, what determines the amount of force that acts upward upon it?
Finally, repeat this experiment if you desire using a test tube closed first by a cork stopper and then perhaps some materials such as iron or mercury which are heavier than water.

IV. APPLICATIONS:

Cargo calculations of ships and boats, determination of specific gravities.

Project Devised By Carl Orcutt

Boston University School of Education, 1950

Adviser, Dr. John G. Read
I. **PRINCIPLE:**

Density of gases shown by convection currents.

II. **APPARATUS:**

Box with clear glass front and 2 chimneys on top, one at either end. Two ordinary wax candles, and a line of silk floss threads or a very light paper turbine, to show direction of air flow.

III. **METHOD OF ASSEMBLING:**

Slide glass front to one side and replace after lighting a candle at one end. Threads will sway away from the end where candle is extinguished, or direction from which cool air is flowing. It might be well to extinguish first candle that was lighted and light other candle and note that the silk floss threads will not flow in the same direction but will flow the opposite way.

Project Devised By J. J. Knowles

Boston University School of Education, 1950

Adviser, Dr. John G. Read
I. **PRINCIPLE:**

Osmosis - Solutions tend to flow from areas of less concentration to areas of greater concentration.

II. **APPARATUS:**

2 beakers - 10 or 12 dried fruits (ex. prunes) - water - sugar.

III. **METHOD OF ASSEMBLING:**

2 beakers (clear glass) set on a table clear of all objects.

Cover the top of beakers with cardboard to prevent entrance of foreign material. Set away for a day, then display.

Project Devised By J. J. Knowles

Boston University School of Education, 1950

Adviser, Dr. John G. Read
WOOD FRAME

SMOKED GLASS

STIFF FIBER

VIBRATING TUNING FORK

MOVABLE FRAMEWORK

BASE
I. **PRINCIPLE:**

The acceleration of a body is proportional to the resultant force acting on the body and is in the direction of that force.

II. **DESCRIPTION OF APPARATUS:**

**Materials Needed:**

- Tuning fork 256 cps
- Stylus
- Shelf brackets
- Board 30"x15" for base
- Grooved boards for upright frame... 2 pcs.
- Piece of plate glass smoked for showing curve trace
- 4 mirror brackets
- 4 hookeyes.

**Construction:** Mount the shelf brackets to the base board and attach the upright grooved boards to the other side of the brackets. Construct a sash that will travel freely up and down the upright stand—hookeyes will serve as guides to keep the sash in the groove and afford a minimum of friction. Drill a hole in the lower cross member of the sash and insert the base of the tuning fork. The stylus may be attached to the prong of the tuning fork by means of candle wax. Smoke the plate glass with camphor or a candle flame and mount the glass in the upright stand so that the stylus will just trace its path when falling.
Suggested Presentation:

Raise the sash to the top of the upright stand and secure it by means of a piece of thread. Set the tuning fork vibrating by bowing and apply a match to the supporting thread. The sash will fall and the stylus will trace a wave shape on the smoked glass.

Remove the glass from the apparatus and mark off every eighth crest of the wave. This will represent time intervals of 8/256, or 1/32 second.

Place the following table on the blackboard:

<table>
<thead>
<tr>
<th>Length of Sector</th>
<th>Average Speed distance per second</th>
<th>Increase of Speed per 1/32 Second</th>
<th>Acceleration increase per x 32 Second</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.51 cm</td>
<td>x 32</td>
<td>48.30 cm</td>
<td>983 cm per sec</td>
</tr>
<tr>
<td>2.47 cm</td>
<td>&quot;&quot;</td>
<td>79.02 &quot;&quot;</td>
<td>30.72</td>
</tr>
<tr>
<td>3.42 cm</td>
<td>&quot;&quot;</td>
<td>109.47 &quot;&quot;</td>
<td>30.43</td>
</tr>
<tr>
<td>4.39 cm</td>
<td>&quot;&quot;</td>
<td>140.37 &quot;&quot;</td>
<td>30.90</td>
</tr>
<tr>
<td>5.35 cm</td>
<td>&quot;&quot;</td>
<td>171.05 &quot;&quot;</td>
<td>30.68</td>
</tr>
</tbody>
</table>

The table is completed as above by measuring the distances between crests and no formula is necessary to compute "g."

III. APPLICATIONS:

Projectiles

Aeronautics

Astronomy

Project Devised by Chalmers Murray
Boston University School of Education, 1950
Adviser, Dr. John G. Read
MECHANICS

I. PRINCIPLE:

Every action has an equal and opposite reaction.

II. CONSTRUCTION:

a. Twelve feet of smooth wire.
   One turn buckle
   Four screw eyes
   Two cylindrical wooden blocks of equal size and shape and
   weight as shown in the diagram.
   Two steel pins made from nails.
   Firecrackers.

b. The two cylindrical weights were turned down from an old
   maple bowling pin. They are exactly the same dimensions
   and hence equal weights. A 1/4" hole was drilled so that
   half the hole was in each block. The screw eyes are used
   to suspend the blocks from the wire that has been made tight
   with the turnbuckle.

III. SUGGESTED TEACHER PROCEDURE:

The wire is strung up and made tight with the turnbuckle. The
blocks are suspended on the wire and lined up with the pins. A mark
is made on the wire directly over the firecracker hole. The firecracker
is then inserted into the hole and lit. How far did each block travel
away from the mark? Try a few firecrackers and although the distance
that the blocks travel is different every time, they always travel equal distances from the center.

IV. APPLICATIONS:

Jet propulsion

Traveling in space

Pile drivers

Project Devised By Harold S. Sossen

Boston University School of Education, 1950

Adviser, Dr. John G. Read
WEIGHTLESS LEVER

I. PRINCIPLE:
   In the lever, the force applied times its distance from the fulcrum equals the weight lifted times its distance from the fulcrum.

II. DESCRIPTION OF APPARATUS:

A. Materials Needed:
   1. Adequate wood
      a. Base and fulcrum supports - at least half inch thickness.
      b. Lever - four feet by one and a half inches by one half inch minimum.
   2. Six inch length of curtain rod or something similar
   3. Five eyelet nuts and bolts with two large washers for each - one U bolt and washers may be used for the fulcrum holder - all nuts and bolts, washers of equal weight.
   4. Nails
   5. Wire to form hooks for holding weights
   6. Weights

B. Construction: Wood for base and fulcrum supports cut to sizes and shapes appropriate for solid support. Sand edges.
   Nail together.
2. Lever rod - two inches from each end on the wider surface, drill a hole such that a jig saw or hand saw blade may be inserted. Cut a slot, from these holes, the length of the rod, leaving two inches of solid wood at each end. Slot size to admit bolts used. Sand down.

3. Attach all bolts through the slot so that eyelets are all on lower side. Washers should be used to prevent nut from cutting into wood.

4. Through the eyelet to be used as the fulcrum connection, place the curtain rod. Tighten so that bolt and fulcrum do not slide along slot.

5. Arrange other bolts to have two on each side of the fulcrum.

6. Wire hooks to hold weights may be attached at these bolts. One bolt at each end should be used for counterweighting such that lever can have one end of greater length from the fulcrum than the other and still have the lever balance.

III. PROCEDURE:

Appropriate study of mechanics and simple machines should be given to lead up to the use of this construction. It may be used by the teacher to illustrate and prove the principle involved or assigned by the teacher as a project for the pupils.
IV. APPLICATIONS:

The principle of the lever is seen everywhere in life. The shovel, the water pump on the farm, acrobats, and the fork or spoon at the dinner table are all applications of this lever principle.

Project Devised By Robert B. McIntyre

Boston University School of Education, 1950

Adviser, Dr. John G. Read
SCREW OR HYDRAULIC JACK

PLATFORM SCALES (24#)

TABLE

PLATFORM SCALES (24#)

FLOOR
I. **PRINCIPLE:**

Newton's Third Law - Every action has an equal and opposite reaction.

II. **DESCRIPTION OF APPARATUS:**

A. **Materials needed** - Two platform scales, 24 lb. capacity, screw or hydraulic automobile jack.

B. **Construction** - One platform scale is set down on the floor, under the edge of a heavy table. The jack is centrally placed on the scale. The second scale is set, right side up, on top of the jack, and lodged tightly under the edge of the table.

III. **PROCEDURE:**

Take an initial reading of the forces registered on the two scales, A and B. The difference in the two scale readings is accounted for by the weight of the jack. Elevate the jack so that scale A, the upper scale, shows a change of approximately 10 lbs. Take a final reading of both scales, subtract the initial readings from the final readings. It will be found that the differences are approximately equal. Repeated trials will establish the equality more definitely.

**Suggested Teacher Presentation:**

This demonstration shows quite clearly the principle that every action has an equal and opposite reaction. It should be pointed out that the reaction is truly opposite and equal. A more dramatic presentation may be gained by covering the lower scale after the initial
reading and asking the class to guess what its final reading would be when the final reading of the upper scale is known.

IV. APPLICATIONS:

Gun recoil, jet plane, ground presses against weight with same force as weight presses against ground.

Project Devised By Arnold A. Rubin

Boston University School of Education, 1950

Adviser, Dr. John G. Read
I. **PRINCIPLE:**

Newton’s Third Law - Every action has an equal and opposite reaction.

II. **DESCRIPTION OF APPARATUS:**

A. **Materials needed:** Three spring scales, four two-foot lengths of twine

B. **Construction:**

Connect the three scales in series by means of the four lengths of twine, as in the diagram.

III. **PROCEDURE:**

Part I. Two pupils grasp the apparatus at the opposite ends and pull so that a force of ten lbs. is registered on the scales nearest them. It will then be seen that the scale in the center will likewise show a force of ten lbs.

Part II. Attach one end of the apparatus to a fixed point. Apply a force of ten lbs. in a direction opposite to the fixed point. This force will be registered on the scale nearest the person applying it. It will be seen that the other scales register approximately the same amount. Repeated trials will establish the equality more definitely.
IV. SUGGESTED TEACHER PRESENTATION:

This demonstration shows clearly that a force exerted in one direction on a body results in an equal force exerted in the opposite direction on the same body. Part 2 demonstrates that a fixed object can be considered as exerting a force. The center spring scales demonstrate that the forces registered are actually composed of five lbs. acting in one direction and five lbs. acting in the opposite direction. The resultant ten lbs. is registered on all three scales.

V. APPLICATIONS:

Gun recoil, jet propulsion.

Project Devised By Arnold A. Rubin

Boston University School of Education, 1950

Adviser, Dr. John G. Read
PROPAGATION OF SOUND

I. PRINCIPLE

Sound is produced by vibrating matter and is transmitted by matter.

II. DESCRIPTION OF APPARATUS

a. Materials: Large oatmeal box, rubber membrane, elastics, candle, feather or pitch-ball.

b. Construction: Stretch rubber membrane over open top of oatmeal box. Secure with elastics. Cut a hole about an inch in diameter in bottom of box.

III. SUGGESTED PROCEDURE:

1. Light Candle

2. Hang feather or pitch ball in line with candle about a foot away.

3. Stand about 2 feet away from the candle, and aim box at it. Snap fingers smartly against membrane. Try farther away, move gradually closer.

4. Class: Have class examine the box before placing the rubber membrane on it. What happened to the candle? the feather or pitch ball? Why? How were these vibrations produced? How were they transmitted?
IV. APPLICATIONS

1. Human voice
2. Phonograph
3. Musical instruments
4. Thunder
5. Microphones.

Project Devised By M. F. Coyle
Boston University School of Education, 1950

Adviser Dr. John G. Read
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The cell is the unit of structure and function in all organisms.

Cells are organized into tissues, tissues into organs and organs into systems - the better to carry on the functions of complex organisms.

The smallest unit of living material capable of existing independently and of maintaining itself is the unit called the cell.

In all organisms, the higher the organization, the greater the degree of differentiation and division of labor and of the dependency of one part upon another.

From the lower to the higher forms of life there is an increasing complexity of structure; and this is accompanied by a progressive increase in division of labor.

The smaller an organism, the greater is the proportion of its surface to its weight, since surface increases as the square its length, weight as its cube.

The distinctive properties of organisms depend upon the complexity of the molecular organization of protoplasm, the one essential constituent of every living thing.

Life and protoplasm in a cell will remain indissolubly associated for an indefinite period of time unless the cell suffers an accident, or becomes diseased, or is unable to throw off toxic waste substances that accumulate with age as a result of normal metabolism.

The colloidal nature of the cell material as a whole furnishes the basis of some of the fundamental life processes.

The bodies of most animals exhibit some degree of symmetry, either spherical, radial, or bilateral.

In plants and animals, organs of the same structural plan are often applied to the most diverse functions.

In fossilization, it is usually the hard parts of organisms that are preserved.

Energy can be transformed into mass, and mass into energy, but the sum total, mass plus energy, remains.
M 15.5 All living organisms (except viruses and bacteriophages) carry on the common life processes: reproduction, growth, nutrition, excretion, respiration, and irritability.

M. 64.5 Food, oxygen, certain optimal conditions of temperature, moisture and light are essential to the life of most living things.

Most cases of fermentation, souring and putrefaction are brought about by living micro-organisms.

In many multicellular organisms body form is secured and maintained either by the consistency of the tissues and the internal pressure of body fluids, or by the secretion of special substances which are formed into supporting structures.

Many of the rhythmic changes of protoplasm such as ciliary action, heart beat, and rhythmic processes in cell division, are based upon reversible changes in the colloidal state.

All plants and a few animals are able to recombine nitrogenous by-products of respiration into proteins by resynthesizing them anew with carbohydrate molecules.

Turgor in cells is maintained in cells by osmotic pressure: cell membranes are semipermeable with respect to water and the substances dissolved in it; when the concentration of salts is higher within the cell than outside, the entrance of water into the cell is accomplished by osmosis.

The size of cells bears no constant relation to the size of the animals or plants in which they are found.

The bodies of most animals exhibit bilateral symmetry which is an adaptation of forward motion.

All individuals of a unicellular species, except asexual species, contain the same number of "similar sets" of chromosomes.

The number of chromosomes in somatic cells of all individuals of a species is a constant; except in chimeras, gynandromorphs, etc.

All cells within one multicellular individual except the gametes in animals and the spores in plants, are characterized by the same chromosomal content, as they all originated by cell division from a common cell.
Throughout the life of every organism, there is a building up and tearing down of protoplasm with constant transformations of energy.

The protoplasm of a cell carries on continuously all the general processes of any living body: the processes concerned in the growth and repair of up-building or protoplasm (anabolism) and the processes concerned with the breaking down of protoplasm and the elimination of wastes from the cell (catabolism). The sum of all these chemical and physical processes is metabolism.

**MOTION**

Most living things differ from non-living things by being able to perform the control functions of irritability and spontaneous movement.

A characteristic of living organisms is the power of independent motion, either by protoplasm within the cell or of a body as a whole.

The power of contraction which results in movement is possessed by all protoplasm to a greater or lesser degree.

**INGESTION, DIGESTION, EXCRETION, EGESTION, STORAGE**

Nutritional processes of different classes of organisms supplement each other in such a manner that they result in nutritional balance among living things.

Plants and animals utilize similar food substances but they are obtained in different ways.

An organism must have certain materials for its life processes and each organism must secure the required materials that it cannot build for itself.

Starches, fats and proteins are produced by plants and it is upon these that all animals depend primarily for food.

An animal cannot live without proteins; they are necessary in cell growth and maintenance, so are necessities in the diets of animals. Plants are able to use carbohydrates and nitrates to build up proteins necessary for growth and maintenance of their cells.
Digestion in plants and animals is carried on by enzymes, or organic catalysts which are made by the organisms themselves and which take part in and speed up the chemical reactions, but do not undergo any permanent chemical change themselves.

Digestion accomplishes two things—it makes food soluble in water, thus enabling the nutrients to pass through membranes, and thereby reach and enter the cells: it reduces complex nutrients (fats, proteins and carbohydrates) to a simple building material which in turn can be rebuilt into whatever living material or structural features is necessary at the place of use.

In organisms the end products of metabolism, water, carbon dioxide and nitrogenous compounds are either stored in the cells as insoluble crystals, are eliminated in solution by diffusion or osmosis (excretion), are incorporated into useful cell products (secretion), or are recombined into food substances within the organism.

The food requirements of every living thing are fuels capable of yielding when oxidized, the supply of energy without which life cannot continue: materials for growth and for replacement for the slight wearing away of the living tissue involved in any activity: minerals, the necessary constituents of cell structures, of cell products, and of the bathing fluid of cells.

**CIRCULATION**

Circulation is carried on in all living organisms. With increase in size and complexity of the body of an organism, there goes a corresponding elaboration of the transportation (circulatory) system.

Diffusion, the spread of fluids with their dissolved substances throughout the protoplasm of a cell or the tissues of an organism, is an important method of conveying oxygen from the surface of the cell to the interior, or digested foods from the place of digestion to the protoplasm that will use them, or the waste material from the place where they are formed to the place where they are stored or excreted.

In animals certain waste products as well as vitamin and endocrine substances exert regulatory effects on the activities of various organs in the body.
Enzymes, vitamins and hormones are chemical regulators (stimulators and suppressors) of the reactions that occur in living organisms.

All chemical processes that belong to life itself are processes that occur in solution.

The fundamental life processes are the same in all organisms, (but each species has other chemical processes peculiar to itself). Bracket part appears only in Milligan and not in Martin.

There are no elements in living matter which are not found in its lifeless environment; the energy by which life is operated is the same energy by which the simplest physical and chemical transformations are brought about.

The phenomena of life involve chemical change so that wherever life processes are being carried on, chemical changes are taking place. However, chemical change may proceed without involving life.

Energy changes accompany all chemical changes in living organisms and every chemical change has its physical concomitants.

The physical and chemical properties of plant and animal protoplasm are similar.

There are no living chemical compounds; life is a property of the coordinated association of the different organic and inorganic substances which make up the protoplasm.

Every influence exercised by micro-organisms upon man and his environment, whether beneficial or detrimental, is the result of a chemical change in the substances from which they secure their nutrition or of a chemical product synthesized from them.

**DISEASE AND CONTROLS**

All communicable diseases are caused by micro-organisms.

For each disease caused by an organism, a specific microbe exists.

The antitoxins produced by the body of an organism are specific.
Infections by micro-organisms is possible only under the following conditions:

1. The infecting organism must enter the host in sufficient numbers.
2. It must enter by an appropriate avenue.
3. It must be virulant.
4. The host must be receptive.

Virus require living cells for their growth and they multiply only within living cells.

ANABOLISM, CATABOLISM, AND DEATH

Decomposition of the carbon compounds of organisms provides a replenishment of carbon in the atmosphere in the form of carbon dioxide. Thus, carbon is continually subjected to a series of cyclic changes from living to non-living substances.

Aerobic decomposition (fermentation) is accomplished at ordinary temperatures by the intervention of special enzymes. Dissimilation occurs in the absence of oxygen - its final products are carbon dioxide and alcohol and free energy is released.

As long as life continues in any organism, energy is being released.

None of the materials present in living protoplasm leave it when death ensues, for a given bit of protoplasm weighs exactly the same after death as when alive.

All cells contain autolytic enzymes that at death are capable of producing digestive changes which result in the final disintegration of the body.

In cells a quantitative gradient in metabolic rate runs from the apical to the basal pole of the cell, and the various formal components of the cell are arranged in definite relation to the gradient.

The amount of oxygen taken into the body of an organism and absorbed by the cells is directly proportional to the amount of energy released in the body.
In cells, the fundamental processes of food intake, digestion, regeneration of lost structures and survival are controlled by the nucleus.

**RESPIRATION**

Oxidation (combustion) furnishes the essential source of heat in the animal body: and other factors remaining constant the more heat produced the warmer the animal body.

The energy which makes possible the activity of most living things comes at first from the sun and is secured by the organism through the oxidation of foods within its body.

Energy and matter are not created or destroyed in the reactions associated with the life processes but are passed on from organism to organism in endless succession.

Physically, all animals are fundamentally mechanisms driven by the energy liberated in the oxidation of food.

All living things, except a few anaerobes (autotrophic bacteria) secure their energy by oxidizing food.

All living cells require oxygen to provide energy or to build new protoplasm.

Oxygen free in the atmosphere or dissolved in water, supplies the respiratory needs of practically all living organisms except for a few parasitic and anaerobic animals and a number of bacteria and fungi which can extract the oxygen needed for their energy production from the organic substances on which they feed.

The respiratory process of both plants and animals involves exactly the same gaseous exchange and accomplishes the same function - the release of energy.

Cellular respiration (aerobic decomposition) occurs in all living cells and all organisms possess structures by means of which it can be carried on. Its first step is intake of oxygen, either directly from the air or dissolved in water; its final product is carbon dioxide, and free energy is released. In the cells it is accomplished at ordinary temperatures by the intervention of special enzymes.
At every stage of development the individual is an integrated organism. All of its cells, tissues, and organs are correlated and act together as a unit.

Protoplasm is the physical basis of all life.

In most organisms large size is accompanied by tissue differentiation and special organs for different kinds of work.

Every cell consists essentially of a mass of protoplasm which is usually differentiated into a central portion, the nucleus, and an outer portion, the cytoplasm.

Water-living organisms do not merely dilute their weight but counteract it by accumulating lighter substances inside themselves.

In the water, free swimming organisms are very light because their specific gravity is only slightly greater than that of the medium in which they live.

**GROWTH**

There is a definite size limit for each species of plant and animal.

Growth and development in organisms is essentially a cellular phenomenon, a direct result of mitotic cell division, and it is always controlled and guided by the axiate organization of the cell.

When anabolism exceeds catabolism, as it does in all young animals growth is inevitable.

All living things grow by intususception or assimilation, making over the materials, which are taken into the body, into the kind of material of which the body is composed.

Growth and repair are fundamental activities of all protoplasm.

**PARASITOLOGY**

It is indispensable to successful parasitic existence that the symbiotic relationship be so adjusted that means are provided for the escape of the parasites or their offspring in order that new generations in the host may be obtained.
A parasitic organism harms its host in various ways and to varying degrees by attacking the tissues, by shedding poisons (toxics) which are distributed throughout the body of the host, by competing with the host for food or even making reproduction of the host impossible.

A characteristic of many parasites is that they have alternate hosts.

Saprophytic organisms are responsible for decay by which process the necessary raw materials for growth of new organisms are released from dead matter.

True parasites secure their nourishment from the host plant or animal without exerting an injurious effect; pathogens damage the host by invading the tissues, multiplying thus, and producing infection.

The parasite-host relationship is usually specific and requires not only marked adaptation of the parasite, but often, also, an adjustment on the part of the host.

**EVOLUTION AND WORLD RELATIONSHIPS**

The existence of organisms depends upon their inter-relations with the environment which includes both the inorganic world and other organisms.

The first forms of life were altogether independent, but evolution has resulted in the general interdependence of organisms.

All the higher forms of terrestrial life are dependent, either directly or indirectly on the soil bacteria for their nitrogen supply.

Parent material for the development of soils is formed through the physical disintegration and chemical decomposition of rock particles and organic matter.

All plant and animal life along with the climate and varying weather, play an active part in helping to form and to change the soil.

Plants and animals are directly or indirectly dependent on the soil.

Stretches of water act as barriers to purely terrestrial animals and stretches of land bar the migration of the inhabitants of water.

Each species of animal or plant tends to extend its range until some impassable barrier is encountered.
In all organisms, increasing complexity of structure is accompanied by an increasing division of labor.

The greater the similarity in structure between organisms, the closer is their kinship: the less the similarity in structure, the more remote is their common ancestry.

Evolutionary relationships in organisms are formulated on the basis of structural similarity.

In general, living things give evidence of definite progression from simple to complex forms.

All living things are continually engaged in an exacting struggle with their environment.

The range of temperature for life activities is very narrow as compared with the range of possible temperature below which, and a maximum temperature above which no life processes are carried on. The temperature range for life processes is from many degrees below zero to nearly the point of boiling water. (Centigrade)

Life is confined to the surface of the earth and to a few miles above and below, and no forms of life can go beyond these petty limits.

Living organisms cannot live in the upper levels of the atmosphere because of no oxygen for respiration and because of a deficiency of pressure upon the exterior of the body and the intense cold.

All plants and animals are engaged in constant struggle for energy.

Those organisms which cannot adjust themselves to their environment lose out in the struggle for existence.

Plants and animals in the course of their generations are changed and molded to meet the requirements of their existence and the individuals and types best adapted to their life situations are the ones that survive.

The present variety in living forms has resulted from the modification through long periods of time of simpler and less varied ancestral types, and by degeneration in many groups of organisms from more complex organisms.
Species not fitted to the conditions about them do not thrive and finally become extinct.

All living things are slowly changing, both structurally and functionally, in response to changes in their physical environments.

The biological functions of color are to conceal, to disguise, or to advertise.

Each species of living organism is adapted or is in the process of becoming adapted, to live where it is found.

Protective adaptations aid survival.

In a living organism adaptation of action and adaptation of structures are necessary for survival.

Some of the differences between related groups of organisms separated by a geographical barrier are due to adaptive responses to slightly different environmental factors.

Every living organism possesses some body parts which are adapted for the life it leads.

The chief difference in the structure of organisms from the lowest to the highest is resultant of the means adopted to perform certain functions under different exigencies imposed by the environment and mode of life.

The more highly specialized an organism is, the more likely it is to become extinct if its environment changes.

An adaptive character may give its possessors a definite advantage over the other members of the species and so in the course of generations due to the elimination of the non-possessors of this character, and of the conferring of this character upon others by heredity, becomes a character of all the members of the species.

The power of living things to change is definitely restricted, specialization reaches the limit of efficiency prescribed by mechanical or chemical laws.
If two or more groups of organisms have similar homologous structures, they have descended from similar ancestors, or from the same common ancestor.

Analogous structures in plants and animals serve to carry on similar functions but are not similar in basic plan or mode of origin.

Similarity between organisms suggest common ancestry: the nature of the difference between them indicating which is the more primitive type.

Isolation of a piece of land or a body of water from the rest of the world always permits its animals and plants inhabitants to evolve along their own peculiar lines, and each race involved tends to become more uniform.

Animals of diverse origin, living among similar surroundings, tend to become at least superficially alike and they often develop parts that have the same function.

In organisms inhabiting similar environments, evolution has often produces convergence--the molding of unrelated stocks into similar forms by the needs of their way of life.

Adult organisms that differ greatly from one another but which show fundamental similarities in embryological development have originated from similar ancestors.

The existing forms of life on the earth are not all the forms of life which have existed: there has been a great variety of animals and plants which have passed away.

Every species of organism is subject to certain checks or controls in the form of enemies and only those members that are most capable of avoiding their enemies survive to reproduce new offspring and thereby transmit many of their characteristics to their offspring.

The surface of the earth and the atmosphere surrounding the earth are undergoing constant changes therefore, in order to survive, organisms must migrate, hibernate, aestivate, build shelters or otherwise become adapted to these changes.
All living organisms have other living things which compete with them for the available energy.

Commensalism usually evolves, not in the direction of mutualism, but toward parasitism.

Fluctuation variations found within a pure line are not inherited and cannot change the character of the offspring permanently.

Protoplasm is built only by protoplasm and every cell comes from a cell.

New types of organisms, different enough to be regarded as new species may spring fully formed from a cross.

Living things, even of the same kind, are never exactly alike, not even with regard to single traits (characteristics) such as color or shape.

The forms of living things have changed slowly but steadily in the past. (Except for those resulting from mutation.)

Living things alter their types. The present species have not always existed but have originated by descent from others which in turn, were derived from still earlier ones and so down to the first, living forms.

Most of the species of modern animals are of relatively recent origin, having evolved from others in the past and probably continuing to evolve in other species of animals.

Variation and heredity together are responsible for the appearance and the continuation of the processes of evolution.

In organisms the more similar the body structure and their mode of origin and the greater the number of such structures, the closer the relationship of the organisms.

All gradations of association occur in intimate association between organisms from those which are mutually beneficial to the individuals concerned (symbiosis) to those in which one member secures all the advantages at the expense of the other (parasitism).
The distribution of any group of land animals will depend upon three factors - first, upon the region where the group happened to originate, second, upon the connections which this region then and later happened to have with other land masses, and third, upon the fate of the group in the different regions to which it obtained access.

Living things are not distributed uniformly or at random over the surface of the earth, but are found in definite zones and local regions where conditions are favorable to their survival.

Only the topsoil, with its rich organic matter, its porous structure and its living organisms, can hold the water and provide the minerals necessary to the life of a plant.

In general the natural flora and fauna of the region is the most luxuriant that it can support.

For most species of organisms, periods of great scarcity of individuals alternate with waves of great abundance: and the peaks of the waves succeed each other in a regular cycle.

Discontinuous widespread distribution is characteristic of old groups of plants and animals and means that they formerly occupied also much of the intervening space.

When new species are introduced into a country, few individuals or species will find themselves in the same balance as in their old home. For the majority, conditions will be unfavorable: they will fail to gain a footing and they will disappear. If introduced species chances to be better suited, especially if it is removed from its old enemies and parasites, its numbers will increase often far beyond anything possible to it in its native country: not infrequently, its abundance will force it into changed habits.

Most regions that are surrounded by barriers are devoid of a very great variety of species of animals or plants. However, the larger the area isolated, the greater the variety of forms.

Organisms whose fossils are found in any quantity, must have lived and died in the period when the strata in which their remains are found were laid down.

As nature progressed in the production of new forms new potentialities were also added.
The earth's position in relation to the sun is a determining factor of life on earth.

The environment of living things changes continually.

Many of the processes of change in the universe are rhythmic, or periodic, and life processes constitute no exception to the rule.

In higher plants and in the higher air-breathing vertebrates, a progressive emancipation from life in water and an adaptation to life on dry land is traceable.

One of the most "constant" features of natural phenomena is variability but the variability is always within definite limits.

Animals resemble each other more and more closely the farther back we pursue them in the embryological development.

All living things die, but life continues from age to age.

Individuality in an organism is maintained throughout life in spite of the fact that the actual chemical constitution of the living substances composing it is constantly changing.

The environment acts upon living things, and living things act upon their environment.

During the main development of any stock, for each type of organism that lives on to be ancestral to the next evolutionary phase, there are considerable numbers thrown off to live in a few tens of thousands of years and die without descendants.

Evolution has needed enormous lapses of time for its operation.

The less parental care given to the offspring, the greater is the need for the animal to be prolific.
The fact of primary importance in the history of life displayed by the geological periods is the orderly succession of living forms.

For most species of organisms the great checks on the increase in numbers are enemies, disease and competition between the individuals of the same species and of one species with another for food and other necessities of life.

Cells within an organism are dependent upon their environment as well as their genes in the process of becoming what they finally become.

When the balance of nature is disturbed, disastrous results often follow.

A balance of nature is maintained through inter-relations of plants and animals with each other and their physical environment.

Life exists from the depths of the ocean to the mountain heights.

The orderliness of the life processes of an organism is not an isolated orderliness, but one aspect of the orderliness of the universe.

Life may exist under conditions of light from bright sunlight to the complete darkness of caves or of depths of soil or water.

Certain associations of plants and animals are the result of a struggle for survival: for example, the community or social life, parasitism, and symbiosis.

The difference in motion and locomotion between animals and plants is one of degree.

There is a cycle, from inorganic substances in the air and soil to plant tissues, thence to animal tissue, from either of the last two stages via excretion or death and decay back to the air and soil. The energy for this everlasting rotation of life is furnished by the radiant energy of the sun.

The energy of solar radiation is continually working changes in the surface of the earth and the atmosphere surrounding the earth; all life on the earth is affected directly or indirectly by these changes.
Similar organisms are grouped together because they are believed to be related through common descent.

The evolution of the earth and the living things inhabiting it has resulted from the operation of natural forces.

Nearly all animals and plants lacking some means of mechanical support are debarred from terrestrial life.

When a large thickness of rocks show every evidence of having been laid down steadily and continuously, year after year, it may well change its character. If it changes its character, the character of the animals and plants which live on it and in it will change too.

Fossils dated by the rocks in which they are found, reveal portions of the actual story of life's past changes by a progression of forms from simple to complex.

The present is the key to the past: the succession of fossils in the rocks show a progressive series from simple to complex.

New species of plants and animals appear at some definite point on the earth and then spread out from that location as a center.

Fossilization is the fate of very few animals and plants. The great majority of dead things simply decay and disappear; and, then material is returned to the general circulation of nature to be built up into bodies of new organisms.

The most primitive and simplest forms of life existed in the oldest rocks, and organisms found in young and younger rocks represent higher and higher forms.

Each formation of sedimentary rock has its peculiar assemblage of fossils, and there is a definite relation between the fossils found in rocks and the position of these rocks in the geologic timetable.

The older layers of rock contain forms which are extremely unlike the now living animals and plants, while the more recent layers contain types more similar to our contemporary ones.

The life history of new individuals tends to recapitulate the history of the race.
The members of any species depend, on the one hand, upon its rate of reproduction and on growth, and on the other, upon its death rate from accidents, enemies and diseases.

Every living species is continually producing a multitude of individuals, many more than can survive, varying more or less among themselves and all competing with each other for the available energy.

Change in the numbers of organisms in communities may be rapid even though the environmental conditions apparently alter slowly and gradually.

The organisms most likely to survive and reproduce are those that are structurally and physiologically best fitted to their environment.

Cell division is the essential mechanism of reproduction, of heredity, and to a large extent of organic evolution.

In plants and animals subject to parthenogenetic development (development from unfertilized germinal cells) reduction of chromosomes does not occur.

In most cases, a character is not determined by a single gene but by the interplay of two or more genes. In this interaction the genes may interfere with, modify, counteract, or reinforce each other.

Genes that lie in the same chromosome tend to remain together in reduction division so that the characters which they determine are linked in inheritance.

The reproductive elements and their union in fertilization are fundamentally the same in plants and animals.

Organisms which have no means of reproduction other than asexual show very little variation.

Reproduction in all organisms is a process of growth and differentiation in which a single cell or a group of cells is separated from the parent body and develops into a new individual.

Certain one-celled organisms escape adverse conditions by forming highly resistant spores which often survive until conditions are again favorable.
Regeneration is almost universal among living things from the simple to the more complex animals the ability to regenerate lost parts and to reproduce asexually fall off, gradually and independently, as the body becomes more specialized.

Sexual union in plants and animals affords a method of variation due to the mixing of different protoplasms.

New types of living things arise through variations in the previously existing kinds.

The fundamental process of reproduction in all organisms whose cells possess nuclei is cell division which results in the precise distribution of the chromatin of the nucleus.

In-breeding in plants and animals results in a uniform strain.

Reversion occurs only when different varieties of plants or animals are crossed, never in genetically pure stocks.

Heredity supplies the native capacities of an organism; environment determines to a large extent how fully these capacities will be developed.

The genes of all organisms are subject to change, such changes producing heritable modifications in the organisms called mutations.

The history of organisms shows that evolution and race divergence has been the result of mutation.

Mutations occur, independently of the activities of individuals, as more or less haphazard hereditary variations.

All heritable variations, which are not the result of recombinations of genes, are mutations which are changes in genes, in some cases induced by environmental agents.

New kinds of living things have arisen through mutation.

Any hereditary change that follows the laws of Mendelian heredity is due to a gene mutation.
The genes in the chromosomes of eggs and sperms are the physical basis of heredity.

The separation of homologous chromosomes at reduction-division in the germ cell is a matter of chance—the separation in any one pair occurs absolutely without reference to what occurred in any other pair in the cell.

In the maturation of the sex cell at the pairing of the chromosomes, except for the single sex chromosomes, the two members of each pair come originally one from the paternal line and one from the maternal line.

In fertilization in most bisexual organisms, the egg contributes half the number of chromosomes to the zygote as does also the sperm.

Each kind of living thing has its characteristic chromosome complement, and the constancy of that complement is preserved at each cell division. Different species show the utmost diversity in numbers, size and form of chromosome.

The germplasm of animals and plants passes on from generation to generation and there has been a continuous stream from the first organisms to the present living organisms.

The fundamental function of the germplasm is the perpetuation of the species: the body or somaplasm serves as the vehicle for the germplasm.

In the vast majority of organisms, it is the male who has the unsymmetrical chromosomes complement and the sperms, therefore, are the decisive begetters either of males or of females.

Throughout the organic world there is a cyclic relation between death and the continuance of organic life.

Acquired characters are not inherited.

Species can and do become extinct, but they usually live on for ages in spite of the death of individuals.

Living organisms, during the growth period, increase the mass of the cell from within through ingestion and utilization of food substances. When the cell reaches a maximum size, mitosis usually results.
Sex is inherited. It follows a given distribution of the chromosomes according to definite Mendelian ratios.

The individuals of the first generation of hybrids, the F generation, are uniform in appearance in alternative inheritance... only one of the two parental characters, the stronger or the dominant one, is shown. In intermediate inheritance, a mixture of the parental characteristics is shown.

In polyhybrid crossings (F individuals with two or more pairs of hereditary characters), all combinations of the parental characters are shown in characteristic ratios.

In a cross of the F2 generation of hybrids, the genes, which determine the characters, are segregated in the gametes so that a certain per cent of the off-spring possess the dominant character alone, a certain per cent the recessive character alone, with a certain percentage again hybrid in nature.

All life comes from preceding life.

Many hereditary characters are subject to non-genetic or environmental variation in expression.

The ability and necessity of members of a species to produce other individuals like themselves is essential for the welfare and maintenance of the species, since no living thing can maintain itself for an unlimited period of time.

Throughout the plant and animal kingdoms there is a general preference for cross fertilization: an avoidance of union of the eggs with the male elements of the same individual. In these animals and in the great majority of plants which are hermaphroditic there are usually precautions to restrain self-fertilization.

Alternation of generations or a somewhat parallel process is characteristic of all higher plants but is comparatively uncommon with animals.

The most primitive method of reproduction employed by organisms is the splitting of the whole body into two halves, each of which grows into a complete new individual.
The hereditary characters in all organisms are determined by the genes which are carried in the chromosomes.

Living things reproduce offspring which possess the genes of their ancestors, though these offspring do not necessarily resemble any of these ancestors.

The sex chromosomes may carry the genes for a number of characters other than sex. Such characters are sex-linked.

During the process of maturation in an egg or sperm, corresponding maternal and paternal chromosomes, with their genes, go to different cells, in the reduction division so that each secondary oocyte or spermatocyte receives one but not both of these chromosomes with its genes.

No relation exists between the common origin of chromosomes from the same gamete and their later distribution during chromosome reduction. Chance alone seems to determine how the chromosomes are distributed.

The greater the distance two genes lie apart in the chromosome, the more often they will separate and cross over when a chromosome fragment and part of it adheres to another chromosome.

The heredity of an individual organism produced by sexual means is determined by what occurs to the chromosomes in the reduction division in maturation and in fertilization.

In plants, the gamete-bearing phase of the life cycle is haploid: the spore bearing phase is diploid. The reduction division occurs during spore formation.

In the second and later generations of a hybrid every possible combination of the parent character occurs and each combination appears in a definite proportion of the individuals.

Every individual organism is composed of distinct hereditary characters (genes.) In a hybrid, the different parental genes are combined. When the sex genes separate again, remaining quite unchanged and pure, each sex cell contains only one of the two genes of one pair.

Since the genes of the two parents combine at random in the germ cells, and since the germ cells meet at random in fertilization, the individuals of any generation occur in certain predictable ratios.
Asexual reproduction in organisms may be brought about by fission (simple division), by external or internal budding or by sporulations.

In organisms, which reproduce by sexual means, fertilization serves two functions—stimulation of the egg to develop and introduction of the heredity of the male parent.

All sexually reproduced individuals begin their careers as single fertilized cells.

Sexual reproduction is an almost universal method of reproduction and occurs in representatives of every phylum of plants and animals.

In sexual reproduction, a male cell from one parent unites with a female cell from the other parent to produce the young (except in the few cases of self-fertilization).

Living things come only from living things.

All modes of reproduction of organic life are alike in their nature, varying only in complexity of development. They fall into two general categories, asexual and sexual reproduction.

Except for those organisms which exhibit metagenesis all living things are able in one way or another to produce new living things like, or nearly like themselves.

Reproduction is a fundamental biological process that provides for the continuance of life on the earth by providing new individuals.

In many organisms the number of young which are produced bears a definite relation to the chance of survival: the smaller the chance, the more numerous the offspring.

Similarities in the embryological development of organisms show hereditary relationships between these organisms; the closer two species are related, the longer they parallel one another in development.

The hereditary characteristics possessed by any organism depends wholly upon the genes that were transmitted to it in the reproductive cells received from the parents.
The nucleus of a cell always contains a complex of protein materials, chromatin, the specialized vehicle which transmits hereditary characters in organisms.

The crises of evolution when they occur are not crises of variation but of selection and elimination; not strange births, but selective massacres. The germ plasm has gone on throwing up mutations at about the same rate age after age.

Hybridization gives variation, isolation gives fixation and fixation gives specialization.

Every cell originated from a cell and every chromosome from a chromosome.

Offspring produced asexually are almost always like the parent; they will have exactly the same or similar chromosomes and the same gene complex.

The genes in the chromosomes of the egg and the sperm are the carriers of the structural characters of the parents to the next generation.

Every animal comes into the world with a certain inherited endowment of congenital behavior.

The greater the period that has elapsed since two stocks diverged, the greater the difference in terminal products.

Meiosis or "chromosome reduction" from the diploid to the haploid number occurs at some stage in all organisms in which sexual processes take place; and when followed by the return to the diploid number of chromosomes at fertilization it keeps the number of chromosomes constant for the species.

Sexual union in plants and animals affords a method of variation due to the combining of the egg and sperm, with their chromosomes and genes, at the time of fertilization.
NERVOUS SYSTEM

In general, the extent of a response is rather definitely fixed for any given nerve cell. If a cell responds at all, it does so to its full capacity.

The nature of the response made by the cell to stimulus is determined by the nature of the responding protoplasm, as well as by the kind of stimulus.

All living things respond to stimuli in their environment.

The multitude of interrelated neurons of the nervous systems of higher animals form a complex system through which every organ of the body is in connection with every other organ.

The intelligence shown by a phylum of animals usually bears a direct relation to the stage of development of the species sense organs and to the proportionate size of the brain.

All animals can modify to some extent their inherent modes of reaction.

Inherent reactions in animals are unlearned, independent of intelligence and more or less inflexible in their operation. Under natural conditions they are usually beneficial to the individual or race.

Much of the behavior of living animals depends on their nervous organization, and they exhibit a great variety of behavior because the nervous organization varies in complexity.

From the simple to the complex organisms there is an increasingly elaborate coordination of receptivity of stimuli and response to stimuli.

EMBRYOLOGY

The embryos of different animals in addition to being more alike each other as development is traced backwards, show also a widening contrast with their parents and their adult destiny.
All cells arise through the division of previous cells (or protoplasm) back to the primitive ancestral cell (or protoplasm).

All embryos start from a single fertilized egg cell and grow through a division and re-division into the form of the organism which produces the egg cell.

The action of "organizers" (probably chemical in character) produced in the developing embryo causes the developing egg, which at first acts as a whole, to produce specialized parts which develop independently.

BIOCHEMISTRY

The secretions of the endocrine glands are absorbed directly into the blood stream from the gland tissue that produces them and are absorbed from the blood by the tissues or the organs whose activities are regulated by these substances.

All cells produce certain chemical compounds, secretions which may be used in the processes going on within the cell, in cavities adjoining the cells, or at considerable distances from the cells where they were produced.

The continuance of higher forms of life in anything like the present kinds and numbers would be impossible without bacteria and molds. They break down the complex carbohydrates and protein substances of dead plants and animals into simpler substances which may be used again by living plants.

Osmosis, the diffusion of molecules of a solvent (usually water) through a semi-permeable membrane (a layer of cells or the membrane of a single cell) concentration, with a stoppage of the flow of molecules of the solute, is a basic process, in plant and animal physiology.

Water is essential to all living things because protoplasmic activity is dependent upon an adequate water supply.

Life, as we know it, is dependent upon complex chemical compounds of carbon, nitrogen, hydrogen, oxygen and other elements.

Carbon and Nitrogen are the basic elements in the protoplasmic compounds.
PHOTOSYNTHESIS

Life depends for its primal food supply upon chlorophyll-bearing plants and for its sustained supply upon bacteria. The whole of life, considered chemically, is one cyclic process from chlorophyll-bearing plants to bacteria and so again to chlorophyll-bearing plants.

Chlorophyll-bearing plants are adapted for food making.

Carbon dioxide set free during the respiration of both plants and animals is absorbed by plants and used as a raw material for photosynthesis.

The oxygen of the atmosphere is removed by the animals and returned by chlorophyll-bearing plants.

In the presence of sunlight the chloroplasts of chlorophyll-bearing plants convert carbon dioxide and water into intermediate substances, and these into sugar, and that into starch, and liberate oxygen: thus, directly or indirectly producing practically all the food in the world.

The forms of all chlorophyll-bearing plants are adapted for carrying on photosynthesis.

All the energy used by chlorophyll-bearing plants in their secondary building processes comes from compounds formed in photosynthesis.

The carbohydrate foods made by the chloroplasts of chlorophyll-bearing plants are the original source of all energy used by plants themselves as well as that used by animals. (except by the autotrophic bacteria)

All living things, except chemo-synthetic bacteria depend directly or indirectly on photosynthesis for food.

In photosynthesis the energy of sunlight is used to lift the carbon to an energy level from which as it descends, it furnishes the energy level for the building of many compounds and for the carrying on of life processes.

The work of the chlorophyll of all chlorophyll-bearing plants is essential to all living things.
I. ASTRONOMY

Movements of all bodies in the solar system are due to gravitational attraction and inertia.

Since the earth rotates from west to east, the exact time (Arlington time) at which the sun is nearest overhead grows continually later as one travels from east to west around the earth's surface.

II. ATOMIC THEORY

Atoms may be broken down by bombarding the nucleus with high speed particles such as protons, alpha particles, or neutrons.

Gases conduct electric currents only when ionized.

The atoms of all radioactive elements are constantly disintegrating by giving off various rays (alpha, beta, and gamma) and form in helium and other elements.

An electric field may be produced in three ways: by rubbing or friction, chemical action, and using a magnetic field.

Two electro-magnetic waves having the same frequency and amplitude and traveling in nearly the same directions will interfere, constructively, or destructively, depending whether they are in phase or out of phase.

The mass of the atom is concentrated almost entirely in the nucleus.

The distances of successive electron shells from the nucleus of an atom and from each other, are much greater than the dimensions of the nucleus itself.

Radioactive emission involves nuclear changes.

Radioactivity is independent of all physical conditions, heat, cold, pressure and chemical state.

An electrical current will flow in the external circuit when two metals of unlike chemical activity are acted upon by a conducting solution, the more active metal being charged negatively.

In a transformer the ratio between voltages is the same as that between the number of turns.
The mass of any substance set free by electrolysis is proportional to the current flowing and the time of flow, if the quantity of electricity is kept constant the mass of various substances set free is proportional to their electro-chemical equivalent.

Positively charged ions of metals may be deposited on the cathode, as atoms, when a direct current is sent through an electrolyte.

Whenever a high frequency oscillating current produces in the field around it oscillating magnetic and electric fields, energy in the form of an electro-magnetic wave is transmitted through space.

Electro-magnetic waves may produce electrical oscillation in a conductor circuit which is so adjusted as to oscillate naturally with the same frequency as the incoming wave.

An electromotive force is induced in a circuit whenever there is a change in the number of the lines of force (magnetic) passing through the circuit.

A magnet always has at least two poles and is surrounded by a field of force.

Pieces of iron, steel, cobalt or nickel may become magnetized by induction when placed within a magnetic field.

Atoms have great subatomic energy.

Some elements have more than one atomic weight due to differences in the neutron content of the nuclei.

All matter is composed of single elements or combinations of several elements.

All substances are made up of small particles called molecules which are alike in the same substance (except for variations in molecular weight due to isotopes) but different in different elements.

The electrons within an atom form shells about the nucleus, each of which contains a definite number of electrons.

Matter may be transformed into energy and energy into matter.

All matter is made up of protons, neutrons, and electrons.
The materials forming one or more substances, without ceasing to exist, may be changed into one or more new substances which are measurably different.

Most atoms have the property of losing, gaining or sharing a number of outer shell electrons.

Protons and neutrons only are found in the nucleus of an atom.

Every pure sample of any substance, whether simple or compound, under the same conditions will show the same physical properties or the same chemical properties.

Energy can never be created or destroyed; it can be changed from one form to another only with exact equivalence.

### III. CHEMISTRY

Oxidation and reduction occur simultaneously and are quantitatively equal.

Electrolytes dissolved in water exist partially or completely as electrically charged particles called ions.

The exchange of the negative and positive ions of acids and bases results in the formation of eater and a salt.

The solubility of solutes is affected by heat, pressure, and the nature of the solute and solvent.

Oxidation always involves the removing or sharing of electrons from the element oxidized while reductions always add or share with the elements reduced.

The energy shown by atoms in completing their outer shell by adding losing or sharing electrons determines their chemical activity.

The valence of an atom is determined by the number of electrons it gains, loses, or shares in the chemical reactions.

Each element has its own characteristic X-ray spectrum.

The properties of alloys are dependent upon the relative amounts of their components, the extent of their compound formation, and upon the crystalline structure of the mixture.
Enzymes, vitamins, and hormones are chemical regulators of reactions that occur in living organisms.

Elements and compounds to which the cells of living organisms react specifically produce physiological effects.

Alcohols oxidize to aldehydes, ketones, and acids.

Alcohols react with acids to form esters and ethers.

Molecules of some compounds undergo polymerization.

The boiling point of hydrocarbons increases with an increase in molecular weight.

Saturated hydrocarbons are relatively inactive chemically, but form compounds by substitution.

Unsaturated hydrocarbons are active chemically, and form many compounds by addition.

Carbon atoms form a number of "type groups" of compounds which are determined by the elements present and by the structural combinations of the atoms within the molecules.

Temperature changes, pressure changes, the presence of electrolytes or the presence of oppositely charged particles may cause colloids to precipitate.

Colloidal particles may carry electrical charges.

Reactions occurring at ordinary temperatures are predominately exothermic.

When a chemical change takes place without the addition of heat from external sources, that substance which has the greatest heat of formation will tend to form.

The heat of formation of any chemical compound equals its heat of decomposition.

Each combustible substance has a kindling temperature which varies with its condition but may be greater or less than the kindling temperature of some other substance.
No chemical change occurs without an accompanying energy change.

Elements may be changed into other elements.

The total mass of quantity of matter is not altered by any chemical changes occurring among the materials composing it.

The products of reacting substances may react with each other to form the original substances.

A pure chemical substance may be prepared from raw materials through utilization of their physical and chemical properties.

The orderly arrangement of molecules, or atoms or ions in crystals give crystals their regular form.

The properties of elements show periodic variations with their atomic numbers.

A few elements are inert or chemically inactive because their atoms are so constructed as to be complete in themselves; i.e., their outer rings have no tendency to gain or lose electrons.

The valence of an atom is determined by the number of electrons it gains, loses, or shares in a chemical reaction.

The energy shown by atoms in completing their outer shell by adding, losing, or sharing electrons determines their chemical activity.

The rate of osmosis is directly proportional to the difference in concentration on opposite sides of the membrane.

Diffusible substances tend to scatter from the point of greatest concentration until all points are at equal concentration.

Atoms of all elements are made up of protons, neutrons, and electrons; and differences between atoms of different elements are due to the number of protons and neutrons in the nucleus and the configuration of electrons surrounding the nucleus.

Colloids have the property of adsorption to an unusual degree.

Colloids show greater chemical activity than the solid substance in mass, since rates of reaction are proportional to the surface area of the solid, other factors being equal.
Surface reactions predominate in all non-homogeneous reactions.

Suspended particles of colloids have a continuous, erratic movement due to colloidan and molecular or ion impacts.

Whenever the product of the concentrations of any two ions in a mixture is less than the value of the ion product in a saturated solution of the compound formed by their union, this compound, if present in the solid form will be dissolved.

Whenever the product of the concentrations of any two ions in a mixture exceeds the value of the ion product in a saturated solution of the compound formed by their union, this compound will be precipitated.

In a saturated solution the product of the molar concentration of the ions is constant.

The solubility of a gas in an inert solvent varies directly with the pressure to which the gas is subjected.

Any substance soluble in two immiscible liquids will distribute itself between the two in proportion to its solubility in the two liquids.

The ingredients of a solution are homogeneously distributed throughout each other.

Salts of strong acids and strong bases undergo negligible hydrolysis while salts of inactive acids and inactive bases undergo more marked hydrolysis.

Simple ionic reactions are typically rapid reactions.

Electrolytes dissolved in water exist partially or completely as electrically charged particles called ions.

The activity of an acid or a base is proportional to the degree of ionization of the compound when in solution.

The exchange of positive and negative ions of bases and acids results in the formation of water and a salt.

The activity of an acid or a base is proportional to the degree of ionization of the compound when in solution.
Acids and bases are substances which in water solution ionize to give hydrogen and hydroxyl ions, respectively, from their constituent elements.

Non-metals comprise a group of elements whose atoms tend to gain electrons and whose compounds, when dissolved in polar solvents, are capable of forming negative ions.

Metals compose a group of elements (other than H\textsubscript{2}) whose atoms have a tendency to lose electrons readily and whose compounds when dissolved in polar solvents are capable of forming positive ions.

Non-metals may be arranged in an activity series according to their tendency to pass into ionic form by gaining electrons.

Metals may be arranged in an activity series according to their tendency to pass into ionic form by losing electrons.

Every chemical element when heated to incandescence in a gaseous state has a characteristic glow and characteristic spectrum which can be used to identify very small quantities of the element and which is related to the molecular and atomic structure of the gas.

The specific heats of any element are approximately inversely proportional to their atomic weights.

Equal amounts of heat raise equal numbers of atoms in the solid state through nearly equal intervals of temperature.

At a definite pressure and temperature, the relative combining volumes of gases and of gaseous products may be expressed approximately in small whole numbers.

Equal volumes of all gases under similar conditions of temperature and pressure contain very nearly the same number of molecules.

The rates of many reactions are affected by the presence of substances which do not enter into the completed chemical reaction.

Chemical reactions may be carried more nearly to completion by any condition that establishes an unusually low concentration of one of the products.
The speed of chemical reaction is increased by increasing the concentration of any of the reactants; and is decreased by decreasing the concentration of any of the reactants.

The gravimetric composition of a compound may be found by multiplying the atomic weights of the elements by their subscript in the formula of the compound.

When different amounts of one element are found in combination with a fixed weight of another element (in a series of compounds) the different weights of the first element are related to each other by ratios which may be expressed by small whole numbers.

In every sample of every compound substance formed, the proportion by weight of the constituent elements is always the same as long as the isotopic conditions of each element are constant.

If stress is applied to a reversible chemical system, there will be a readjustment in the system to relieve the stress.

All chemical reactions which start with the same quantities of original substances, liberate the same amounts of energy in reaching a given final state, irrespective of the process by which the final state is reached.

IV. ELECTRICITY AND MAGNETISM

When a current-carrying wire is placed in a magnetic field, there is a force acting on the wire tending to push it at right angles to the direction of the lines of force between the magnetic poles, providing the wire is not parallel to the field.

The force of attraction or repulsion between two magnetic poles varies directly as the pole strengths and inversely as the square of the distance between the poles.

Magnets depend for their properties upon the arrangement of the metallic ions of which they are made up.

Electrostatic induction is the separation of charges on a conductor through the influence of a neighboring charge.
The force of attraction or repulsion between two small charged bodies varies directly as the product of the two charges and inversely as the square of the distance between the charges.

In an uncharged body there are as many protons as electrons and the charges neutralize each other; while a deficiency of electrons produces a plus charge on a body and an excess of electrons produces a negative charge.

Electrons have both a magnetic and an electric field.

Electrons will always flow from one point to another along a conductor if this transfer releases energy.

The resistance of a metallic conductor depends upon the kind of material from which it is made, varies directly with the length, inversely with the cross sectional area, and increases as the temperature increases. The amount of heat produced by an electric current is proportional to the resistance, the square of the current, and the time of flow.

Electrical power is directly proportional to the product of the potential difference and the current.

Energy in kilowatt hours is equal to the product of amperes, volts, and time (in hours) divided by one thousand.

An induced current always has such a direction that its magnetic field tends to oppose the motion by which the current was produced.

The magnitude of an induced e.m.f. is proportional to the rate at which the number of lines of magnetic force change and to the number of turns of wire in the coil.

In a parallel circuit the total current is the sum of the separate currents, the voltage loss is the same for each branch, and the total resistance is less than the resistance for any one branch.

In a series circuit the current is the same in all parts, the resistance of the whole is the sum of the resistance in the parts, and the voltage loss of the whole is the sum of the voltage losses of the parts.

Condenser capacity varies directly with the area of the plates, and inversely as the thickness of the insulation between them.
Alternating current charges a capacitor twice during each cycle inducing opposite charges on the two plates with the result that a current appears to flow through the condenser.

By means of high-frequency generators or vacuum-tube oscillators sustained or continued oscillations can be produced in a condenser circuit. Their intensity is made to vary with audio-frequency currents in a transmitter circuit to produce radio waves.

Like electrical charges repel, and unlike electrical charges attract.

In an uncharged body there are as many protons as electrons, and the charges neutralize each other, while a deficiency of electrons produces a plus charge on a body and an excess of electrons produces a negative charge.

An electrical charge in motion produces a magnetic field about the conductor its direction being tangential to any circle drawn about the conductor in a plane perpendicular to it.

All materials offer some resistance to the flow of electric current, and that part of electrical energy used in overcoming this resistance is transformed into heat energy.

The resistance of a metallic conductor depends on the kind of material from which the conductor is made, varies directly with the length, inversely with the cross-sectional area, and increases as the temperature increases.

The electrical current flowing in a conductor is directly proportional to the product of the potential difference and inversely proportional to the resistance of the resistance.

Electrical power is directly proportional to the product of the potential difference and the current.

V. GAS

The higher the temperature of the air the greater is the amount of moisture required to saturate it.

The atmospheric pressure decreases as the altitude increases.
Heat is liberated when a gas is compressed, and is absorbed when a gas expands.

The volume of an ideal gas varies inversely with the pressure upon it providing the temperature remains constant.

A gas always tends to expand throughout the whole space available.

If the same pressure is maintained, the volume of a gas is varied directly as the absolute temperature.

If the volume of a confined body of gas is kept constant, the pressure is proportional to the absolute temperature.

When a mixture of gases is confined, each exerts its own pressure without reference to the pressure exerted by others.

The atmospheric pressure decreases with increasing water vapor content, other things being equal.

In the northern hemisphere great volumes of air tend to revolve in a counter-clockwise direction, and in the southern hemisphere, they revolve in a clockwise direction.

In moving air, wind pressure increases as the square of the velocity.

The speed of diffusion of gases varies inversely with the square root of their densities.

Gases may be converted into liquids by reducing the speed of their molecules.

The rate of evaporation of a liquid varies with the temperature, area of exposed surface, and saturation and circulation of the gas in contact with the liquid.

The rate of vaporization decreases with an increase in concentration of the vapor in the gas in contact with the liquid, the temperature remaining constant.

Heat is conducted by the transfer of kinetic energy from molecule to molecule.
When two bodies of different temperature are in contact, there is a continuous transfer of heat from the body of higher temperature to the body of lower temperature, the rate of which is directly proportional to the difference of temperature.

VI. GEOLOGY

The natural movements of air, water, and solids on the earth are due chiefly to gravity plus the rotation of the earth.

Strata of rocks occur in the earth's crust in the order in which they were deposited, except in the case of overthrust faults.

The earth's surface may be elevated or lowered by interior forces.

When elevations or depressions are created upon the surface of the earth, the elevations are usually attacked by the agents of erosion and the materials are carried to the depressions.

The rate of erosion is inversely proportional to the resistance of rocks to decomposition and disintegration.

Continual erosion results in decreasing the average density of continental masses, and continual deposition in increasing the average density of rocks under the ocean.

Streams potentially have a regular cycle: youth, maturity, and old age.

Streams generally are lowering the surface land in some places and building it up on other places.

Falls and rapids tend to develop in a stream bed whenever the stream flows over a hard stratum to a soft one.

The transporting power of streams varies approximately as the fifth power of the velocity.

Glacial conditions are, as a rule, approached by increasing latitudes or altitudes.

Glacial abrasion occurs in proportion to the weight of the ice and the velocity of its movement.
Under the high pressures which occur in the earth's interior, materials that are usually solid have the capacity to flow slowly and thus bring about equalization of pressure differences on the surface.

Forces within the earth may cause breaks to appear in the earth's crust.

Earthquakes are produced by the sudden slipping of earth materials along faults.

Rocks may be folded to form mountains.

Igneous rock may be formed from materials intruded into other rocks.

Parent materials for the development of soils is formed through the physical disintegration and chemical decomposition of rock particles and organic matter.

Rocks may be metamorphosed, or changed, by heat, pressure, and flexion.

Rocks may be formed by the compacting and cementing of sediments.

Rocks may be formed by the cooling and solidifying of molten material.

VII. HEAT

Radiant energy travels in waves along straight lines, its intensity at any distance from a point source is inversely proportional to the square of the distance from the source.

The more nearly vertical the rays of radiant energy, the greater the number that will fall upon a given horizontal area, and the greater is the amount of energy that will be received by that area.

The amount of heat developed in doing work against friction is proportional to the amount of work thus expended.

The average speed of molecules increases with the temperature and pressure.
Solids are liquified and liquids vaporized by heat; the amount of heat used in this process, for a given mass and given substance, is specific and equals that given off in the reverse process.

The lower the temperature of a body the less the amount of energy it radiates; the higher the temperature, the greater is the amount of energy radiated.

The amount of heat which a constant mass of a liquid or solid acquires when its temperature rises a given amount is identical with the amount given off when its temperature falls by that given amount.

Heat is transferred by convection in currents of gases or liquids, the rate of transfer decreasing with an increase in the viscosity of the circulating fluid.

When a gas expands, heat energy is converted into mechanical energy.

The principal causes of wind and weather changes is the unequal heating of different portions of the earth's surface by the sun; thus all winds are convection currents caused by unequal heating of the earth's atmosphere, and they blow from places of higher atmospheric pressure to places of lower atmospheric pressure.

Most bodies expand on heating and contract on cooling; the amount of change depending on the change in temperature.

Bodies of land heat up and cool off more rapidly than bodies of water.

Substances which expand upon solidifying have their melting points lowered by pressure; those which contract upon solidifying have their melting points raised by pressure.

The boiling point of any solution becomes lower as the pressure is decreased and higher as the pressure is increased.

The freezing point depression and the boiling point elevation are proportional to the concentration of the solution.

The presence of a dissolved substance will cause the resulting solution to boil at a higher temperature and to freeze at a lower temperature than pure water.

Every pure liquid has its own specific boiling and freezing points.
The total change in the length of a metal bar is equal to its coefficient of linear expansion times the original length times the change of temperature.

Heat is conducted by the transfer of kinetic energy from molecule to molecule.

The atmosphere of the earth tends to prevent the heat of the earth's surface from escaping, and the earth begins to cool only when the amount of heat lost during night exceeds the amount of heat gained during the day.

Condensation will occur when a vapor is at its saturation point if centers of condensation are available and if heat is withdrawn.

If the vapor pressure of the water of hydration exceeds that of the moisture in the air, crystals will gradually yield up water to the air and VV.

VIII. LIGHT

Dark, rough, or unpolished surfaces absorb or radiate energy more effectively than light, smooth, or polished surfaces.

The darker the color of a surface the better it absorbs light.

Light travels in straight lines in a medium of uniform optical density.

Waves travel in straight lines while passing through a homogeneous or uniform medium.

If a beam of light falls upon an irregular surface, the rays of light are scattered in all directions.

When light is reflected the angle of incidence is equal to the angle of reflection.

Electrons are emitted from any sufficiently hot body.

Electrons change energy levels emitting or absorbing energy.
In a tube which contains gas at low pressure subject to an intense electric field, cathode rays, streams of electrons, move away from the negatively charged terminal at high speed.

A number of substances will emit electrons and become positively charged when illuminated by light.

Atoms or molecules may lose electrons when struck by high speed electrons or ions.

When a stream of high speed electrons strikes a body, the atoms of the body emit X-rays.

Incandescent solids and liquids emit all wave lengths of light and give a continuous spectrum.

When white light passes through a substance that absorbs some waves and not others, certain bands of color with the production of an absorption spectrum.

The speed of light in any given substance bears a constant ratio to the speed of light in air.

The dispersion of white light into a spectrum by a prism is caused by unequal refraction of the different wave lengths of light.

Whenever an opaque object intercepts radiant energy travelling in a particular direction, a shadow is cast behind the object.

The colors of objects depend upon the light rays they transmit, absorb, or reflect.

When a body which emits a bright-line spectrum is moving toward or away from the observer, the lines are shifted toward the short or long wave length, respectively.

Each vibrating particle in a wave front of any wave motion may be considered as a secondary source of spherical wavelets which spread out from their sources with the velocity of the primary wave.

All rays passing through the center of curvature of a mirror are reflected upon themselves.
Luminous vapors and gases emit only certain kinds of light producing bright-line spectra.

When parallel light strikes a concave spherical mirror the rays, after reflection, pass directly through the principal focus only if the area of the mirror is small compared with the radius of curvature.

The curvature of a wave front will be changed a given amount by a lens, namely, \( 1/F \).

An image appears to be as far back of a plane mirror as the object is in front of the mirror and is reversed.

When light is incident upon a medium in which it will travel faster and when the angle of incidence is greater than the critical angle, it is totally reflected.

The sum of the reciprocals of the conjugate focal lengths of a lens or mirror equals the reciprocal of the principal focal length.

In a plane mirror a line running from any point on the object to the image of that point is perpendicular to the mirror.

The dimensions of an image produced by a lens or a mirror are to the dimensions of the object as their respective distances from the lens or mirror are to each other.

A beam of light may become plane polarized as a result of any circumstance which results in the suppression of one of the rectilinear components of the vibration without affecting the component at right angles to it.

Parallel light rays may be converged or focused by convex lenses or concave mirrors; diverged by concave lenses or convex mirrors.

When light rays pass obliquely from a rare to a more dense medium, they are bent or refracted toward the normal and when they pass obliquely from a dense to a rarer medium, they are bent away from the normal.

Radiant energy travels in waves along straight lines; its intensity at any distance from a point source is inversely proportional to the square of the distance from the source.
The intensity of illumination decreases as the square of the distance from a point source.

When light rays are absorbed, some of the light energy is transformed into heat energy.

When waves strike an object they may be absorbed, transmitted, or reflected.

Energy is often transmitted in the form of waves.

IX. LIQUIDS

A liquid will rise in a capillary tube if the contact angle between the liquid and the side of the tube is less than 90 degrees and will be depressed if the contact angle is greater than 90 degrees.

The height to which a liquid rises in a capillary tube is directly proportional to the surface tension of the liquid and inversely proportional to the density of the liquid and to the radius of the tube.

A body immersed or floating in a fluid is buoyed up by a force equal to the weight of the fluid displaced.

The pressure of a fluid in the open is equal to the weight of the fluid above a unit area including the point at which the pressure is taken; it therefore varies with the depth and average density of the fluid.

A fluid has a tendency to move from a region of higher pressure to one of lower pressure; the greater the difference, the faster the movement.

The pressure at any point in a fluid is the same in all directions.

Fluids have no elastic limit for compression.

The free surface of a liquid contracts to the smallest possible area due to surface tension.

The pressure of a saturated vapor is constant at a given temperature. It increases with an increase in temperature.
As the velocity of flow through a constricted area increases, the pressure diminishes.

All liquids are compressible but only to a slight degree.

When pressure is applied to any area of a liquid in a closed container, it is transmitted in exactly the same intensity to every area of the container in contact with the liquid.

Any homogeneous body of liquid free to take its own position will seek a position in which all exposed surfaces lie on the same horizontal plane.

X. MECHANICS

In the lever the force times its distance from the fulcrum equals the weight times its distance from the fulcrum.

When there is a gain in the mechanical advantage by using a simple machine, there is a loss in speed, and vice versa.

The work obtained from a simple machine is always equal to the work put in less the work expended in overcoming friction.

The amount of momentum possessed by an object is proportional to its mass and to its velocity.

When one body exerts a force on a second body, the second body exerts an equal and opposite force on the first.

The acceleration of a body is proportional to the resultant force acting on that body and is in the direction of that force.

When the resultant of all the forces acting on a body is zero, the body will stay at rest if at rest, or it will keep in motion in a uniform straight line if it is in motion.

When two forces act upon the same object, the resultant is the diagonal whose sides represent the direction and magnitude of the two forces. A single force represented by the diagonal may be resolved into two forces represented by the sides of the parallelograms.
The energy which a body possesses on account of its position or form is called potential energy, and is measured by the work that was done in order to bring it into the specified condition.

The energy which a body possesses on account of its motion is called kinetic energy and is proportional to its mass and the square of its velocity.

A spinning body offers resistance to any force which changes the direction of the axis about which the body rotates.

The period of a pendulum swinging through short arcs is independent of the weight of the bob but varies directly as the square root of the length and inversely as the square root of the acceleration of gravity.

At any point on the earth's surface all bodies fall with a constant acceleration which is independent of the mass or the size of the body if air resistance be neglected.

The distance a body travels, starting from rest with a constant acceleration, is equal to one half the acceleration times the square of the time.

Centrifugal force is directly proportional to the square of the velocity to the mass, and inversely proportional to the radius of rotation.

Bodies in rotation tend to fly out in a straight line which is tangent to the arc of rotation.

Any bodies attract one another with a force which is directly proportional to the attracting masses and inversely proportional to the square of the distance between their centers of mass.

The distortion of an elastic body is proportional to the force applied provided the elastic limit is not exceeded.

Sliding friction is dependent upon the nature and condition of the rubbing surfaces, proportional to the force pressing the surfaces together, and independent of the area of contact.
Musical tones are produced when a vibrating body sends out regular vibrations to the ear while only noises are produced when the vibrating body sends out irregular vibrations to the ear.

The frequency of vibration of a stretched string is inversely proportional to its length, diameter, and square root of its density; and directly proportional to the square root of the stretching force.

Two sound waves of the same or nearly the same frequency will destructively interfere with each other when the condensations of the one coincide with the rarefactions of the other provided that the directions of propagation are the same.

Sound waves or other energy impulses may set up vibrations in a body the amplitude of which is increased if the impulses are exactly timed to correspond to any one of the periods of vibration of the body.

Harmonious musical intervals correspond to very simple frequency ratios.

The speed of sound increases with an increase in temperature of the medium conducting it.

The velocity of sound is directly proportional to the square root of the elasticity modulus and inversely proportional to the square root of the density of the medium transmitting it.

When energy is transmitted in waves, the medium which transmits the wave motion does not move along with the wave, but the energy does.

Sound waves are reflected in a direction such that the angle of incidence equals the angle of reflection.

The speed of a wave is equal to the product of its frequency and its wave length.

The loudness of a sound depends upon the energy of the sound waves and if propagated in all directions, decreases inversely as the square of the distance from its source.
Smooth surfaced tubes may be used to confine the direction of sound waves and thus prevent the rapid decrease of intensity with distance from the source, which would otherwise take place.

When a sounding body is moving toward or away from an observer the apparent pitch will be higher or lower, respectively, than the true pitch of the sound emitted.

The quality of a musical tone is determined by the pitch and intensity of the different simple tones or harmonics into which it may be resolved.

Sound is produced by vibrating matter and is transmitted by matter.

The higher the pitch of a note, the more rapid the vibrations of the producing body, and vice versa.