THE CONSTRUCTION AND USE OF STUDENT-MADE APPARATUS FOR HIGH SCHOOL PHYSICS CLASSES

by

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CHAPTER I

INTRODUCTION

Many physics teachers have been confronted with various problems created by poor apparatus or lack of proper equipment. This is particularly true in smaller high schools where sufficient funds are not always available. A number of educators have recognized this difficulty and have suggested school-constructed apparatus as a means of coping with such a situation.

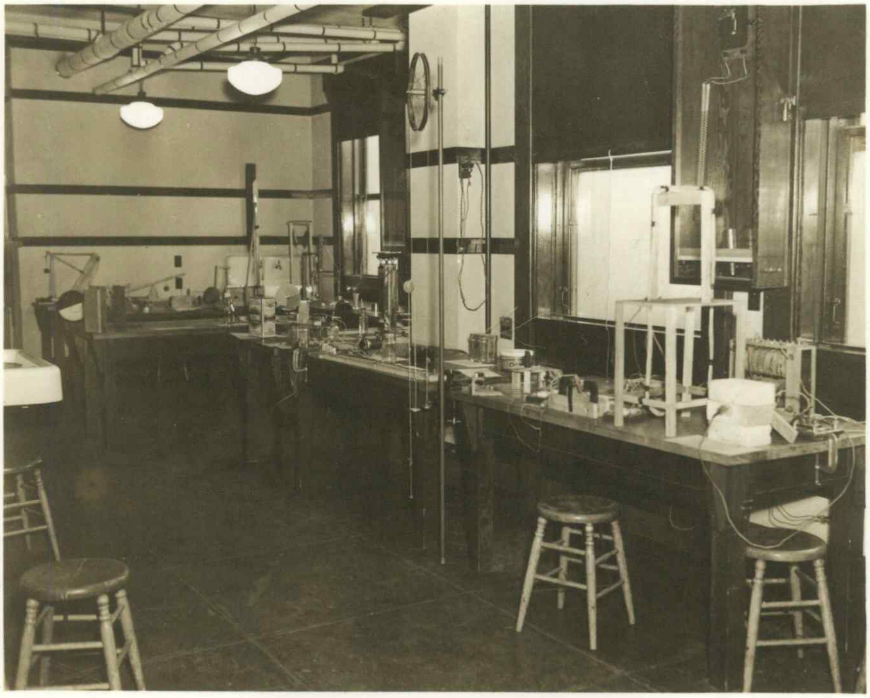
Such difficulties have been experienced by many teachers in Oregon. This fact was brought out in a talk given at a meeting of the Oregon Chapter of the Associated Physics Teachers in McMinnville, Oregon, November, 1938, at which a teacher referred to the lack in her high school of proper apparatus for the teaching of physics. As a result of this complaint, the writer became interested in this problem and decided to make an investigation and present the results at the next meeting of the Association the following February. This study was selected in the hope of suggesting a solution for the problem mentioned by the teacher, but it led to further investigation which furnished the foundation for this thesis. It was decided that the problem might be solved by having the students construct the apparatus. The details of the project were planned by a committee of three high school teachers and a college physics professor.

To encourage students to use their ingenuity rather than burden the teacher, the construction of the apparatus in this project was assigned to a small group of high-school students. These students were selected because they had time for and an interest in the work. During a brief period of three weeks, these few students constructed sufficient apparatus to supply a high school laboratory for a course in physics. Pictures of the apparatus built by these students may be seen on pages 3 and 4. These pictures were taken immediately after the demonstration referred to above. The students were present at the conference to answer questions or to demonstrate the use of the apparatus.

Purpose and Value.

The original purpose of this project was to provide teachers with enough apparatus at a minimum cost for a complete course in physics. In addition to fulfilling the purpose for which this investigation was originally

Some Examples of Student-constructed Apparatus



Some Examples of
Student-constructed Apparatus

intended, this project had other educational values. It developed in the students who took part in the work a clearer understanding of the principles of physics and a sense of responsibility. It also tended to create a feeling of confidence and gave the students a chance to use their ingenuity. Last, but not least, was the increased interest which the students manifested in the scientific principles as the work proceeded.

Source of Data.

In order to complete this study, it was necessary to secure information dealing with three phases of the investigation: (1) the experiments considered essential to a course in high-school physics by the majority of the workbooks, (2) how apparatus may be made from inexpensive materials in the school itself, and (3) by whom the apparatus should be made.

The problem of finding experiments considered essential to a high-school course in physics was easily solved. The group of teachers, which included the writer, planned this study, analyzed all available laboratory manuals, and selected experiments which were considered essential to a course in high-school physics. Another study, by Kiebler and Curtis, which presented an analysis of eight different workbooks, was used to verify the findings of the survey above.

To discover how apparatus can be inexpensively made, several studies on school-constructed apparatus were consulted. These studies include (1) articles on school-constructed apparatus in the various educational periodicals, (2) a few books on the subject, and (3) information contributed by each member of the group of teachers from his own laboratory experience. Some studies described simple home-made apparatus, with the inference that it should be made by the teacher; but only two studies suggested student-made apparatus.

Treatment of Data.

As indicated above, this study involved the following three steps: (1) analysis of workbooks in accordance with the Oregon course of study; (2) preparation of a list of the essential experiments; and (3) determination of apparatus which could be used for these experiments and which could be made by the students selected.

In the analysis of workbooks, the Oregon course of study for high-school physics suggests that the program be divided into eight units. Using these eight headings, the latest editions of eleven available workbooks were analyzed and the experiments were listed under the correct units.

The number of experiments on each topic was indicated in the columns under specific headings. After being listed in table form, as shown in Chapter Three, the data were analyzed, and experiments appearing in over 50 per cent of the workbooks were designated as essential. The remaining experiments were considered supplementary. Each experiment listed as essential was then analyzed to determine the material needed to construct the apparatus.

The next step was to discover how to make the apparatus required for these experiments. The directions for making the apparatus were obtained from one of the printed sources* or were evolved by the committee of teachers. Several methods of constructing the equipment were found. The teacher, the Industrial Arts department, or the students themselves could make the apparatus. It was evident from the start that the teacher would not have the time to make all of the apparatus. Also it seemed probable that women teachers might experience difficulty in constructing the necessary pieces. In order that this study might be effective in helping to solve the problem of lack of apparatus in all high schools, it was considered

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*Sources refer to studies mentioned in page 6 and include: "The Science Classroom", "School Science and Mathematics", "Science Education", "The Science Masters' Book", by G. H. J. Adlam, "The Laboratory Workshop", by Duckworth and Harries, "Science Experiences with Home Equipment", and "Science Experiences with Inexpensive Equipment", by C. J. Lynde.

essential that the means of construction of the equipment should be available to all high schools. The use of the Industrial Arts department was abandoned since many of the smaller schools do not offer this type of work. It was concluded, therefore, that the student should be asked to undertake the construction of the equipment so that he might have the additional experience in using his ingenuity. When the list of essential experiments was complete, four students, who had both time for and interest in the project, were selected from two physics classes in the Corvallis High School. These students were assigned pieces of apparatus required by the experiments in each of the units suggested in the State Course of Study. Each student completed the pieces of apparatus for his list and prepared himself to explain the principles of physics involved.

<u>Limitations</u>.

As this study progressed, certain limitations became apparent:

(1) When the student-constructed apparatus was assembled and the experiments were performed, it was found that in some cases the results were not quite as accurate as those obtained by using commercial equipment. However, as Mr. G. H. Hyde remarks in an article on "Home-made Apparatus

for the Physics Class", accuracy rather than the principle of physics may often become the end sought by the student.

(2) Although each item of the suggested apparatus was planned for student-construction, part of the equipment was not actually prepared. Two reasons accounted for this: (a) one student was ill and unable to complete the pieces assigned to him, and (b) several pieces of equipment were added to the list after the project was completed. However, these pieces were carefully selected with simplicity of construction as the first consideration, and most of the equipment which was not tried had been used by other writers and found to be suitable for student-construction.

<u>Summary</u>.

This chapter has presented a short history, the purpose, the sources of the data, the limitations and an outline of the treatment of the data. In the succeeding chapters the problem of constructing the apparatus for a complete physics course will be discussed more fully. Chapter Two deals with similar studies; Chapter Three presents an analysis of workbooks to determine the experiments essential for a course in high school physics. Chapter Four Describes each experiment and explains the process of constructing the various pieces of equipment. A summary of the entire study is given in Chapter Five.

CHAPTER II

REVIEW OF SIMILAR STUDIES

There are a few studies which deal with one or more phases of the problem of laboratory apparatus for the high school physics class. Those studies which have a direct bearing on the problem of this thesis have been carefully reviewed; other studies are merely mentioned when they deal with only one phase of the investigation.

The source material reviewed included articles, theses, and books. The material fell naturally into two distinct classes: (1) studies dealing with the course content of high school physics, and (2) studies dealing with school-constructed physics apparatus.

STUDIES ON CONTENT OF LABORATORY COURSE

Kiebler and Curtis' Study.

This is the only study reviewed which dealt wholly with content of the laboratory course in physics. E. W. Kiebler and F. D. Curtis (54:252)[‡] in a study made at the University of Michigan in 1929, conducted an analysis of eight laboratory manuals*. Two purposes for this investiga-

‡ (54:252), 54 refers to the reference number and 252 to the page number in the bibliography.
* Six of these same manuals, in later editions, were analyzed for this thesis.

tion were outlined by the authors: (1) to study the relative frequency of the appearance of experiments in widely used manuals, and (2) to ascertain the relative importance assigned to these experiments in the judgment of competent experts. The manuals selected by Kiebler and Curtis were: Fuller and Brownlee, Conrad, Black, Good, Chute, Millikan and Gale, Dull and Henderson.

Kiebler and Curtis divided the entire course into five classifications: Mechanics, Heat, Light, Sound, and Electricity. After the experiments found in the eight workbooks had been listed under the appropriate headings, copies of the list were sent to 100 qualified experts who were asked to designate each experiment as: (1) essential, (2) desirable, or (3) undesirable.

A summary of the results of this study by Kiebler and Curtis as indicated in Table I show:

(1). No experiment was considered essential by all of the experts. Four experiments appeared in all eight manuals. Twenty-five exercises appeared in more than 50 per cent of the workbooks and were also considered essential by over half the experts, as shown in Table I. Twelve exercises were contained in over half of the manuals, but were not considered essential by at least 50 per cent of the experts. Twenty experiments which were not found in half of the workbooks were considered essential by over 50 per cent of the authorities. The authors state that a rich laboratory course for a high school physics class could be constructed from the 56 experiments listed in the three columns of Table I.

(2). Only two exercises were added by the experts to those found in the workbooks; hence the workbooks must contain the exercises appropriate to the laboratory course in physics.

(3). Of seventy-three exercises which appeared in not more than one workbook, six were considered essential by over half the authorities. Thirty-five of these were considered desirable by the investigators.

(4). Only one experiment, "Latent Heat of Fusion", was considered essential by all the evaluators. In general, exercises appearing in but few workbooks were considered essential by few experts.

Table I.

Experiments Considered Essential in a High School Physics Course According to Kiebler and Curtis

Considered Essential by:			
Classification	Most authorities and most workbooks*	Most authorities*	Most workbooks*
	Archimedes' principle Specific gravity Light solids Heavy solids Boyle's law	Measurement of a triangle Specific gravity by hydrometer Principle of moments	Comparison of Metric and English systems Volume of irregular body The barometer
Mechanics	Resultant of two forces Parallel forces Laws of the pendulum Hooke's law Levers Inclined plane Heat of vaporization Expansion coefficient Specific heat	Laws of friction	Efficiency of a machine
Heat	Latent heat of fusion Boiling point Evaporation Humidity Zero point of a thermometer		

*Most here means over 50 per cent.

Table I (continued)

Experiments Considered Essential in a High School Physics Course According to Kiebler and Curtis

Considered Essential by:			
Classification	Most authorities and most workbooks*	Most authorities*	Most workbooks*
Electricity and Magnetism	Lines of magnetic attraction Cells (primary) Magnetic effect of a current Dynamo and motor	Electroscope Wheatstone bridge	Electrolysis Electrotyping Electric bell Resistance by volt-ammeter Grouping of cells Induced currents E. M. F. Ohm's law Storage battery
Sound	Laws of vibrating strings Velocity of sound	Frequency of vibration of tuning fork	Length of sound wave Resonance
Light	Refraction Image in plane mirror	Photometry Refraction in water Concave mirror Telescope and microscope	Reflection Dispersion Lenses-images Focal length of lenses

*Most here means over 50 per cent.

STUDIES ON SCHOOL-CONSTRUCTED APPARATUS

Haupt's Bibliography

G. W. Haupt, (43:251) in an article in the magazine "School Science and Mathematics", presents a list of references on how to construct various pieces of laboratory and demonstration apparatus. Mr. Haupt lists the references under the usual headings of mechanics, solids, liquids, gases, heat, light, sound, magnetism, electricity, invisible radiations, wireless, and unclassified. The author presents the following information along with each of his references: (1) title of the article as stated by its author, (2) contributor's name, (3) source of the article, including volume, page numbers, and year of publication, (4) a few brief comments giving a clue to the nature and possible uses of the appliance, as an aid to selection, (5) in many cases a statement of materials required for construction and manipulation of device.

The topics for which Mr. Haupt lists references are classified under the usual headings as follows:

I. <u>Mechanics</u> (solids)

Acceleration, Atwood machine, falling bodies, free-fall machine, acceleration of gravity, falling body for elementary work, guinea and feather experiment, path of projectile, pendulum movements, momentum balance, impulse apparatus for Newton's second law of motion, wall-form bending apparatus, roof truss, foot apparatus, hammer and nail, concurring forces and volumenometer.

II. Liquids

Archimedes' principle, liquid pressure, modified pressure guage, specific gravity balance, hydrostatic paradox, and capillarity.

III. Gases

Barometer, Boyle's law, Cartesian diver, specific gravity bottle for gases, dessicated siphon, spirometer, density of air, equality of expansion of gases and air pump.

IV. Heat

Linear expansion, extensimeter, coefficient of expansion of air, gas and electric furnaces, pyrometer, air thermometer, gas meter and steam trap.

V. Light

Index of refraction, index meter, refraction in water, refraction in glass blocks, study of a sunbeam, the heliostat, camera and object holder, optical bench, simple demonstration of color mixtures, superimposing colors, projecting and blending colors, scioptican, and polariscope.

VI. Sound

Gasometer, pendulum and simple wireless method for velocity of sound, velocity of sound in air, model for lecture demonstration of beats, singing tube, vibrating strings and rods.

VII. Magnetism

Dip-needle demonstration.

VIII. Electricity (static)

Model to demonstrate charge and discharge of condensers, simple induction device.

IX. Electricity (current)

Galvanometers, switchboard for electric testing, bell system on 220 volt mains, convenient lamp bank, "home-made" high frequency coil, device for testing electric wiring.

X. Invisible Radiations

Geissler tubes from electric light bulbs.

XI. Wireless

An inexpensive wireless set.

XII. Unclassified

How to make slides, simple way to project microscope slides, hectograph, mimeoscope, a few articles a tinner can make for the science department, modification of old experiments in physics, a visible fire extinguisher, some experiments with a piece of iron wire, accurate weighing without the use of a small weight, devices useful for demonstration purposes, alcohol burner for the laboratory, blackboard compass, uses in general science of a burned-out electric light bulb, attachment for automatic distillation.

Harrington's Study

An article dealing with school-constructed apparatus was written by E. R. Harrington (41:251) of Albuquerque, New Mexico. The purpose of Mr. Harrington's article is suggested by its title "How to Increase Laboratory Equipment". The author started with "junk" which he collected from the janitor's room in his own school. Other discarded material was collected from electrical concerns and from other schools in the neighborhood. Radio parts were contributed by a local radio firm. Horseshoe magnets were obtained from a local garage. Iron filings were secured from a machine shop. For magnetism, spokes from a bicycle wheel were found to be better than knitting needles.

With the aid of the Industrial Arts classes, Mr. Harrington started what he termed "an instrument-making factory". Among the pieces of equipment made were electromagnets, a transformer, Magdeburg hemispheres, an air compressor, a steam boiler, steam engine, (with generator attached), parallelogram of force board, 224-liter box, resonator, a movable table for physics demonstrations, a demonstration case, choke coils, rheostats, condensers, a Tesla coil, an air blower, and a centrifugal pump.

In his project Mr. Harrington sought the cooperation of other departments. Castings were made in a small experimental foundry; sheet metal work was done in the auto mechanics shop. The Commercial department mimeographed the tests for the project and also shared stop watches and metronomes with the physics department. The Art department constructed various kinds of color wheels. The Chemistry department loaned electrical apparatus and saved scraps of felt. The Printing department printed all the experiments for the class and also turned over the copper and zinc cuts to the project. The zinc cuts were melted and dropped in water to serve as "mossy" zinc to make hydrogen.

Harrington has much praise for the various departments which he says cooperated with him in every way. He also noted that the enrollment for his courses had increased by over 300 per cent during the five year period of the project.

Hyde's Study

G. H. Hyde, (46:252) in an article "Home-made Apparatus for the Physics Class", describes 33 pieces of apparatus which can be constructed by the teacher in either the shop or the laboratory. The purpose of the article, as defined by Mr. Hyde, is to aid the teacher in the small high school with his problem of assembling apparatus which lack of funds prevents him from buying.

Hyde first lists certain basic materials which he says must be bought, and which should cost less than ten dollars. The list includes: $\frac{1}{4}$ pound spools of sizes 18, 22, and 28 D. C. C. copper wire, small spools of sizes 18 and 22 brass wire, some piano wire, assorted glass tubing, assorted rubber tubing, 2 or 3 pounds of assorted rubber stoppers, $\frac{1}{2}$ dozen thistle tubes, 3 glass funnels, 6 250-500 cc. flat-bottom flasks, 3 500 cc. distilling flasks, 2 dozen 4 and 6 inch test tubes, 4 burette clamps, 6 iron clamps, 6 ring stands, 6 3-4 inch ring clamps, 4 Hoffman clamps, 6 glass T tubes, 1 square foot each of copper, lead and zinc sheeting (B. S. #20), 1 meter brass strip, 2 dozen binding posts, 3 each iron, steel and lead balls (drilled), alcohol stoves, spool of stove pipe wire and some packing crates.

Given such material the author claims that it is possible to construct the 33 pieces of apparatus shown below. This equipment if secured from a manufacturer of scientific apparatus would cost at least ninety-five dollars. The pieces of apparatus described by the author are: (1) Boyle's law apparatus, (2) Wheatstone bridge, (3) demonstration vernier, (4) three-horse evener, (5) cohesion figures, (6) hand rotator, (7) inclined plane, (8) capillary plates, (9) pendulum support, (10) inertia ball, (11) barometer tubes, (12) governor, (13) centrifugal-force machine, (14) Hooke's law experiment, (15) pinhole camera, (16) induction coil, (17) contracting helix, (18) Ampere's rule apparatus, (19) helix through cardboard, (20) resistance coils, (21) spark gap, (22) telegraph key and sounder, (23) liquid pressure guage, (24) Cartesian diver, (25) heat shields, (26) leaning tower, (27) refraction tubes, (28) demonstration siphon, (29) composition of force board, (30) conduction tester, (31) electro-magnet, (32) double mercury cup, and (33) dew-point apparatus.

From his observations the author concludes that while accuracy is important, accurate results are often the only things which the student remembers about the experiment. He believes that the student really has a better understanding of the principles of physics when what he terms "flivver apparatus" is used.

Lynde's Works.

C. J. Lynde (118 and 119:257) is the author of three books dealing with the problem of "Science Experiences". One of these books, "Science Experiences with Home Equipment", illustrates, describes, and explains two hundred experiments with equipment which is found in the home. These experiments deal with such things as: atmospheric pressure, flying, air streams, compressed air and expanded air, compressed gas, water wheels and turbines, buoyancy of liquids, water pressure and air pressure, liquid surfaces, other properties of water, balance, experiences with one's body, inertia, marbles, science toys, and heat.

Another of the author's books describes, illustrates and explains eighty-four experiments with home equipment, and one hundred and sixteen with other inexpensive apparatus. These experiments deal with: baseball curves, centrifugal force, other mechanical principles, gases, liquids, heat, water pressure, atmospheric pressure, siphons, air compressed and expanded, other gases, Bernoulli's effect, liquids and heat.

A third book by Lynde, "Science Experiences with Ten-cent Store Equipment", was announced for publication in August 1939. This book, "Science Experiences with Ten-cent Store Equipment", will illustrate, explain, and describe two hundred experiences in electricity, light, and sound which can be developed with ten-cent store equipment.

In the foreword, Dr. Lynde makes three observations which pertain to the problem of student-constructed apparatus. These observations are: (1) "Knowledge begins with wonder", (2) "All thought is based on experience", and (3) "One experience is worth ten demonstrations".

While Dr. Lynde's books contain directions for many science experiences, they do not deal solely with physics experiences. Although some of the experiences are applicable to physics, the majority are more useful to the general science classes.

<u>Adlam's Study</u>

G. H. J. Adlam (116:258) has compiled the notes on apparatus and experiments found in the "School Science Review", an English publication, and put them in book form. This book, "The Science Masters' Book", deals with experiments on such subjects as:

1. Mechanics and properties of matter: (a) acceleration, (b) Boyle's law, (c) density, (d) elasticity, (e) force, (f) pressure, (g) rotation of the earth's surface, (h) tension, (i) viscosity, and (j) wave motion.

2. Heat: (a) calorimetry, (b) change of state, (c) convection, (d) expansion, (e) maximum density, (f) radiation, and (g) specific heat ratio.

3. Light: (a) cameras, (b) color, (c) diffraction, (d) dispersion, (e) eclipse of sun, (f) fluorescence, (g) interference, (h) photometry, (i) reflection, (j) refraction and (k) scattering.

4. Sound: (a) audibility, (b) detectors, (c) diffraction, (d) Doppler effect, (e) interference, (f) reflection, (g) resonance, (h) transmission, (i) vibration in pipes, (j) vibration in rods, (k) vibration of strings, and (l) wave machines.

5. Magnetism: (a) electromagnetism, (b) magnetic measurements, (c) magnetostriction, and (d) magnetic poles.

6. Electricity: (a) alternating current, (b) ammeters, (c) cells, (d) condensers, (e) direct current, (f) electroscopes, (g) electrostatics, (h) electro-magnetic induction, (i) fuses, (j) galvanometers, (k) motors, (l) neon lamps, (m) Ohm's law, (n) oscillators, (o) potentiometers, (p) resistance, and (q) wireless.

7. Unclassified apparatus.

In the preface of his book, Adlam speaks of the lack of continuity of the project and remarks that in places there is a rapid transition from work suitable for the middle school to that of the sixth form. This also applies to its use in our secondary schools. Some of the apparatus described is probably more suitable to general science than to physics; while some of the experiments described are more suitable to a college course in physics. There are, however, many experiments which could be adapted to high school laboratories. Some of these also contain a description of the means of construction of apparatus at small cost. Other experiments which might be adaptable to high school laboratories either do not contain descriptions of how to make the apparatus or the apparatus described is too expensive for the budget of the small high school.

The articles compiled in this book are aimed primarily at solving a problem in the English schools, and no doubt their problems are somewhat different from our own. The English schools also seem to spend less time than we do on certain subjects, such as Pascal's law, and to spend more time on some other subjects such as neon lights.

Miscellaneous Studies

Popular Science Magazine publishes a leaflet ("The

Science Classroom") for the use of teachers of science. This leaflet contains new, simple and interesting experiments which can be performed in the high-school science classes. The method of construction of the apparatus needed for such experiments is also described. Among these experiments are some suitable for a physics class.

Two other studies touch upon the problem of school-constructed apparatus. They are: (1) a study on "Economy of Administration of the High School Laboratory", by Paul Harvey Jacobs, and (2) "High School Physics in Porter County with Special Emphasis on Storage Facilities and Waste in Apparatus", by Charles Wefler.

In his study, Mr. Jacobs deals with a number of methods of effecting economies in the high school laboratory. One of these is by having the students make the apparatus. Mr. Jacobs' study is one of the two studies which suggested student-made apparatus.

Mr. Wefler, in a survey in Porter County of the apparatus for storage facilities and the waste in apparatus, found "home-made" apparatus in all the schools, some having only a few pieces of this school-constructed apparatus and others many pieces.

SUMMARY

A review of similar studies, which are discussed in the chapter, reveals the following facts:

(1). About fifty-six experiments were considered essential to a complete course in physics by most of the experts and authors, according to Kiebler and Curtis.

(2). Many teachers have contributed articles on how to make certain pieces of equipment. Haupt has assembled references to a number of such articles for the benefit of the teacher.

(3). An "instrument factory" was started by Harrington with the cooperation of all the departments in the high school to make apparatus. An increase of 300 per cent in enrollment was noted as a result of this project.

(4). A list of the material needed for, the cost of the material needed, and how to construct thirty-three pieces of physics laboratory equipment is given by Hyde. The students are not so likely to consider accuracy the most important part of the experiment if "flivver apparatus" is used, according to Hyde.

(5). A review of the literature fails to reveal a single study which purports to prescribe a laboratory course in physics based on a plan of student-constructed apparatus. However, three books for use <u>by the student</u> in gaining experiences in science have been written by Lynde. Three fundamental ideas are emphasized: (1) "Knowledge begins with wonder", (2) "All thought is based on experience", and (3) "One experience is worth ten demonstrations".

(6). A series of articles telling how to construct various pieces of equipment and how to set up apparatus for a large number of physics laboratory experiments has been compiled by Adlam in his "Science Masters' Book".

(7). There were references to "home-made" equipment in several miscellaneous studies and in one student-constructed apparatus was mentioned as a means of reducing laboratory cost.

CHAPTER III

THE SELECTION OF THE EXPERIMENTS ESSENTIAL TO A LABORATORY COURSE IN HIGH SCHOOL PHYSICS

To determine the laboratory apparatus required and how it may be made by high school students, it is necessary first to find which experiments are considered essential to a complete course in high school physics. This may be done in a number of ways, such as: (1) analysis of workbooks, (2) opinion of experts, (3) determination of the most important needs of the graduate, and (4) analysis of college requirements. In this investigation an analysis of all the available workbooks and the judgment of a few experts was employed because they required less time and were considered to be sufficiently reliable.

A number of the most widely used workbooks were examined by the committee of teachers mentioned in Chapter One, and experiments prescribed by a majority of the authors were selected to constitute a laboratory course upon which to base this study. These experiments were analyzed to determine the apparatus required in each, and a method of constructing the pieces of apparatus was then found. The data obtained from an analysis of the workbooks are shown in the next section.

ANALYSIS OF WORKBOOKS

Eleven workbooks which were available for analysis and which have wide use in the high schools throughout the country were selected. The workbooks which were analyzed to determine the essential laboratory program for high school physics were:

1. R. A. Millikan and H. G. Gale, A Laboratory Course in Physics, Ginn and Company, Boston, New York, 1906.
2. J. C. Packard, Everyday Physics--A Laboratory Manual, Ginn and Company, Boston, New York, 1917.
3. Frederick F. Good, Laboratory Projects in Physics, The Macmillan Company, New York, 1920.
4. B. L. Cushing, A Laboratory Guide and Workbook, Ginn and Company, New York, 1937.
5. S. C. Cook and J. C. Davis, A Combined Laboratory Manual and Workbook in Physics, Metzger-Bush and Company, New York and Chicago, 1936.
6. W, D. Henderson, Physics Guide and Laboratory Exercises, Lyons and Carnahan, New York, 1936.
7. S. R. Powers and H. E. Brown, Workbook in Physics, Allyn and Bacon, Boston, 1932.
8. H. F. Turner, Workbook and Laboratory Manual in Physics, College Entrance Book Company, Incor-

porated, New York City, 1937.

9. C. L. Fletcher and S. Lehman, Laboratory Manual for Unified Physics, McGraw-Hill Book Company, New York, 1938.

10. N. H. Black and E. C. Weaver, Laboratory Experiments and Workbook to Black and Davis' 'Elementary Practical Physics, The Macmillan Company, New York City, 1938.

11. R. W. Fuller, R. B. Brownlee and D. L. Baker, Laboratory Exercises in Physics, Allyn and Bacon, Boston, 1932.

The analysis, which is shown in the following eight tables, is based on the classification suggested by the Oregon course of study: Table II A, Introduction, Table II B, Properties of Fluids, Table II C, Force and Motion, Table II D, Work and Heat, Table II E, Magnetism and Electricity, Table II F, Wave Motion and Sound, Table II G, Light, and Table II H, Electronics and Invisible Radiations. The figures listed under Column "Av." represent the average number of experiments that were found on each topic.

Analysis Showing Relative Emphasis Given Different Topics in Eleven Physics Workbooks

Table II A

INTRODUCTORY MATERIAL

Topics	Workbooks*											Av.
	1	2	3	4	5	6	7	8	9	10	11	
Measurements	2	3		2	2	5	2	2	1	1	2	2
Density	1	2		1	1		1	1	1	1	1	1
Fundamental Physical Concepts	1											
Properties of Materials											1	
Balance				1		1						

It is evident from the table above that the majority of the workbook authors consider two experiments on measurements and one on density essential for an introduction to the study of physics.

*The numbers given in the table above refer to the workbooks listed at the beginning of Chapter III.

Table II B

PROPERTIES OF FLUIDS

Topics	Workbooks											Av.
	1	2	3	4	5	6	7	8	9	10	11	
Specific Gravity		2		3	1	4	3	4	5	2	3	2
Archimedes' Principle	3	1	2	2	2	1	1	2	3	1	2	2
Boyle's Law	1	2	2	1	1	1	1	1	1	1	1	1
Force and Pressure	1	3	4	1			1	1	1		1	1
Measurement of Gas Pressure	1	1	3		1			1	1		1	1
Atmospheric (Barometric) Pressure		1			1	1	2		2	1	1	1
Siphon			2			1			1		1	
Pascal's Law		1	1				1					
Pumps			3				1				1	
Capillarity and Surface Tension					1						2	
Molecular Motion							3					

On examination of Table II B it appeared that the experiments considered essential under Properties of Fluids are: two experiments on each of the following:

Archimedes' Principle, and specific gravity, and one on each of the following: force and pressure, atmospheric pressure, measurement of gas pressure and Boyle's law.

Table II C

FORCE AND MOTION

Topics	Workbooks											Av.
	1	2	3	4	5	6	7	8	9	10	11	
Parallelogram of Forces		1		1	3	2	2	3	2	2	2	2
Laws of the Pendulum	1	1	2	1	1	2	1	1		1	1	1
Hooke's Law	1			2	1	3		2	1	1	1	1
Gravity							1	1	1		1	
Crane				1								

In the unit on Force and Motion, as shown above, there are two experiments recommended for parallelogram of forces, while one each is suggested for the laws of the pendulum, Newton's three laws, and Hooke's law.

Table II D

WORK AND HEAT

Topics	Workbooks											Av.
	1	2	3	4	5	6	7	8	9	10	11	
Levers	1	1	1	4	1	3	4	1	1	3	2	2
Heat of Fusion	3	1	1	2	1	1		2	2	2	2	2
Coefficient of Linear Expansion	2	1		1	1	1	3	1	1	2	2	1
Pulleys		1	1	1	1	2	2	2	2		2	1
Friction		1		2	1		1	1	2	1	1	1
Specific Heat of a Metal	2	1		2	1	1	1	1	1	1	1	1
Fixed Points on a Thermometer	1	1	1	1	1	1	1	1	1	1	2	1
Inclined Plane	1	1	1	1	1	1	1	1	1	1	1	1
Transference of Heat			2		1	1	2		1		2	1
Efficiency		2	2			1	1		1	1	1	1
Evaporation			2				1	1	1		1	1
Humidity		1	2	1		1	1		1			1
Charles' Law					1	2	1	1	1		1	1
Dew Point			1	1	1			1	1	1	1	1
Heat of Vaporization				1	1	1		1	1	1	1	1
Work and Heat Energy (Mechanical Equivalent)	1						3					
Heating and Ventilation of Buildings			4									
Steam Engine							1					

Table II D
(continued)

Topics	Workbooks											Av.
	1	2	3	4	5	6	7	8	9	10	11	
Boiling Point	1		1				1				2	
Internal Combustion Engine			1				1					
Machines (Jackscrew, etc.)				1			1					
Power and Energy		1		1			1					
Automobile			2									
Potential and Kinetic							1					
Distillation							1					
Freezing Points							1				1	
Cost of Cooking by Gas									1			

Seventeen experiments were considered essential by the authors in the unit of Work and Heat. These experiments include two experiments on each of the following subjects: levers, and heat of fusion; and one on each for pulleys, inclined plane, friction, efficiency, Charles' Law, fixed points on a thermometer, coefficient of linear expansion, specific heat of a metal, heat of vaporization, dew point, humidity, evaporation, and transference of heat.

Table II E

MAGNETISM AND ELECTRICITY

Topics	Workbooks											Av.
	1	2	3	4	5	6	7	8	9	10	11	
Resistance												
Laws of Resistance				1	1		1	3	1	1	3	1
Ohm's Law	2	1	1	1		1	1		1	1	1	1
Wheatstone Bridge	1	1		1	1	1	1	1	1	1	1	1
Combination of Cells				2	1	1	2	2	1	1	3	1
Effect of Temperature on Resistance	1					2	1	1	1	1	1	1
Cells												
One Fluid	1	1		1	1	1	1	1	1	1	1	1
Two Fluid		1		1				1	1		1	
Storage	1		3	1	1	1	1	1	1	1	1	1
Laws of Magnetic Attraction	2	1	2	1	3	1	1	2	2	1	2	1
Electrolysis	1	1	1		1	2	1			1		1
Electrotyping											1	
Electroplating				1				1	1		1	
Motor		1	3	1	1		1	1	1	1	2	1
Magnetic Effect of a Current	2	1		1	1		1	1	1	1	1	1
Efficiency		2	2	1	1	1		2	1		1	1
Induced Currents		1		1	1		2	1	1	1	1	1

Table II E
(continued)

Topics	Workbooks											Av.
	1	2	3	4	5	6	7	8	9	10	11	
Electric Bell and Telegraph	1		2				1	1	1		2	1
Heating Effect of a Current			1		1	1	1		1	1	1	1
Measurement of Electric Power in the Home				1				1	1	1		
Generator				1		1	1	1		1	1	
Static Electricity	1				1	2	1				1	1
Electromagnet				1	1			1	1		1	
Car Ignition		1	3									
Measurement of an Electric Current			2				1					
Alternating Current and Why Used							1					
Rectifier						1						
Study of a Dry Cell											1	
Transformer					1			1				
Condenser Action								1				
Induction Coil	1											
Oersted's Principle		1										
Reactance and Impedence								1				
Study of a Flashlight						1						
Study of a Fuse		1										
Units of Electrical Power and Energy							1					

That Electricity and Magnetism is one of the most important units in the study of physics is indicated by the fact that there are 16 experiments listed as essential by a majority of the authors. These 16 experiments are distributed as follows: five experiments on resistance, (laws of resistance, Ohm's law, Wheatstone bridge, combination of cells, effect of temperature on resistance); two experiments on cells, (the one fluid cell, and the storage cell); and one on each of the following: laws of magnetic attraction, static electricity, electrolysis, magnetic effect of a current, heating effect of a current, electric bell and telegraph, induced currents, motor, and efficiency.

Table II F

WAVE MOTION AND SOUND

Topics	Workbooks											Av.
	1	2	3	4	5	6	7	8	9	10	11	
Vibrating Strings	1	1	1	1	1	1	1	1	1	1	1	1
Frequency of a Tuning Fork	1	2		1	1	1		1	1	1	1	1
Resonance	1			1	1	1	1	1	1		1	1
Speed and Transmission	1	1		1	1	1	1		1	1	1	1
Musical Sounds							1					
Open and Closed Pipes					1		1					
Sympathetic Vibrations					1				1		1	
Phonograph			2									
Control of Sound Energy							1					
Interference							1					
Wind Instruments			1									

While there were a number of experiments suggested for Sound, only the following four were considered essential by a majority of the workbooks reviewed: speed and transmission of sound, resonance, frequency and vibration of a tuning fork, and vibrating strings.

Table II G

LIGHT

Topics	Workbooks											Av.
	1	2	3	4	5	6	7	8	9	10	11	
Optical Instruments	3	2	9	1	2	1	1	2	3	1	1	2
Image Formation with Lenses	1	1	2	2	1		2	2	1	1	1	1
Refraction		1	1	1	1	1	1	1	2	1	2	1
Photometry	1	2	1	1	1	1	1	1	1	1	1	1
Image Formation with Mirrors	1	1		1	1	1	2	1	2	1	2	1
Reflection	1	1	1		1		1	1	1	1	2	1
Illumination			2				1		1	1		
Focal Length of Lenses						1	1		3	1	2	1
Image Formation with a Plane Mirror				1	1			1	1		1	
Total Reflection	1				1		1		1		1	
Color and Wave Length			1				1					
Dispersion					1				1		1	
Spectra	1					1	1					
Focal Length of Mirrors									1			
Study of the Eye		1										
Intensity			1									
Interference					1							
Pinhole Camera											1	
Ratio of Speed in Water and Air	1											
Speed							1					
Shadows									1			

Analysis of Table II G reveals a number of interesting experiments on Light. However, the majority of the workbook writers agree that the following experiments are essential to a high school physics course: two experiments on optical instruments; and one each on the following topics: reflection, photometry, refraction, image formation with lenses, focal length of lenses, and image formation with mirrors.

Table II H

ELECTRONICS AND INVISIBLE RADIATIONS

Topics	Workbooks											Av.
	1	2	3	4	5	6	7	8	9	10	11	
Radio Tube and Receiving and Transmission			2*	1	1		1	1		1		1
Cathode and Roentgen Rays							1					
Radio Activity							1					

Electronics and Invisible Radiations are generally treated with less emphasis than other topics in high school physics as is shown by the fact that only one experiment is recommended by the majority of the authors. This experiment as shown in Table II H above is the one

*Refers to wireless telegraph.

on the radio tube.

A summary of analysis of the Tables II A to II H reveals the fact that one half the workbook writers list the following sixty-three experiments as essential to the complete high school course in physics.

1. Introduction: two experiments on measurements, and one on density.
2. Properties of Fluids: two experiments each on specific gravity and Archimedes' principle; and one on each of the following: force and pressure, atmospheric pressure, measurement of gas pressure and Boyle's law.
3. Force and Motion: two experiments on the parallelogram of forces, and one each on the laws of the pendulum, Newton's three laws, and Hooke's law.
4. Work and Heat: two experiments each on levers and the heat of fusion; one each on pulleys, inclined plane, friction, efficiency, Charles' law, fixed points on a thermometer, coefficient of linear expansion, specific heat of a metal, heat of vaporization, dew point, humidity, evaporation and transference of heat.
5. Magnetism and Electricity: five experiments on resistance, (laws of resistance, Ohm's law, Wheatstone bridge, combination of cells, effect of temperature on resistance); two experiments on cells, (one fluid cells, and storage cells); one on the laws of magnetic at-

traction, static electricity, magnetic effect of a current, heating effect of a current, electric bell and telegraph, induced currents, motor, efficiency and electrolysis.

6. Wave Motion and Sound: one experiment each on speed and transmission, resonance, frequency of a tuning fork, and vibrating strings.
7. Light: two experiments on optical instruments; and one each on reflection, photometry, refraction, image, formation with lenses, focal length of lenses, image formation with mirrors.
8. Electronics and Invisible Radiations: one on the radio tube and receiving and transmission.

A total of sixty-four experiments appeared in at least one workbook and some of them were found in as many as five. These, in addition to the sixty-two considered essential by a majority of the workbook writers, makes a total of one hundred twenty-six experiments. Consideration of so many experiments is not possible in this short study so it is desirable to consider only the ones essential to the high school physics course. However, the additional sixty-four experiments are listed below:

1. Introduction: fundamental physical concepts, properties of material, and balance.
2. Properties of Fluids: Pascal's law, molecular motion,

capillarity and surface tension, pumps and the siphon.

3. <u>Force and Motion</u>: gravity and the crane.

4. <u>Work and Heat</u>: power and energy, potential and kinetic energy, distillation, freezing points, steam engine, the internal combustion engine, the automobile, heating and ventilation of buildings, boiling point, work and heat energy, machines (jackscrew, etc.), and cost of cooking with gas.

5. <u>Magnetism and Electricity</u>: electrotyping, electroplating, rectifiers, measurement of electric current, electromagnet, induction coil, transformers, reactance and impedence, Oersted's principle, study of a fuse, ignition of a car, study of a flashlight, alternating current and why used, study of a dry cell, condenser action, units of electric power and energy, generator, measurement of electric power in the home and two fluid or Daniel cell.

6. <u>Sound and Wave Motion</u>: interference, musical sounds, sympathetic vibrations, wind instruments, the phonograph, control of sound energy and open and closed pipes.

7. <u>Light</u>: speed of light, dispersion, illumination, shadows, interference, total reflection, ratio of speed in air and water, focal length of mirrors, pin-hole camera, color and wave-length, spectra, study of the eye, and image formation with a plane mirror.

8. <u>Electronics and Invisible Radiations</u>: cathode and Roentgen rays and radio activity.

Apparatus is, of course, necessary to the performing of such experiments as have just been listed as essential to a high school physics course by a majority of the workbook writers. Chapter Three has shown the experiments considered essential. Apparatus will be described in detail and its application explained in Chapter Four.

CHAPTER IV

DESCRIPTION, CONSTRUCTION AND USE OF HIGH SCHOOL PHYSICS APPARATUS

The first three chapters of this study describe the reasons for undertaking the project of student-constructed apparatus for high school physics. Consideration is also given to the procedure which was used in determining the selection of experiments in which the apparatus is needed. The object of this chapter is to present for each essential experiment (1) the purpose, (2) a list of the materials required, (3) a detailed description of the actual construction of the various pieces of apparatus used, (4) the method of procedure used in the experiment, and (5) a comparison of the cost of the student-constructed apparatus and similar commercial apparatus. A diagram or description of each piece of apparatus is included to serve as a guide for the construction of the equipment.

The descriptions of experiments when completed were examined by Dr. W. R. Varner, Assistant Professor of Physics at Oregon State College and Mr. Elmer Glen, Instructor of Physics at the high school in Corvallis, Oregon. Two students at Corvallis high school, William Milne and Glen Warren, were then given the directions and asked to read them. The clarity of instruction and direction was established by questioning the students in regard to each experiment.

In addition to explaining the procedure to be used in constructing each piece of apparatus, other important items of information are included in this chapter. To be of practical value to those schools that may desire to construct their own physics apparatus, it was considered advisable to indicate: (1) the cost of materials, and (2) the sources from which some of these materials may be obtained with little or no cost.

Materials required for each experiment are indicated in the following descriptions. However, it should be realized that some of the materials should be purchased, if possible, at the beginning of the course. Many of these items may be secured at little or no cost from some of the sources listed in a succeeding paragraph. A few of these items, as in the case of insulated wire taken from obsolete electrical equipment, would be more satisfactory if purchased new. The following is a list of basic materials needed for the construction of apparatus described in this thesis:

Quantity	Size	Material	Cost
1 pound spool	#22	Double Cotton Covered Copper Wire	$1.25
$\frac{1}{4}$ " "	#18	Double Cotton Covered Copper Wire	.85
$\frac{1}{4}$ " "	#28	Double Cotton Covered Copper Wire	.55
$\frac{1}{4}$ " "	#22	Double Cotton Covered German Silver Wire	.65
Small spools	#18	Bare Brass Wire	.10
" "	#22	Bare Brass Wire	.10
" "		Stove Pipe Wire	.10
5		Banjo strings	.25
3 pounds		Assorted glass tubing	1.35
15 feet		Rubber tubing	.55
2 pounds		Assorted rubber stoppers	1.10
		Assorted test tubes	.25
Package		Small brass bolts	.50
1 dozen		Large ball bearings	.60
3		Burners	1.20
		Thermometers	1.50
10		Lenses	1.00
3		Tuning forks	2.50
		Total	$13.85

The cost of the materials listed above according to present prevailing prices is thirteen dollars and eighty-five cents. Other inexpensive materials such as packing crates, solder and chemicals may be required from time to time. However, the total cost of all the materials required for all of the experiments listed for a class of 25 or 30 students may be secured for less than twenty dollars in any community, if care is used in the assignment of experiments to the different groups which are working together. Also, many of the materials described may be used for general science and chemistry.

There are a number of sources of equipment suitable for the high school laboratory which are available to most communities. Discarded radio tubes may be obtained from a broadcasting station. Obsolete transformers, meters and switches may be obtained from the local power company. Equipment such as rectifiers, motor generator sets and other such equipment may be frequently obtained from the telephone company. Outmoded diathermy and X-ray equipment may be often secured from doctors or hospital supply houses. Arcs, motors, motor generators, as well as obsolete sound equipment may be obtained from theaters. A local machine shop may be consulted in regard to castings. Garages often have old equipment such as generators or tungar bulbs which they would gladly donate to a school. Automobile wrecking houses should be consulted for many pieces of equipment. Spark equipment might be obtained from steamship companies. Lenses and optical equipment may often be obtained from a pawn shop or from a local optometry shop at small cost. Salvage materials are often listed in the want ad section of scientific or "pulp" magazines. Various pieces of equipment are often obtained from army posts, navy yards, oil companies, old saw mills and railroad companies. The students may find useful materials in attics and storerooms.

INTRODUCTION

Experiment 1.

The Measurement of a Cube and a Triangle

Purpose. To familiarize the student with the units of measurement and give experience in measuring regular solids and the angles of a triangle.

Materials Required. Measuring stick (inches and centimeters), wooden block, tables of measurements, and protractor.

Construction of the Apparatus. The only apparatus required in addition to rulers and protractors, is a wooden block which can be made by sawing off a short piece of a 2" x 4".

Procedure. The wooden block is measured in inches, then converted to centimeters, (or multiply by 2.54). The results are checked with the centimeter rule. (See Figure 1)

A triangle is drawn with its base four or five inches long, as shown in Figure 2. Each of the angles A, B and C are measured with a protractor and the sum of the angles, A + B + C, is obtained. The difference between this sum and 180° is the error, and the percentage of error may be obtained by dividing this error by 1.80, or

$$\text{per cent error} = \text{fraction} \times \frac{100}{180}.$$

Comparative Cost. No commercial apparatus was found for this experiment so that there is no convenient way of making a comparative cost.

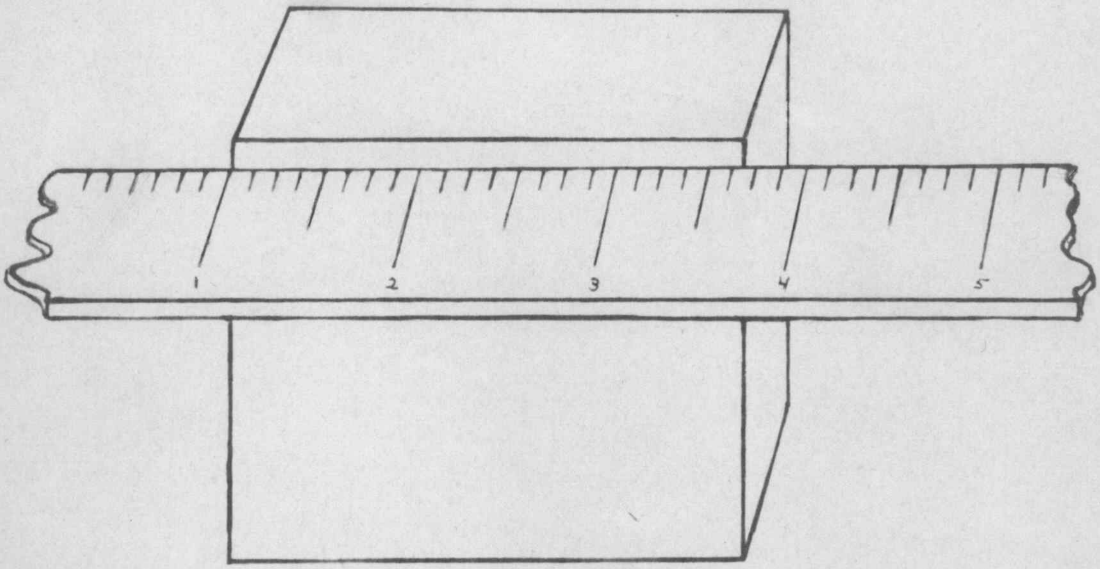

Figure 1 Measurement of a Cube

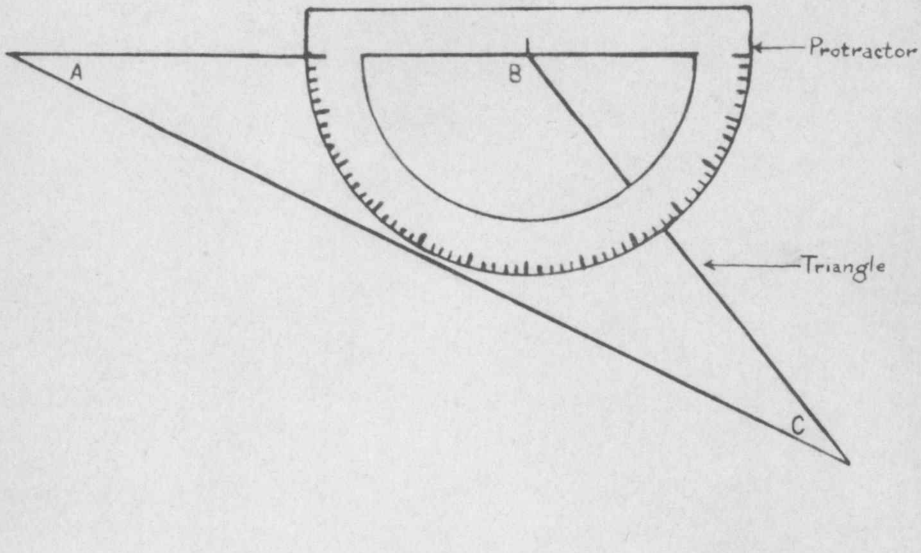

Figure 2 Measurement of a Triangle

Experiment 2.

Measurement of a Cylinder and a Sphere

Purpose. To familiarize the student with fairly accurate methods in measurements.

Materials Required. Tomato can, balance, measuring stick, (in either English or Metric systems), two small wooden blocks, and a steel ball bearing.

Construction of the Apparatus. Two rectangular blocks are placed so that their sides A and B fit snugly against the edge of a ruler, as shown in Figure 3. A micrometer scale is drawn on face B. This is accomplished by marking off seven-eighths of an inch and dividing it into eight equal spaces as shown in Figure 4.

Procedure. The student is to determine by actual measurements the dimensions from which to compute the inside volume ($\pi r^2 h$) of the tomato can; these measurements are verified by weighing the water content of the can (1cc. weighs 1 gram).

The diameter of the sphere is measured by placing it between rectangular blocks as shown in Figure 3. The ends of the blocks A and B must fit snugly against the edge of the measuring stick. The distance between the blocks can be read from the measuring stick and micrometer scale on face B. Three determinations should be made to insure accurate measurement of the diameter. Radius r is $\frac{1}{2}$ the diameter. The volume of the sphere may be figured from the radius by use of the formula, $V = \frac{4}{3}\pi r^3$.

<u>Comparative Cost</u>. The apparatus described for this experiment would cost only a few cents, whereas accurate commercial verniers cannot be bought for less than one dollar, and a demonstration vernier costs over two dollars.

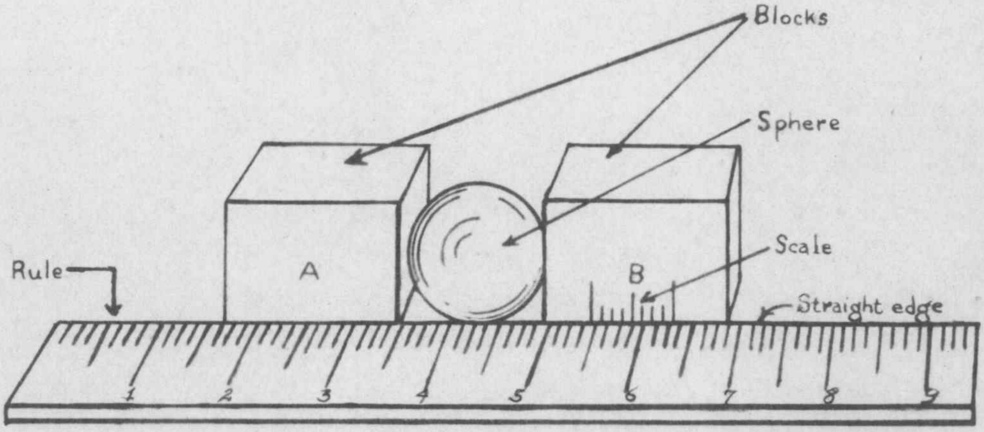

Figure 3 Apparatus for Measuring a Sphere

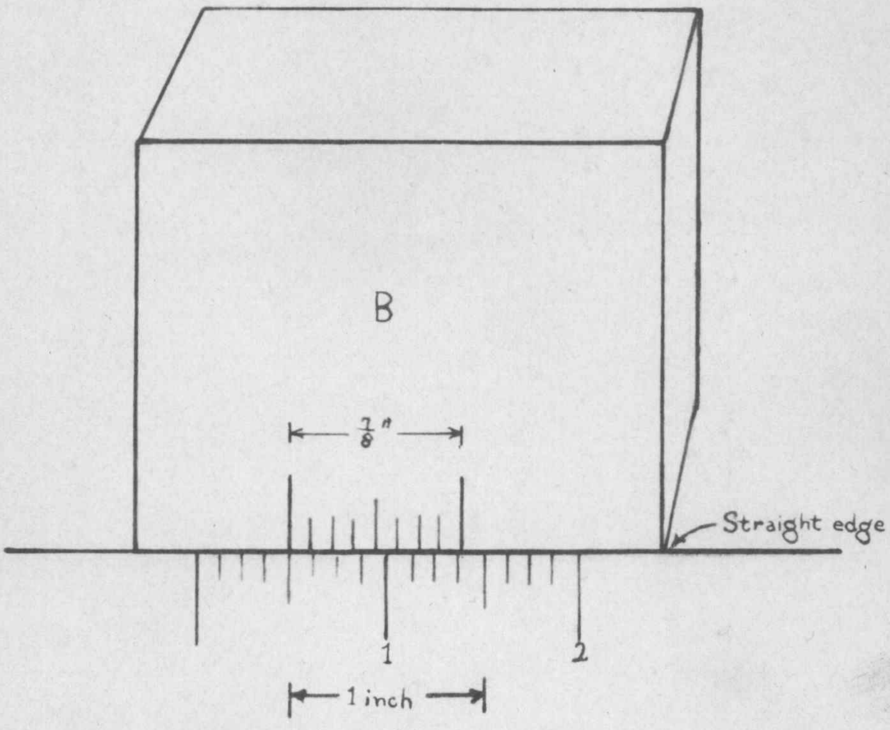

Figure 4 Construction of a Vernier Scale

Experiment 3.

Density

Purpose. To familiarize the student with the meaning of density, and to measure the density of symmetrical solids.

Materials Required. Balance and blocks of different substances.

Construction of the Apparatus. There is nothing to be constructed in this experiment.

Procedure. The blocks of different substances are measured, the volume and weight are found and the density is calculated by the formula, $D - \frac{M}{V}$.

Comparative Cost. No commercial apparatus is required for this experiment, consequently there is no way of comparing costs.

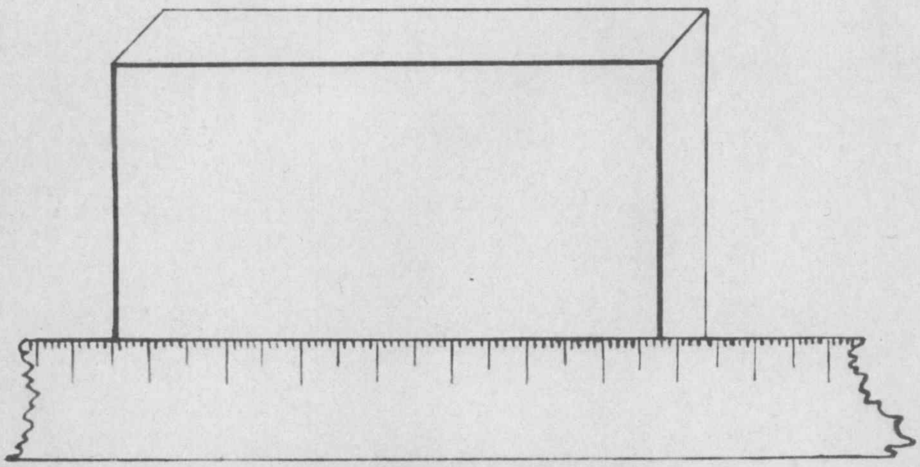

Figure 5 Measuring One Edge of a Block

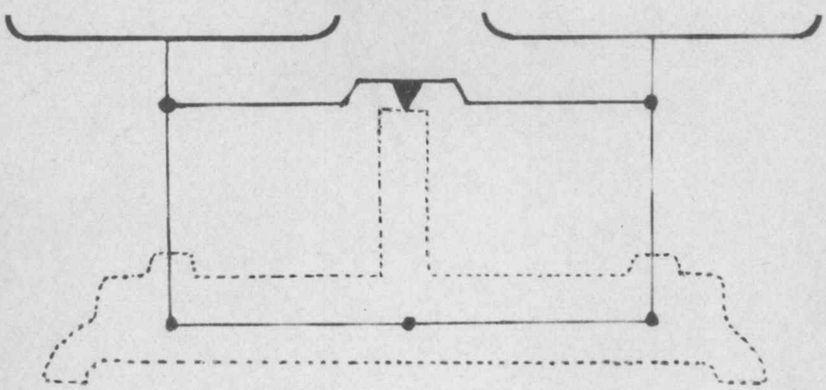

Figure 6 Diagram of a Platform Balance

PROPERTIES OF FLUIDS

Experiment 4.

Force and Pressure

Purpose. To enable the student to learn from experiments the difference between force and pressure.

Materials Required. Block, tape, three pieces of iron pipe (one piece of 2" and two pieces of $\frac{1}{4}$" iron pipe, each about six inches long), one $\frac{1}{4}$" elbow, one 2" elbow, one 2" to $\frac{1}{4}$" reducer, and two wooden plugs (one 2" and one $\frac{1}{4}$" in diameter).

Construction of the Apparatus. For the experiment showing the difference between force and pressure, a block four inches square is sawed into eight equal one inch cubes, as shown in Figure 7.

For the experiment showing the force acting on the side of a containing vessel, a pasteboard box is cut so that one side is hinged to the bottom with adhesive tape, as shown in Figure 8.

A model hydraulic press can be made with the use of two pieces of $\frac{1}{4}$" pipe, a $\frac{1}{4}$" elbow, a piece of 2" pipe, a 2" elbow, a 2" to $\frac{1}{4}$" reducer, and two wooden plugs, connected as shown in Figure 9.

Procedure. The whole block including the eight cubes is weighed to illustrate force. Then two of them are weighed to show pressure per square unit.

The pressure on a dam, represented by the formula $F = AHD$, where H is the average height, is demonstrated by filling the hinged box with sand and then releasing the hinged side.

The force required to balance the wooden plug in the smaller cylinder of the hydraulic press shown in Figure 3 against the wooden plug in the larger cylinder plus a known weight, is determined by the use of the formula $\frac{F}{f} = \frac{A}{a} = \frac{D^2}{d^2}$, and verified by actual trial.

Comparative Cost. Some companies advertise hydraulic presses for thirty-five dollars or more. The other equipment is not listed in most of the catalogues.

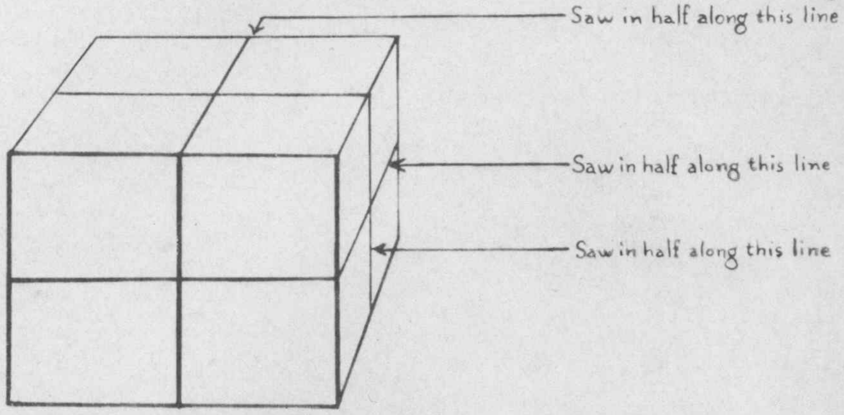

Figure 7 Difference Between Force and Pressure

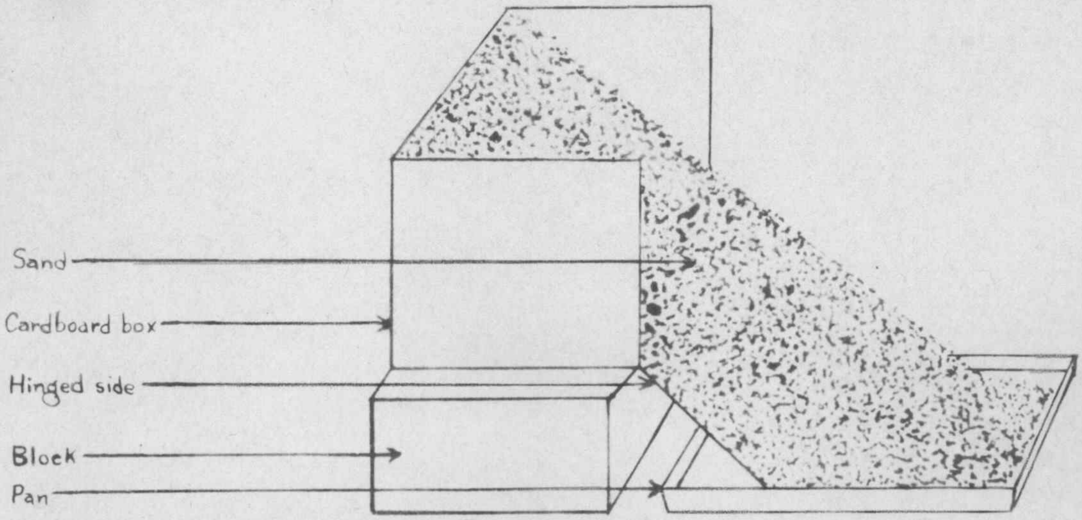

Figure 8 Demonstration of the Force on the Side of a Containing Vessel

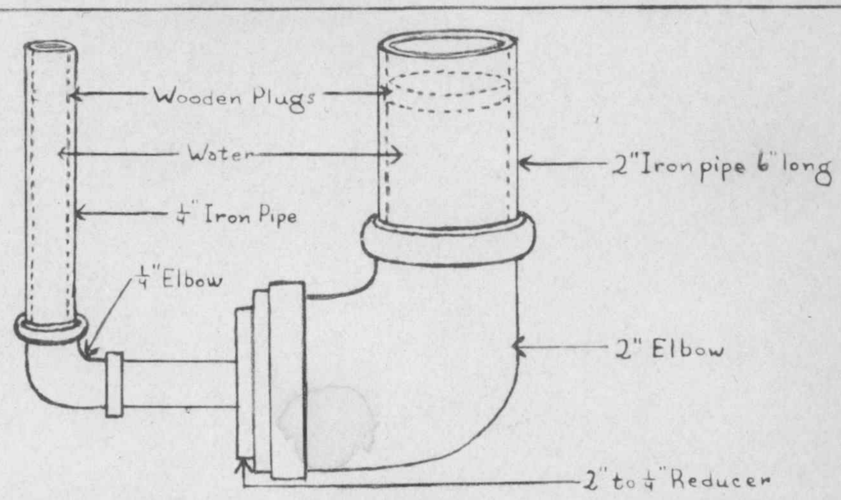

Figure 9 Principle of the Hydraulic Press

Experiment 5.

Archimedes' Principle

Purpose. To enable the student to prove to his own satisfaction the truth of Archimedes' principle.

Materials Required. Tomato can, tuna can, $\frac{1}{4}$" pipe 3" long (or other tube available), balance, water and bob.

Construction of the Apparatus. The apparatus necessary for this experiment consists of an over-flow can and catch bucket, both of which can be made from tin cans. A tin tube or a piece of quarter inch pipe is inserted into a hole drilled about one inch from the top of a tomato can which has had the top removed by use of a Vaughn Safety Roll can opener and the joint is made water tight either by soldering or by the use of sealing wax. The catch bucket is simply a shorter can, for example, a tuna fish can with the top removed in the same way, and which will fit under the spout built into the tomato can as shown in Figure 12.

Procedure. A balance or a spring balance is suspended, or placed, in a position above the over-flow can so that a plumb bob may be suspended from one side of the balance, Figure 10, or from the hook of the spring balance, Figures 10 and 11, to allow the bob to hang into the over-flow can. The bob is weighed first in air and the over-flow can is filled with water and the surplus allowed to run off through the over-flow pipe. After the flow has stopped, the catch bucket is weighed and placed under the spout. Then the bob is immersed in the water in the over-flow can and again weighed. The catch bucket and water are weighed, and the gain in weight due to the water displaced by the bob, should equal the apparent loss in weight of the bob.

Comparative Cost. Tin cans may be found on any junk pile and the cost of soldering or of sealing wax should be slight, whereas most companies ask a dollar or more for a catch bucket and over-flow can.

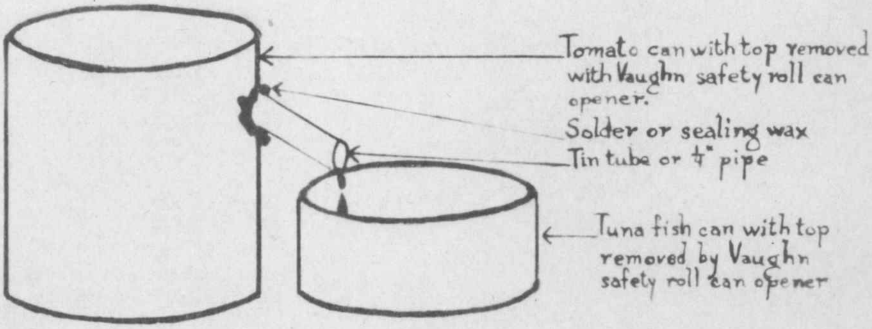

Figure 10 Overflow Can and Catch Bucket

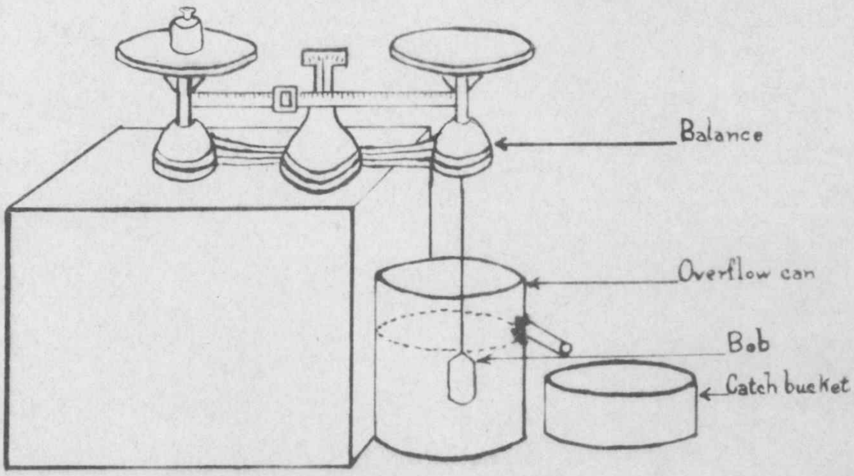

Figure 11 Archimedes' Principle

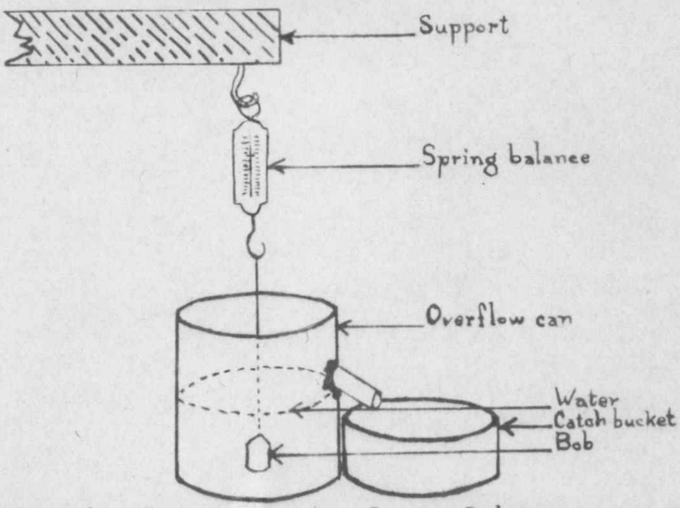

Figure 12 Archimedes' Principle with a Spring Balance

Experiment 6.

Archimedes' Principle - A Floating Body

Purpose. To permit the student to find the buoyant force on a floating body.

Materials Required. Tomato can, tuna fish can, small tube 3" long (described in Experiment 5), balance, water, wooden block and salt solution.

Construction of the Apparatus. The same equipment is used in this experiment as was used in the first experiment in Archimedes' Principle on page 64.

Procedure. The block is weighed accurately on the balance. The catch bucket is weighed empty. The over-flow can is filled with water and the water is allowed to flow out through the spout until it is just level with the over-flow tube. The block is floated on the surface of the water and the displaced water is caught in the catch bucket. The catch bucket is weighed with the water in it and the weight of the empty catch bucket is subtracted from the total weight. The result of the subtraction is the weight of the displaced water, and should be equal to the weight of the block. This procedure is repeated using a salt solution.

Comparative Cost. As explained in the first experiment on Archimedes' Principle, (page 64) an overflow can and a catch bucket would cost more than a dollar whereas the student-constructed one would cost only a few cents.

Experiment 7.

Specific Gravity of Solids

Purpose. To enable the student to find the specific gravity of solids either lighter than water, or heavier than water, using Archimedes' principle.

Materials Required. Balance, pieces of brass, aluminum or iron, block of wood (coated with paraffin to keep it from absorbing water), thread, jar, sinker, and cotton cord.

Construction of the Apparatus. The only piece of equipment necessary to construct in this experiment is a jar similar to a battery jar. This may be made from a round quart glass bottle, a one-half gallon glass jug or gallon glass jug, or some other suitable glass container. First, a cotton cord is wrapped around the bottle at the place where it is to be cut, and tied securely. The bottle is held as shown in Figure 15 B against the edge of an emery wheel so that the wheel follows the cord, the bottle being turned around until a groove is cut completely around the surface of the bottle. The bottle is tapped on the upper side of the cord, as shown in Figure 15 C and the jar should break off at the line formed by the groove. The sharp edges are filed as shown in Figure 15 D.

Procedure. It was demonstrated in the experiments on Archimedes' principle that any body immersed in a liquid is buoyed up by a force equal to the weight of an equal volume of the displaced liquid. This principle is applied to the determination of specific gravity as follows: A piece of brass, aluminum or iron is weighed accurately in air. Then it is weighed under water as shown in Figure 13. The results are recorded and the specific gravity found using the formula: specific gravity = $\frac{W}{W - W'}$, where W = weight in air and W′ = weight in water. The same procedure is applied to other bodies heavier than water.

To find the specific gravity of the body lighter than water, for example a wooden block, the block is first weighed in air. Then a sinker S is tied to the block and weighed in water with the block suspended in air, as shown in Figure 14 B. Then both the block and the sinker are weighed in water as in Figure 14 C. Then if (W + S) represents the weight of the block in air plus the weight of the sinker in water and (W′ + S) represents the weight of both the block and sinker in water, (W + S) - (W′ + S) = W - W′, and may be substituted in the formula given above to find the specific gravity.

<u>Comparative Cost</u>. The jar is the only piece that can be compared to commercial equipment. Battery jars are listed from twenty-five cents upward, whereas, the one in this experiment costs nothing.

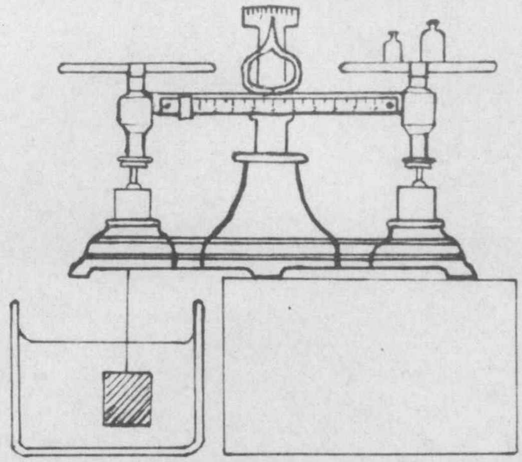

Figure 13 Specific Gravity of Bodies Heavier Than Water.

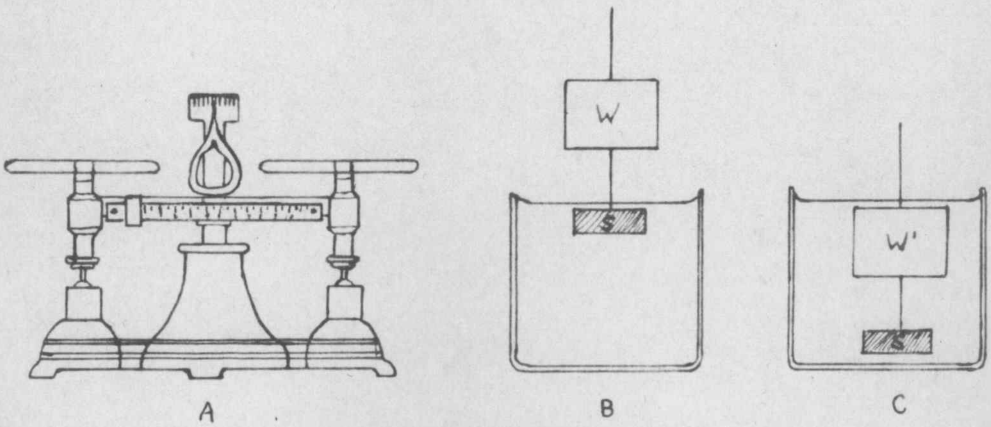

Figure 14 Specific Gravity of Bodies Lighter Than Water

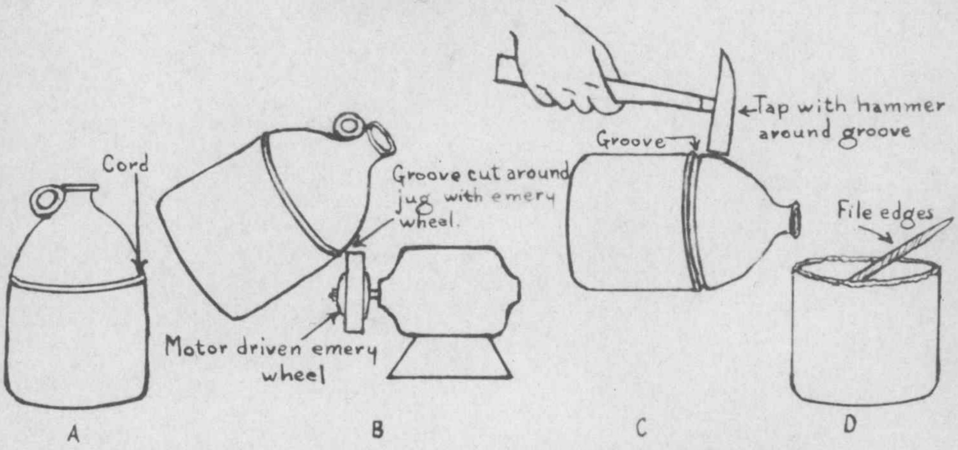

Figure 15 Construction of a Jar for Specific Gravity Experiments

Experiment 8.

Specific Gravity of Liquids

Purpose. To enable the student to understand the principle of hydrometry and to construct and calibrate a hydrometer with the aid of a specific gravity bottle.

Materials Required. Piece of wood $\frac{1}{2}$" x $\frac{1}{2}$" x 6", nail, glass stoppered bottle, balance, water, alcohol, salt solution, any other liquid desired or available for measurement, 18" glass tubing, and mercury.

Construction of the Apparatus. The specific gravity bottle may be made from a perfume bottle or other bottle which has a ground glass stopper. The stopper is removed and the side of the stopper is scored as shown in Figure 16 B leaving a V shaped channel up the side of the stopper.

The hydrometer may be made from a small strip of wood $\frac{1}{2}$" on a side and 6" long. A nail is driven in one end to make the stick stand upright in the liquid. The stick is placed in water and a mark is drawn at the level of the water on the stick, as in Figure 17 A. This process is repeated for other liquids.

A piece of glass tubing is heated near the middle with a burner and bent slowly to form a tube in the shape of a "U" as in Figure 18. Mercury is poured into the tube and it is attached to a stand which is made from a 1" x 2" x 8" board and a 1" x 4" x 6" board as in Figure 18.

Procedure. The wooden hydrometer is constructed first and the levels to which it sinks in various liquids are marked. The specific gravity bottle is first weighed empty, then the bottle is filled with water, the stopper forced into the bottle, the outside wiped off and the bottle and contents weighed. The weight of the bottle is subtracted from the weight of the bottle and contents to obtain the weight of the water. The process is repeated with other liquids available. Then the specific gravity of the various liquids is obtained by the use of the formula: specific gravity of a liquid $= \frac{\text{weight of a liquid}}{\text{weight of water}}$. The results obtained are compared with the results obtained by the use of the school-constructed hydrometer.

Water is poured in one side of the "U" tube described above and some other liquid (such as alcohol) to be tested in the other side until both sides are the same height, as shown in Figure 18. Then both sides are measured and the proportion of the length of the column of the liquid to the length of the column of water should give the specific gravity of the liquid.

Comparative Cost. A specific gravity bottle in most instances would cost at least fifty cents. Hydrometers vary in price from thirty cents to one dollar or more. The apparatus described here would cost nothing.

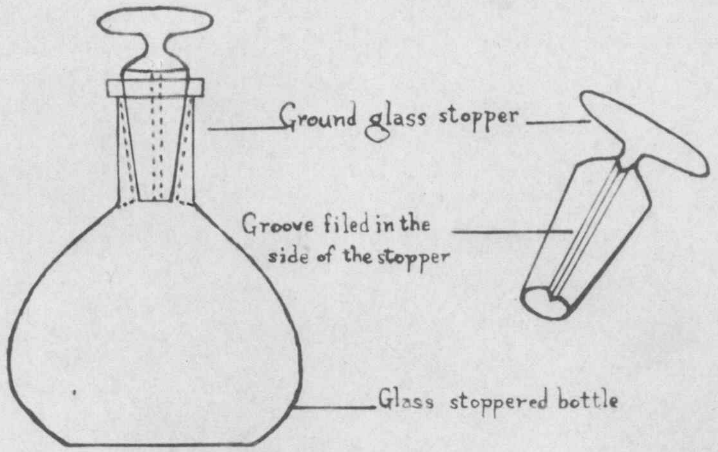

Figure 16 Specific Gravity Bottle

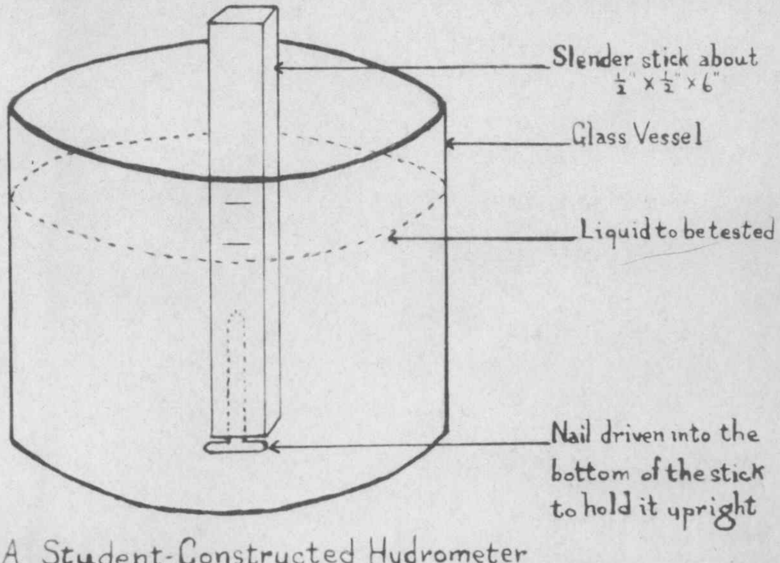

Figure 17 A Student-Constructed Hydrometer

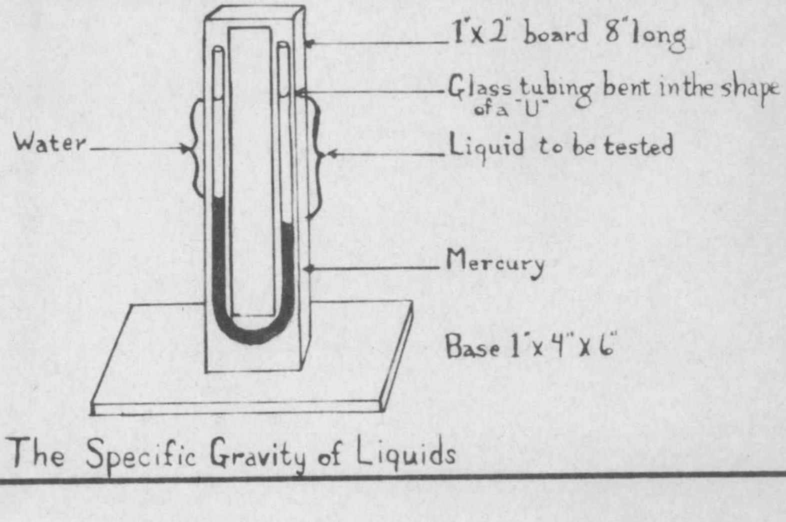

Figure 18 The Specific Gravity of Liquids

Experiment 9.

Measurement of Gas Pressure

Purpose. To enable the students to measure gas pressure.

Materials Required. Piece of glass tubing 18" long, 1" x 4" x 6" board, 1" x 2" x 9" board, nails, gas jet, vacuum cleaner or some other source of gas pressure to measure and mercury.

Construction of the Apparatus. An open end manometer may be made from a piece of glass tubing 18" long. The glass tube is held over a flame allowing the flame to heat the middle section as in Figure 19 A. The tubing is bent into the shape of a "U" leaving the sides far enough apart to permit a ruler to be placed between them, as in Figures 19 B and C. One side of the "U" is heated about $1\frac{1}{2}$" from the open end and bent at right angles as shown in Figures 19 D and E. A stand for this manometer may be made from a piece of board 1" x 4" x 6", and another 1" x 2" x 9". The 1" x 4" board is the base as in Figure 10. The "U" tube is then fastened to the stand and a ruler is attached to the stand inside the "U" as shown in Figure 20. Mercury is poured into the "U" tube so that the level of the mercury on both sides of the tube can be read on the scale formed by the ruler, as in Figure 20.

Procedure. The height of each column of mercury in the manometer is read and the readings recorded. A source of gas pressure is attached to one end by means of a rubber tubing. New readings of the height of the column of mercury on each side are taken, and the difference between the readings is obtained. With this reading and the density of mercury, the pressure of the gas is obtained.

Comparative Cost. A manometer tube costs forty to fifty cents and it may be made as described in this experiment for a few cents.

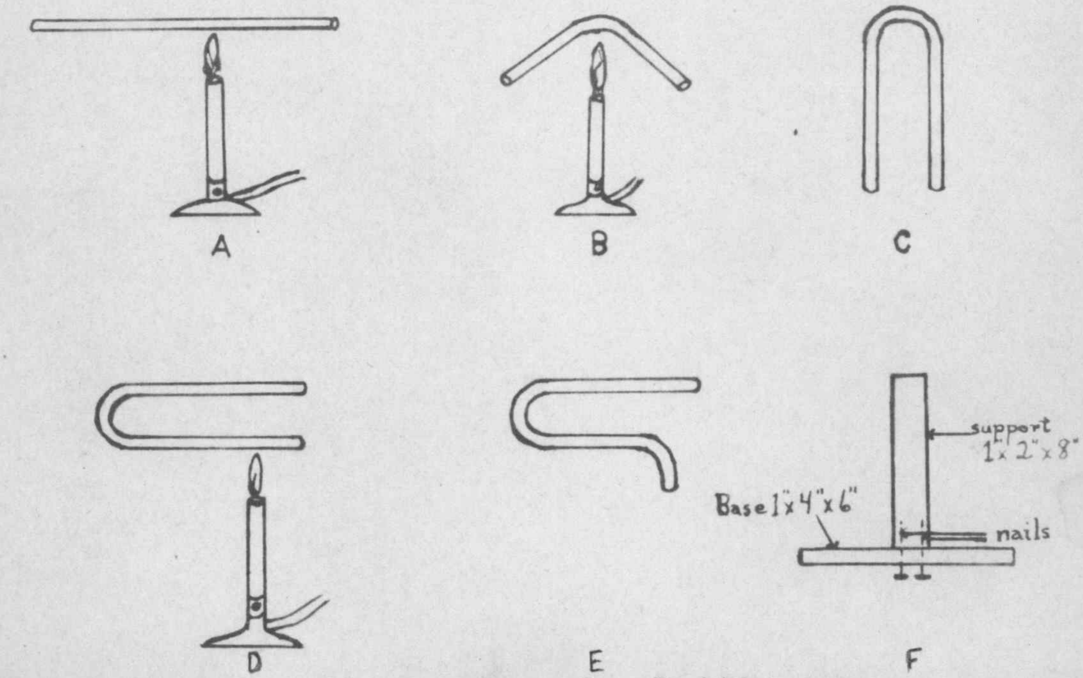

Figure 19 Bending a Glass Tube For an Open End Manometer

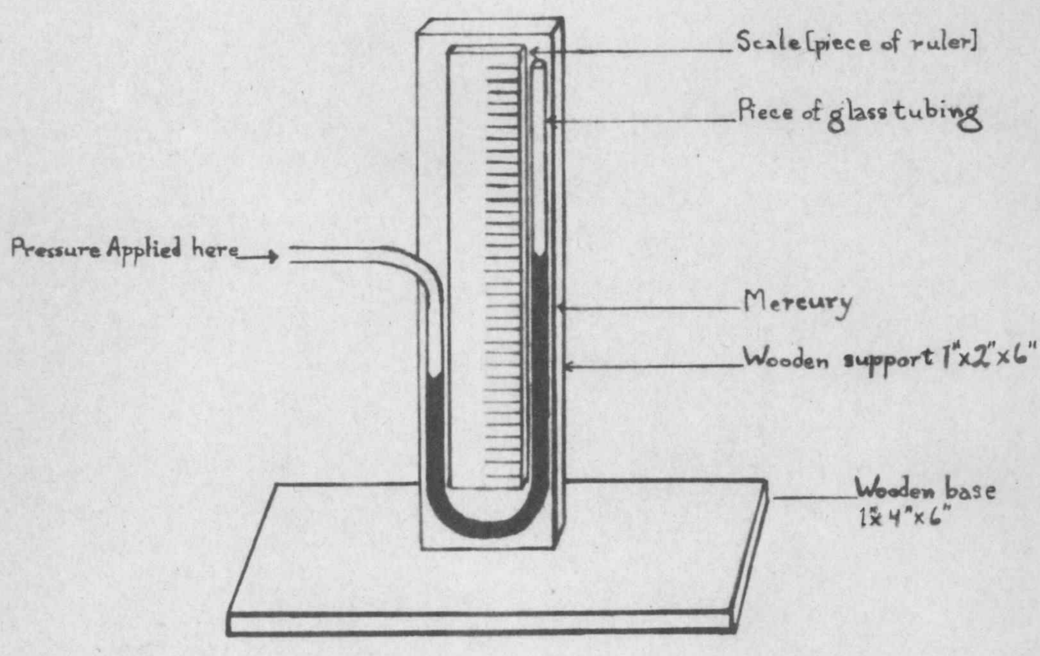

Figure 20 Open End Manometer

Experiment 10.

Boyle's Law

Purpose. To permit the student to demonstrate the fact that volume varies inversely as to pressure.

Materials Required. Glass tubing, mercury, small funnel, measuring stick, and short piece of rubber tubing.

Construction of the Apparatus. Two pieces of glass tubing about 12" long, one of which has one end closed by heating over a flame, as in Figures 21 A, B and C, are attached together by means of a short piece of rubber tubing. This apparatus is now bent in the form of a "U" and attached to a stand made from a 1" x 2" x 16" board and another one 1" x 4" x 6" as shown in Figure 21 D. A ruler is attached to the stand between the sides of the "U" as shown in Figure 22. A small funnel is placed in the tube with the open end and the mercury is poured in it until the height of the column is approximately the same on each side.

Procedure. Using the apparatus just described above the length of the column of air trapped by the mercury is recorded and the height of the mercury in each tube is ascertained. More mercury is added and the height of each column and the length of the column of air is read as before. The increase of the volume of mercury times the density gives the additional pressure applied to the gas which is compared to the loss in length of the column of air.

Comparative Cost. A Boyle's Law tube is listed at sixty-five to seventy-five cents whereas the apparatus described in this experiment would not cost over ten cents.

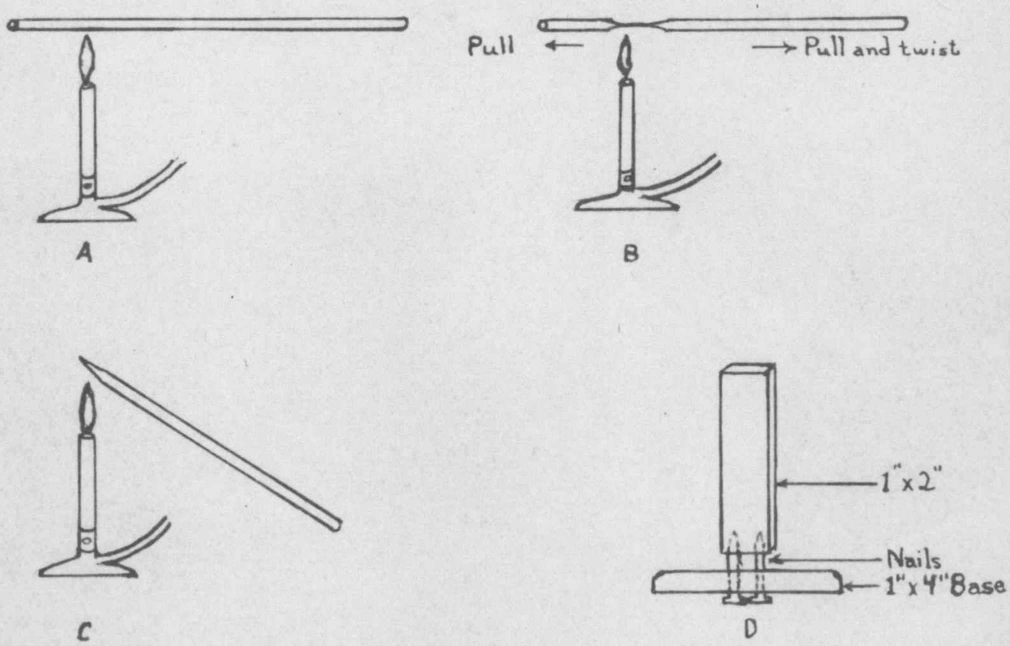

Figure 21 Construction of Boyle's Law Apparatus

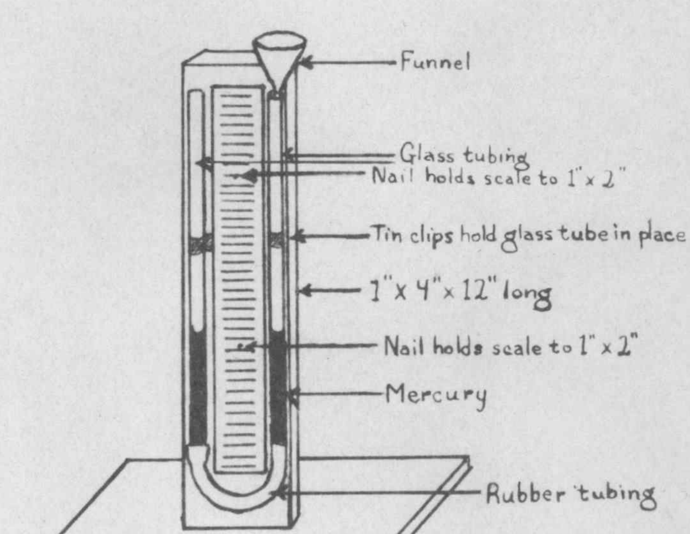

Figure 22 Boyle's Law Apparatus

Experiment 11.

Atmospheric Pressure

Purpose. To familiarize the student with the effects of air pressure.

Materials Required. Pan, milk bottle, length of glass tubing thirty-six inches long, dish, mercury, and varnish can.

Construction of the Apparatus. There is nothing to make in this experiment except the tube with the closed end, which can be constructed by sealing one end of the tube in a flame.

Procedure. A milk bottle is filled with water and a paper placed over the top held in position and the bottle inverted. Air pressure holds the paper against the mouth of the bottle. The mouth of the bottle is immersed in a pan of water, and the paper is removed. The water remains in the bottle as shown in Figure 23.

The glass tube with the closed end is filled with mercury, making sure that no air bubbles remain, and inverted in a dish of mercury as in Figure 24. The height of the column of mercury is measured, and compared with theoretical values.

A small amount of water is placed in a varnish can (or any other can with an air tight top) and the water is allowed to boil until the can is full of steam. Then the top is forced on the can and the can suddenly thrust under cold water, as in Figure 25.

Comparative Cost. A Torcelli or barometer tube costs around fifty cents and the one made by annealing one end of a piece of glass tubing costs less than five cents.

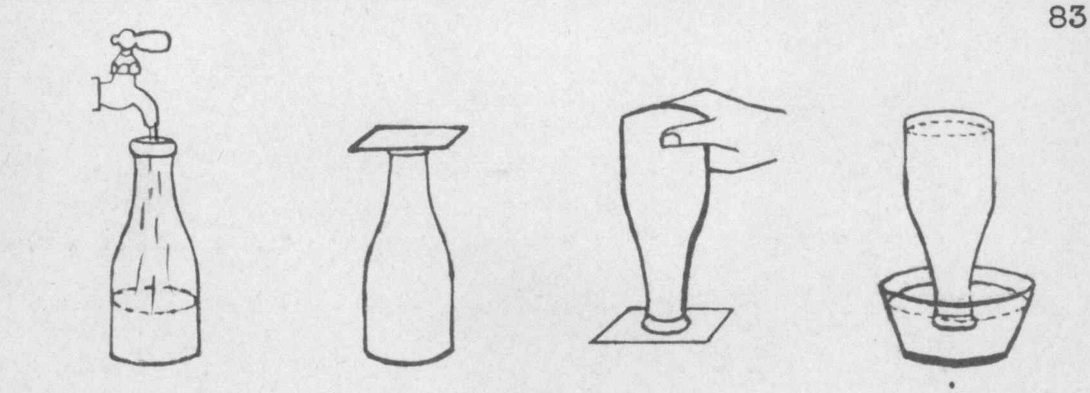

Figure 23 Atmospheric Pressure

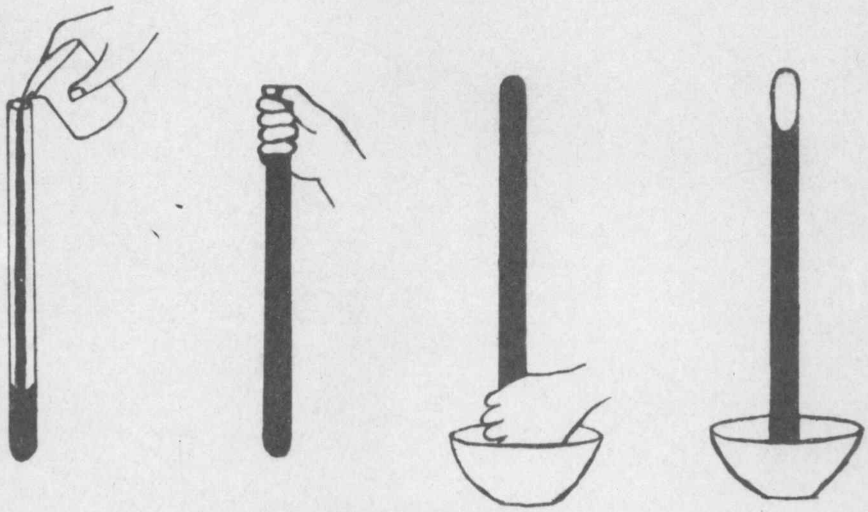

Figure 24 Mercury Barometer

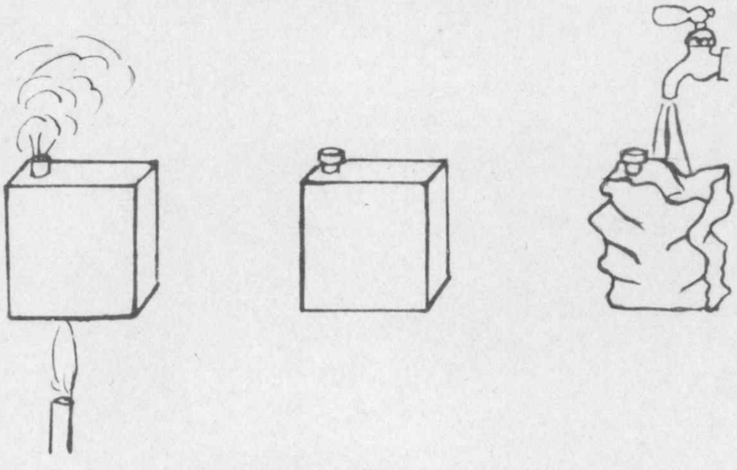

Figure 25 Atmospheric Pressure

FORCE AND MOTION

Experiment 12.

Parallelogram of Forces, Resultant, Component, and Parallel Forces

Purpose. To enable the student to study the composition of forces.

Materials Required. Three spring balances, four pieces of wood, 1" x 2" x 24" long, nails, table, paper, and string.

Construction of the Apparatus. A parallelogram of force frame may be made by nailing the four pieces of 1" x 2" together to form a square 25" on each side. Small nails are placed at various distances along the upper and lower edges of the sides as shown in Figure 26.

Procedure. To demonstrate the parallelogram of forces, the hooks of two spring balances are attached together with the length of string about 12" long. Short pieces of string about 8" long are tied to the rings in the top of the balances and attached to nails at the top on the parallelogram of force frame. Another short piece of string is attached to the center of the string connecting the hooks of the scales and attached to the hook of a third balance. The third balance is attached to the bottom of the parallelogram of force frame by means of another string as shown in Figure 27. A piece of paper is placed under the intersection of the strings connecting the hooks of the three balances, the parallelogram of forces is plotted on this paper, two angles of the parallelogram being equal to the angle between the two upper scales, and the sides proportional to the readings. The angles may be changed by moving the strings to various nails on the frame.

To study parallel forces the string connecting the balances is removed and a meter stick or a stick of sufficient strength, at least $\frac{3''}{8}$ x $\frac{3''}{4}$, is fastened to each of the balances so that they are parallel. The lower balance is attached by a string to the other side of the stick and to the bottom of the frame as shown in Figure 28.

Comparative Cost. A composition of force board is listed in most catalogues at prices from two dollars and up, while the apparatus just described costs only seventy-five cents, including the scales.

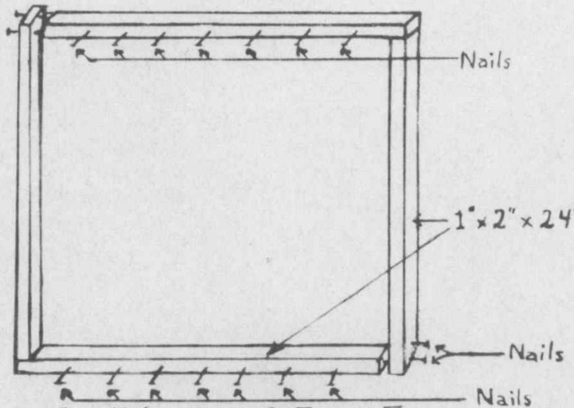

Figure 26 A Parallelogram of Force Frame

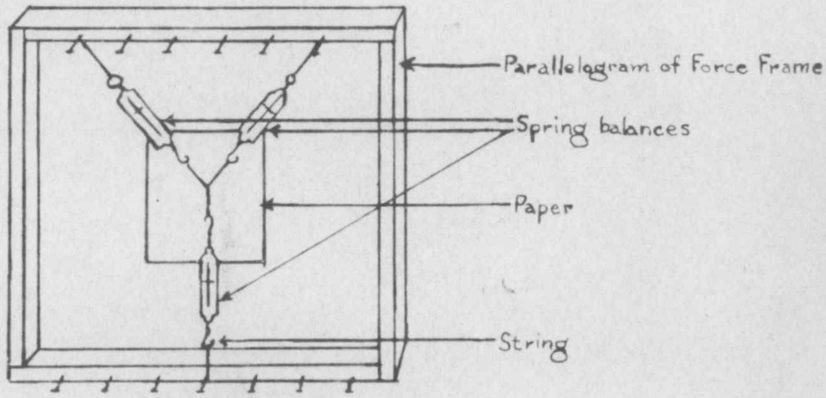

Figure 27 The Parallelogram of Force

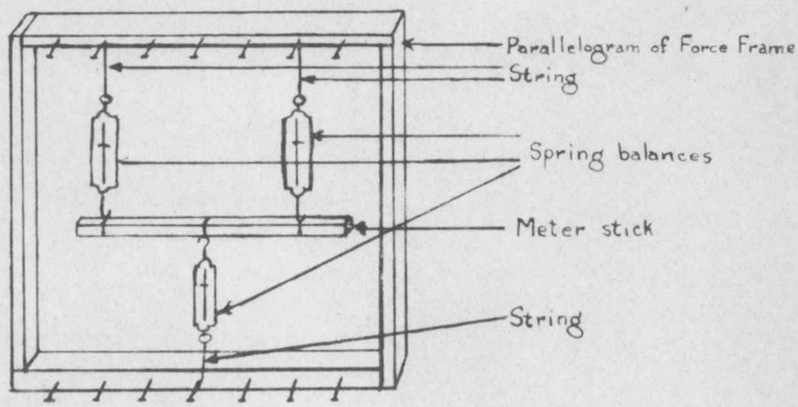

Figure 28 Parallelogram of Forces

Experiment 13.

Parallelogram of Forces,
The Simple Crane

Purpose. To study the resolution of forces and the principle of the simple crane.

Materials Required. There are two alternatives for this experiment. The first piece of apparatus requires: string, two pairs of spring balances, bucket of sand, piece of a broomstick about 24" long, two pieces of wood 1" x 4" x 24", two screw eyes and nails. The other requires: two spools, 1" x 4" x 36" board, 2" x 4" x 18" board, two stove bolts, four screw eyes, two pairs of spring balances, string and bucket of sand.

Construction of the Apparatus. For the first piece of apparatus mentioned above, the two pieces of 1" x 4" x 24" are nailed together so that they form a right angle as shown in Figure 29 A, and a screw eye is placed on the inside near the end of one leg of the angle. Another screw eye is placed in one end of the broomstick, a small nail is driven into the other end and the head of the nail is either filed off or cut off, as in Figure 29 B.

For the second piece of apparatus mentioned above, a rectangular hole is cut in the center of the 1" x 4" x 36" board, and made sufficiently large to receive the two spools and allow the broom handle to pass between them, as shown in Figure 30 A. The 2" x 4" x 18" is nailed on the end of this board to serve as a support as shown in Figure 30 A. Then $\frac{1}{4}$" holes are drilled in the 36" board edgewise to hold the stove bolts, which serve as axles for the spools as shown in Figure 30 A. A screw eye is inserted in each end of the 36" broomstick, as shown in Figure 30 B. Two screw eyes are inserted on opposite sides of the board to serve as supports for the spring balances.

Procedure. For the first piece of apparatus a string is attached to the ring in the top of one of the balances, and to the screw eye on the inside of the angle described above. Another string is attached to the hook of the balance and run through the screw eye in the end of the broomstick which has been placed so that the nail rests in the apex of the angle and a pail of sand is weighed and attached to the other end of the string, as shown in Figure 29 C. Another string is tied to the screw eye and to the hook of another spring balance, pressure being applied to the ring in the top of this balance until the nail at the other end of the broomstick begins to pull away from the base. The readings of all balances are recorded, paper is placed beneath the intersection of the scales and the angles and vectors are plotted in accordance with the angles and readings of the scales.

For the second piece of apparatus mentioned, the broom handle with the screw eyes at each end is inserted between the spools as shown in Figure 30 C. The string is attached to the screw eye at the top of the board and to the ring in the top of one of the spring balances. Another string is attached to the hook of the spring balance and to the screw eye in the end of the broomstick as shown in Figure 30 C. Another spring balance is fastened to the screw eye on the other side of the board. A string is tied to the hook of the spring balance, threaded through the screw eye in the other end of the broom stick, and attached to the pail of sand as in Figure 30 C.

Comparative Cost. No similar commercial apparatus has been found.

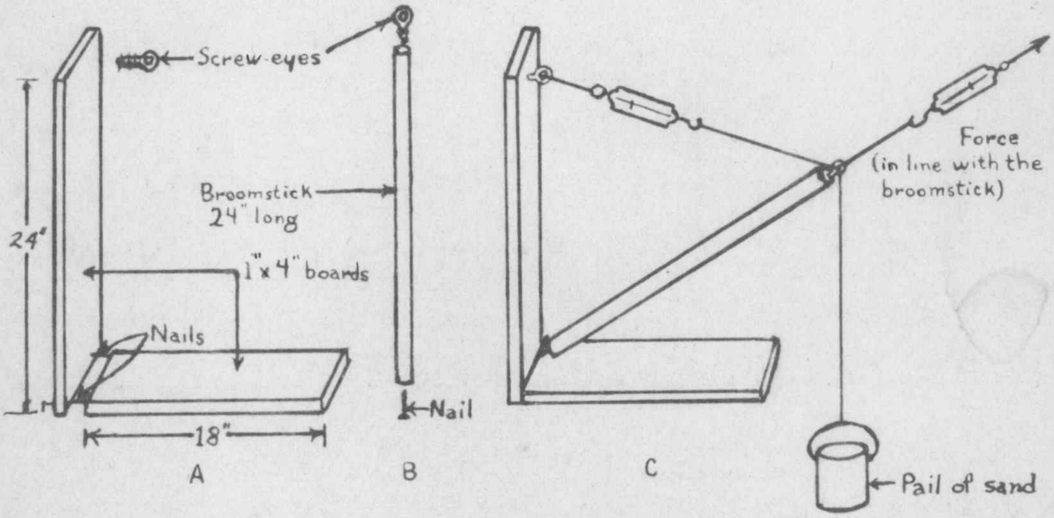

Figure 29 Construction and Use of a Simple Crane

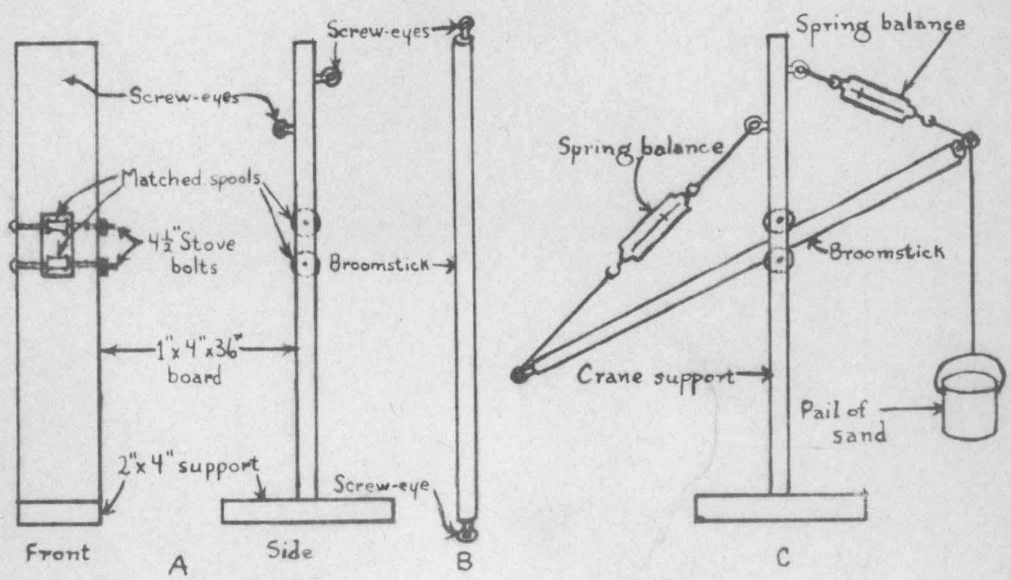

Figure 30 Another Type of Simple Crane

Experiment 14.

The Pendulum

Purpose. To enable the student to understand the laws of the pendulum and to study the difference between the simple and compound pendulum.

Materials Required. Steel ball (ball bearing from an automobile), lead or babbit ball, marble, string, measuring stick, support for the pendulum, ball bat, four screw eyes, sealing wax or solder, and watch (stop watch if possible).

Construction of the Apparatus. Screw eyes are fastened to balls of different kinds of materials by means of sealing wax or solder, as shown in Figure 31. Marbles and steel balls may be obtained about the same diameter. A lead or babbit ball may be made by making a plaster of Paris mold of either the marble or the steel ball and melting either the lead or babbit and pouring it into the mold. A compound pendulum is made by putting a screw eye in the handle end of the ball bat and fastening under a hook in the support as shown in Figure 33 A, or a sand pendulum may be constructed from 4 large washers, a funnel, paper, sand, a 1" x 2" board and a piece of 11" x 12" board as shown in Figure 33 B.

Procedure. A string is attached to each of the balls by means of the screw eye designated above and fastened to the support so that the length of the string may be varied from 6" to 6'.

The compound pendulum is studied from the apparatus described above and compared with the simple pendulum.

Comparative Cost. The commercial apparatus similar to the apparatus described in this experiment would cost from one to two dollars whereas the apparatus described in this experiment would cost less than fifteen cents.

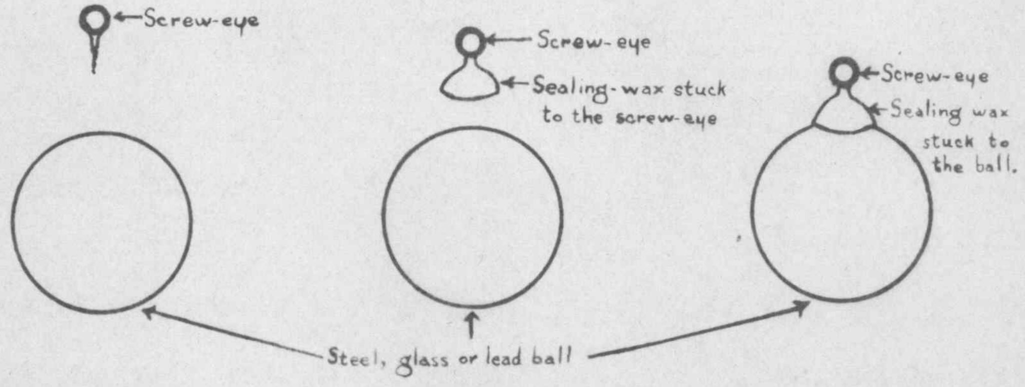

Figure 31 Pendulum Bobs Made From Balls of Different Materials

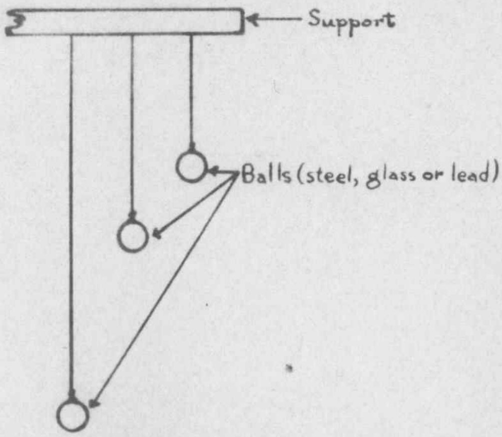

Figure 32 The Simple Pendulum

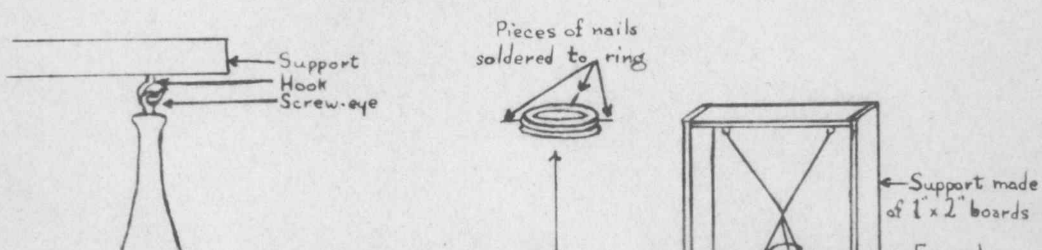

Figure 33 Compound Pendulums

Experiment 15.

Newton's Three Laws of Motion

Purpose. To demonstrate with simple equipment Newton's three laws of motion.

Apparatus Required. Two small ten-cent trucks, piece of spring from a curtain roller, weights, four steel balls, 1" x 4" x 8" board, 1" x 4" x 18" board, piece of veneer board 4" x 18", nails, bicycle or tricycle wheel, pulley, coin and card.

Construction of the Apparatus. An apparatus to demonstrate inertia is made as follows: small sections about one inch square are cut in opposite ends of one edge of a 1" x 4" x 8" board as shown in Figure 34 A. A piece of veneer board 4" x 8" is nailed to one side of the 1" x 4" x 8" board mentioned above, as in Figure 34 B. A hole is drilled in the center of the board for a nail which holds the board to the table so that the board will turn on an axis, as shown in Figures 34 B and C.

The two small trucks are fastened together with the curtain spring as shown in Figure 34 E.

An Atwood machine is made by fastening the tricycle wheel, from which the rubber tire has been removed, to an upright 2" x 4" as shown in Figure 35 B by means of a large nail or bolt.

Several steel balls are equipped with screw eyes as described in Experiment 14 and attached with strings to a support so that the steel balls just touch one another as shown in Figure 36 B.

Procedure. To demonstrate the effect of inertia, a coin is placed on a card directly above the first finger as shown in Figure 34 D, and the card flipped from under the coin. Another demonstration is given by holding one of the small trucks, putting a few weights in the other one, pulling it back against the spring and releasing them suddenly. Again the effect of inertia may be demonstrated by placing a steel ball in each of the notches made in the 1" x 4" x 8" board and placing it so that one of them is in the notch which extends over the edge of the table and the other is in the notch which is directly over the table as shown in Figure 34 C. The board is struck behind the ball directly over the table as shown in Figure 34 C. To show the effect of centrifugal force a short iron bar is placed in a hand drill, the string fastened to the lower end of the iron bar with beeswax and a small weight tied on each end of the string as shown in Figure 34 F, and the drill is whirled. Another demonstration may be given by rolling a dollar around and nearly perpendicular to the sides of a dishpan, as in Figure 34 G.

Newton's second law may be demonstrated by placing a weight in one truck and a weight twice its size in the second truck pulling them apart so that the spring is stretched, and measuring the distance through which each moves as they come together as shown in Figure 35 A. Second, a cotton cord about 6' long is placed over the Atwood machine described above, equal weights are attached to each end of this cord, then additional weights are added to one side and the relative acceleration noted. (See Figure 35 B.)

Newton's third law may be illustrated with the two trucks by letting them come together and noting their reaction. Also it may be demonstrated by use of the four balls hanging from the support described above by pulling out one ball and releasing it and noting the reaction. (See Figure 36 B.)

Comparative Cost. The complete apparatus for this experiment is listed at five dollars in many apparatus catalogues. The cost of the apparatus described in this experiment would be twenty-five to fifty cents.

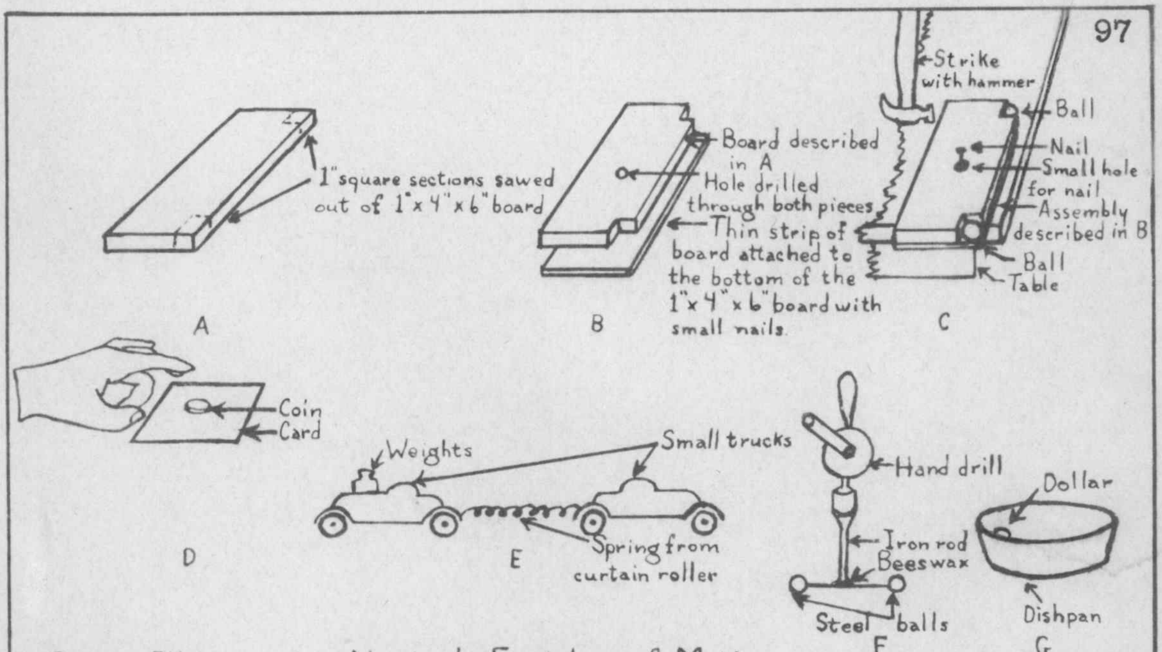

Figure 34 Newton's First Law of Motion

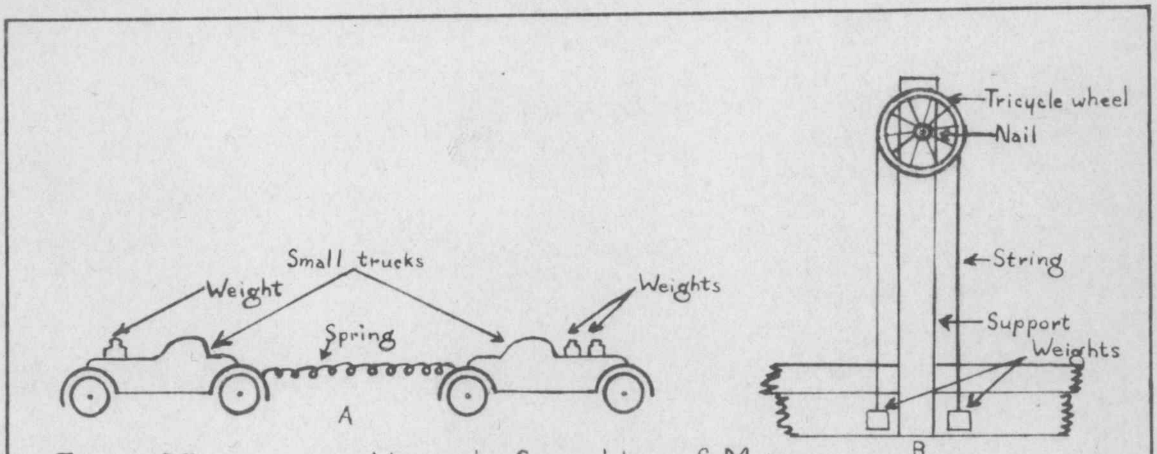

Figure 35 Newton's Second Law of Motion

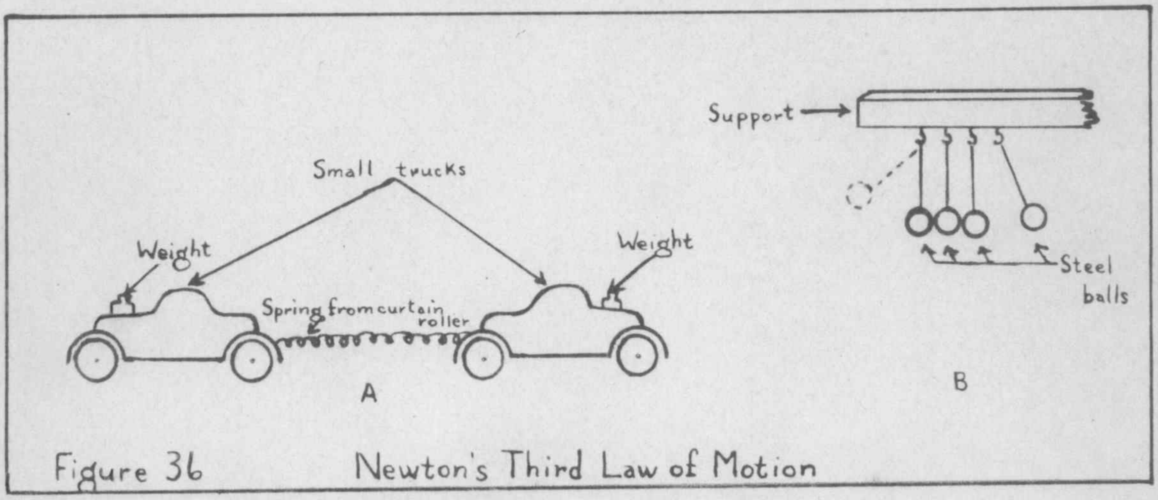

Figure 36 Newton's Third Law of Motion

Experiment 16.

Hooke's Law

Purpose. To give the student the opportunity to investigate the mathematical relations existing between stress and strain when an elastic body is stretched, twisted or bent.

Materials Required. Small tin jar lid, stove pipe wire, small piece of tin, spring (from the inside of a curtain roller), metal rod, steel wire, piece of a yard stick, small block of wood, and weights.

Construction of the Apparatus. The spring is removed from the curtain roller and a hook twisted on each end as shown in Figure 37 A. A weight pan may be made by punching four holes around the flange of a jar lid equal distances apart and making two bails from the stove pipe wire as shown in Figure 37 C. A pointer is made for the spring by cutting a strip of tin to a sharp point and rolling the other end around the hook of the spring as shown in Figure 37 B. A scale is made by nailing a short piece of the yard stick on the front of the wooden block as shown in Figure 37 D.

Procedure. The spring described above is attached to a support. The pointer is fastened just above the hook on the lower part of the spring and the balance pan described above is attached to the hook. The scale is placed behind the pointer as shown in Figure 37 E.

The metal rod is fastened at one end in a small ten-cent store vise or a small "C" clamp and the scale is set up behind the other end of the rod and the balance pan is attached as shown in Figure 38 A.

Another method is to lay a metal rod across two blocks, a wire attached to the center of the rod and a tin pointer fastened around this wire and the balance pan fastened to the end of the wire as shown in Figure 38 B. The scale is placed behind the pointer as shown in the figure.

A steel wire is attached to a hook in the ceiling or in some support sufficiently high and a pointer is fastened around the lower end and the balance pan fastened on below the pointer and the scale is again placed behind the pointer as shown in Figure 39.

Comparative Cost. The mirror scale for Hooke's Law with a metal support is listed in most catalogues for more than one dollar and twenty-five cents. Spring and weight holders are listed around twenty-five cents, a steel rod around ten cents, making a total somewhere near two dollars. The equipment for the experiment described above would cost not more than five cents.

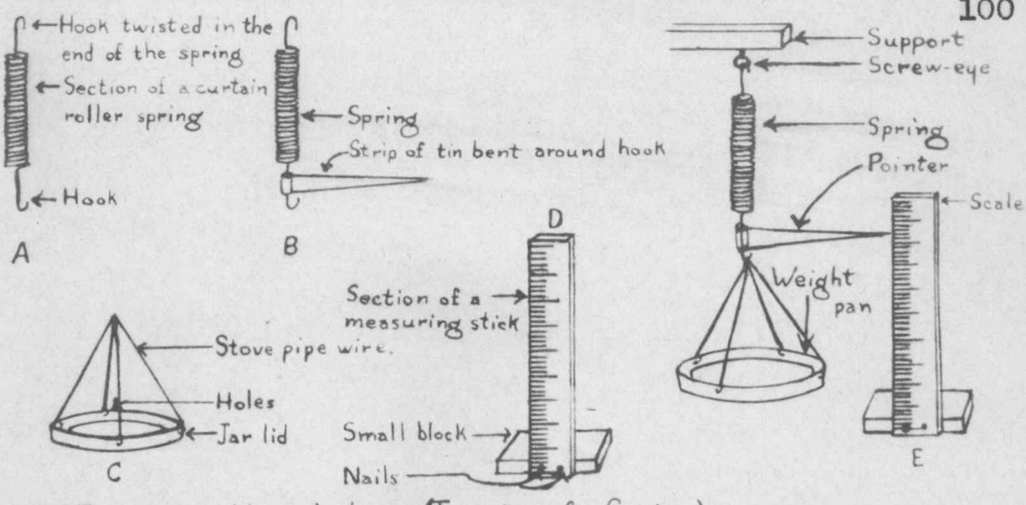

Figure 37 Hooke's Law (Twists of a Spring)

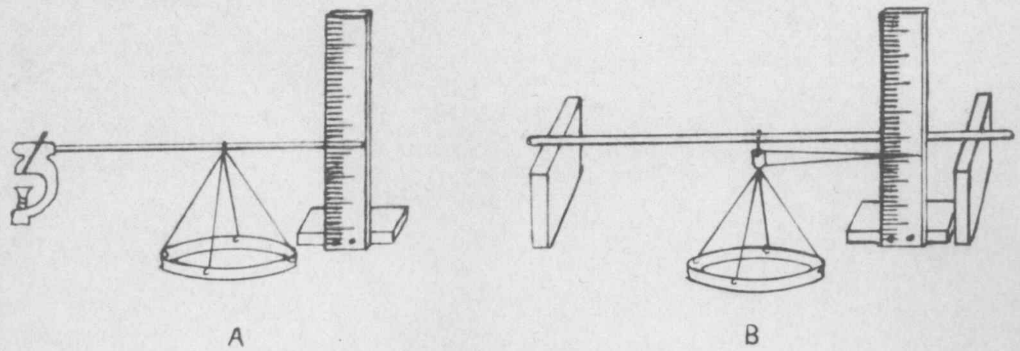

Figure 38 Hooke's Law (Bending of a Rod)

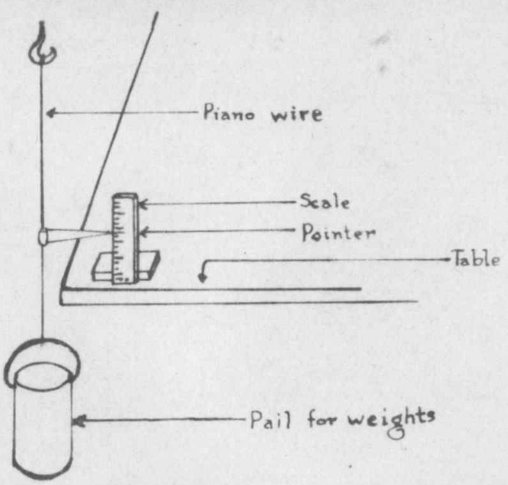

Figure 39 Hooke's Law (Stretching of a Wire)

Experiment 17.

Pulleys

Purpose. To enable the student to study the principle of work and to determine the mechanical advantage.

Materials Required. Heavy corrugated carton or large piece of heavy corrugated cardboard, small screw eyes, small thin pieces of wood*, string, weights, spring, measuring stick and balance.

Construction of the Apparatus. Pulleys may be made, as follows: A circle of the desired size is drawn on the corrugated cardboard, with a compass. The circle is cut out with a very sharp knife or a razor blade as shown in Figure 40 A. The back of a knife is used to crease a groove around the outer edge of the wheel. A pin or small nail may be used for an axle. Wheels may be made for all the pulleys in this manner. Two thin strips of wood are used for the sides of the pulley and the pin is driven through both sides and through the center of the wheel. Small blocks of wood are attached above and below the wheel as shown in Figure 40 B, and small screw eyes pulled slightly open to make the hooks are placed in each of the blocks. Double pulleys for the block and tackle may be

*A series of pulleys obtainable at the ten-cent store may be used instead of the home-made pulleys if desired.

made in a similar manner as shown in Figure 40 C. A wheel and axle may be made by using one wheel, made of corrugated cardboard as described above, 8" in diameter and another 2" in diameter fastened to the same axle and glued together as shown in Figure 40 D.

Procedure. A string is attached to a support and run through a pulley to which a weight has been attached, and a spring balance is applied to the other end of the string as shown in Figure 41 A.

The pulley is attached to a support, a string is run through the pulley, then a spring balance is attached to one end of the string and a weight to the other as shown in Figure 41 B.

The pulley is attached to a support, a string is tied to the bottom of the pulley, then run through another pulley to which a weight has been connected, then brought back over the first pulley and attached to a spring balance as shown in Figure 41 C.

A block and tackle is arranged as shown in Figure 41 D.

The wheel and axle is attached to a support, a weight is connected to the smaller wheel and a spring balance to the larger wheel, as in Figure 41 E.

Comparative Cost. Apparatus manufacturers list pulleys at from twenty cents to sixty cents per set. The ones required in this experiment cost one dollar or more and a wheel and axle is listed in most apparatus catalogues at one dollar and twenty-five cents or more, whereas the actual cost of the ones described in this experiment is about ten cents.

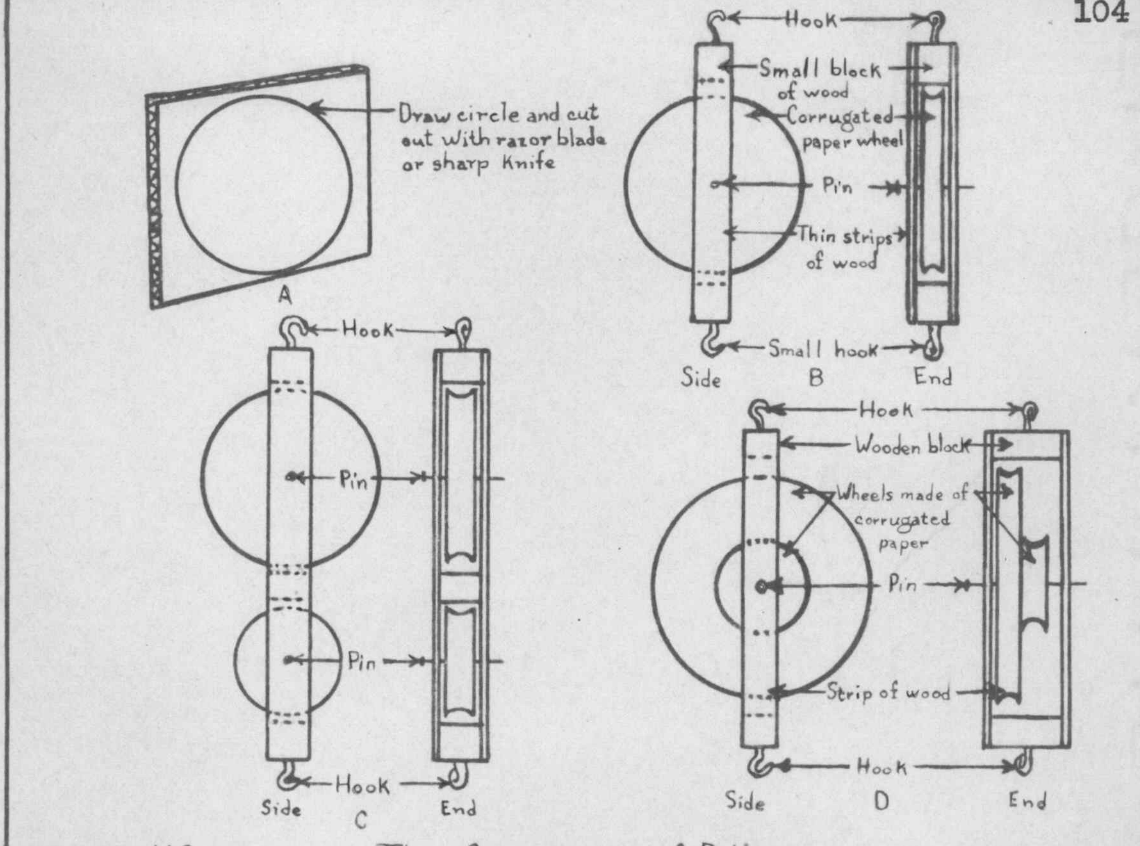

Figure 40 The Construction of Pulleys

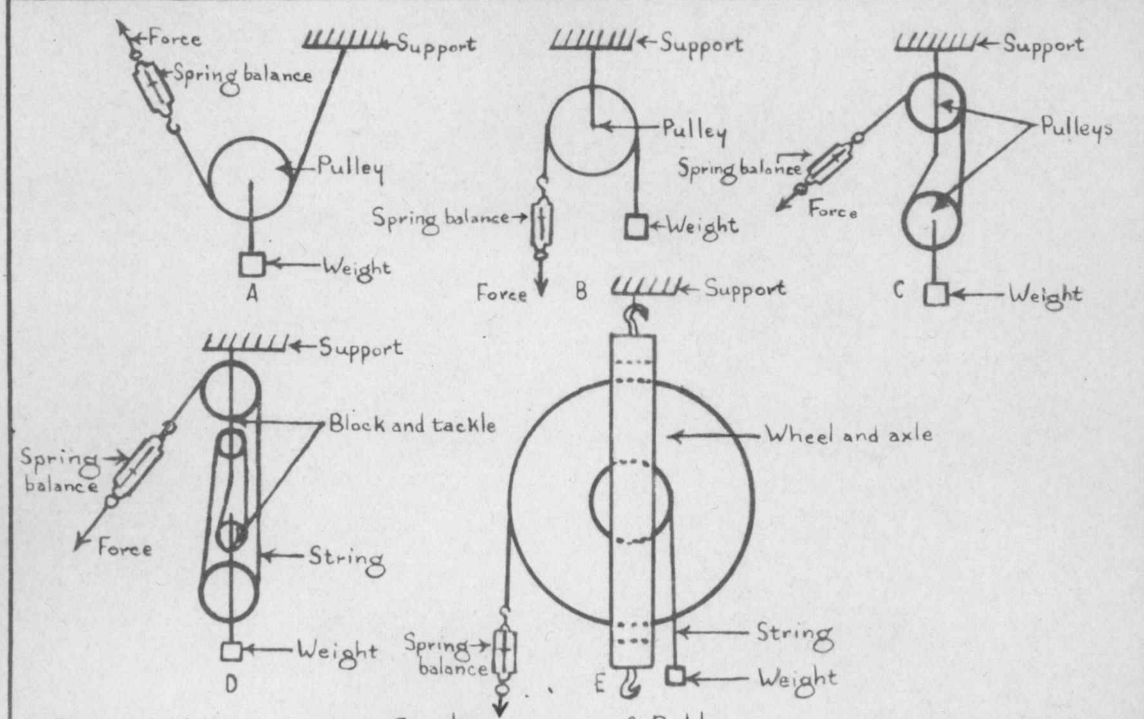

Figure 41 Combinations of Pulleys

Experiment 18.

The Simple Lever

Purpose. To enable the student to find the mechanical advantage of several different kinds of levers.

Materials Required. Wooden stick about 1" x 1" x 36", block of wood 2" x 4" x 6", block 2" x 4" x 4", block 1" x 6" x 6", spring balance, weights, string and measuring stick.

Construction of the Apparatus. One notch is sawed in the center of the 1" x 1" x 36", and another near one end, as shown in Figure 42 E. A triangle is sawed from the 1" x 6" x 6" as shown in Figure 42 A. This triangle is nailed to a short piece of 2" x 4" to form a fulcrum as shown in Figure 42 B. The 2" x 4" x 2" is split in the manner shown in Figure 42 E, and attached to a support as shown in Figure 42 D.

Procedure. The 1" x 1" x 36" stick is placed so that the notch rests on the apex of the triangle or fulcrum, and weights are hung at various distances in accordance with the principle $W_1 L_1 = W_2 L_2$, as in Figure 43 A.

The stick is now moved so that the notch near the end rests on the fulcrum, as shown in Figure 43 B. A spring balance is attached to the other end and the weight is moved to various positions between the fulcrum and the spring balance.

The 1" x 1" x 36" stick is placed under the fulcrum so that the groove fits over the point as shown in Figure 43 C, and a weight is attached to the other end. A spring balance is attached at various points between the weight and the fulcrum, and readings taken at each setting.

Comparative Cost. Commercial apparatus required for this experiment consists of a meter stick which sells for twenty-five cents or more, a fulcrum which costs fifteen cents or more and a lever holder support which costs fifty cents or more; making a total cost of seventy-five cents to one dollar, whereas the cost of the materials described in this experiment is only a few cents.

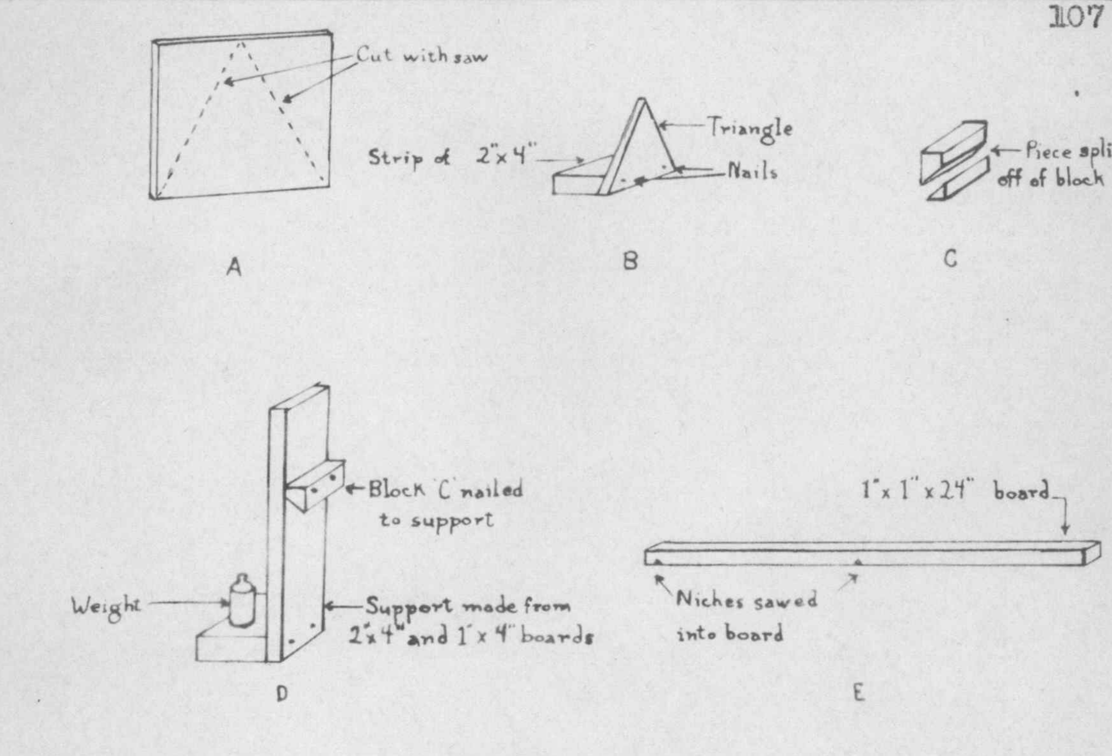

Figure 42 Construction of Levers

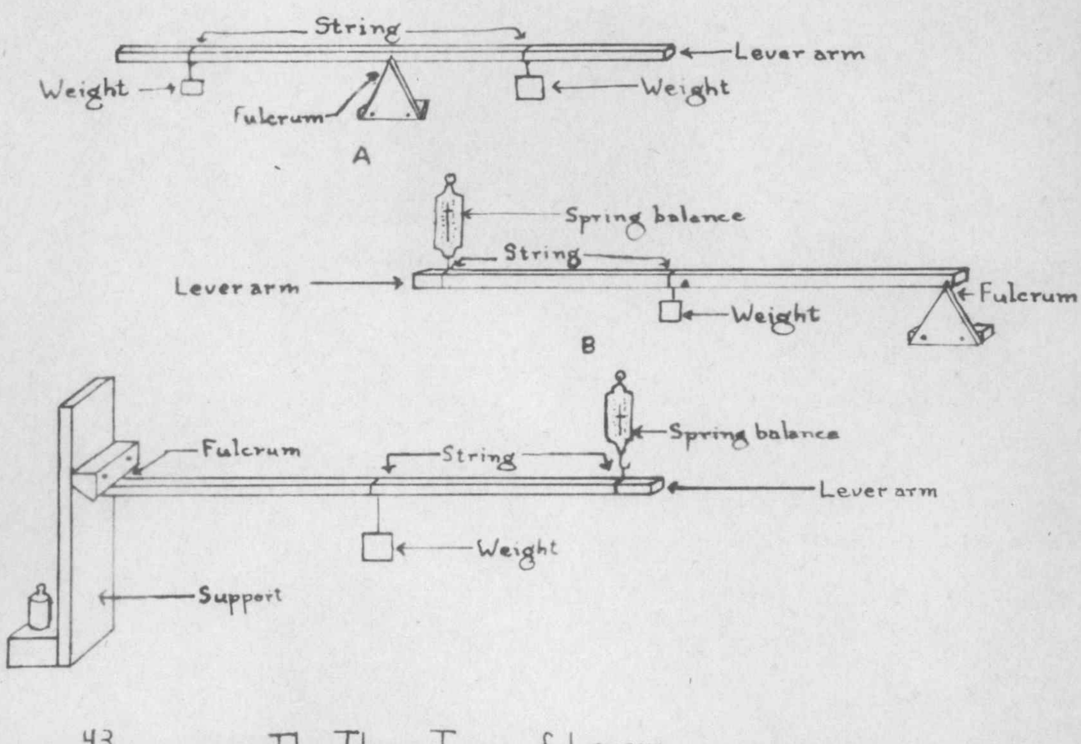

Figure 43 The Three Types of Levers.

Experiment 19.

The Compound Lever

<u>Purpose</u>. To find how two or more forces may be balanced and the condition of equilibrium for a compound lever system.

<u>Materials Required</u>. Three small screw eyes, board measuring 1" x 2" x 24", board measuring 1" x 2" x 18", small butterfly hinge and screws, spring balance, string, pail of sand and measuring stick.

<u>Construction of the Apparatus</u>. The boards are fastened together with the hinge and screws as shown in Figure 44. One screw eye is placed about 3 inches from the top of the 24" board, another one about 6 inches below the top and another one 9 inches below the top as shown in Figure 44.

<u>Procedure</u>. The apparatus described above is attached to a firm vertical support. A piece of string about 36" long is attached to the ring of a spring balance and the hook of the spring balance is placed through the first eye in the 24" board. The string is then brought down and attached to the end of the 18" board, so that when the pail of sand is attached to the end of the string, the 18" board and the 24" board will be at right angles to one another. However, before the pail of sand is attached, the reading of the balance is taken while the balance is

supporting the 18" lever arm. This is known as the zero reading. The pail of sand is attached to the string, the reading of the spring balance is recorded and the arms D and D′ are measured as shown in Figure 45. Readings are also taken with the spring balance attached to the second and third eyes on the 24" board.

Comparative Cost. No apparatus was found comparable to the apparatus described in this experiment.

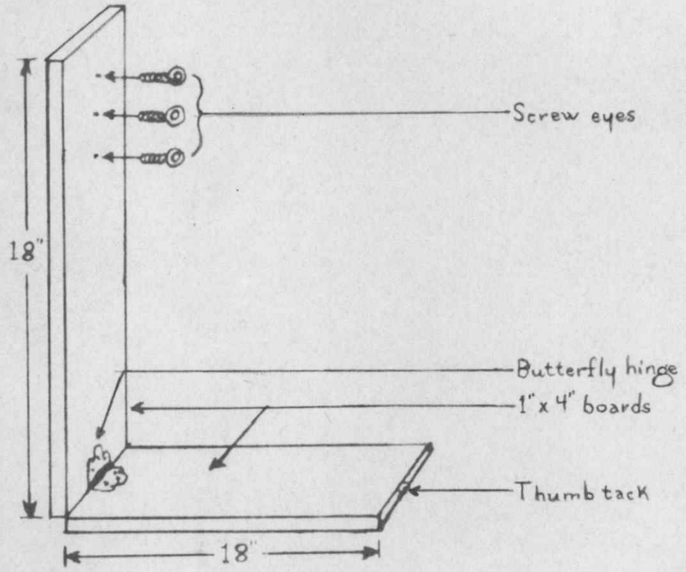

Figure 44 Construction of a Compound Lever

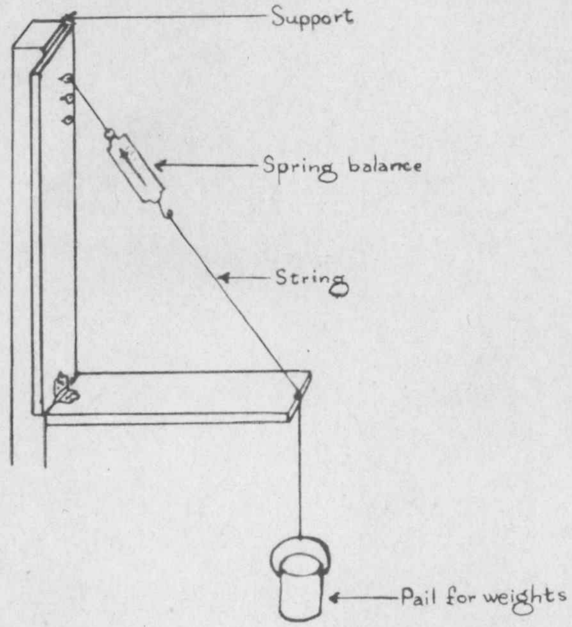

Figure 45 The Compound Lever

Experiment 20.

Inclined Plane

Purpose. To learn to calculate the forces involved and the work done when objects are lifted by means of the inclined plane.

Materials Required. Two boards, one 1" x 4" x 24", one 1" x 4" x 18", spool, ten-cent store truck, weights, string, block 2" x 4" x 6", small hinge with screws, measuring stick, paper, and $4\frac{1}{2}$" stove bolt.

Construction of the Apparatus. A notch is sawed in one end of the 1" x 4" x 24" board large enough to receive the spool and a nail is driven through the end of the board forming an axle for the spool as shown in Figure 46 A. The 24" board is then fastened to the 18" board by means of the hinge as shown in Figure 46 B.

Procedure. The 2" x 4" x 6" block is placed between the two boards and set on the table. The string is tied to the front of the truck, strung over the spool at the end of the 24" board and a weight or spring balance is attached to the end. Equilibrium is obtained by putting weights in the small truck, as shown in Figure 46 C.

To show the relation between the inclined plane and the screw, a right triangle is drawn on a piece of paper and cut out. This triangle is wrapped around a pencil as shown in Figure 46 D.

Comparative Cost. An inclined plane board with the car is listed in most catalogues at two dollars and upwards. The apparatus described in this experiment costs about twenty cents.

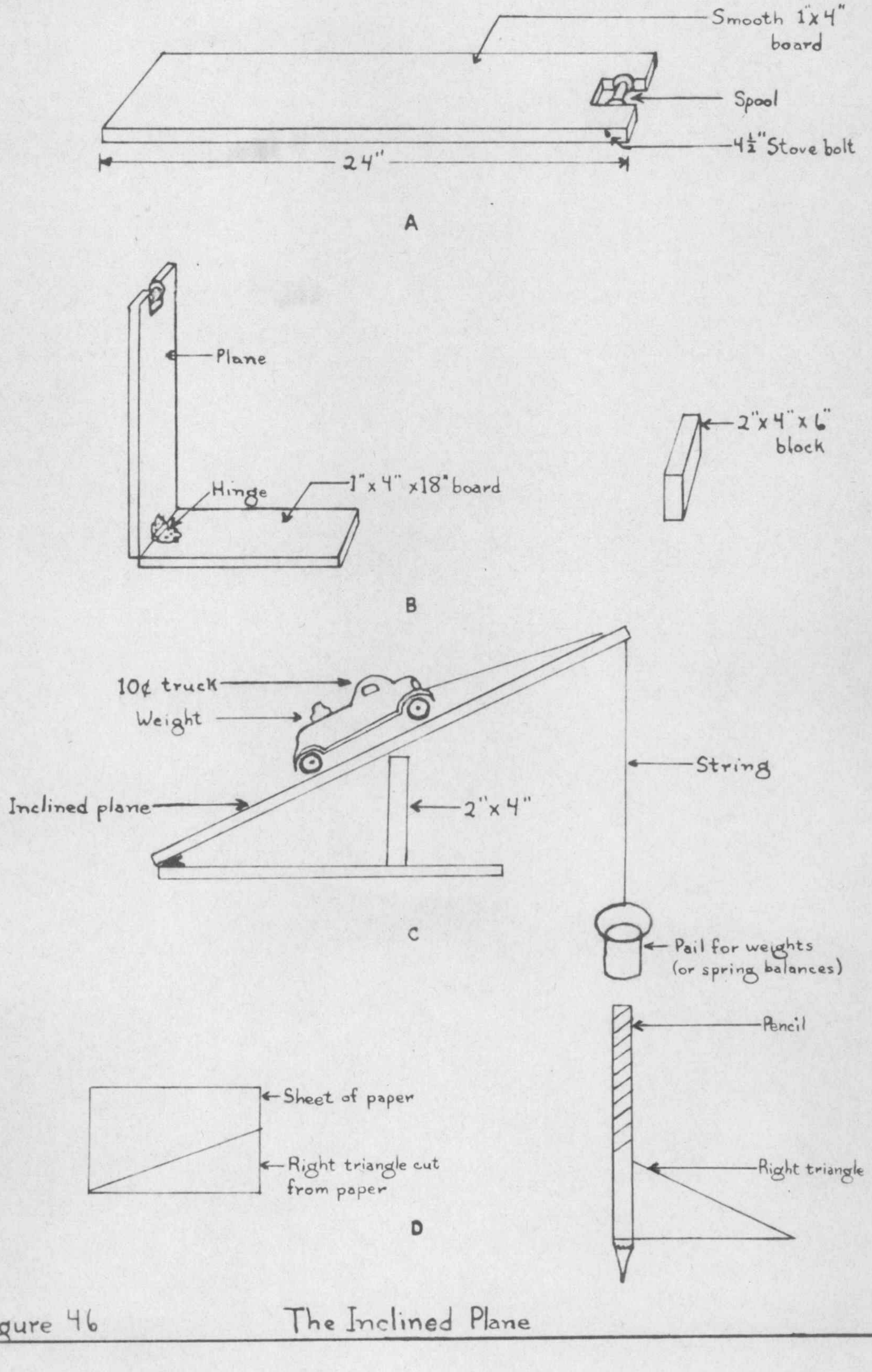

Figure 46 The Inclined Plane

Experiment 21.

Friction

Purpose. To make a quantitative determination of the effect of friction and to study some of the means of reducing it.

Materials Required. Hard wood block 2" x 4" x 8" (or any other similar size obtainable), smooth board 1" x 4" x 24", string, weights, strip of smooth metal (or cold rolled steel), block of iron with smooth sides, round lead pencils, oil and spring balance.

Construction of the Apparatus. There is no additional apparatus in this experiment.

Procedure. The apparatus is assembled as shown in Figure 47. The wooden block may be slid along its end on its side with various weights added on top of the block. The round lead pencils may be placed under the block and the block slid along. The iron block may be slid along first without oil and then with oil on the smooth metal.

Comparative Cost. No similar commercial apparatus was found.

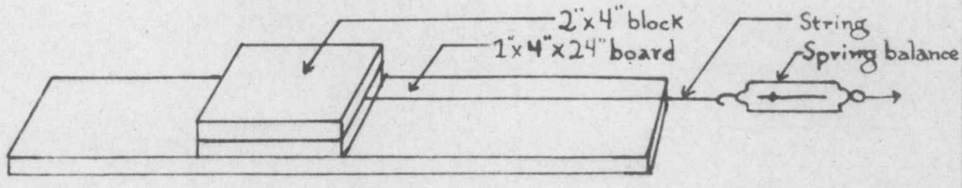

Figure 47 Coefficient of Friction

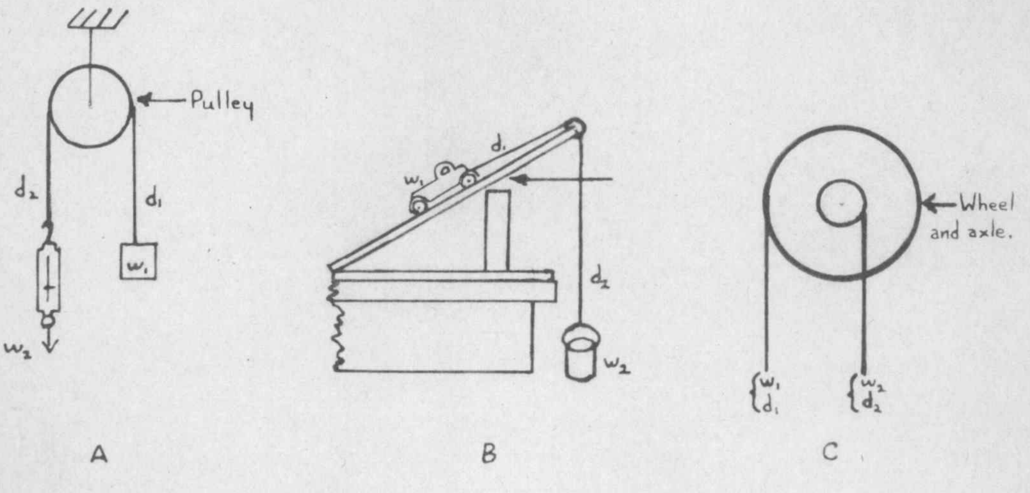

Figure 48 Efficiency of Machines

Experiment 22.

Efficiency of Machines

Purpose. To give the student an opportunity to find the mechanical advantage of an inclined plane, of a set of pulleys, and of a wheel and axle.

Materials Required. Inclined plane (as described in Experiment 17), spring balance, weights, string, and measuring stick.

Construction of the Apparatus. The apparatus required for this experiment has been described in the experiments on pulleys and the inclined plane.

Procedure. Readings are taken as weights are raised with the aid of the pulleys, wheel and axle, block and tackle, or the inclined plane, as in Figure 48. The distance through which the weight moves, the distance through which the listing force moves in pulling it up, the weight of the object raised and the reading of the spring balance are taken on each of the machines. The efficiency of the machine is computed by means of the formula,

$$\text{Efficiency} = \frac{\text{Useful work (output)}}{\text{Total work (input)}}$$

Comparative Cost. The pieces of apparatus required in this experiment have been used in other experiments and the comparative cost discussed.

Experiment 23.

Fixed Points on a Thermometer; The Effect of Pressure on the Boiling Point

Purpose. To test the accuracy of a mercury thermometer at the freezing point and the boiling point, and to find the effect of variation of pressure on the boiling point.

Materials Required. Fahrenheit thermometer, Centigrade thermometer, beaker, support for the funnel, varnish can, two-hole rubber stopper, short piece of glass tubing, short length of rubber tubing, crushed ice or snow, and pressure manometer.

Construction of the Apparatus. Only one piece of apparatus, the steam boiler, which has not been described before, is required. It can be constructed from an empty varnish can (or some similar can which has a screw top). A thermometer and a small glass tube are inserted in a two-hole rubber stopper which is selected to fit the spout of the can. Corresponding holes are cut into the tin cap. The cap is slipped over the top of the stopper as shown in Figure 49 A, and the entire assembly is screwed on to the spout as shown in Figure 49 B.

Procedure. Crushed ice or snow is placed in the funnel which is supported as shown in Figure 50 A. Two thermometers (a Centigrade and a Fahrenheit) are inserted in the funnel as shown in the Figure. Readings of each are taken. The boiler described above is placed on a stand over a burner and the short piece of glass tubing is connected by means of the rubber tubing to an open end manometer as shown in Figure 50 B.

Comparative Cost. A steam boiler or steam generator costs two dollars and fifty cents to three dollars. The one described here costs about five cents.

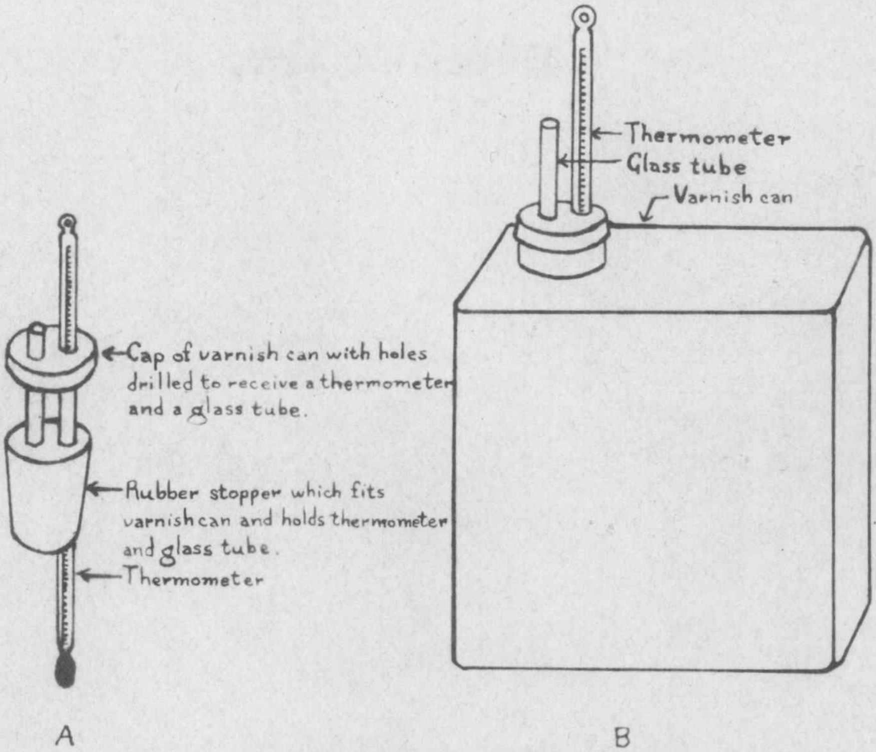

Figure 49 Construction of a Steam Boiler

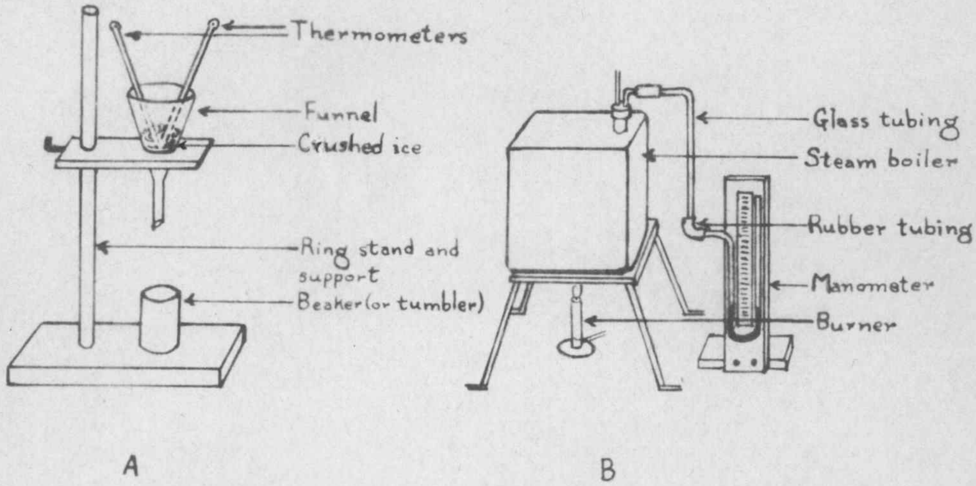

Figure 50 Fixed Points of a Thermometer and Effect of Pressure on the Boiling Point.

Experiment 24.

Coefficient of Linear Expansion

Purpose. To learn how to measure the amount of expansion in an iron pipe when heated, and to calculate the coefficient of expansion.

Materials Required. Steam boiler, two pieces of $\frac{1}{4}$" iron pipe (one three feet long and the other one, one to three inches long), 8" piece of stiff wire, 2' of rubber tubing, ruler, 2" x 4" x 8" block, and the top of a baking powder can.

Construction of the Apparatus. The steam boiler was described in Experiment 23. A roller as shown in Figure 51 A may be made by soldering a piece of stiff wire about 8" long to a 3" piece of $\frac{1}{4}$" pipe. A scale as shown in Figure 51 B may be made by nailing a segment of a yard stick or a ruler to the edge of the 2" x 4" x 8" block.

Procedure. The steam boiler containing water is placed on a stand over a burner. The glass tube from the steam boiler is connected by means of a rubber tube to the 3' length of the $\frac{1}{4}$" pipe. A small block 1" x 2" sitting on edge is placed under the end next to the boiler. Under the other end is placed the pointer described above which rests on a 1" x 2" block lying on its side. The scale is placed behind the pointer and the baking powder lid is put under the pipe as shown in Figure 52. A reading is taken on the scale before the steam has started through the pipe and again after the steam has started through. The amount of expansion is calculated.

Comparative Cost. Linear expansion apparatus is listed in most catalogues with the prices ranging from four dollars and up. The cost of this equipment should not exceed fifty cents.

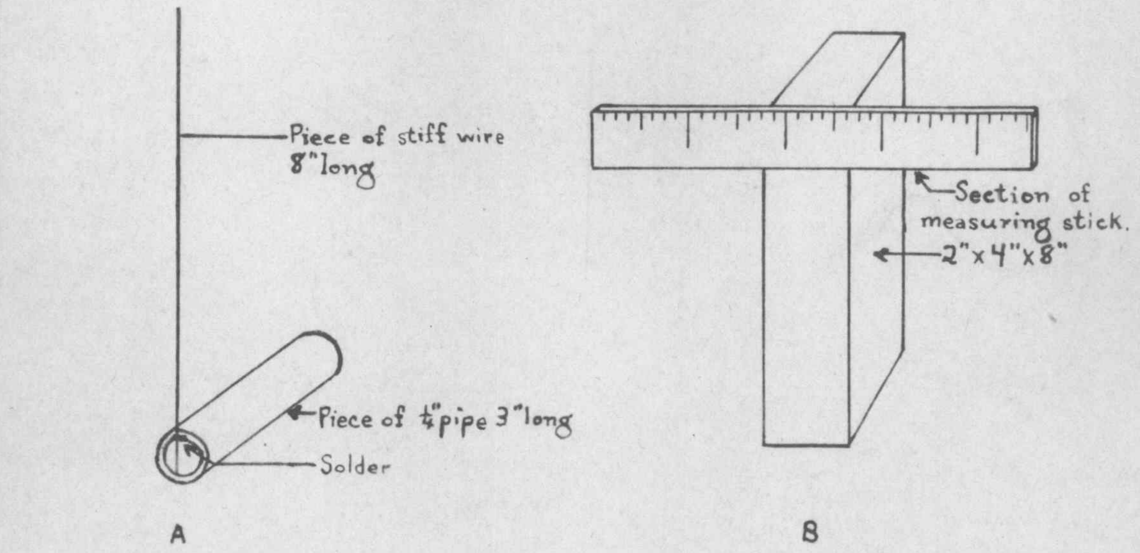

Figure 51 Construction of a Pointer and a Scale.

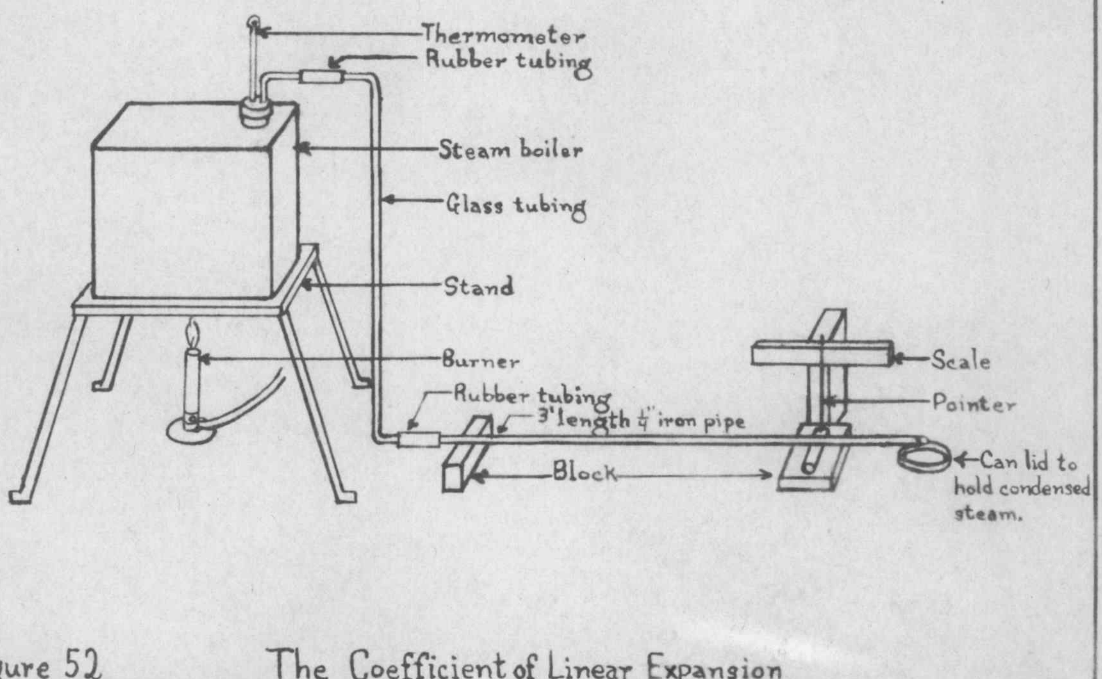

Figure 52 The Coefficient of Linear Expansion

Experiment 25.

Specific Heat of a Metal

Purpose. To study the heat holding capacity of various substances and to determine their specific heats.

Materials Required. Two tin cans of sizes such that one will fit inside the other (or an aluminum double boiler), vessel for heating water (tea kettle), burner, Centigrade thermometer, balance or scales, 500 gram piece of iron and a piece of lead or other metal.

Construction of the Apparatus. The only piece of apparatus used in this experiment which has not been described before is a calorimeter. A calorimeter may be made from two tin cans, one smaller than the other so that it will fit inside of the larger one leaving an air space between them. Insulate them so that they do not touch each other, with some kind of non-conducting material such as paper or wood as shown in Figures 53 B and C. A lid for the calorimeter may be made from a piece of balsa wood or a piece of graphited asbestos. A stirring rod may be made out of a piece of wire twisted as shown in Figure 53 D.

Procedure. A container (tea kettle) which is half full of water is heated. The iron is placed in the tea kettle with a string attached, as shown in Figure 54 A, and left in the water for at least five minutes. Make sure that it reached the temperature of boiling water. While this is being done, 300 grams of cold water at about 5° below room temperature is weighed into the calorimeter. The cold water is stirred and the temperature is recorded. The hot iron is transferred from the tea kettle to the calorimeter after making sure that no drops of water cling to the iron. The water in the calorimeter is stirred and the temperature rise is noted. A barometric reading is taken and from this reading the boiling point of water is computed for the conditions prevailing at the time.

Comparative Cost. A calorimeter with cover and stirring rod is listed at one dollar and fifty cents and up, whereas the cost of the apparatus described in this experiment should not amount to over twenty-five cents to fifty cents.

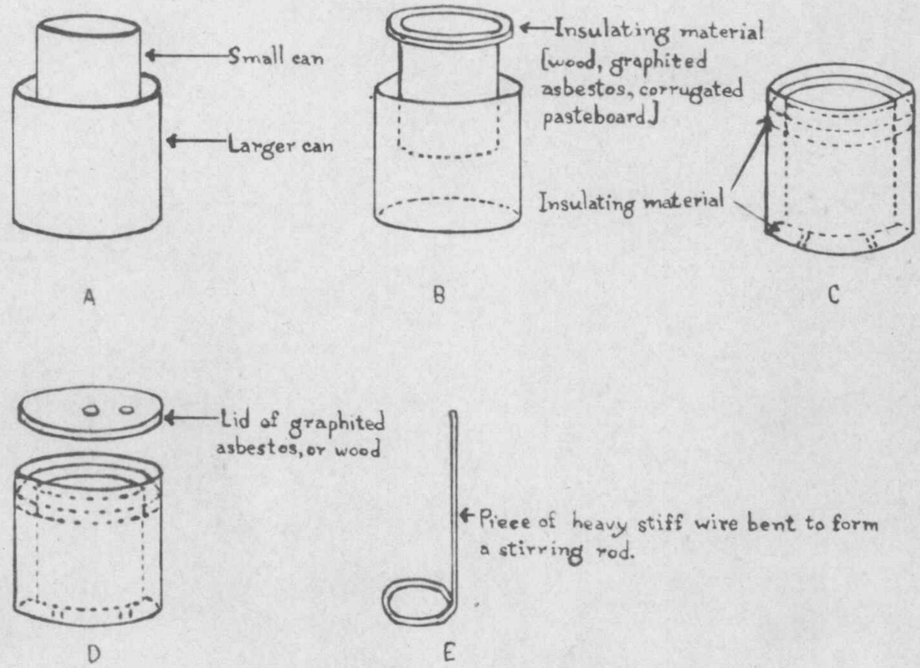

Figure 53 The Construction of a Calorimeter.

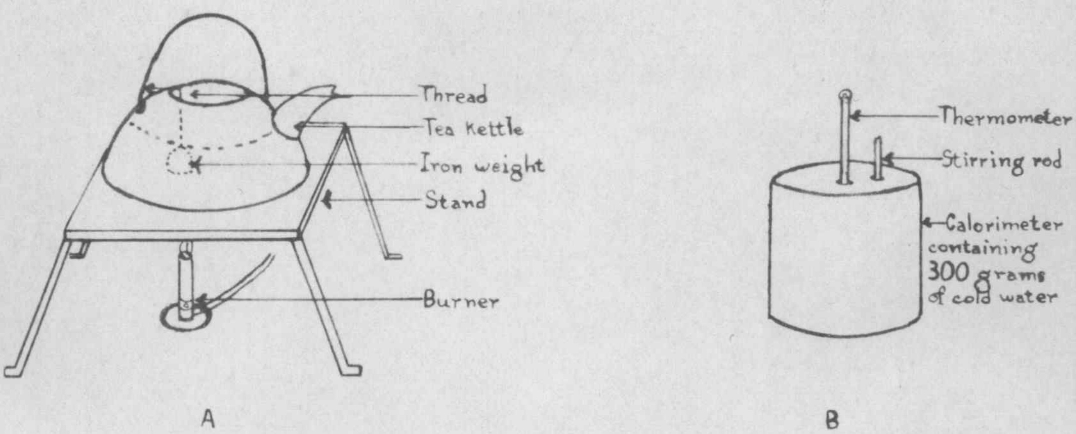

Figure 54 The Specific Heat of a Metal

Experiment 26.

Heat of Fusion of Ice

Purpose. To determine the number of calories of heat necessary to melt one gram of ice. This quantity is called the heat of fusion of ice.

Materials Required. Cracked ice (about 100 grams), calorimeter as described in Experiment 25, Centigrade thermometer, balance, cloth or paper towel, steam boiler and burner.

Construction of the Apparatus. There is no piece of apparatus in this experiment which has not been described before.

Procedure. The calorimeter is weighed empty, and then approximately 300 grams of water at a temperature of 35° Centigrade are added and weighed exactly. The water is stirred thoroughly and the thermometer read, some ice is broken into small pieces, and about 100 grams of ice are added to the water all at once. (Each piece is dried with a piece of cloth or a paper towel). The water is stirred constantly until the last piece is melted. The temperature is read again and the calorimeter weighed.

Comparative Cost. It is not necessary to compare the cost of the apparatus in this experiment since it has been used in earlier experiments.

Experiment 27.

Cooling Through a Change of State

Purpose. To determine by actual measurement how rapidly the temperature of a substance changes: (a) as it cools in a liquid state, (b) as it solidifies, and (c) as it cools in the solid state.

Materials Required. Acetamide or naphthalene crystals, test tube ($\frac{1}{2}$" in diameter), thermometer (0° to 100° C.), one hole rubber stopper, beaker, stand with support for beaker, clamp to hold test tube, wire gauze and a burner.

Construction of the Apparatus. There is nothing to construct in this experiment.

Procedure. The test tube is filled about $\frac{2}{3}$ full with the acetamide or naphthalene crystals, and the equipment is set up as shown in Figure 55. Water is placed in the beaker around the test tube and heated until the crystals are melted. The thermometer is then placed in the test tube, supported by the rubber stopper so that the bulb is completely immersed in the crystals. Heating is continued until the thermometer reads 95° C. for acetamide, or 100° C. for naphthalene. Then the burner is removed. The thermometer is read every half minute and the temperatures recorded, as well as the temperature when the crystals begin to form. Readings are continued until the temperature reaches 50° C. for acetamide, or 70° for naphthalene. The temperatures are plotted in the form of a curve.

Comparative Cost. There is no equipment on which to compare cost.

Experiment 28.

Dew Point

Purpose. To determine the temperature at which water begins to condense from the air.

Materials Required. Test tube, thermometer, short length of glass tubing, piece of rubber tubing and thermometer.

Construction of the Apparatus. The only piece of equipment necessary to make in this experiment is a piece of glass tubing which is bent in the form of a right angle.

Procedure. The apparatus is arranged as in Figure 56, and a column of air is blown in through the rubber tube until the moisture begins to form on the outside of the test tube. The temperature at which this happens is recorded.

Comparative Cost. Dew point apparatus is listed in some catalogues at prices ranging from seventy-five cents to one dollar, whereas the equipment described above would not cost over a few cents.

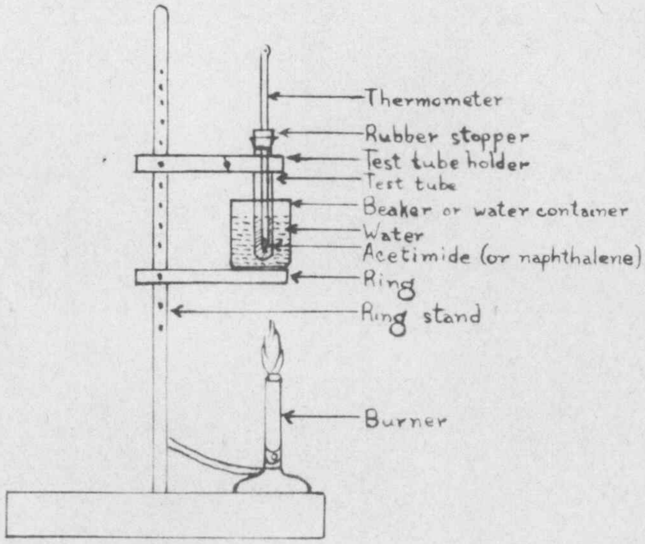

Figure 55 Cooling Through a Change of State

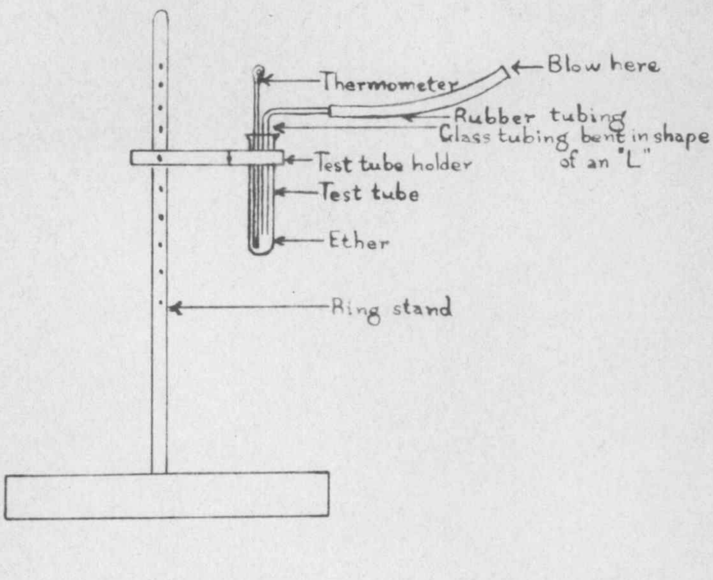

Figure 56 Dew Point

Experiment 29.

Heat of Vaporization of Water

Purpose. To determine how many calories of heat are necessary to change one gram of water at the boiling point at atmospheric pressure into steam at the same temperature.

Materials Required. Steam boiler, burner, bottle (or test tube), two-hole rubber stopper, glass tubing, rubber tubing, cloth, calorimeter, thermometer and balance.

Construction of the Apparatus. The only piece of apparatus required in this experiment which has not been described before is a steam trap. This may be made by bending a piece of glass tubing about 12" long in the shape of an "L", (see Figure 57 A), and placing one of the sides through one hole of the rubber stopper as shown in Figure 57 C. It is pushed down into the bottle (or test tube), so that the end of the tube is near the end of the bottle. Another piece of glass tubing is bent in the form of the "U" as shown in Figure 57 B. The short side of the "U" is placed through the other hole in the rubber stopper so that the end just appears at the top of the bottle, as in Figure 57 D.

Procedure. The steam trap described above is connected by means of a short rubber tubing to the steam boiler, and the other end of the trap is immersed in water in a calorimeter as shown in Figure 58. Heat is applied to the water in the boiler. The calorimeter is weighed empty and then filled about half full of water at 5° C., and again weighed and then placed under the outlet from the steam trap so that the end of the glass tubing is immersed in the water; the water is stirred and the steam is passed through until the temperature reaches 35° C. and the water is again weighed. (The trap should be wrapped with a cloth after the steam starts to form.)

Comparative Cost. Steam traps are listed in apparatus catalogues at from twenty-five cents to fifty cents. The cost of the steam trap described above should not be over five cents.

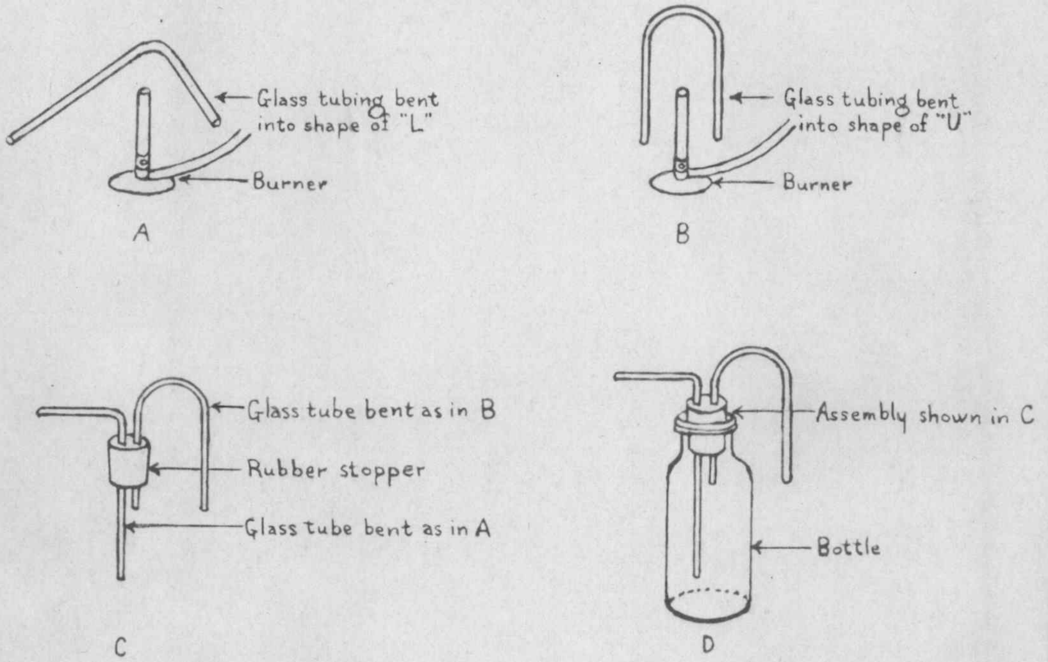

Figure 57. Construction of a Steam Trap

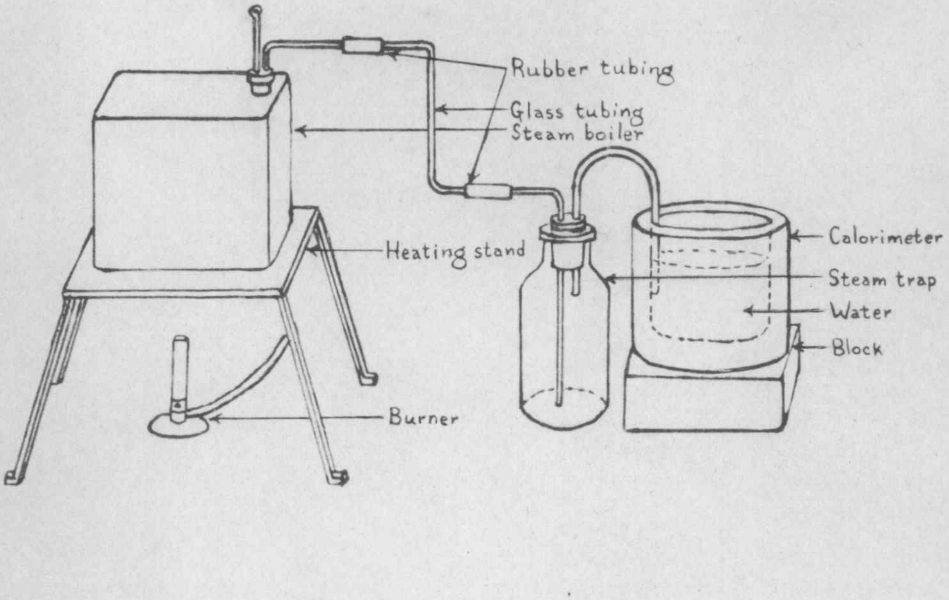

Figure 58 The Heat of Vaporization of Water

Experiment 30.

Transference of Heat

Purpose. To study the three methods of heat transmission.

Materials Required. Rods of different kinds of materials having about the same diameter, paraffin, test tube, burner, small wooden box (about 12" on each side), paper, cellophane, two coffee cans, black and white paint, two soda pop bottles, two short pieces of glass tubing, two rubber stoppers, two thermometers, two pieces of board 1" x 2" x 6" and one board 1" x 4" x 6".

Construction of the Apparatus. A rack is required for the experiment on conduction. This is made by nailing the two pieces of 1" x 2" x 6" board to the top of the 1" x 4" x 6" as shown in Figure 59. Apparatus or equipment to show convection currents in air may be made by boring two holes each about an inch in diameter about 6" apart on the top of the small wooden box. A piece of paper is rolled to form a tube and inserted in each hole. The strip of cellophane is fastened over the open end of the box as shown in Figure 60 C. A piece of equipment to show convection currents in water may be made by joining the two rubber stoppers together with the two pieces of glass tubing and inserting the stoppers in the soda pop bottles in the manner shown in Figure 60 B. Equipment to show radiation may be made from two one pound coffee cans or two baking powder cans, one of which is painted black and the other white. A hole is punched in the top of each can to receive a thermometer as shown in Figure 61.

Procedure. An experiment illustrating conduction may be performed by rolling small balls of paraffin and placing them at equal intervals on each of several different kinds of rods (for instance, copper, steel and aluminum), of about the same diameter, as shown in Figure 59. The rods are laid on the rack described above so that the ends converge over a burner as shown in the figure. A burner is placed under the junction of the three rods and the time required for the balls of paraffin to melt away from noted.

A lighted piece of punk or a taper is held above one of the tubes in the convection apparatus described and the path of the smoke is noted, as in Figure 60 C.

In the apparatus demonstrating convection currents in water, one of the pop bottles is filled with hot water colored with ink and set on a table. The other pop bottle is filled with cold water and one of the rubber stoppers is inserted in the top of the bottle. A finger is held over one of the glass tubes, the bottle is inverted and the other stopper is inserted in the bottle containing the hot water as shown in Figure 60 B.

Another experiment illustrating convection currents in water may be performed by filling the test tube about $\frac{2}{3}$ full of water. The bottom part of the test tube is held in the hand and the upper part of the test tube is heated as shown in Figure 60 A.

The experiment demonstrating radiation is performed by filling the painted cans described above with water, inserting a thermometer in each and setting both in the sun. Frequent readings of the thermometers are taken.

Comparative Cost. Conductometers are listed in catalogues varying in price from thirty-five cents on up. A radiation demonstration apparatus is listed at one dollar and up. Convection in liquids apparatus is listed at prices ranging from one dollar and twenty-five cents and up. A convection apparatus for gases similar to the one described in this experiment is listed at prices varying from one dollar and seventy-five cents upward. The total cost of all of the materials required in the construction of the apparatus in this experiment would not be over fifteen cents.

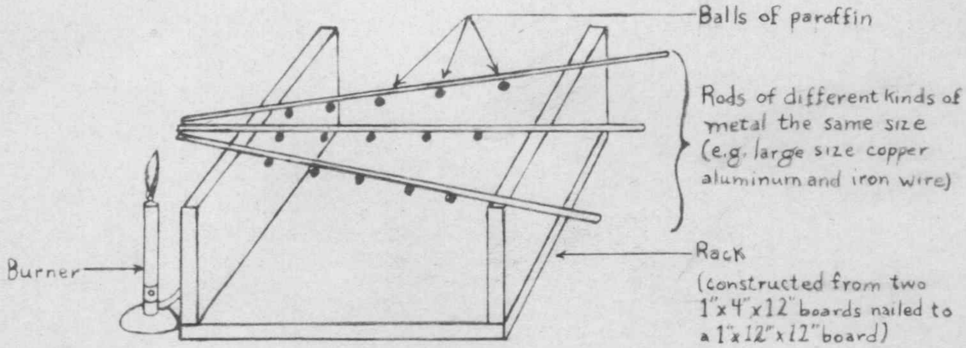

Figure 59 Transference of Heat by Conduction

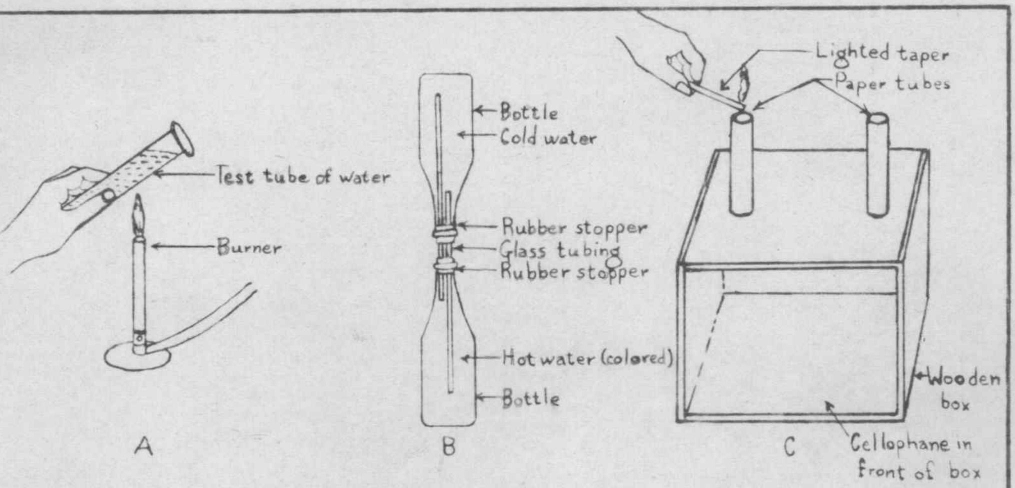

Figure 60 Transference of Heat by Convection

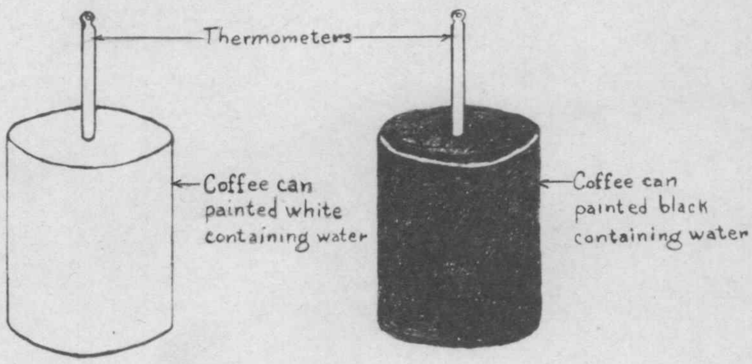

Figure 61 Transference of Heat by Radiation

Experiment 31.

Charles' Law

Purpose. To find how the volume of a gas changes if the gas is heated while the pressure remains constant.

Materials Required. Pyrex test tube or similar glass container, thermometer, two pieces of stiff wire about one foot long, piece of small glass tubing about 18" long, rubber bands, mercury and measuring stick.

Construction of the Apparatus. One piece of wire is bent to form a rack* as shown in Figure 62 C which will hold the thermometer and the glass tube solidly in the test tube. A stirring rod is made from the other piece of wire as shown in Figure 62 D. One end of the piece of glass tubing is annealed as shown in Figure 62 A and a column of about 7" of air is trapped in the closed end of the tubing by means of a small quantity of mercury as shown in Figure 62 B.

Procedure. The glass tubing and the thermometer are fastened together and to the wire rack described above by means of rubber bands. The stirring rod is placed around the thermometer and tubing and the whole assembly is inserted in the test tube as shown in Figure 63. Water is placed in the tube surrounding this assembly and the

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*Science Masters' Book, by G. H. J. Adlam, page 51.

tubing is fastened to a support with a measuring stick behind it so that readings may be taken while the tube is being heated as shown in Figure 63. The variation in length of the column of air is recorded at different temperatures. The relationship between the temperature and the volume is determined.

Comparative Cost. Charles' law apparatus is listed in most catalogues at prices of one dollar or more whereas the apparatus described in this experiment may be procured for about five cents.

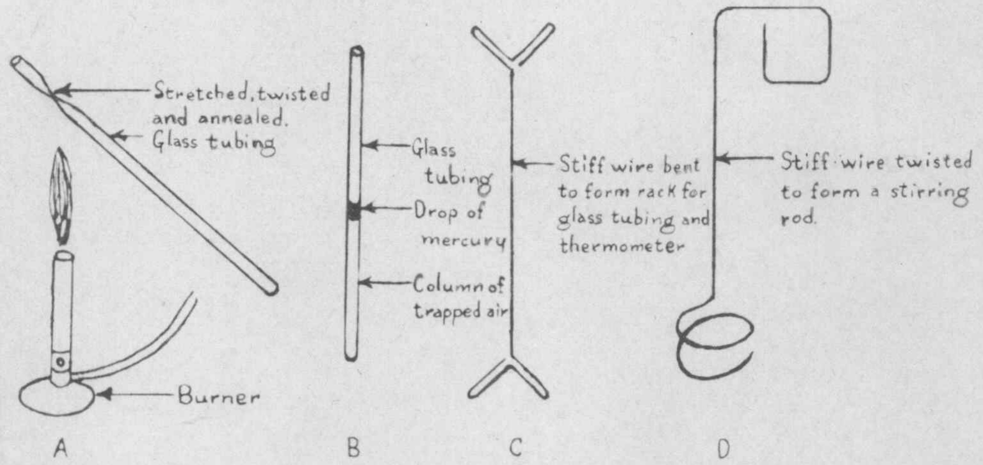

Figure 62 Construction of Apparatus for Charles' Law

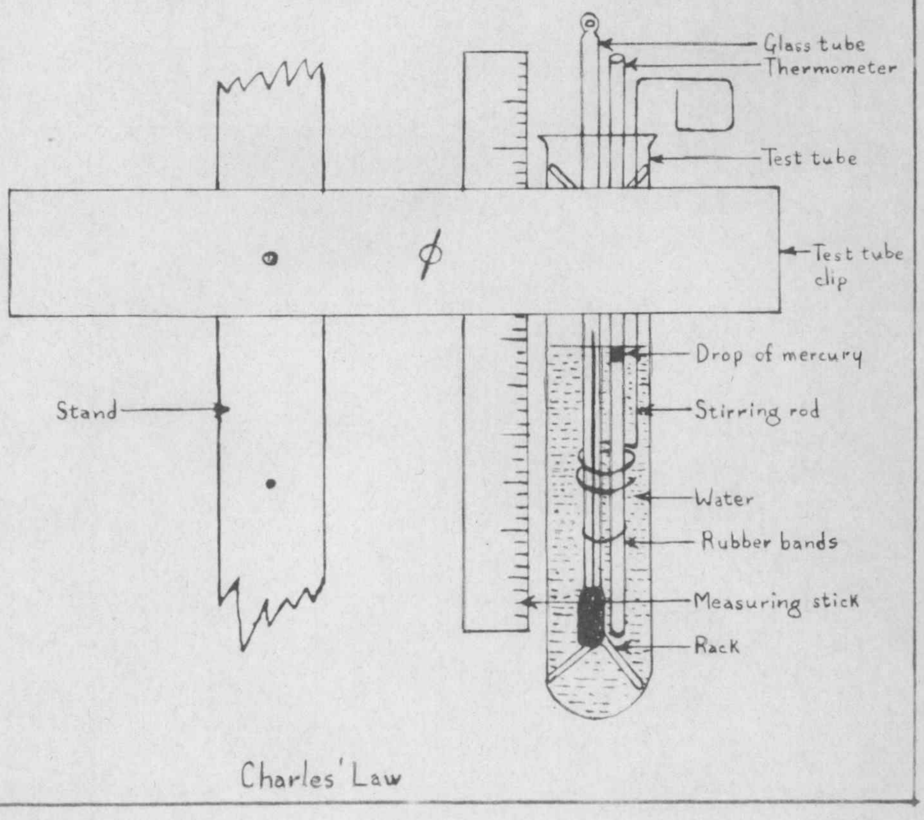

Figure 63 Charles' Law

Experiment 32.

Relative Humidity

Purpose. To study the degree of saturation of water vapor in the air, how to express it and its importance to us.

Materials Required. Two Fahrenheit thermometers, piece of lamp wick or similar material, and beaker.

Construction of the Apparatus. The two thermometers are suspended from a support as shown in Figure 64. The bulb on one of the thermometers is wrapped with the wick and the other end of the wick is immersed in the water in the beaker.

Procedure. The apparatus is arranged as shown in Figure 64, and several readings are taken at different times during the day. With the aid of a chart,* relative humidity is figured from the difference in the readings of the thermometers.

Comparative Cost. A wet and dry bulb hygrometer is listed in catalogues for as much as five dollars, whereas, thermometers can be procured for ten to twenty-five cents apiece making the cost of the apparatus for this experiment, as described above, fifty cents or less.

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*Handbook of Chemistry and Physics, Twenty-second Edition, 1937-1938, page 1438.

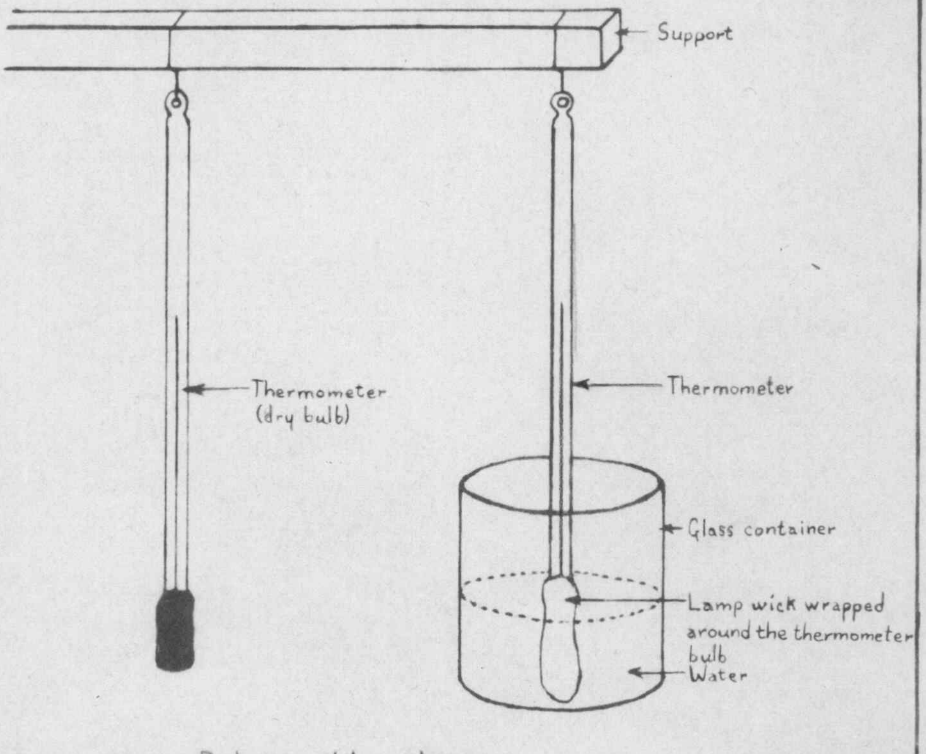

Figure 64 Relative Humidity

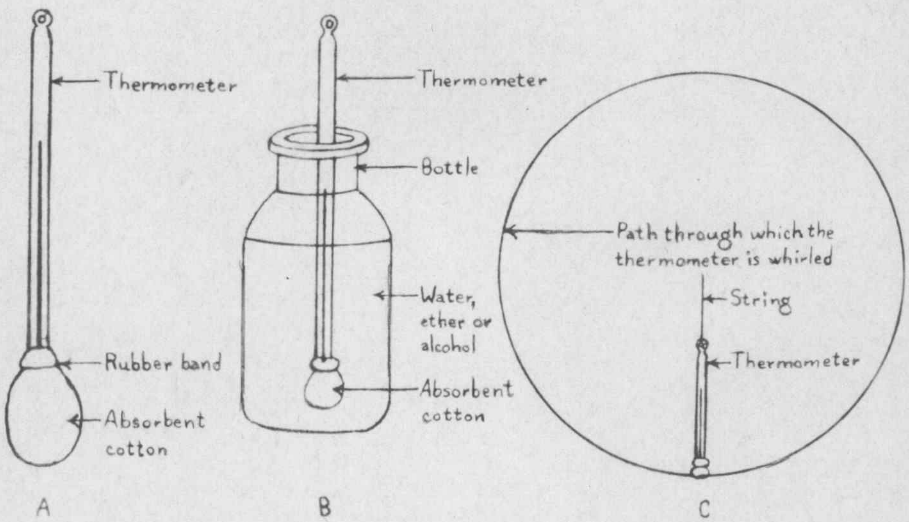

Figure 65 Cooling by Evaporation and Solution

Experiment 33.

Cooling by Evaporation and Solution

Purpose. To study the effect of evaporation and of solution on the temperature.

Materials Required. Thermometer, absorbent cotton, small beaker (or water glass), bottles of water, alcohol and ether at room temperature, and sodium thiosulphate (hypo).

Construction of the Apparatus. It is not necessary to construct any apparatus for this experiment.

Procedure. A small amount of cotton is wrapped around the bulb of the thermometer and tied securely, as shown in Figure 65 A, and dipped in a bottle of alcohol. The thermometer is then removed from the alcohol and fastened to a support so that the thermometer bulb is in the bottle just above the surface of the alcohol. The temperature is read when it is removed from the alcohol and again two or three minutes after it has been removed.

The thermometer above is dipped in the alcohol and the temperature noted,as in Figure 65 B. This time it is completely removed from the bottle and whirled in the air for two or three minutes by means of a string tied securely to the thermometer as shown in Figure 65 C. The temperature is again recorded at this time. The cotton is replaced with some fresh dry cotton and dipped into water and again whirled and the temperature recorded as above.

The same process is repeated with ether.

A small beaker (or water glass) is filled about half full of water. The temperature is recorded, a small amount of hypo is added, and the temperature is noted. The salt is added until no more will dissolve, and the final temperature is recorded.

Comparative Cost. There is no way of making a comparison of costs since the materials used in this experiment must be purchased.

MAGNETISM AND ELECTRICITY

Experiment 34.

The Laws of Magnetism

Purpose. To study the laws of magnetic induction and the magnetic fields surrounding a permanent magnet.

Materials Required. "U" magnet, iron filings, nails, sewing needle, compass, copper wire, iron wire, pieces of glass, zinc, copper, nickel and aluminum, sheets of aluminum, iron and glass, sheet of white paper, salt shaker, bars of soft iron, soft iron ring (large washer) and string.

Construction of the Apparatus. There is nothing in this experiment to construct.

Procedure. Soft iron bars may be magnetized by placing the bar parallel to a bar magnet and placing a short iron bar perpendicular to the bar and magnet at each end as shown in Figure 66 A, and striking each end with a hammer.

Induction is shown by holding one end of a demagnetized nail near a magnet and placing the other end in some iron filings on a piece of paper, as shown in Figure 66 E. Attempts are made to pick up various substances such as copper, glass, iron or tin, etc., as well as to pick up iron filings through sheets of other materials. A sheet of cardboard is placed over a magnet and compasses are moved about on the cardboard above the magnet, the needles will line up as shown in Figures 66 B and G. A wire rack is made and suspended from a support by means of a string and a magnet placed in the rack as shown in Figure 66 C. One pole of another magnet is brought close to each pole of the suspended magnet and the effect observed.

Magnets are placed under a sheet of paper and the magnetic lines of induction are illustrated by sifting iron filings over the paper with the salt shaker, as shown in Figures 66 D, F, H, I, J, K, and L. The poles of the magnet are separated further and a washer is inserted between them, then a paper is laid over them and iron filings are sprinkled on the paper as shown in Figure 66 M.

Comparative Cost. Magnets are listed at various prices depending on the quality of the magnet, at from ten cents to ninety cents, and compasses from twelve cents to seventy-five cents. It is very desirable to have good magnets if possible. Ford magnets will do nicely and may be secured at most any auto wrecking establishment. Compasses may be purchased at most ten-cent stores.

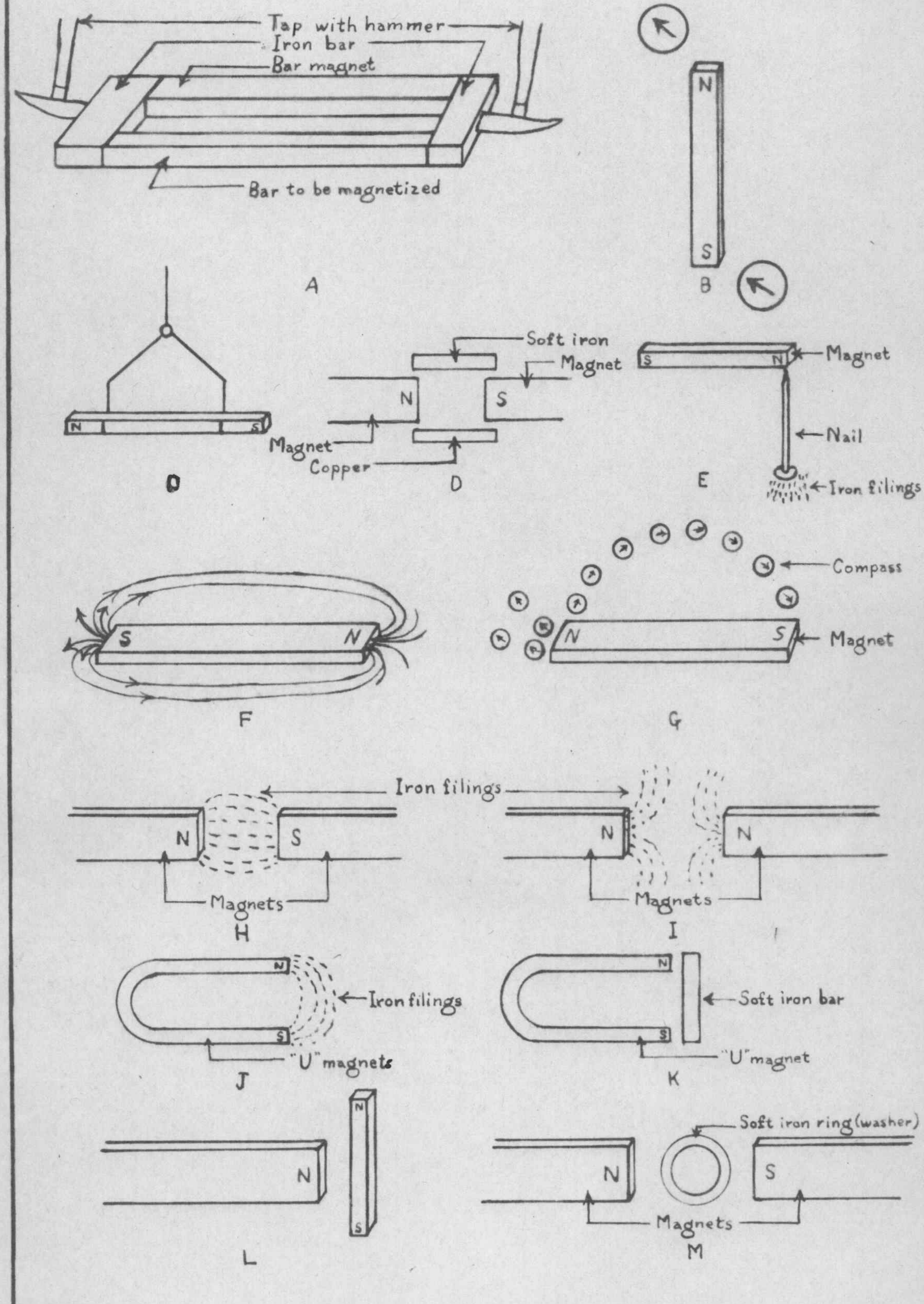

Figure 66 Laws of Magnetism

Experiment 35.

The Phenomena of Static Electricity

Purpose. To study the phenomena of static electricity.

Materials Required. Rods of glass, hard rubber (or sealing wax), pieces of silk and of flannel cloth, milk bottle, brass rod, small brass disk, cork to fit the milk bottle, beeswax, aluminum foil and flowers of sulfur.

Construction of the Apparatus. To construct an electroscope the brass rod is bent in the manner shown in Figure 67. The cork is hollowed out and the brass rod is inserted through the hole, a small quantity of flowers of sulfur is heated to fusion and poured into the cork. The brass disk is soldered to the top of the brass rod. A strip of aluminum foil is fastened to the bend in the rod with beeswax. The whole assembly is then inserted in the milk bottle as shown in Figure 67.

Procedure. A wire sling is suspended by a silk thread from a support. A glass rod is rubbed with the dry silk cloth and suspended on the sling. Another glass rod is again rubbed on the silk cloth and the rubbed ends of the rods are brought together as shown in Figure 68 A. A glass rod is again rubbed, placed on the sling and a rubber rod is rubbed with a warm dry flannel cloth and the end of the rubber rod is brought close to the end of the glass rod.

One of the charged rods is held close to some small bits of paper. A charged glass rod is held near the brass disk on the electroscope as shown in Figure 68 B. Again a freshly charged glass rod is held near the brass disk of the electroscope and the disk is touched with the finger as shown in Figure 68 C. The finger is removed, then the charged glass rod is removed. Again the glass rod is brought close to the brass disk of the electroscope. A rubber rod is charged by rubbing the flannel and brought near the disk of the charged electroscope.

Comparative Cost. An electroscope of the type described is listed in most catalogues at prices ranging from seventy-five cents upwards, whereas the one described above may be made at a cost of fifteen cents or less.

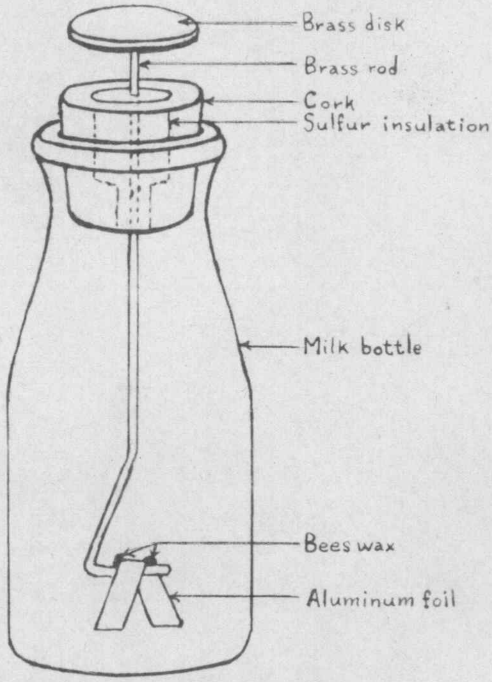

Figure 67 Construction of an Electroscope

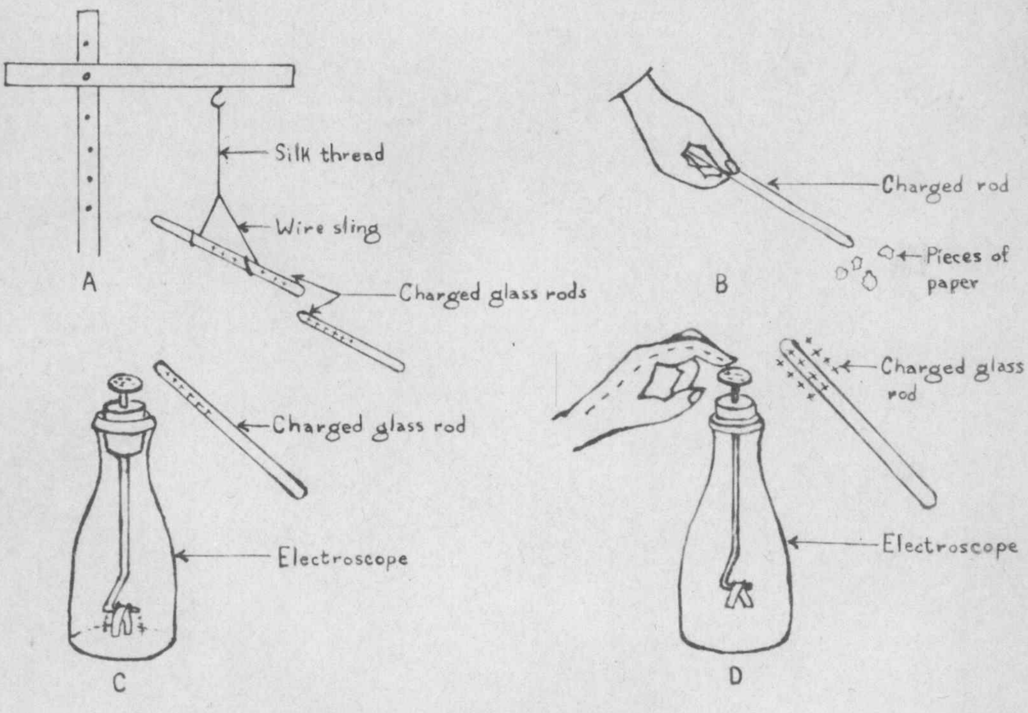

Figure 68 Static Electricity

Experiment 36.

A Simple Cell

Purpose. To study the principles and the action of the simple galvanic cell.

Materials Required. Glass tumbler, block of wood 1" x 2" x 4", two brass bolts, plates of copper, zinc, carbon, iron, aluminum, nickel, etc., sulfuric acid, acetic acid, hydrochloric acid, a "U" magnet, #22 cotton covered copper wire, #40 silk wound copper wire, batten strips 2' long to hold the magnet in place, #30 bare copper wire, small piece of a mirror, small brass bolts $1\frac{1}{4}$" long, strips of brass (brass linoleum stripping may be used), coffee can, block of wood 2" x 2" x 8", measuring stick, board 1" x 6" x 24", small section of a wooden curtain roller, and glass tumblers.

Construction of the Apparatus. Two strips of brass are cut so that they measure about $\frac{1}{4}$" x 2". A hole is drilled in one end large enough to receive a small brass bolt. Holes are then drilled in each end of a wooden block 1" x 2" x 4" to receive the brass bolts. The strips of brass are bolted one on each side of the block as shown in Figure 69. An extra nut is placed on each bolt to form a binding post.

To construct a galvanometer*, a "U" magnet is fastened in an upright position at one end of the 1" x 6" x 24" board by means of some pieces of batten stripping and nails in the manner shown in Figure 70. A small coil is made by using 30 turns of large cotton covered copper wire (#18 or #22). A scaffold is made of three pieces of thin wood (batten strips split in half) fastened together with brads and wired to the poles of the magnet as shown in Figure 70. The coil of copper wire is fastened to the scaffold so that the coil hangs between the poles of the magnet, by means of a #30 bare copper wire and the other end of the coil is then attached to the base by means of a small coil of #40 silk wound copper wire in the manner shown in Figure 70. A small switch is made from brass strips and fastened on the side of the board. Three small brass bolts are fastened in front of the magnet in the position shown in Figure 70 to serve as binding posts. A and V are connected by means of #40 silk wound copper wire. The bare copper wire holding the coil is connected with binding post A and one pole of the knife switch is connected with binding post A by means of a brass rod or very large copper wire. The other pole of the knife switch is connected by means

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* <u>A Home-made Galvanometer</u>, by C. H. Dwight, School Science and Mathematics, 21:270-271, November, 1921.

of the #20 cotton covered copper wire to binding post B. A small mirror is fastened to the top of the coil to complete the galvanometer assembly as shown in Figure 70.

A scale* is made by cutting a slot in one side of a coffee can as shown in Figure 71 A. A light socket and globe are attached to the other end of the board serving as the base for the galvanometer assembly and the coffee can described is placed over the light so that the light from the hole shines on the mirror in the galvanometer. A 2" x 2" board is fastened in an upright position behind the can and a measuring stick (yard stick) is fastened to the 2" x 2" in such a manner that the reflection of the light from the mirror shines on the measuring stick. See Figure 71 B.

A key switch is made by drilling small holes to receive small brass bolts in each end of a strip of brass $\frac{1}{2}$" x 4". The strip of brass is then bent in the manner shown in Figure 72 A. A small section from a curtain roller (about $\frac{1}{2}$") is fastened to one end by means of a small screw as shown in Figure 72 B. The other end is bolted by means of a small brass bolt to a 1" x 2" x 4" board. Another small brass bolt is placed through the board in such a manner that it is directly under the screw holding

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* Science Masters' Book, by G. H. J. Adlam, page 197.

the wooden knob. Two nuts are placed on each bolt as shown in Figure 72 C, making a key switch as shown in Figure 72 D.

Procedure. A strip of zinc and a strip of copper are placed in the plate holder shown in Figure 69. A dilute solution of sulfuric acid is poured in a glass tumbler and the plates are immersed in the liquid. Using insulated wire, one binding post of the cell is attached to one pole of the key switch; the other pole of the key switch to one pole of the galvanometer; the other pole of the galvanometer to the other binding post of the cell, as shown in Figure 73. Readings of the galvanometer are taken. One plate is bent so that they are closer together and another reading is taken. The plates are pushed farther down into the solution increasing the exposed area and another reading is taken. The zinc plate is replaced with an aluminum, iron or nickel plate and more readings are taken. The zinc and copper plates are placed in other tumblers containing different electrolytes.

Comparative Cost. A demonstration cell such as the one described in this experiment would cost fifty cents to one dollar. A key switch is listed in most catalogues at prices ranging from seventy-five cents upward. A galvanometer ranges in price from two dollars and fifty cents to fifteen dollars. The apparatus described in this experiment could be built at a cost of not over twenty-five cents.

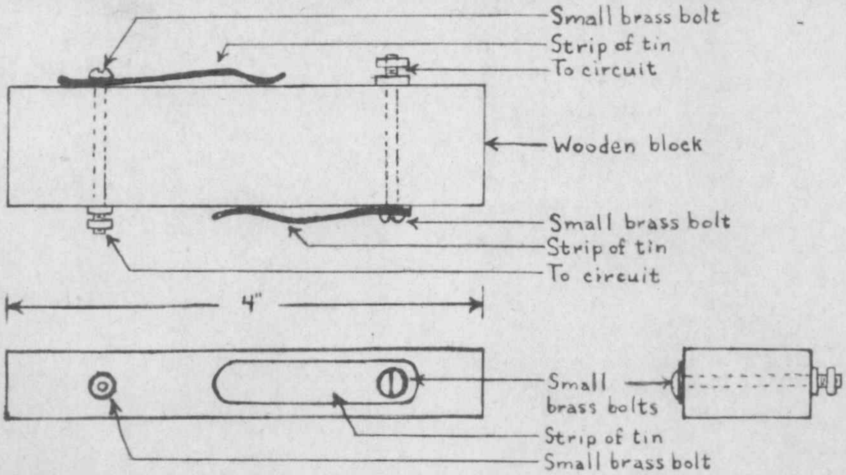

Figure 69 Construction of a Clamp to Hold Plates for a Cell

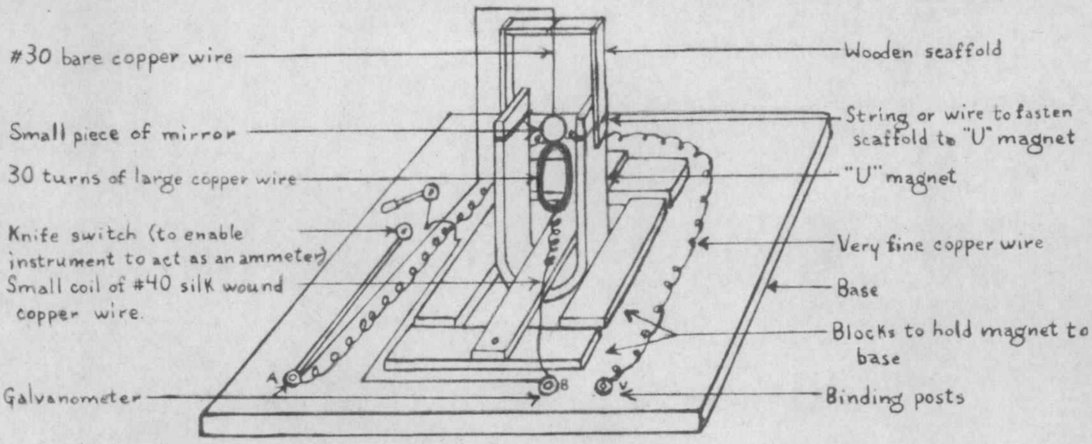

Figure 70 Construction of a Galvanometer Assembly

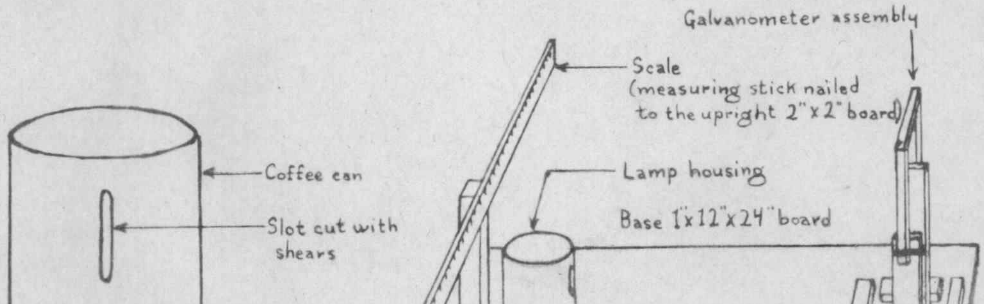

Figure 71 Construction of a Scale for the Galvanometer Assembly

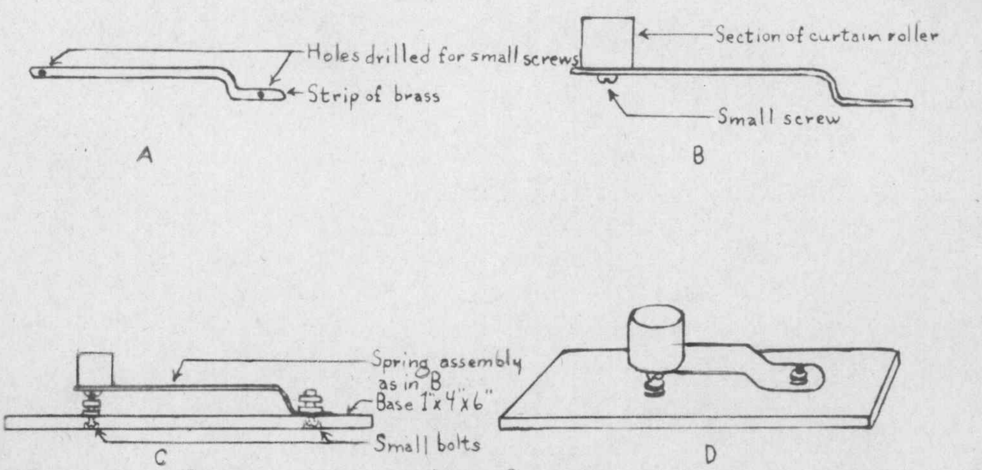

Figure 72 Construction of a Key Switch

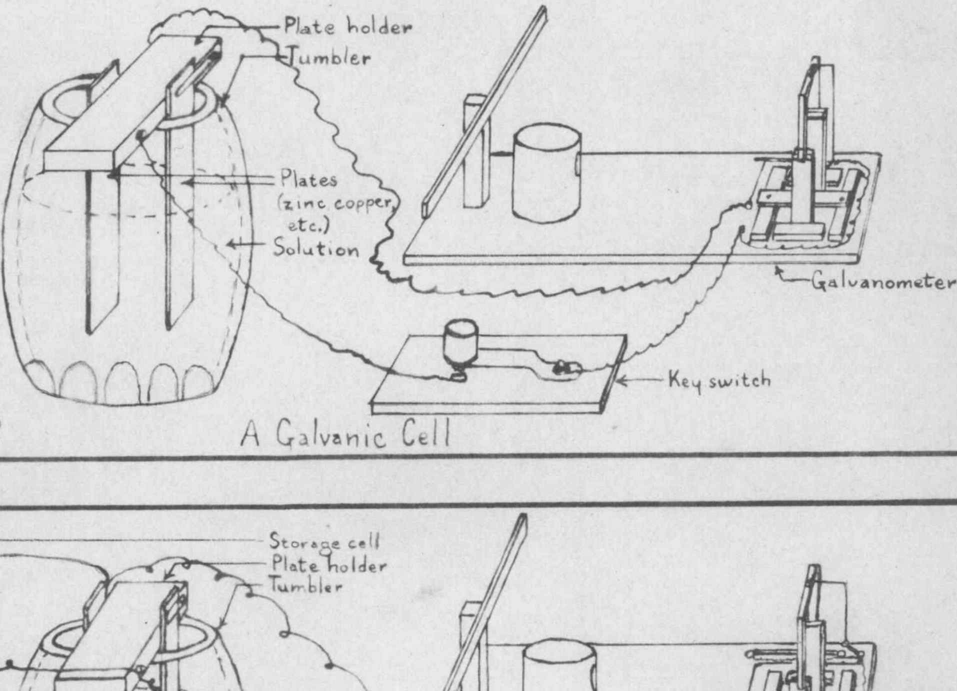

Figure 73 A Galvanic Cell

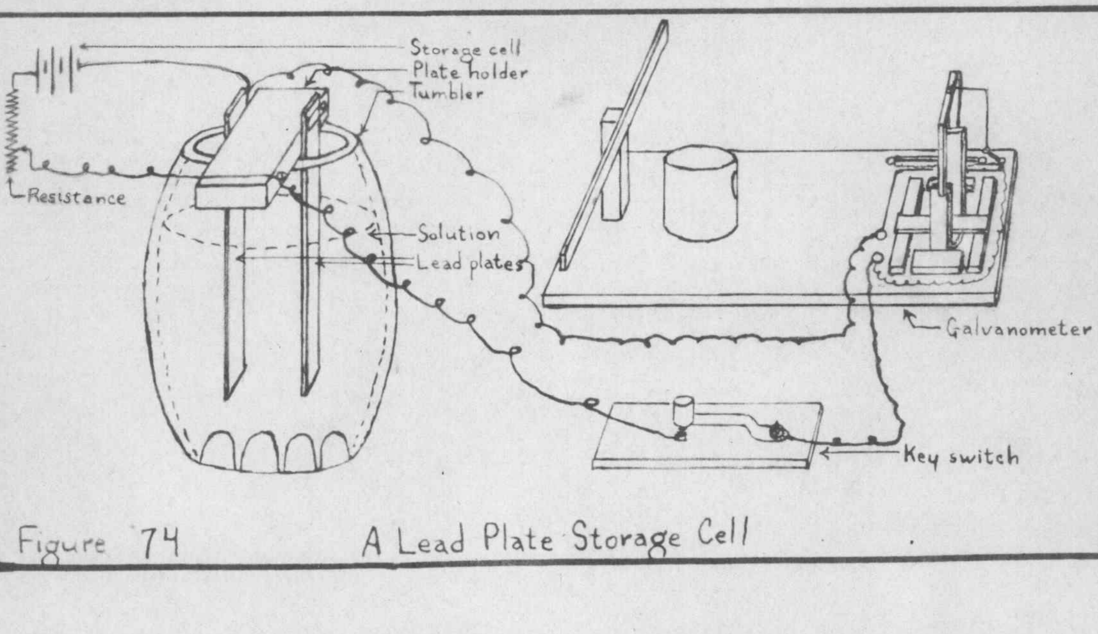

Figure 74 A Lead Plate Storage Cell

Experiment 37.

The Lead Storage Cell

<u>Purpose</u>. To find the changes that take place in a storage cell during charge and discharge.

<u>Materials Required</u>. Galvanometer, lead strips, plate holder, tumbler, storage battery, key switch, variable resistance rheostat and wire for connections.

<u>Construction of the Apparatus</u>. The same apparatus which was required for Experiment 36 may be used for this experiment. No additional apparatus is necessary, except the storage battery and variable resistance rheostat.

<u>Procedure</u>. Two clean pieces of lead about 1" x $\frac{1"}{16}$ x 6" are placed in the plate holder described in Figure 69. The plates are immersed in a tumbler containing dilute sulfuric acid. One pole of the plate holder is connected with one pole of the key switch; the other pole of the key switch is connected to a galvanometer; the other pole of the galvanometer is connected with the other pole of the plate holder, as shown in Figure 74. After a minute or two the lead plates are removed and examined. The two lead plates are again replaced in the acid and a storage battery and variable resistance rheostat are connected to the poles of the cell as shown in Figure 74 and allowed to stand for a short time, and they are examined while so

connected. After a few minutes the battery is disconnected, the key switch is pressed and the effect noted. The galvanometer hook-up is disconnected and the cell is short circuited with the wire for a few minutes. The two lead strips are examined again and the cell is again connected with the galvanometer, the key switch is pressed and the effect noted.

Comparative Cost. The same apparatus is required in this experiment as that required in Experiment 36, with the exception that this experiment requires a storage battery and a variable resistance rheostat which is described in Figure 83.

Experiment 38.

The Electrolysis of Water

Purpose. To study the chemical effect of an electric current as demonstrated by electrolysis.

Materials Required. Two pieces of small glass tubing each about 8" long, two small strips of tin $\frac{1}{2}$" x 2", 1" x 2" x 8" board, two small screws, two short pieces ($\frac{3}{4}$") of #18 platinum wire, mercury, two test tubes, glass battery jar, sulfuric acid, water, burner, three dry cells and wire for connections.

Construction of the Apparatus. The two pieces of glass tubing are bent with the aid of the burner into a shape as shown in Figures 75 A and B. A piece of platinum wire is placed in the shorter end of the "U" so formed and held with pincers and the end of the glass tubing is annealed sealing the platinum wire into the end of the glass tube as shown in Figure 75 C. When the tubing has cooled place the wire on a metal block and flatten with a hammer as shown in Figure 75 D to form an electrode. Mercury is then poured into the glass tube until the tube is nearly full as shown in Figure 75 E. A 1" x 2" x 4" board is prepared as shown in Figure 75 F. Strips of tin are cut and drilled as in Figure 75 G. The strips of tin are fastened by means of small screws so that they form a clip to hold the test tube in the notches provided for them. (See Figure 75 H). The longer ends of the electrodes as in Figure 75 E are then inserted in the holes drilled for them in the board as shown in Figure 75 H. The test tubes are fitted into the notches and the whole assembly is adjusted as shown in Figure 75 I.

Procedure. A battery jar is filled almost full of water and a small quantity of sulfuric acid is added to the water. The apparatus described in Figure 75 I, is then placed on top of the jar as shown in Figure 76 and connected with three dry cells as shown in the figure.

Comparative Cost. An electrolytic decomposition apparatus without the battery jar is listed in most catalogues at prices ranging from one dollar and seventy-five cents upwards. The cost of the apparatus described in this experiment would not be over thirty-five cents.

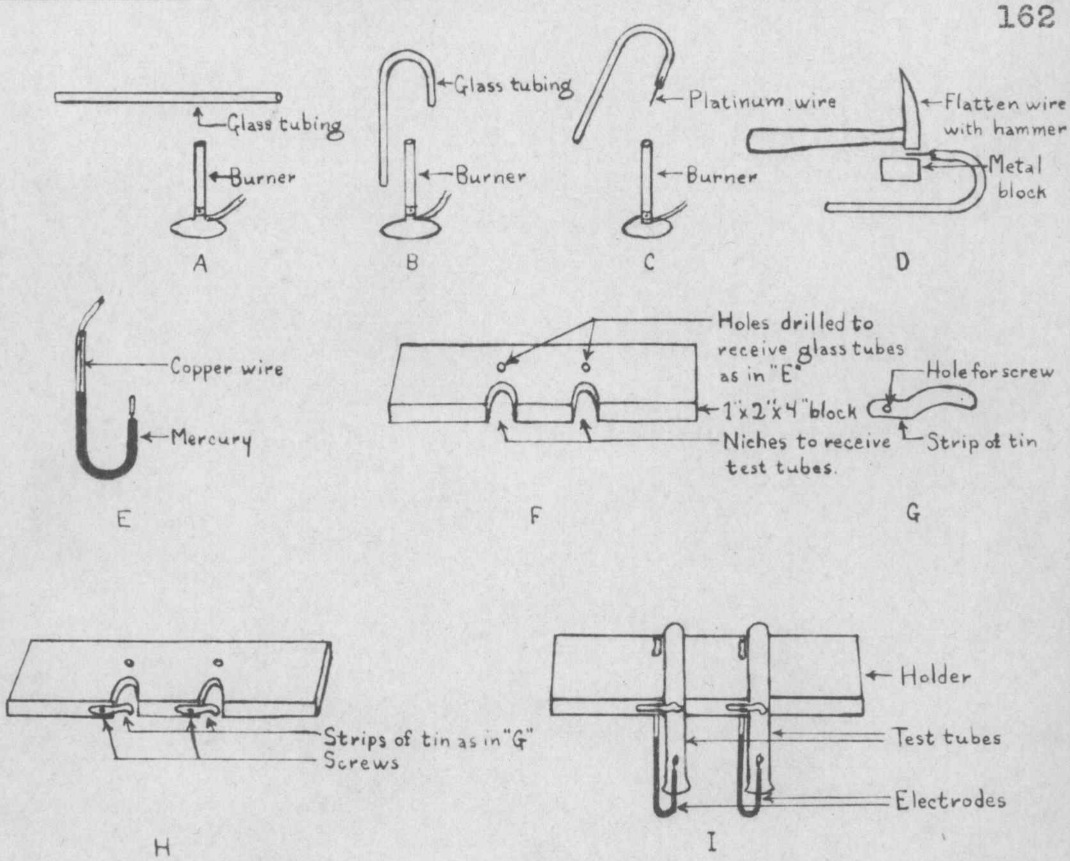

Figure 75 Construction of the Apparatus for the Electrolysis of Water

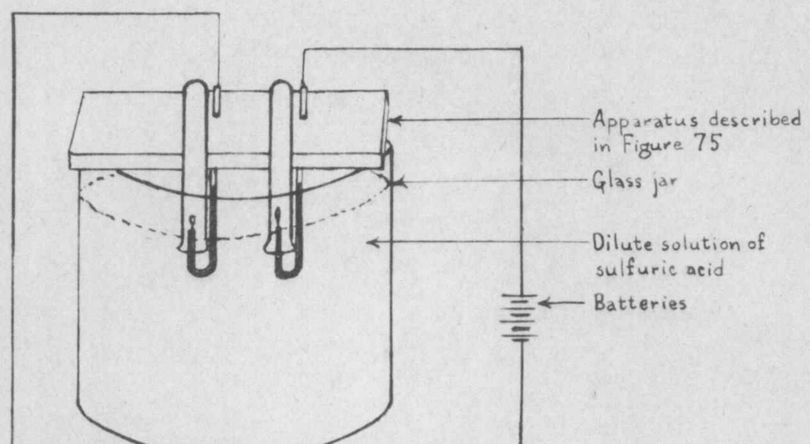

Figure 76 The Electrolysis of Water

Experiment 39.

Resistance by the Voltmeter-Ammeter Method

Purpose. To measure the resistances of coils and other appliances by use of a voltmeter, an ammeter and Ohm's Law.

Materials Required. Five spools, 30 meters of #22 cotton covered copper wire, 30 meters of #28 cotton covered copper wire, 10 meters of #22 cotton covered German silver wire, seven small brass bolts $1\frac{1}{4}$" long, five screws long enough to fasten the spools to a board, board 1"x 4" x 6", section of a spring from a curtain roller about 6" long, small piece of doweling about $\frac{1}{4}$" in diameter and 18" long, strip of galvanized iron about 4" long, piece of 1" x 2" x 12" board, section of a measuring stick, about two feet #22 silk wound German silver wire, screws and nails, galvanometer, key switch, four $1\frac{1}{2}$ volt dry cells (or crowfoot or Weston cell), wire for connections and thread.

Construction of the Apparatus. To construct a variable resistance*, two small holes are drilled through the flange of the wooden sewing thread spools (300 yard cotton thread spool, 1" in diameter and $1\frac{1}{2}$" long are desirable), one near the body of the spool and one near the outer

*Home-made Apparatus for the Physics Class, Science Education, 15:159-174, March, 1931.

edge as shown in Figure 77 A. Ten meters of #22 cotton covered copper wire is wound on one spool inserting one end of the wire in the hole in the flange nearest the center as shown in Figure 77 B, winding the wire as evenly as possible and then inserting the other end of the wire in the hole nearest the outer edge of the flange as shown in Figure 77 C. A second spool is wound in the same manner with 20 meters of #22 cotton covered copper wire. A third spool is wound with 10 meters of #28 cotton covered copper wire. A fourth with 20 meters of #28 cotton covered copper wire and a fifth with 10 meters of #22 German silver wire. The spools are then attached to a board 1" x 4" x 6" with the ends of the wire down, by means of screws. Holes are drilled in one edge of the board to receive six small brass bolts each of which is fitted with two nuts, and the coils just described are connected with the brass bolts as shown in Figure 77 D, and the lower nut screwed down tightly on the connection.

The hot wire ammeter* is made as follows: a slot is cut (wide enough to receive the #22 silk wound German silver wire) in two 1" x 2" boards (one 8" long and one 2" long). These two boards are attached by means of small screws to a wooden base 1" x 4" x 18" by means of screws. A strip of galvanized iron is attached to the

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* Science Masters' Book, G. H. J. Adlam, page 173.

upper end of the 1" x 2" board, by means of two small nails, to act as a fulcrum. A notch is cut in the piece of doweling in the center to fit over the fulcrum. One end of the doweling is pointed with a sharp knife. A small brass bolt $1\frac{1}{4}$" long is placed in each end of the base and a piece of #22 silk wound German silver wire is attached between the two bolts passing through the slot in each of the uprights. A thread is tied around the German silver wire and fastened to the doweling on one side of the fulcrum and a spring is attached to the doweling on the other side of the fulcrum, by means of a wire, and to the 2" wooden block (by means of a staple) as described in Figure 78. A piece of a measuring stick long enough to serve as a scale for the pointer is attached to a block (1" x 2" x 2") and the block is screwed to the base.

Procedure. The instruments used in this experiment should first be calibrated. The galvanometer may be calibrated by means of dry cells, (a crowfoot cell or Weston cell* is better if it is possible to secure one), each dry cell having an E. M. F. of approximately $1\frac{1}{2}$ volts. The resistances are already known since the wire was measured onto the spools. The resistance on each spool may be

* Construction of a Weston cell is described in Science Masters' Book, by G. H. J. Adlam, page 176.

found accurately by multiplying the resistance per meter for the kind and size of wire used by the number of meters used. The ammeter then may be calibrated by connecting it with a galvanometer, known resistances, a key switch and four dry cells, as shown in Figure 79. By varying the resistance and use of the formula $I = \frac{E}{R}$, a scale for the ammeter is marked off. After the instruments have been calibrated, unknown resistances may be substituted for the known resistances and by means of the readings of the galvanometer (or voltmeter), the ammeter and the formula $I = \frac{E}{R}$, the resistance may be computed.

Comparative Cost. Resistance coils are listed at prices varying from twenty-five cents to one dollar per coil. Ammeters are listed at prices ranging from nine dollars upward. The Ohm's Law apparatus complete ranges in price from twelve dollars upward. The cost of the apparatus described in this experiment would be approximately one dollar and twenty-five cents.

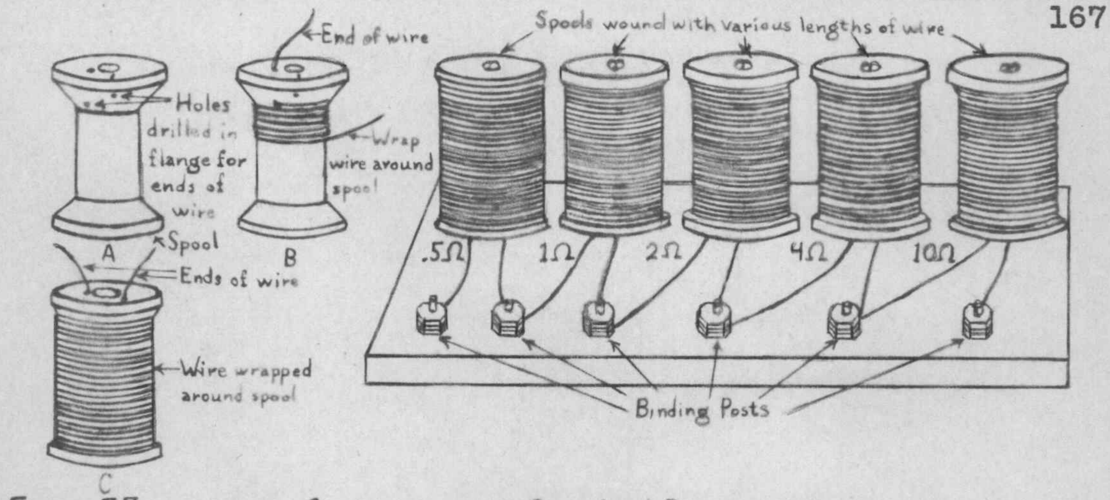

Figure 77 Construction of Standard Resistances

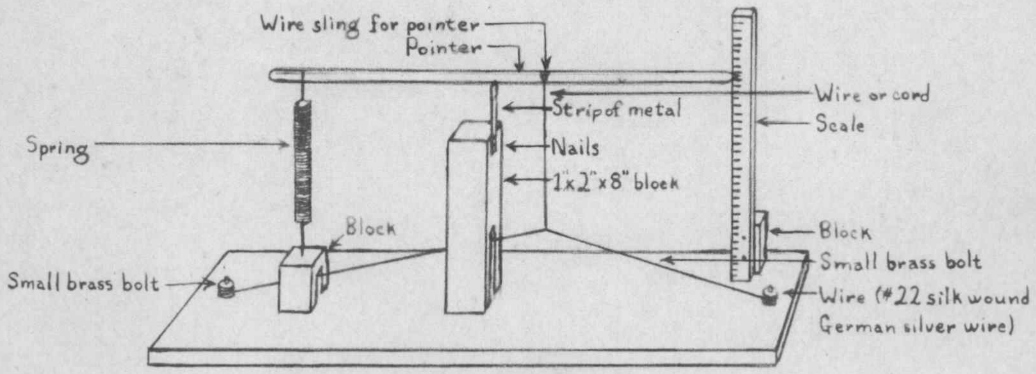

Figure 78 Construction of a Hot-Wire Ammeter

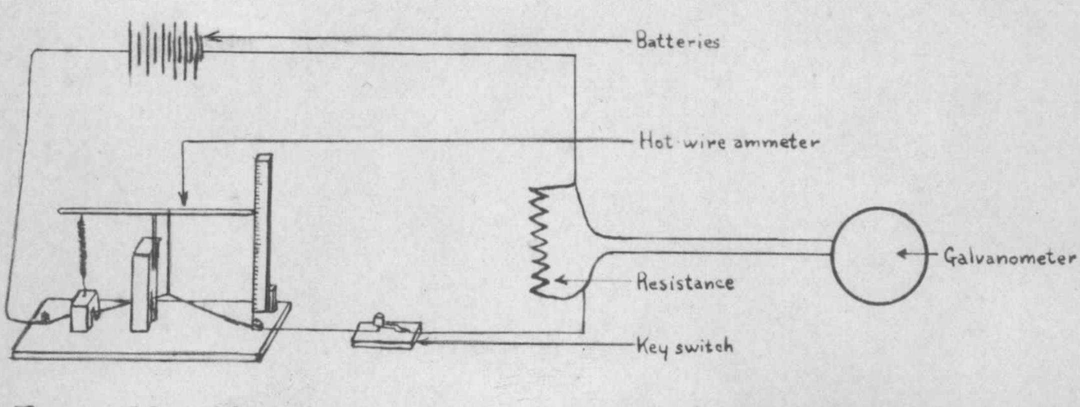

Figure 79 Measurement of Resistance by the Ammeter-Voltmeter Method

Experiment 40

Battery Resistance, Combination of Cells

Purpose. To study the internal resistance of a cell, and the result of connecting cells in series and in parallel.

Materials Required. Two dry cells, voltmeter (or galvanometer), ammeter and variable resistance.

Construction of the Apparatus. No additional apparatus is required for this experiment.

Procedure. An ammeter and one cell are connected together in series as shown in Figure 80, and a reading is taken. Resistance is added until the current is just half as great. The amount of resistance required is recorded by the use of Ohm's Law, $I = \frac{E}{R}$. The internal resistance of the cell is obtained as follows: the first resistance is simply the resistance of the cell, therefore the resistance added is equal to the internal resistance of the cell; this is called the half current method of finding the resistance of a cell.

Two cells are then connected in a series and in turn they are connected with an ammeter and a .5 ohm resistance in series as shown in Figure 81. The current is recorded. The resistance is changed to 20 ohms, and again the current is recorded.

Two cells are connected in parallel and connected to a circuit as shown in Figure 82 and the current which they send through a .5 ohm and 20 ohm resistance respectively is recorded.

Comparative Cost. Since the apparatus required in this experiment has already been described a comparison of the cost has been made.

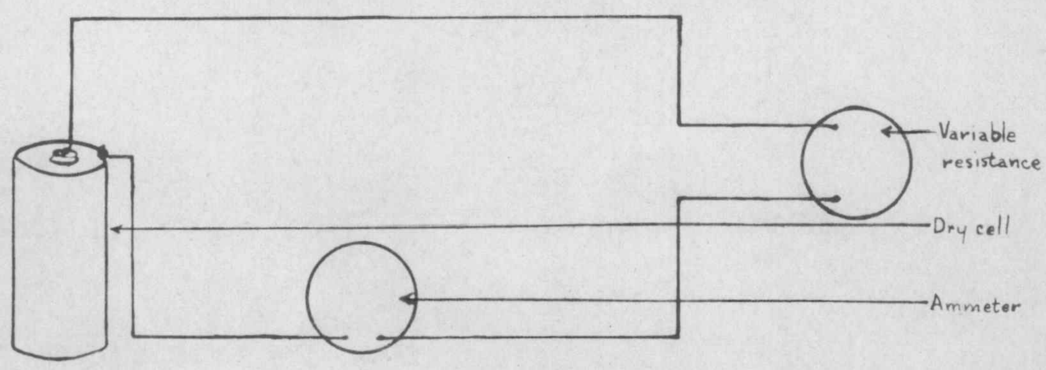

Figure 80 The Resistance of a Cell

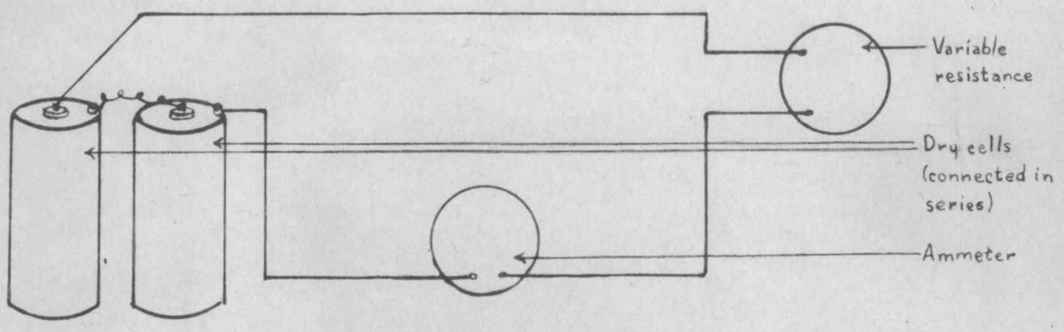

Figure 81 Combination of Cells (Series)

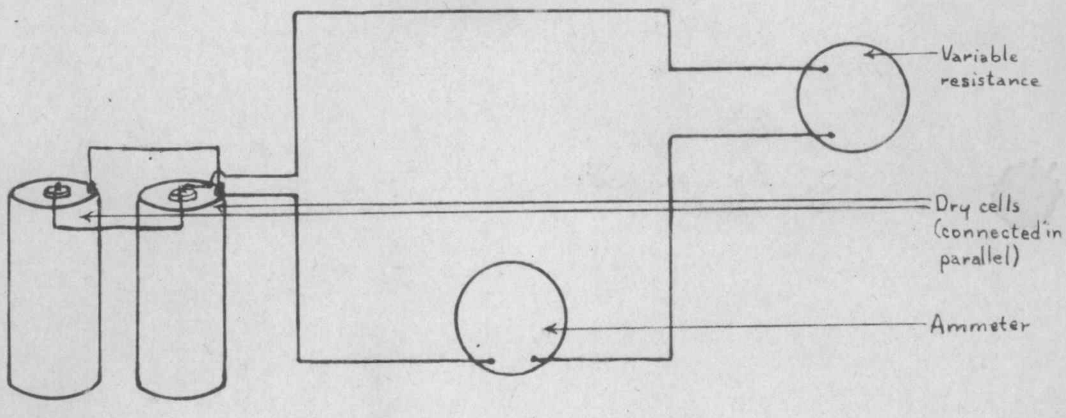

Figure 82 Combination of Cells (Parallel)

Experiment 41.

Laws of Resistance

Purpose. To study the laws relating the resistance of wires to the flow of electric current.

Materials Required. Four meters of #28 copper wire, four meters of #22 copper wire, two meters of #28 iron wire, source of direct current (10 volts or more), rolling pin or piece of doweling about 2" in diameter and about one foot long, two small blocks 1" x 4" x 4", small piece of doweling $\frac{1}{2}$" x 12", brass screws and bolts, small block 1" x 1" x 1", piece of sheet asbestos about 12" square, 100 ' of #30 bare German silver wire, ammeter, galvanometer, key switch and wire to connect the various pieces of apparatus.

Construction of the Apparatus. A variable resistance rheostat* is made as follows: The handles are sawed off the rolling pin. A sheet of asbestos is trimmed so that it covers the entire surface of the rolling pin where it is glued in place or fastened with metal clips at each end, as shown in Figure 83 A. A board 1" x 4" x 4" is nailed to each end of the rolling pin as shown in Figure 83 B. A brass bolt is put through one corner of one of

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* Variable resistance rheostats may be procured for from twenty-five cents to twenty-five dollars. For most purposes a twenty-five cent one is sufficient.

these boards and one end of the 100' of #22 German silver wire is fastened to the bolt. The wire is then carefully wrapped around the rolling pin, care being taken to wrap the wire so that the turns do not touch each other, the other end of the wire is fastened down with a tack as shown in Figure 83 C. A hole is bored in the small block (1" x 1") to receive the $\frac{1}{2}$" doweling. A short piece of copper wire is fastened to the under side of the block by means of a brass bolt, the doweling is nailed to the tops of the 1" x 4" boards at each end of the rolling pin and the copper wire is attached so that it touches the German silver wire wrapped on the rolling pin as shown in Figure 83 D.

A resistance board* may be constructed by fitting six brass bolts into one end of a board 1" x 6" x 42". Tacks or small nails are placed near the other end, so that a line perpendicular to one end of the board passing through the nail would pass about half way between two of the brass bolts at the other end. One end of a #28 copper wire is connected with one of the brass bolts. The nut is fastened down tightly. The wire is passed over the first nail, back and around the second binding post, over the second nail, back and fastened to the third

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* A Combined Laboratory Manual and Workbook in Physics, by S. G. Cook and I. C. Davis, page 203.

binding post, thus making two loops of the #28 copper wire. One end of the #22 copper wire is attached to the third binding post, passed over the third nail, back and around the fourth binding post, over the fourth nail, back and fastened to the fifth binding post. One end of the #28 iron wire is fastened to the fifth binding post, passed around the fifth nail, and back to the sixth binding post. A second nut is placed on each of the brass posts to enable them to serve as binding posts as shown in Figure 84.

Procedure. The rheostat is adjusted so as to permit $\frac{1}{2}$ ampere of current to flow through the wires. Then with the voltmeter (galvanometer described in Experiment 36), the voltage drop across the various loops of wire is recorded. The resistance in each case is then calculated. The experiment is repeated using 1 ampere instead of $\frac{1}{2}$ ampere and again the resistance is calculated. Resistances obtained may be compared with actual resistances found in the table in the handbook.

Comparative Cost. Slide wire rheostats are listed in most catalogues at prices ranging from five dollars upward, and a resistance board is listed in most catalogues from three dollars and fifty cents upward, whereas, the cost of the apparatus described in this experiment would not be more than eighty-five cents.

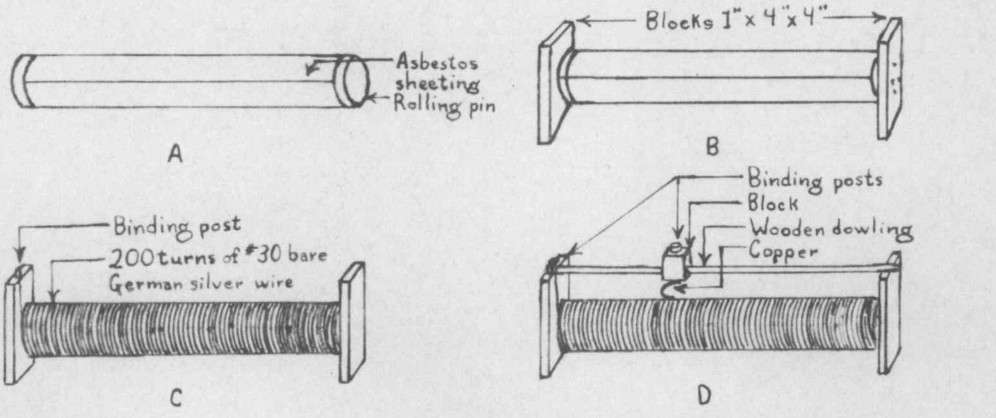

Figure 83 Construction of a Variable Resistance Rheostat

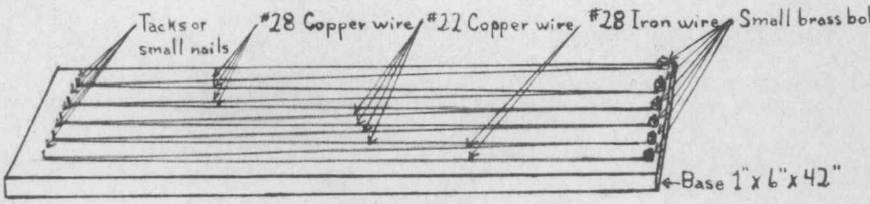

Figure 84 Construction of a Resistance Board

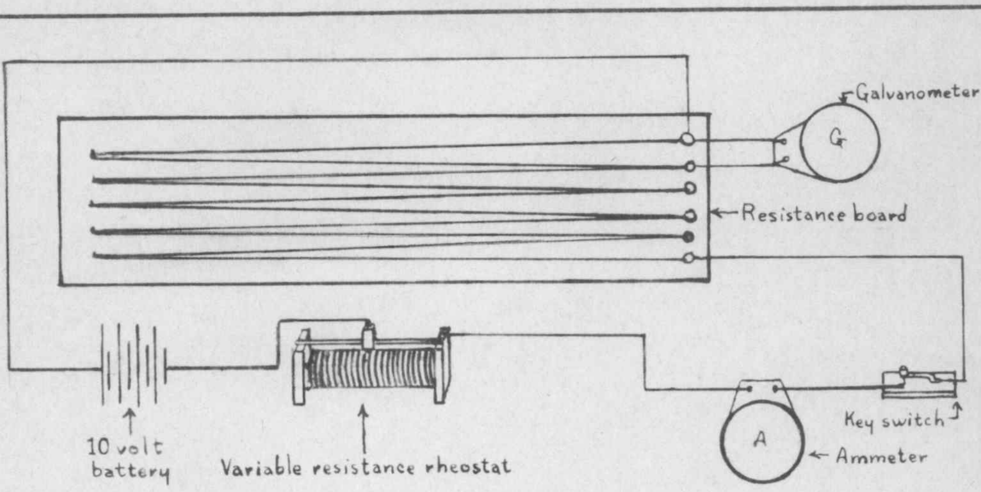

Figure 85 The Laws of Resistance

Experiment 42.

Wheatstone Bridge

Purpose. To measure various unknown resistances such as wires and appliances by means of the Wheatstone Bridge.

Materials Required. 1" x 2" x 2" block, 2" x 2" strip of tin, $\frac{1}{2}$" x 2" strip of thin brass, section of a curtain roller, eight small brass bolts $1\frac{1}{4}$" long, brass strip $\frac{1}{4}$" x $\frac{1}{2}$" x 30" (brass linoleum stripping may be used), two short brass strips $\frac{1}{4}$" x $\frac{1}{2}$" x $3\frac{1}{2}$", yard stick or meter stick, three feet to one meter of #22 bare German silver wire, board 1" x 4" x 42", coils of wire of various resistances, 50 watt tungsten lamp, toaster, galvanometer, variable resistance, dry cell, connecting wires and key switch.

Construction of the Apparatus. A slot which is sufficiently large to receive the meter stick or the yard stick is sawed through the center of the 1" x 2" block. A section of the curtain roller is fastened to the thin brass strip $\frac{1}{2}$" x 2" by means of a brass screw. The brass strip is fastened to the block above the slot by means of a brass bolt. A strip of tin is cut to fit over the bottom of the assembly as shown in Figure 86 A. The piece of #22 bare German silver wire is laid on top of the yard stick, the assembly described in Figure 86 A is fitted around the yard stick and wire. The tin strip is nailed to the bottom of the block securing the assembly in Figure 86 A to the yard stick. The yard stick is placed on two small blocks about $\frac{1"}{16}$ square (to enable the assembly to slide along the yard stick) and the yard stick is fastened in place with small nails. A short brass strip $\frac{1}{4}$" x $\frac{1}{2}$" x $3\frac{1}{2}$" is bolted into a position perpendicular to the yard stick at each end of the yard stick by means of two small brass bolts about $1\frac{1}{4}$" long. The ends of the German silver wire are secured to the two brass strips, one end to each strip. A brass strip $\frac{1}{4}$" x $\frac{1}{2}$" x 30" is fastened to the side opposite the yard stick in a parallel position by means of three small brass bolts $1\frac{1}{4}$" long, as shown in Figure 86 B.

Procedure. A variable resistance, the Wheatstone bridge, a galvanometer, an unknown resistance, a dry cell and a key switch are connected as shown in Figure 87. A known resistance is selected by using the variable resistance described in Figure 77, a low resistance shunt is connected across the galvanometer terminals, the switch is pressed and the sliding contact is pushed against the German silver wire at about the center of the yard stick. If the galvanometer shows a deflection the sliding contact is moved to the right. If the deflection becomes less it is moved further to the right, if greater, moved further to the left. The sliding contact is moved in this manner until a point is found where there is no appreciable deflection of the galvanometer. The shunt is removed and a fine adjustment is made with the sliding contact until there is no deflection of the galvanometer needle. The reading of the length of wire on the right and on the left side is then taken, the reading on the right being called R_2 and the reading on the left R_3. The known resistance is R_4 and the unknown resistance is R_1. R_1 is found by use of the formula $R_1 = \frac{R_2 R_4}{R_3}$. Various other unknown resistances such as coils of wire, toasters or tungsten lamps are substituted and readings taken.

Comparative Cost. A Wheatstone bridge similar to the one described is listed in most catalogues at four dollars or over, whereas, the actual cost of the bridge described in this experiment would not amount to over twenty-five cents.

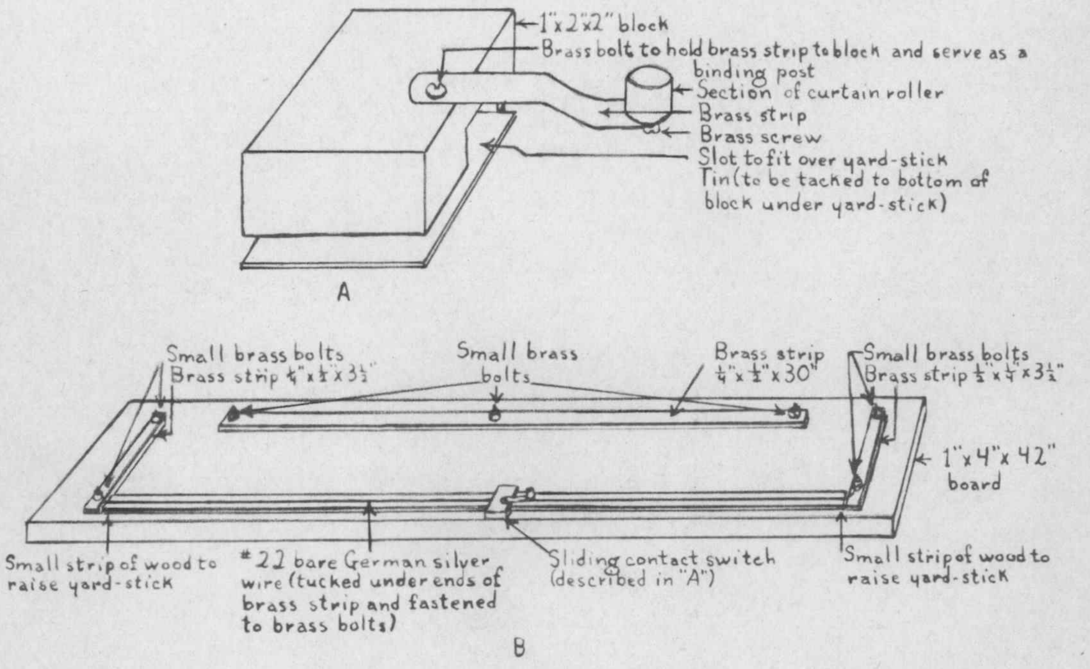

Figure 86 Construction of a Wheatstone Bridge

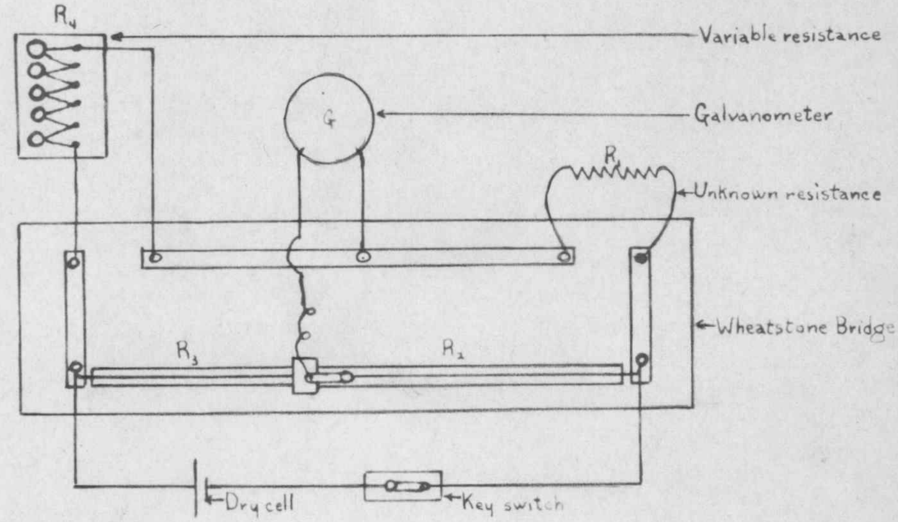

Figure 87 The Measurement of Resistance with a Wheatstone Bridge

Experiment 43.

Effect of Temperature on Resistance

Purpose. To observe the change in resistance on various conductors with the change in temperature.

Materials Required. Porcelain insulating tube, iron wire, two 1" x 2" x 2" blocks, short piece of $\frac{1}{4}$" doweling, two small brass bolts $1\frac{1}{4}$" long, burner, ammeter, dry cells or storage battery and wire to connect apparatus.

Construction of the Apparatus. A hole is drilled in one side of each of the small wooden blocks large enough to receive the short piece of doweling, which is fitted to the inside of the porcelain tube. A brass bolt is then fitted into each block as shown in Figure 88 A. The porcelain tube is then wound with iron wire to form a coil as shown in Figure 88 B. A block is fastened to each end of the tube and the ends of the iron wire are connected to the brass bolts on the blocks, one end to each block, as shown in Figure 88 C.

Procedure. The ammeter, the coil of iron wire and the batteries are connected in series. A reading of the ammeter is taken and recorded. Heat is then applied to the iron wire coil by means of a burner with a wing top as shown in Figure 89. Another reading of the ammeter is taken when the coil becomes red hot. The iron wire coil is then replaced with the German silver wire coil and the procedure above is repeated.

Comparative Cost. No similar commercial apparatus could be found. The materials required for the experiment above cost only a few cents.

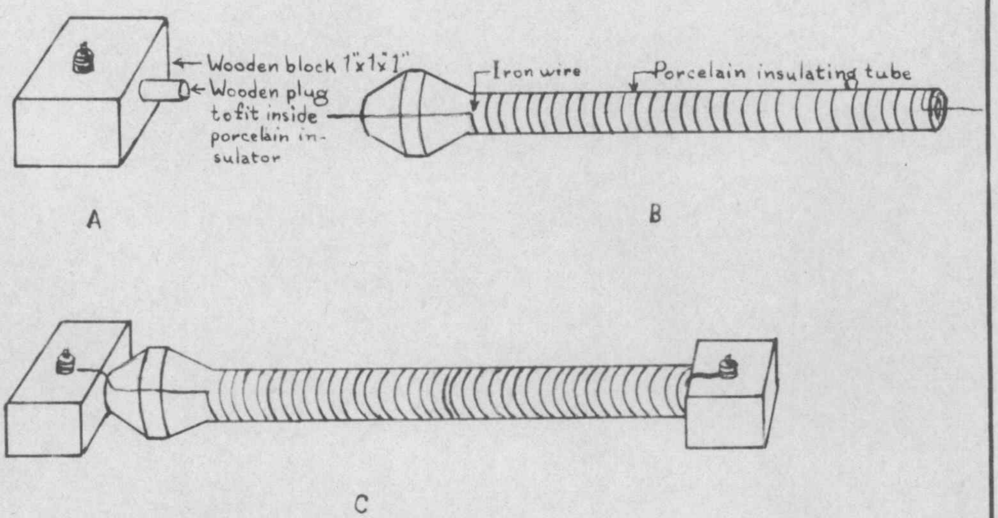

Figure 88 Coils for Heating

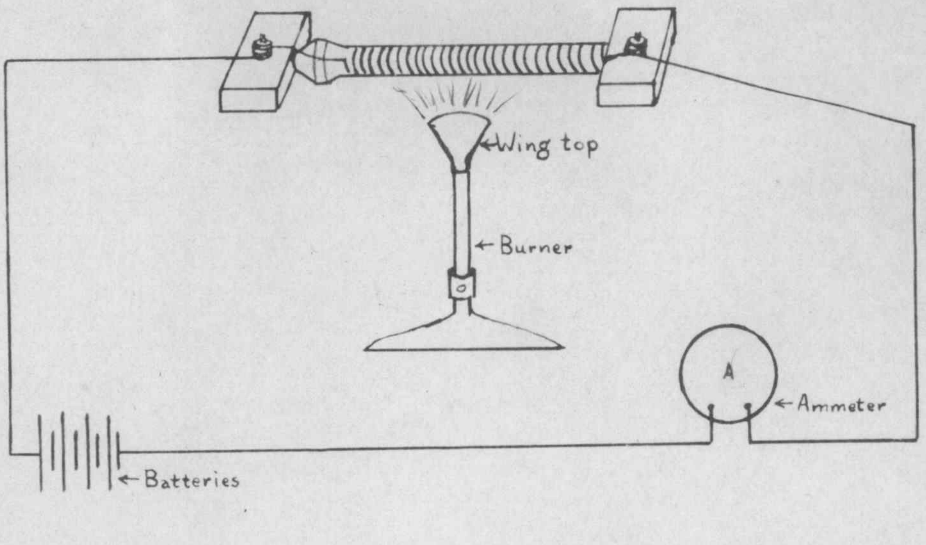

Figure 89 The Effect of Temperature on Resistance

Experiment 44.

Magnetic Effect of a Current

Purpose. To determine the direction of the magnetic lines of force about a wire carrying an electric current, and change in distribution of magnetic flux passing through a coil when a soft iron core is inserted.

Materials Required. Ten feet of 1" batten stripping, three feet of 1" x 2" board, 1" x 4" x 12" board, sheet of cardboard 16" x 16", 3" iron bolt, 225' of #22 cotton covered copper wire, four small brass bolts $1\frac{1}{4}$" long, pencil, battery, key switch, compass and wire for connections.

Construction of the Apparatus. A rectangular frame 1'x 3' is made by nailing the batten strips together with small nails. A cleat made of a piece of batten strip 1' long is nailed to each side of the frame in a horizontal position as shown in Figure 90 A. Notches are then sawed in 1" x 2" boards to receive the frame in such a manner that the 1" x 2" boards will serve as feet as shown in Figure 90 A. Twenty-five turns of #22 cotton covered copper wire are then wrapped around the outside of the frame and both ends are attached to brass bolts, one of which is placed in each foot. The piece of cardboard is then fitted around the wooden frame so that it rests on the cleats as shown in Figure 90 B.

A piece of cardboard 4" x 12" is marked off with a divider and holes are punched at equal distances along each side of the cardboard as shown in Figure 90 C. #22 cotton covered copper wire is then strung through the holes, forming a helix, as shown in Figure 90 D. Two pieces of wood 1" x 2" x 4" are then nailed in an upright position on a 1" x 4" x 12" board, a brass bolt is fitted in each 1" x 2" upright, the helix is then tacked to the top of the upright (1" x 2") boards and each end of the copper wire is attached to a brass bolt as shown in Figure 90 E.

Two card board washers are cut to fit a small 3" bolt. They are then placed on the bolt and the nut is screwed on the bolt and one washer is placed at each end as shown in Figure 90 G. Next a strip of cardboard is cut to fit tightly between the two cardboard washers and is rolled around the bolt as shown in Figure 90 G, and fastened with glue. One end of #22 cotton covered copper wire is inserted in a hole of one of the washers and 25 turns of wire are wound upon the bolt. The other end of the wire is then inserted through another hole in the original washer. Later 25 more turns of #22 cotton covered copper wire are added.

Procedure. A dry cell is connected to a switch and the wire is then held over a compass so that the current is led from south to north, over the compass as shown in Figure 91 A. The current is reversed. Then the wire is passed under the compass without changing the direction of the current. The apparatus described in Figure 91 B above, is connected with a source of 110 volts alternating current and iron filings are sprinkled on the cardboard with the aid of a salt shaker. The apparatus in Figure 91 C is connected with a battery and the compass is pushed by means of a pencil to various positions inside the helix as shown in Figure 91 C. A few turns of #22 cotton covered copper wire are wrapped around a pencil and connected in series with a battery and a key switch (as shown in Figure 91 D) to test with a compass the magnetic qualities of the helix. The current is reversed and the effect noted. The pencil is replaced with an iron nail and the effects are observed. The electromagnet described in Figure 91 E (25 turns) is connected in a series with a key switch and a battery, and its strength, as shown by ability to lift a small iron block, is determined. 25 more turns of #22 cotton covered copper wire are added and the effect on the strength of the electromagnet is observed.

Comparative Cost. No apparatus exactly like the apparatus described was found. However, helices are found at prices ranging from two dollars upward, and electromagnets are listed at prices ranging from two dollars upward, whereas the apparatus described in this experiment would not cost over ninety cents.

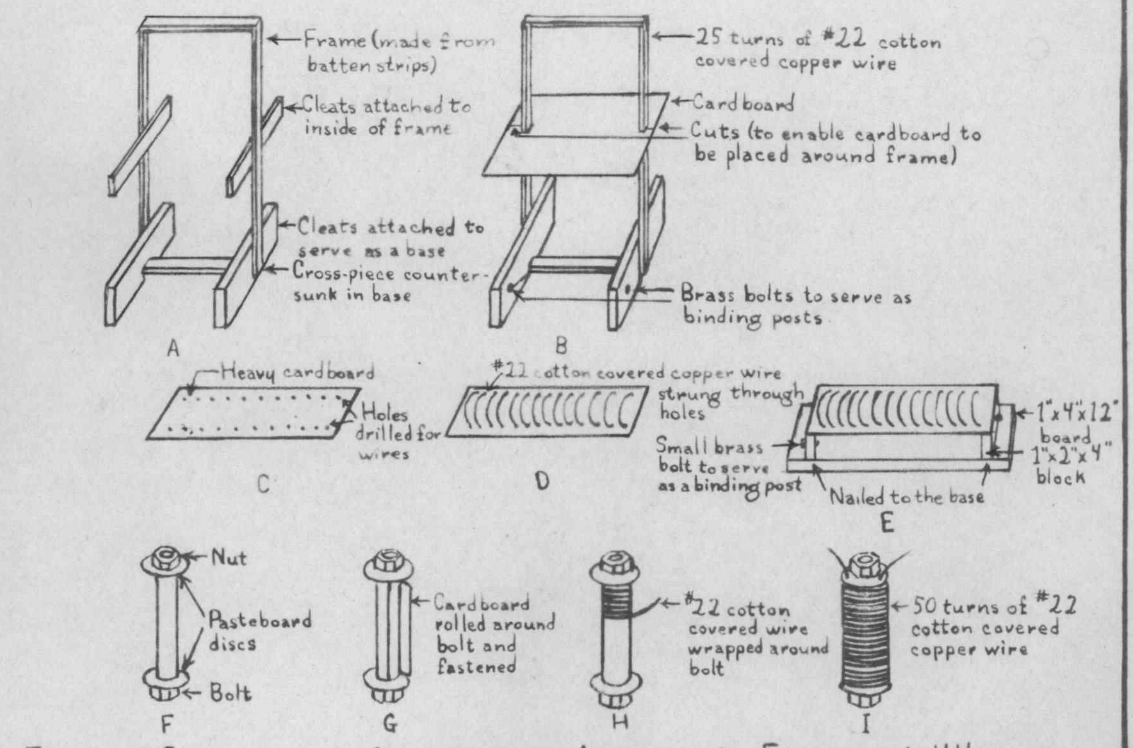

Figure 90 Construction of Apparatus for Experiment 44

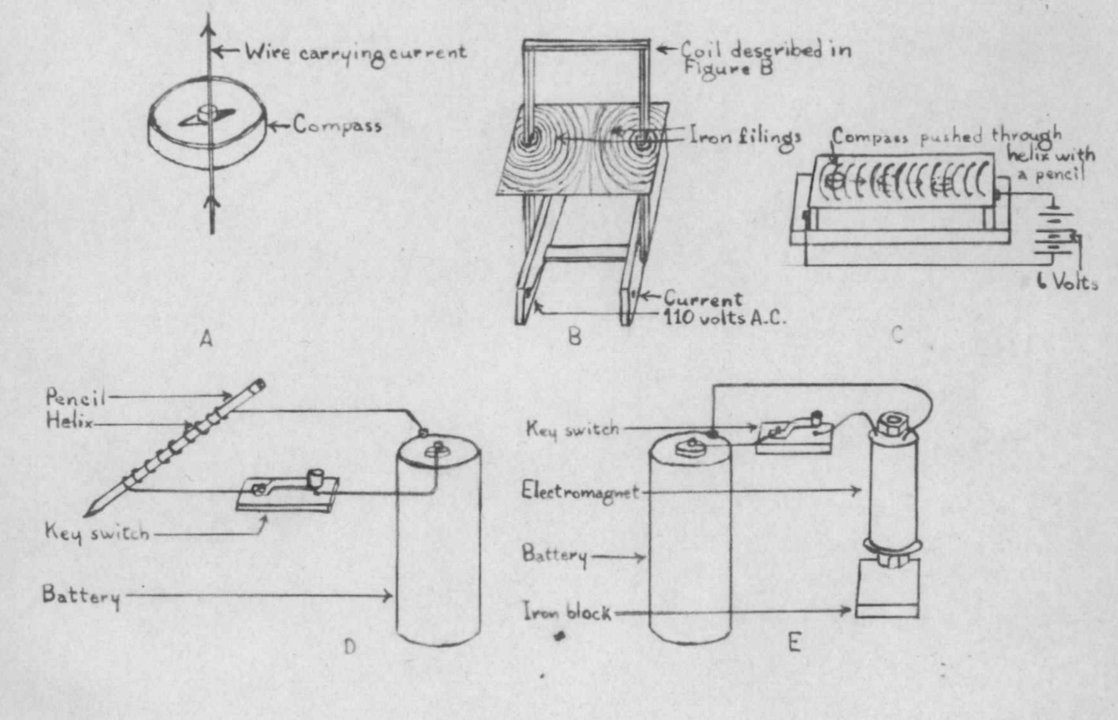

Figure 91 The Magnetic Effect of a Current

Experiment 45.

The Electric Bell and Telegraph

Purpose. To study two applications of the electromagnet,- the electric bell and the telegraph.

Materials Required. Electromagnet as described in Experiment 44, two $\frac{1}{2}$" brass strips (one 2" long and another 4" long), soft iron strip $\frac{1}{2}$" x 2", 1" x 6" x 8" board, 1" x 4" x 6" board, two blocks 1" x 1" x 3", one block 1" x 1" x 1", 20 penny nail, small staples, small nails, five brass screws, five small brass bolts $1\frac{1}{4}$" long, two rubber bands, strip of tin 1" x 3", insulated wire for connections, solder and small bell or baking powder lid.

Construction of the Apparatus. An electric bell may be constructed as follows: The long brass strip is tapered at one end and a small nut is fastened to the tapered end with solder. The shorter brass strip is bent into shape as shown in Figure 92 A. The two brass strips and the iron strip are assembled and soldered together as shown in Figure 92 B. The assembly is fastened by means of small nails to a 1" x 1" x 1" block, (the block is screwed to the base, a 1" x 6" x 8" board) as shown in Figure 92 E. The nut from one brass bolt is filed on one edge so that the edge fits in the slot of a small brass screw. This nut is soldered to the screw as shown in Figure 92 C.

A brass bolt is screwed into the nut as shown in Figure 92 D. The brass screw is screwed into the base behind assembly B, as shown in Figure 92 E. A bell or baking powder lid is fastened to the base so that the nut on the end of the brass strip is close enough to strike the bell. The electromagnet is fastened in position by means of a tin clamp which is fastened to the base with brass screws as shown in Figure 92 E. Two brass bolts are placed through one end of the base and the bell is connected so that the brass bolts serve as binding posts.

To construct a telegraph, two small blocks 1" x 1"x $2\frac{1}{2}$" are fastened to a base 1" x 4" x 6" by means of nails or screws. The blocks are adjusted so that they will support a 20 penny nail leaving a small part of the nail hanging over each end, the electromagnet described in Experiment 44 is placed in an upright position between the two blocks, and the wires of the electromagnet are fastened to two small brass bolts inserted in one side of the base block. Small nails are driven in the top of each of the upright 1" x 1" blocks and adjusted so that the nail comes close to the top of the electromagnet as shown in Figure 92 F. A staple is driven down over the top of the 20 penny nail immediately over each small nail. A rubber band is fastened over one end of the 20 penny nail and to the staple directly below it as shown in

Figure 92 G.

Procedure. The electric bell is connected in series with a dry cell and a key switch as shown in Figure 93 A. The connection is removed from the contact point and made elsewhere to form a single stroke bell or gong.

The electric telegraph is connected in series with a battery and a key switch as shown in Figure 93 B. Observations are made. Two students (or groups of students) should also connect two telegraph instruments as shown in Figure 93 C.

Comparative Cost. A telegraph key and sounder cost in most cases four dollars or more. An electric bell is listed at thirty cents or more. The total cost of the apparatus in this experiment would not be more than ten cents.

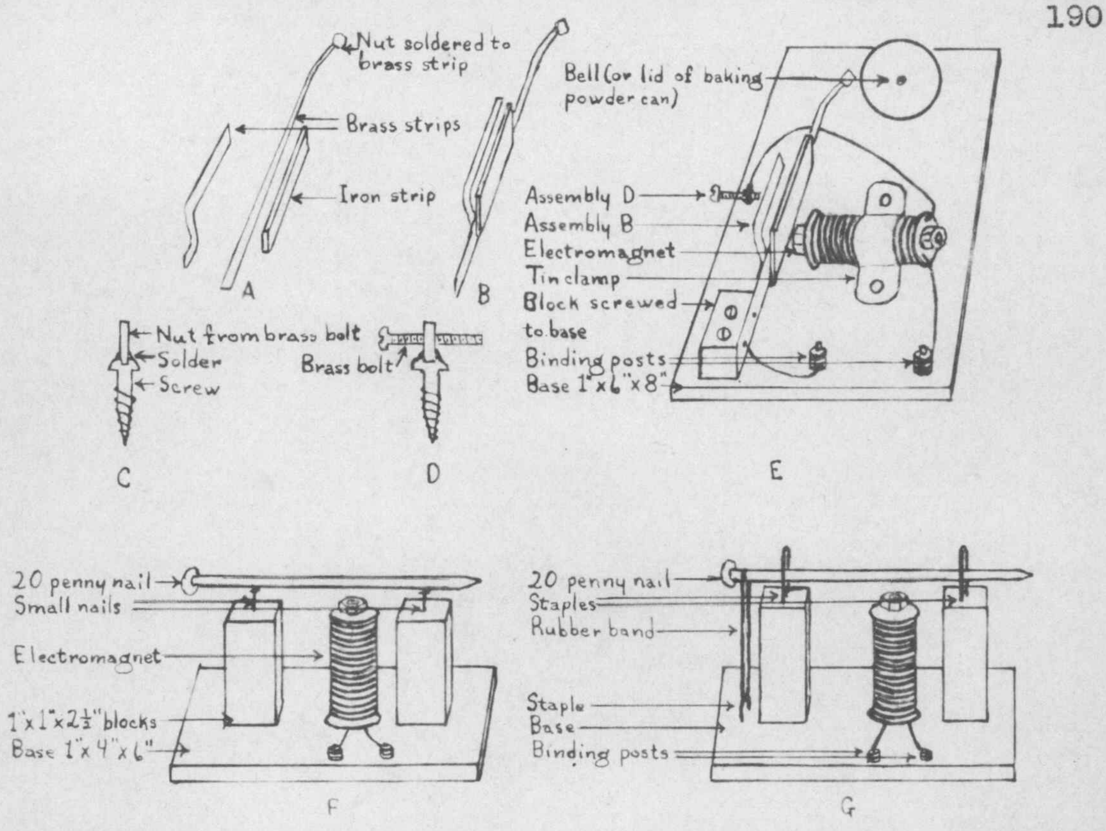

Figure 92 Construction of the Electric Bell and Telegraph

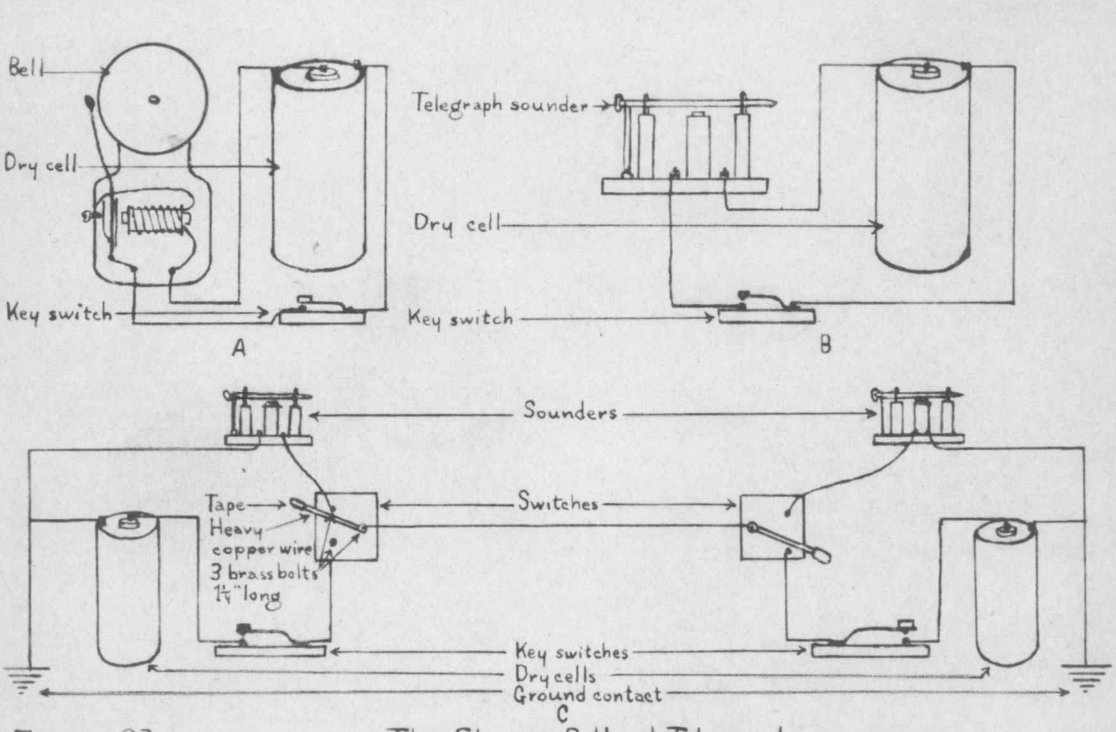

Figure 93 The Electric Bell and Telegraph

Experiment 46.

The Electric Motor.

Purpose. To observe the effect of a magnetic field on a current bearing conductor and to study the construction and operation of an electric motor.

Materials Required. Two feet of #14 insulated copper wire, two strips of tin $\frac{1}{2}$" x 2", board 1" x 4" x 8", two small brass bolts $1\frac{1}{4}$" long, "U" magnet, support, key switch, dry cell, wires for connections, large cork $1\frac{1}{2}$" to 2" in diameter, smaller cork $\frac{1}{2}$" to $\frac{3}{4}$" in diameter, 14' of #30 double cotton covered copper wire, short piece of glass tubing, sheet of very thin copper (or copper foil), two small brass screws, 1" x 4" x 12" board and two 1"x 2"x 4" blocks.

Construction of the Apparatus. To demonstrate the principle of the electric motor, holes are drilled in each end of two strips of tin as shown in Figure 94 A. The tin is bent to form a socket as shown in Figure 94 B. The 1" x 4" x 8" board is fitted to the support and the two sockets made from the tin strips are fastened to the board by means of small brass bolts as shown in Figure 94 C. The #14 insulated copper wire is bent to form a loop 10" long and 2" wide in the manner shown in Figure 94 D. The ends of the wire are inserted in the sockets of the assembly described in C and the whole assembly is fastened to the support, so that the lower end of the loop hangs between the poles of a "U" magnet as in Figure 94 E.

To construct an electric motor, two thin strips of copper, or copper foil, are fastened around the smaller cork so that they do not touch each other (leaving two gaps as shown in Figure 94 F). The copper, or copper foil, is fastened to the cork by means of forcing the ends of the copper strip into the cork as shown. The larger cork ($1\frac{1}{2}$" to 2" in diameter) is wound longitudinally with 12' of #30 double cotton covered copper wire as shown in Figure 94 G. The two corks are carefully driven onto a knitting needle, making sure that the knitting needle goes through the center of each cork and the ends of the wires on the armature (described in G) are connected to the two strips of copper on the commutator (described in F), one end to each copper strip. A short piece of glass tubing is annealed at both ends and a piece about $\frac{1}{2}$" long is filed off at each end as shown in Figure 94 H, to serve as bearings. Two 1" x 2" blocks about 4" long are fastened in an upright position on a 1" x 4" x 12" board just far enough apart to permit the knitting needle to rest with one end on each block. One bearing is placed over each end of the knitting needle and the bearings are fastened to the two blocks as shown in Figure 94 I. A

"U" magnet is fastened in an upright position so that one pole is on each side of the armature as shown in the figure. Two very thin copper wires (#30 bare copper) are fastened to the top of one block, so that the ends of the wires touch the commutator, by means of two small brass screws which also act as binding posts.

Procedure. The apparatus described in Figure 94 E is connected in series with a battery and a key switch. Contact is made by means of a key switch and the effect observed. The circuit is reversed and again the effect observed. The motor described in Figure 94 I is then connected with the battery and the effect observed. The poles are reversed and the effect is again observed.

Comparative Cost. Small motors are listed in most catalogues of scientific apparatus at prices ranging from one dollar and fifty cents upward. Motors for assembling are slightly higher with prices ranging from two dollars and fifty cents upward, whereas the apparatus used in this experiment would cost only twenty cents.

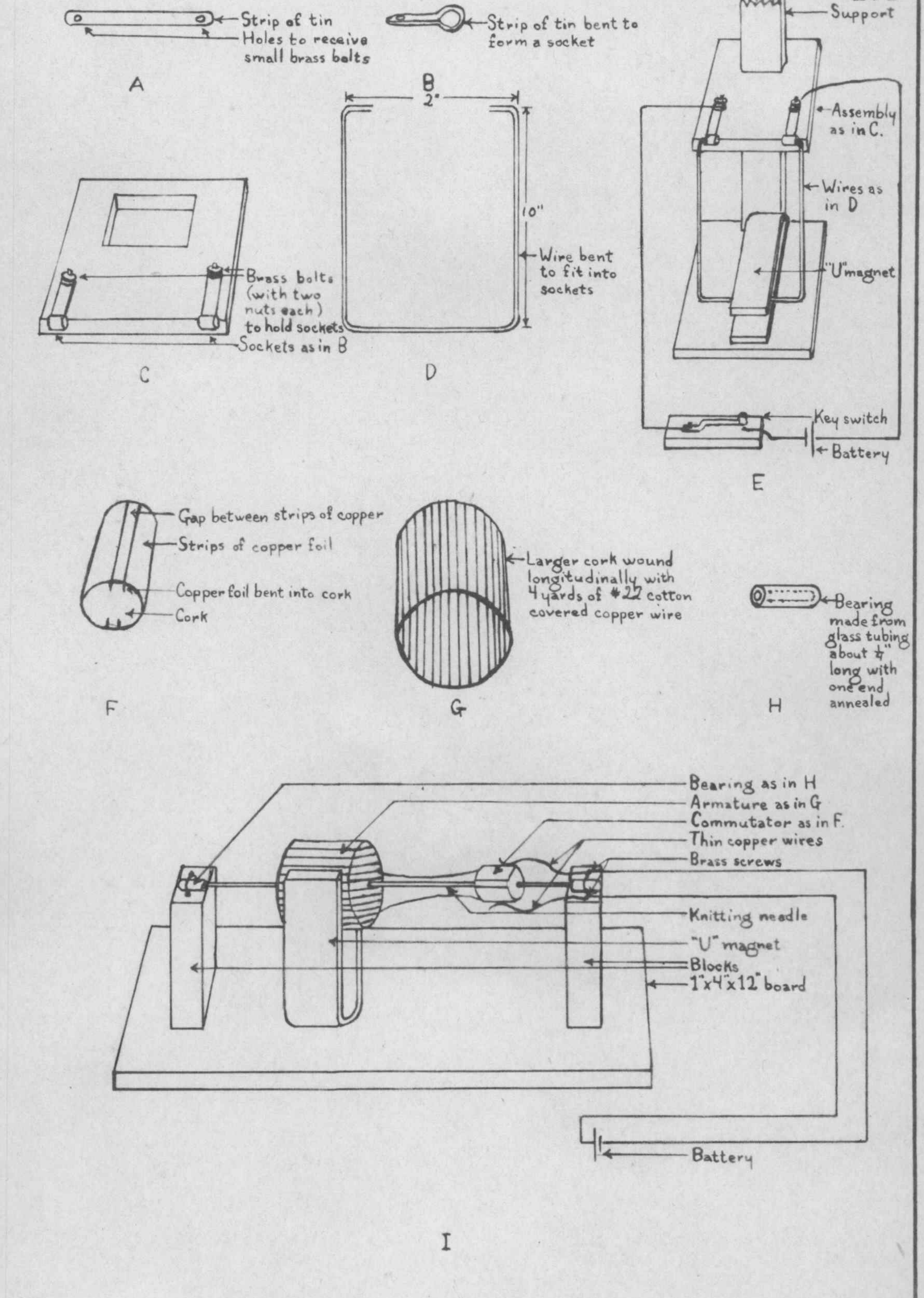

Figure 94 The Principle of the Electric Motor

Experiment 47.

Power and Efficiency of a Motor, Prony-Brake Method

Purpose. To determine the efficiency of a direct current shunt motor at varying loads by the Prony-brake method.

Materials Required. Automobile starter motor, 2" x 10"x8" board, three 2" x 4" x 10" boards, $\frac{1}{4}$" iron bolt 6" long with a nut and washer, piece of flat belting about 2' long, two spring balances (capable of weighing up to 30 pounds), two small bolts $\frac{1}{4}$" x $2\frac{1}{2}$" with washers, four screws 3" long, nails, variable resistance rheostat as described in Figure 83, knife switch, wire for connections and strip of metal to hold motor to base.

Construction of the Apparatus. Two 2" x 4" x 10" boards are fastened in an upright position (each in a corner) of a 2" x 10" x 8" board by means of 3" screws. A 2"x 4"x10" is nailed across the tops of the upright 2" x 4" boards as shown in Figure 95 A. $\frac{1}{4}$" holes are drilled in the top 2" x 4" to receive hooks which hold the spring balances. The heads are sawed off of two $\frac{1}{4}$" iron bolts 6" long as in Figure 95 B, and a hook is bent in the end of each as shown in Figure 95 C. The hooks are inserted in the holes drilled for them in the scaffold. A washer is placed under the nut on each hook. An automobile starter motor is fastened to the 2" x 10" x 8" board by means of a strip of metal and two bolts($\frac{1}{4}$" x $2\frac{1}{2}$"), so that the motor pulley is in line with the hooks on the scaffold. A spring balance is hung over each hook and a piece of belting is cut and fastened over the pulley of the motor and to the hook of each balance so that it may be pulled tightly by means of the nuts as depicted in Figure 95 D.

Procedure. The motor described above is connected to a six volt storage battery and to a variable resistance rheostat so that all the current at first goes to the shunt field, and then is gradually loaded on the motor as shown in Figure 96. The ammeter is placed in the circuit as shown in the figure. The output in horse power is figured by the use of the formula:

$$\text{Horse power} = \frac{F \times 2r \times R.P.M.}{33{,}000},$$

where F is the difference in the readings of the two scales, and R. P. M. is revolutions per minute, and r is the radius of the pulley. Efficiency (per cent) = $\frac{\text{Output}}{\text{Input}}$, (Input = $\frac{\text{Volts x Amperes}}{550}$).

Comparative Cost. No apparatus could be found which could be compared with the apparatus described in this experiment.

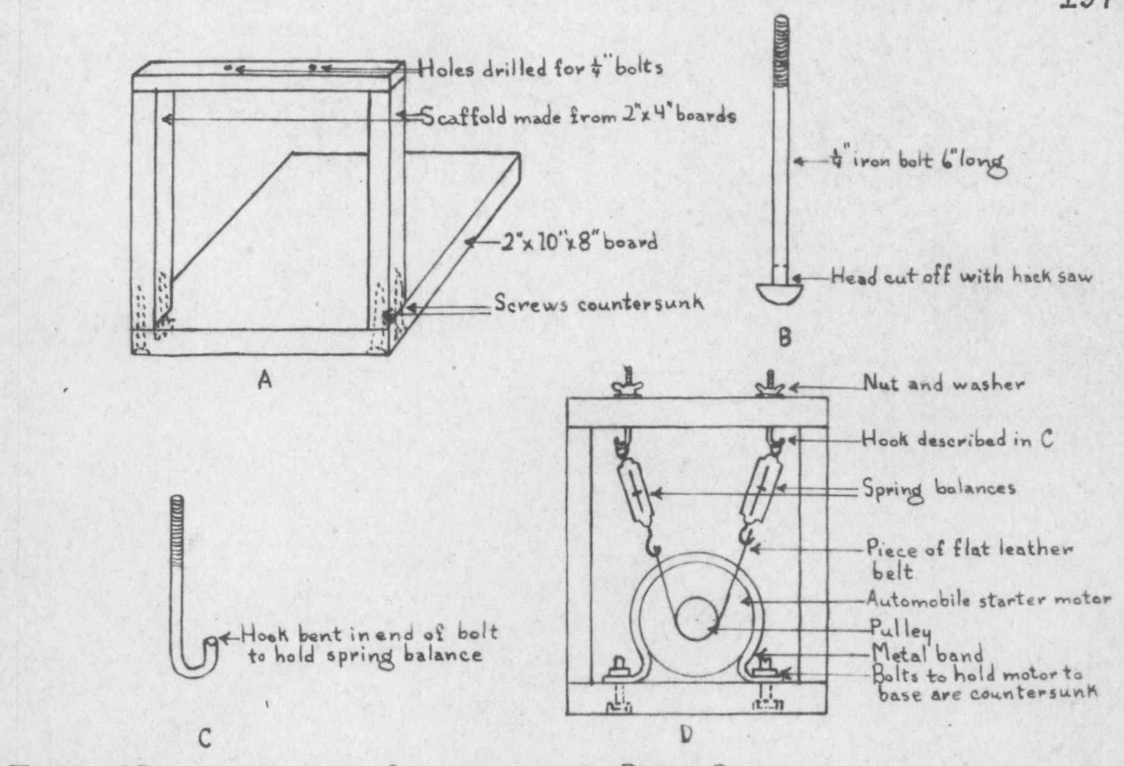

Figure 95 Construction of a Prony Brake

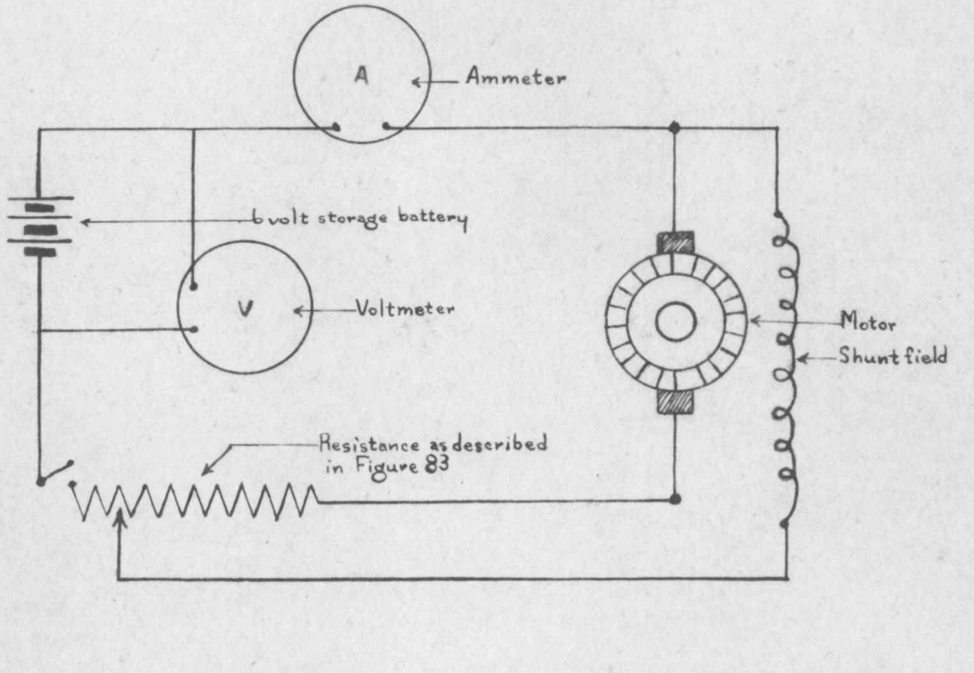

Figure 96 The Power and Efficiency of an Electric Motor

Experiment 48.

Heating Effect of an Electric Current

Purpose. To determine the relation between electric current and the amount of heat given off by it.

Materials Required. Wide mouth glass bottle with cork to fit, wooden block $\frac{1}{2}$" x 2" x 2", two small brass bolts about 2" long, 18" of #22 German silver wire, voltmeter, ammeter, thermometer, knife switch, variable resistance rheostat, four dry cells, and wire for connections.

Construction of the Apparatus. The cork of the bottle is bolted to the wooden block and a coil of the #22 German silver wire is fastened to the heads of the brass bolts as shown in Figure 97 B. A hole is drilled through the center of the cork and the block large enough to receive a thermometer.

Procedure. The wide mouth bottle is filled about half full of water. The assembly described in 97 B is inserted in the bottle so that the coil is under the surface of the water, and a thermometer is inserted through the cork into the bottle as in Figure 97 C. The bottle is connected in series with an ammeter, a knife switch, a variable resistance rheostat and four dry cells as shown in Figure 98. The voltmeter is connected across the circuit as shown. The weight of the water, the time which the current flowed, the rise in temperature of the water and the number of watts supplied to the helix are recorded, and the heat value is obtained by use of the formula $H = .24\ I^2Rt$.

Comparative Cost. No apparatus could be found which is comparable to the apparatus described.

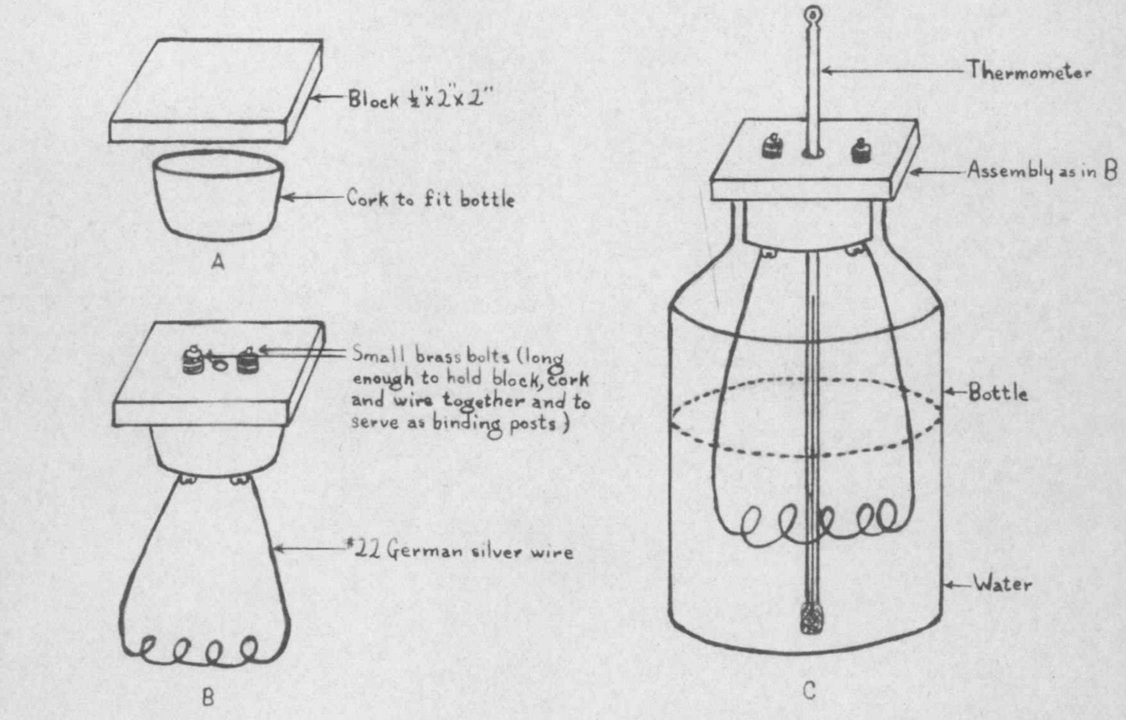

Figure 97 Construction of Apparatus to Show Heating Effect of an Electric Current

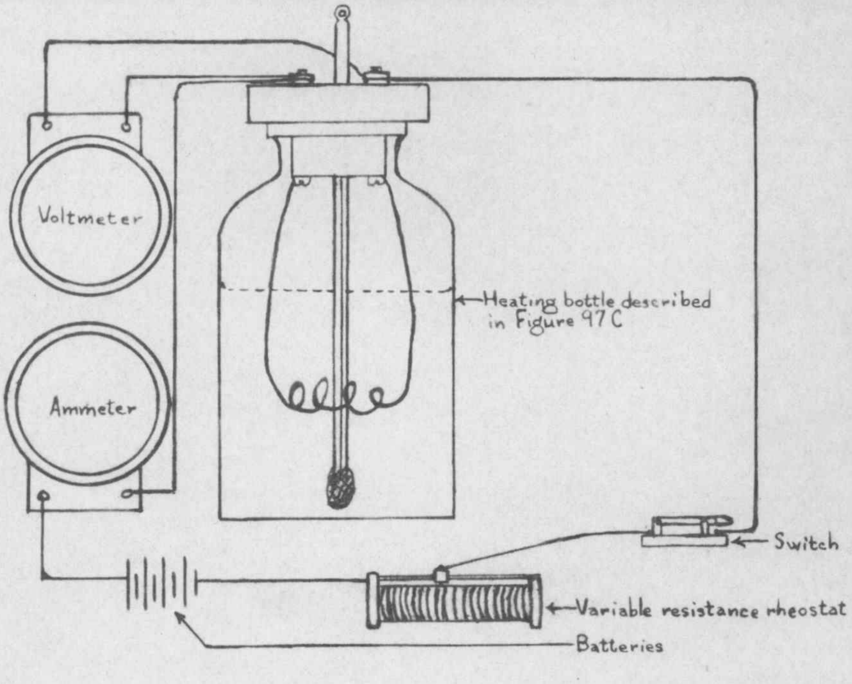

Figure 98 The Heating Effect of an Electric Current

Experiment 49.

Electromagnetic Induction

Purpose. To study the laws of electromagnetic induction.

Materials Required. 70' of #22 double cotton covered copper wire, 1" x 2" x 2" block, short sections of mailing tube, "U" magnet, short pieces of batten stripping for cleats, 1" x 4" x 8" board, soft iron rod about 1' long, galvanometer, battery, thread, nails and wire for connections.

Construction of the Apparatus. 15 turns of #22 cotton covered copper wire are wrapped around the 1" x 2" block as shown in Figures 99 A and B, leaving the ends about 2' long. The coil so formed is removed from the block and fastened together with thread as in Figure 99 C. A hole is punched in one end of a short section of a mailing tube, one end of a #22 cotton covered copper wire is inserted in the hole and 50 turns of the wire are wrapped around the tube as shown in Figures 99 D and E. The other end of the wire is then pushed through a hole punched through the other end of the tube as shown in Figure 99 F. Two cleats are pushed under the edges of a "U" magnet which is sitting in an upright position on a 1" x 4" x 8" board until they hold the magnet in an upright position. The magnet is removed, the cleats are nailed in place and two additional cleats are nailed between the cleats just mentioned so that they touch the edges of the magnet as shown in Figure 99 H.

Procedure. The two ends of the coil described in Figure 99 C are attached to a galvanometer. The coil is then brought down over one pole of the "U" magnet as shown in Figure 100 A, and the effects observed. The same process is repeated for the other pole of the magnet, as shown in Figure 100 B, and the effect observed. The coil is placed between the two poles of the magnet and turned as shown in Figure 100 C, and again the effects are observed. The 50 turn coil described in Figure 99 F is connected with the galvanometer and the north pole of the magnet is thrust into the tube of the coil as shown in Figure 100 D and the galvanometer is read. The same process is repeated with the south pole of the magnet, and the process is again repeated using the coil of 100 turns in place of the coil of 50 turns. The coil of 50 turns is connected with a battery and the coil of 100 turns is connected with the galvanometer, they are placed side by side in a parallel position and a soft iron rod is thrust through both coils, as shown in Figure 100 E, and the effects are noted.

Comparative Cost. Induction coils are listed in most catalogues at prices ranging from seventy cents upwards.

The apparatus described in this experiment can be constructed at a cost of only fifteen cents.

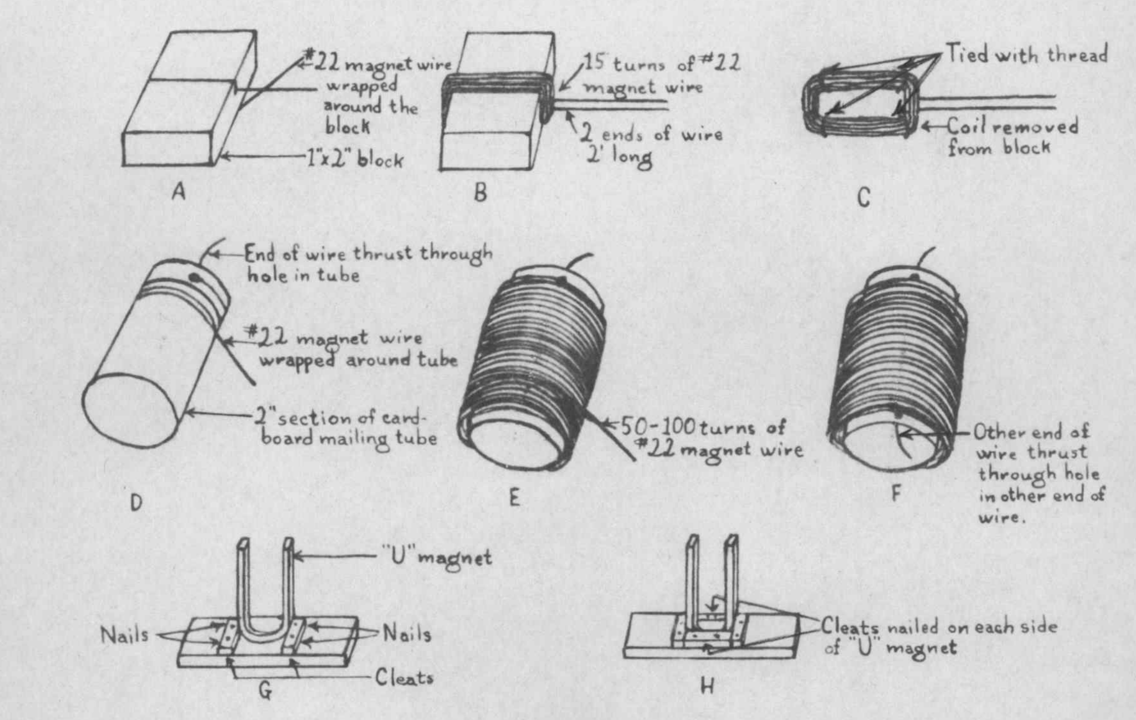

Figure 99 Construction of the Apparatus for Experiment 49

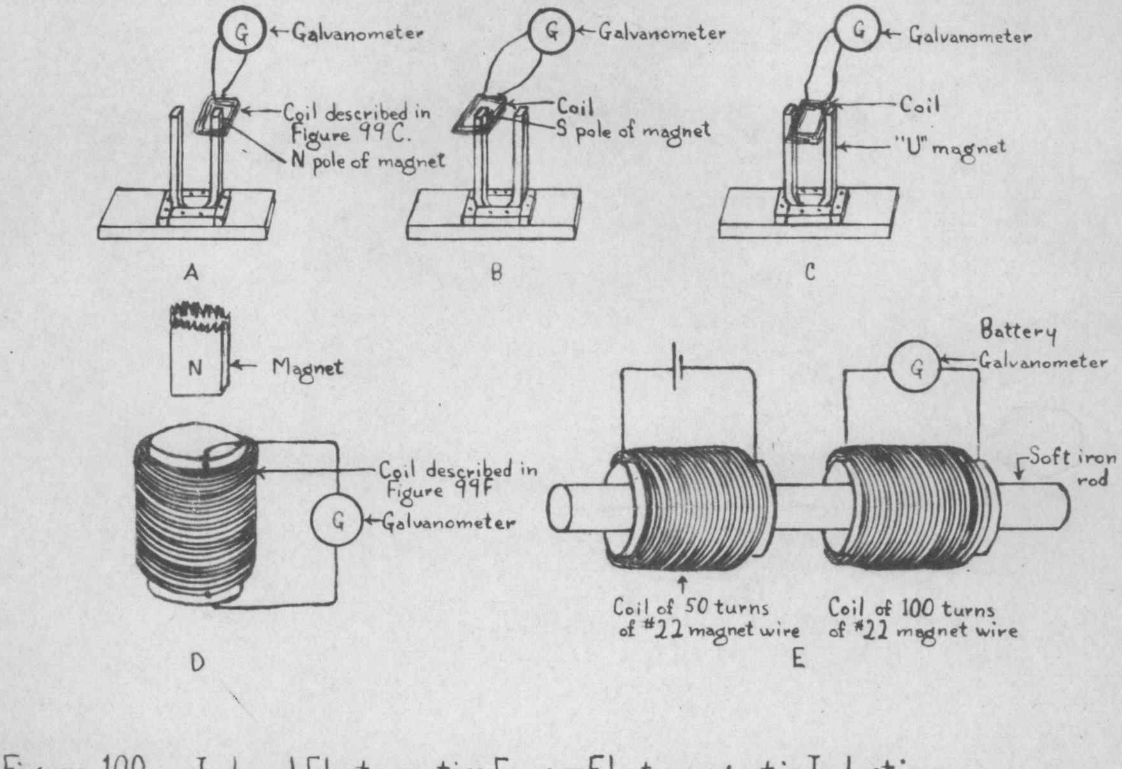

Figure 100 Induced Electromotive Force—Electromagnetic Induction

SOUND

Experiment 50.

Vibration Frequency of a Tuning Fork

Purpose. To determine the number of vibrations per second of a tuning fork by actual count using laboratory equipment.

Materials Required. Strip of galvanized iron $\frac{1}{2}$" x 8", brass screw, heavy nut, pin, strip of tin 2" long, glass plate 2" x 8", piece of doweling 18" long, small stove bolt about 1" long, four small stove bolts about 3" long, two pieces of small quarter round about 1' long, four blocks 1" x 1" x 4", board 1" x 8" x 18", board 1" x 2" x 8", piece of camphor, matches or burner, nails and tuning fork.

Construction of the Apparatus. To construct a vibrograph, holes are drilled in each end of the 8" strip of galvanized iron and a heavy nut is fastened to one end by means of a 1" stove bolt. A pin is fastened between the nut and the galvanized strip as shown in Figure 101 A. The other end of the strip of galvanized iron is fastened to the 1" x 2" x 8" board by means of a brass screw as in Figure 101 B. A hole is bored in the other end of the 1" x 2" x 8" board so that it fits over the doweling and a pin is driven through to hold it in position as designated in Figure 101 G. A strip of tin is cut into a triangular shape so that it forms a pointer as in Figure 101 C. This pointer is attached by means of wax or liquid solder to a tuning fork as shown in Figure 101 D. A glass plate is smoked by holding it over a smoky flame (such as a gas flame with an insufficient air supply, burning camphor or even an ordinary match). The glass is moved around over the flame to get an even coating and to prevent breaking in the manner shown in Figure 101 E, (whiting mixed with alcohol, or Bon Ami may be used in place of the lamp black if desired). A crank is made from a piece of $\frac{1}{4}$" doweling and a piece of batten strip as in Figure 101 F. The doweling is fitted snugly into the hole of a spool as described in Experiment 39. Two blocks (1" x 1" x 4") are placed so that one block is on top of the other and two holes are drilled through both, and also through the 1" x 8" x 18" board base, and 3" stove bolts are inserted in the holes, as shown on the left of Figure 101 F. The handle of a tuning fork is then placed between these two boards and the bolts are tightened as shown in Figure 101 F. A hole is bored in the 1" x 12" x 18" board so that when the doweling, holding the support is inserted in the hole the pendulum will hang in position so that the point of the pin is directly in front of and a very short distance from the pointer of the tuning fork as shown in Figure 101 G. The smoked glass is laid in a position under the tuning fork and pendulum and a piece of small quarter round is nailed into position on each side of the glass to form a guide for the glass as shown in Figures 101 G and H. The spool is fitted into a notch and the crank described in Figure 101 F is inserted as shown in Figure 101 G. The pointer of the tuning fork and the pin on the pendulum are then adjusted so that they barely touch the glass and will make a mark in the lamp black as in Figure 101 H.

Procedure. The pendulum is set to swinging through a small arc and the tuning fork is set to vibrating by pinching the prongs together with the thumb and finger and then releasing them suddenly. The glass is moved along with a slow steady motion toward the right until there is at least one complete vibration of the pendulum. The number of oscillations made by the tuning fork for each oscillation of the pendulum is recorded and the glass is again blackened and the process is repeated. Two or three trials should be made.

With a stop watch, or the second hand of an ordinary watch, the number of oscillations of the pendulum for one minute are counted and from this the number of complete vibrations (two oscillations) is computed for one second. From the records made on the glass plates the average number of complete vibrations of the tuning fork for a complete vibration of the pendulum is computed. The number of complete vibrations per second of the pendulum is found by dividing the number of oscillations per minute by two and then by 60. The frequency or the number of complete vibrations per second of a tuning fork is found by multiplying the number of complete vibrations of the tuning fork for each complete vibration of the pendulum by the number of complete vibrations per second of the pendulum.

Comparative Cost. Vibrographs are listed in most catalogues at prices ranging from five dollars and up, whereas the apparatus required for this experiment can be secured for less than one dollar and fifty cents, including the tuning fork.

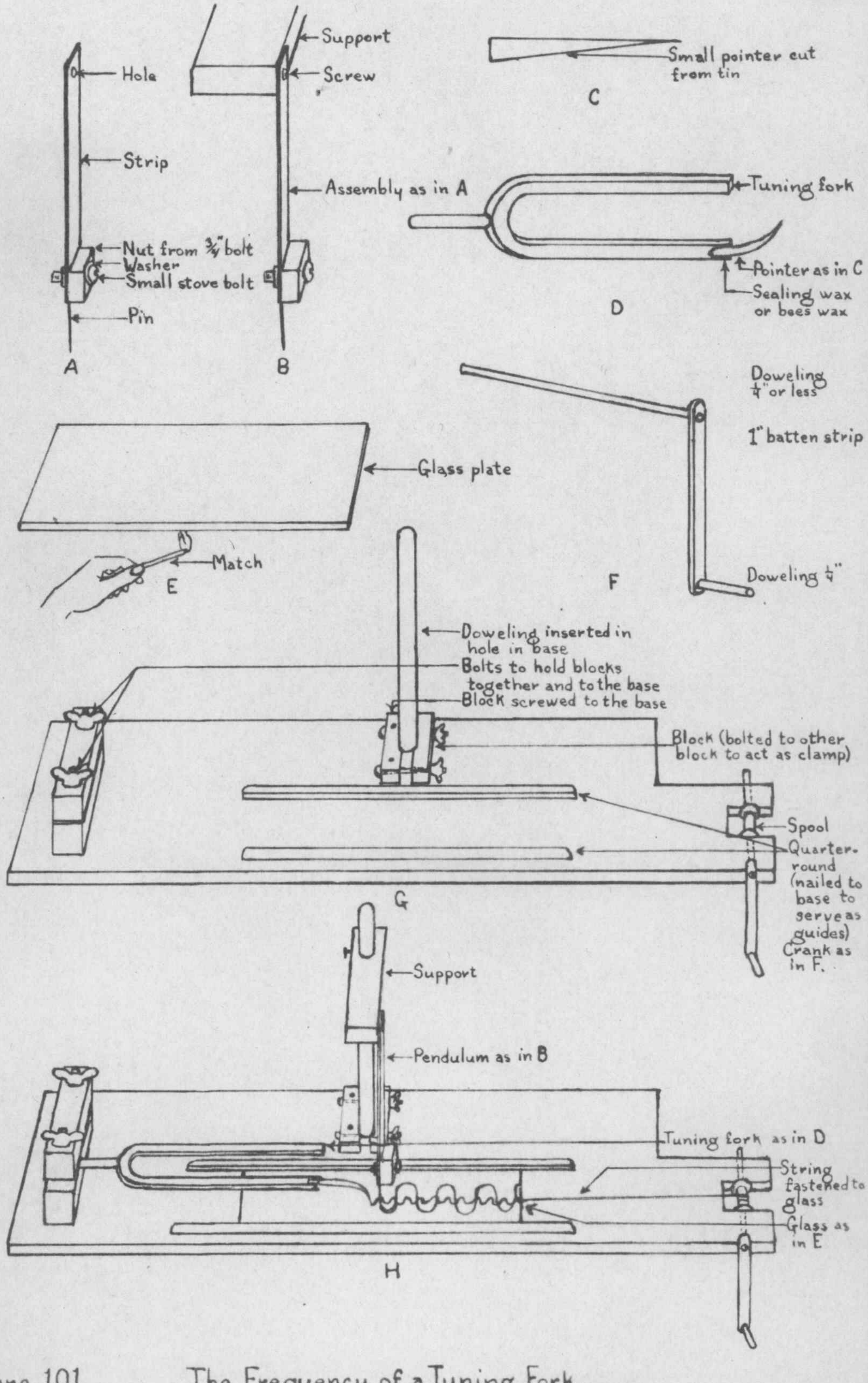

Figure 101 The Frequency of a Tuning Fork

Experiment 51.

Velocity of Sound in Air

Purpose. To determine the velocity of sound in air by direct measurement.

Materials Required. Pistol, blank cartridges, measuring tape (50' to 100'), stop watch (ordinary watch may be used in place of a stop watch if stop watch is not available) and a thermometer.

Construction of the Apparatus. There is nothing in this experiment to construct.

Procedure. The class is divided into two groups which are placed 350 to 400 yards apart. One group has a pistol and the other the watch. At a pre-arranged signal from the group with the watch, the pistol is fired. The instant the flash is seen the watch is started. The instant the sound is heard the watch is stopped and read. Since for ordinary distances the speed of light is instantaneous the time between seeing the flash and hearing the sound is the time it took the sound to travel from the person firing the pistol to the one holding the watch. This experiment is tried several times with varying distances until it takes just one second after the flash for the sound to be heard. When the group has agreed on the proper position results are checked two or three times and the distances accurately measured with a tape and the temperature is recorded. If there is a wind one set of readings should be taken with the sound coming from the same direction as the wind and the other with the sound coming from the opposite direction. The average of the two distances may be taken for the velocity of sound in still air at the temperature recorded.

Comparative Cost. There is no commercial equipment for this experiment.

Experiment 52.

Wave-length of Sound by Resonance

Purpose. To determine the wave-length of a sound of known vibration frequency by measuring the length of the column of air which vibrates so as to reinforce the original tone.

Materials Required. Piece of gas pipe $1\frac{1}{4}$" to 2" in diameter 3' long, piece of $\frac{1}{2}$" doweling $3\frac{1}{2}$' long, round wooden plug to fit inside the pipe, wooden block to serve as handle, two wooden blocks(2" x 4" x 4"), and two "C" clamps, (or glass tubing about 1" to $1\frac{1}{2}$" in diameter and 18" long, rubber bands, large glass cylinder 3" in diameter and 18" high, water, tuning fork and measuring stick.

Construction of the Apparatus. A hole is bored into the plug, which fits inside the 2" iron pipe, large enough to receive a piece of $\frac{1}{2}$" doweling. A $\frac{1}{2}$" hole is also bored in the block which serves as a handle. The doweling is then inserted in the plug and in the block, as shown in Figure 102 B, and secured by means of nails. The assembly described in B is then pushed into the iron pipe until the top of the plug is even with the other end of the iron pipe, as shown in Figure 102 C. A mark is then made on the doweling at the end of the pipe from which the handle protrudes to enable the operator to measure the length of the resonance chamber. The length of the resonance chamber may be varied by pushing the plunger in or out of the pipe.

Another resonance chamber may be made by fastening a measuring stick to a $1\frac{1}{2}''$ glass tube as in Figures 102 E and F by means of rubber bands. A glass cylinder is then filled almost full of water and one end of the tube is thrust under the surface of the water in the manner shown in Figure 102 G. The length of the resonance chamber may be varied by raising or lowering the tube in and out of the water.

A rubber mallet for striking the tuning fork may be made by inserting a short metal tube, rod or pencil into the hole of a rubber stopper, as in Figure 102 D.

Procedure. The tuning fork is struck with the rubber mallet and held over the open end of a resonance tube. The length of the resonance tube is changed until a position is found where the sound is reinforced the greatest amount. The length of the air column at this position is determined carefully. During the time in which the pulse traveled down the tube and back the prong of the fork made one half a complete vibration. Hence the distance down the tube and back traversed by the pulse must be one-half a wave-length of the tone emitted by the tuning fork, and the length of the air column in the tube is one-fourth the wave-length.

A slight correction must be made in this result. The actual distance traveled is a little greater than the distance traveled in the tube. The correction is .4 x inside diameter of the resonating tube. The true one-quarter wave-length l = the measured length l' + .4 x diameter d of the tube or $\frac{1}{4} l = l' + .4d$. The room temperature is recorded.

Comparative Cost. Resonance tubes with support and piston are listed in most catalogues at prices ranging from three dollars and fifty cents upward. The apparatus used in this experiment would not cost over fifty cents.

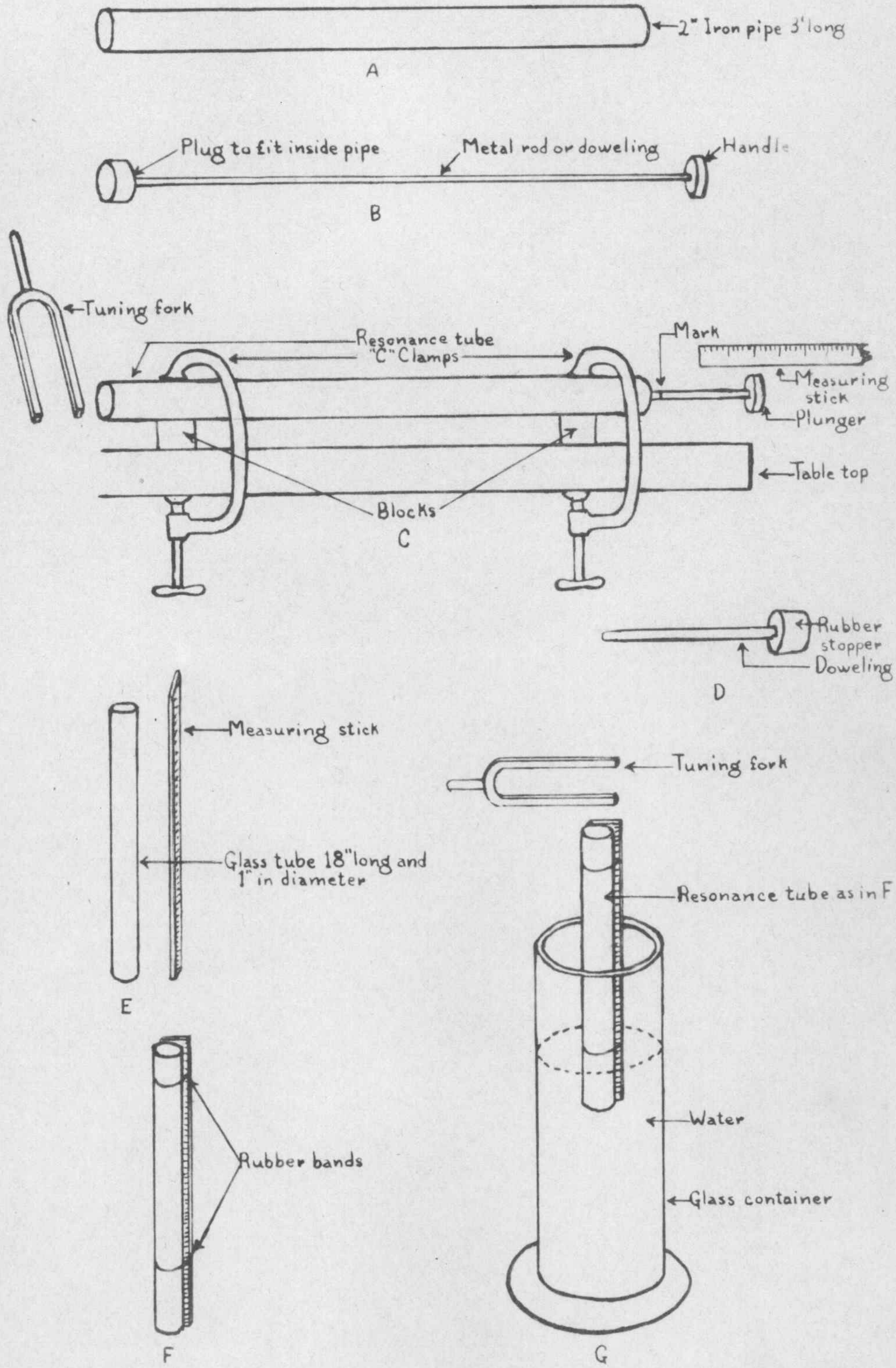

Figure 102 Wave Length of Sound by Resonance

Experiment 53.

Vibrating Strings

Purpose. To determine the effect of length and tension upon the vibrating frequency of a string.

Materials Required. 1" x 4" x 24" board, spool, $\frac{1}{4}$" x 5" bolt and nut, screw eye, two 1" x 1" x 3" straight grain blocks, spring balance, pail of water, banjo string or piece of piano wire about 3' long, "C" clamp, G and C tuning forks and rubber mallet.

Construction of the Apparatus. A sonometer may be constructed by cutting a notch in the end of a 1" x 4" x 24" board large enough to receive a spool as shown in Figure 103 A. A hole is drilled through the board edgewise to receive the $\frac{1}{4}$" bolt. A $\frac{1}{4}$" x 5" bolt is then thrust through the board and the spool, the nut is screwed on the bolt and a screw eye is inserted in the position near the other end of the 1" x 4" x 24" board as in Figure 103 B. Two triangular shaped bridges are made from the 1" x 1" x 3" blocks by sawing or with the aid of a sharp knife as depicted in Figure 103 C. A quantity of water is placed in a pail and weighed with the aid of a spring balance. The assembly described in B is then fastened to a table top with the aid of a "C" clamp, a banjo string or piano wire is fastened to the screw eye, laid across the tops of the two triangular bridges, over the spool at the other end of the board and the pail of water is suspended from the other end of the wire as in Figure 103 E.

<u>Procedure</u>. The bridges on the sonometer are placed about 24" apart. There should be about three quarts of water in the pail to begin with. The wire is plucked about half way between the bridges with the forefinger. A "C" fork is set into vibration by striking one prong with the rubber mallet described in Experiment 52, and holding the tuning fork against the sonometer. The tension on the wire is changed by adding water to the pail until the string and the tuning fork vibrate at the same frequency. (When there are no beats both the string and the tuning fork have the same frequency). The pail of water is weighed and the weight (G) is recorded for the tension of the wire. Also the length of the wire between the bridges is recorded. The process is repeated for a C fork, and for other forks available. Compute $\frac{n_G}{n_C}$, $\frac{L_G}{L_C}$ and $\frac{\sqrt{T_G}}{\sqrt{T_C}}$ where n_G= vibration rate for the G fork, n_C= vibration rate for the C fork, L_G= length of the wire required to vibrate in unison with the G fork, L_C= the length of wire required for the C fork, T_G= tension required for the G fork, and T_C= tension required for the C fork.

<u>Comparative Cost.</u> Sonometers are listed in most catalogues at prices ranging from eight dollars and fifty cents

upward. The apparatus described in this experiment can be constructed at a cost of not more than fifteen cents.

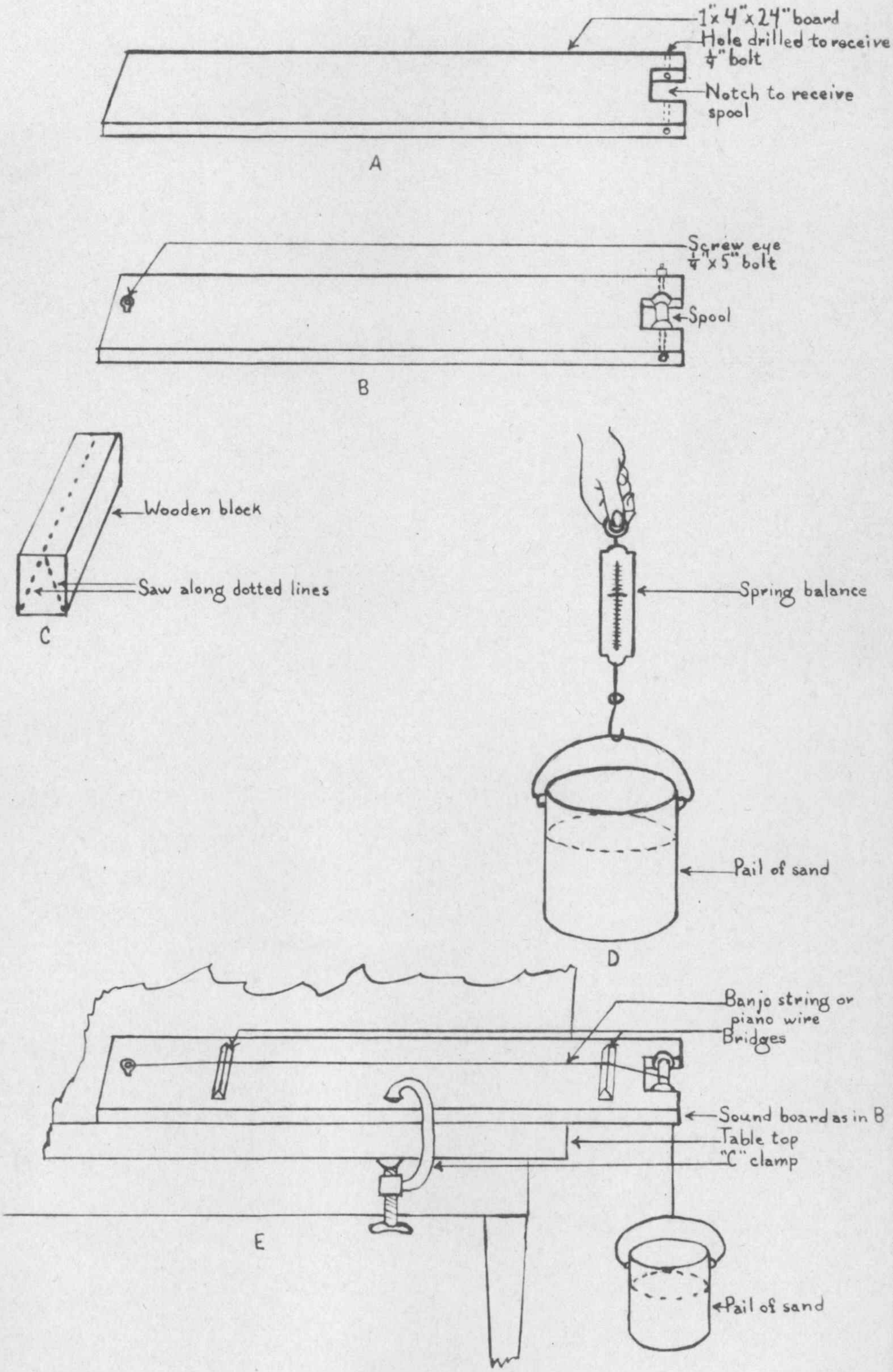

Figure 103 The Laws of Vibrating Strings

LIGHT

Experiment 54.

The Law of Reflection of Light

Purpose. To locate the mirror image and to determine the law of reflection of light.

Materials Required. Small rectangular mirror, block 1" x 2" x 3", old drawing board (bread board or piece of plywood or beaver board 2' x 2') ruler, pins, and rubber band.

Construction of the Apparatus. There is no apparatus to construct for this experiment.

Procedure. A small rectangular mirror is fastened to a 1" x 2" x 3" block horizontally by means of a rubber band as in Figure 104 A. The mirror is placed in a vertical position on a sheet of paper, which is fastened to the drawing board, so that the silvered side of the mirror coincides with the mirror line. A pin is stuck into the board about 2" in front of the mirror and labelled O. A ruler is placed on the board to the left of the object and used to sight at the image in the mirror. A line is drawn along the ruler to the face of the mirror. The ruler is used again to sight at the image from the right side of the object and a line is drawn to the mirror as before. The mirror is then removed and the two lines are extended until they meet, (the position of the image O'). The parallelogram is completed as shown in Figure 104 B. A perpendicular is drawn to the mirror line at the place where the incident ray hits the mirror, (point of incidence). This line is labeled normal. The angle of incidence and the angle of reflection are determined and measured.

Comparative Cost. Reflection apparatus is listed in catalogues at prices ranging from four dollars upward. The cost of the apparatus used in this experiment would be only a few cents.

Experiment 55.

Index of Refraction

Purpose. To find the index of refraction of plate glass.

Materials Required. Piece of plate glass (square or rectangular), ruler, board described in Experiment 54, pins and paper.

Construction of the Apparatus. There is no apparatus in this experiment to construct.

Procedure. The piece of plate glass is laid on a piece of paper which has been fastened to the board used in Experiment 54 and the glass is outlined with pencil on the paper. Then the glass is removed and a line making an angle of about 45° with the upper edge of the glass is drawn on the paper. An arrow is drawn along this line and pins are stuck near the ends of the line. The plate glass is then replaced and with the aid of the ruler the pins are sighted from the other side of the glass as shown in Figure 105. A line is drawn along the edge of the ruler to the face of the plate glass. The glass is then removed again and the line drawn along the ruler is labeled CD (represents the ray of light leaving the glass). The point at which the ray enters the glass B is then connected with the point at which the ray leaves the glass C. The line BC then represents the path of the light through the glass. If the work has been done carefully the entering ray AB and the emerging ray CD will be parallel. A perpendicular is drawn to the face of the glass at B and labeled normal. The angle of incidence and the angle of reflection are labeled. With B as the center and BC as the radius, two arcs are drawn to intersect the ray in both the air and the glass. Perpendiculars to the normal are drawn where the arcs intersect the rays, (at F and C) BEF and BGC are right angle triangles.

$$\text{Sin i} = \frac{EF}{BF}, \ \text{Sin r} = \frac{GC}{BC},$$

The index of refraction $= \dfrac{\text{Sin i}}{\text{Sin r}} = \dfrac{\frac{EF}{BF}}{\frac{GC}{BC}} = \dfrac{EF}{GC}$, since

GF = BC (radii of the same circle).

The measured results are compared with the actual index of refraction.

Comparative Cost. Pieces of plate glass for the purpose of this experiment are listed at prices of about twenty-five cents. However, small pieces of plate glass which should be suitable for this experiment may be obtained in most localities at no cost or at the most they will cost only a few cents.

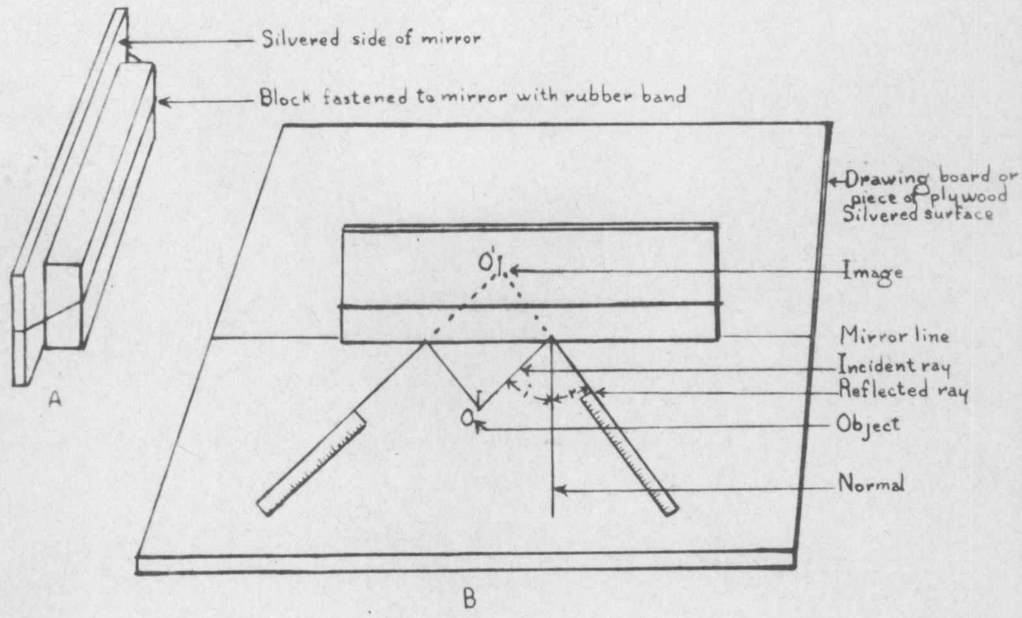

Figure 104 The Law of Reflection

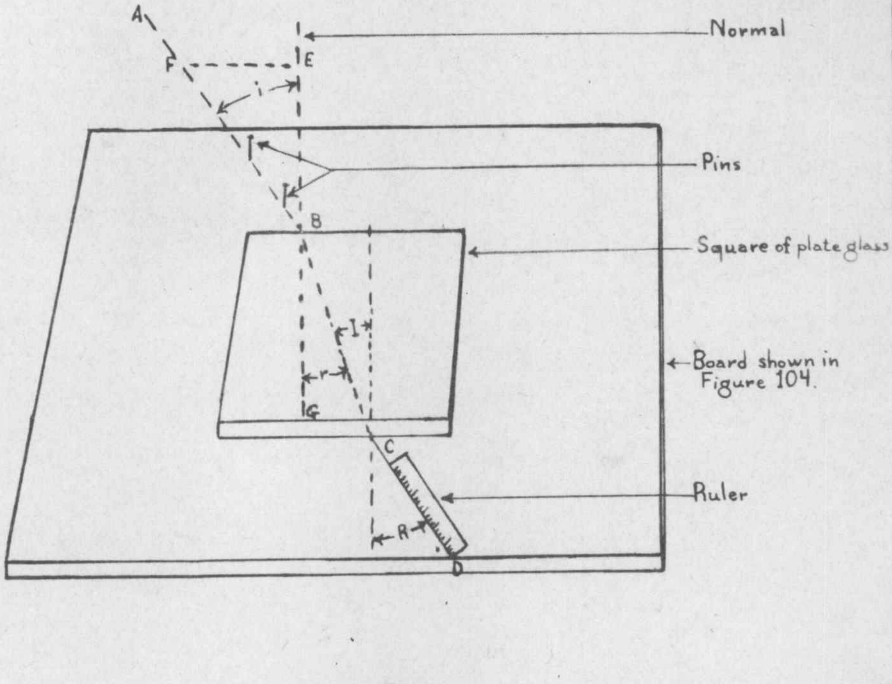

Figure 105 Index of Refraction

Experiment 56.

Measurement of Candle Power

Purpose. To measure the brightness of a source of light by comparing it with a standard lamp.

Materials Required. Four blocks 1" x 2" x 2", yard stick or meter stick, two blocks 2" x 4" x 4", two small blocks of paraffin, small sheet of tin foil, cardboard box (container for roll of films will do nicely), two lamp sockets from the ten-cent store, lead wire, two plugs, standard candle and 15 watt, 25 watt and 50 watt tungsten bulbs.

Construction of the Apparatus. A slot is sawed about half way through each of the 1" x 2" x 2" blocks as shown in Figure 106 A, so that a yard stick or meter stick just fits into it. Round holes are cut into one side of the cardboard box and in each end and the box is secured to the top of one of the 1" x 2" x 2" blocks as shown in Figure 106 B. Two blocks of paraffin are trimmed so that they fit snugly on the inside of the cardboard box. A piece of tin foil just the size of the blocks of paraffin is placed between them and this assembly is fitted to the center of the cardboard box so that it is in front of the hole in the side of the cardboard box as in Figure 106 C. Wires and the two plugs are attached to the two light sockets (so that they may be attached to a source of current) and the sockets are fastened to the tops of the two 2" x 4" x 4" blocks in which slots have been cut to fit over the yard stick, as shown in Figure 106 D. One of the blocks described in Figure 106 A is fitted over each end of the yard stick (or meter stick) to serve as supports for it. Another 1" x 2" x 2" block is fitted on the top of the yard stick and a standard candle is attached to the top of the block. The photometer described in Figure 106 C is placed upon the yard stick at about the middle and the block holding the electric light is attached to the other end of the yard stick in the manner shown in Figure 107.

Procedure. A standard candle is placed on the block as described in the construction of the apparatus and a 15 watt tungsten bulb is placed in the lamp socket. The position of the photometer is changed until the blocks of paraffin are illuminated equally. The position of the photometer is read on the yard stick and the values are recorded as d_1 and d_2, d_1 being the distance from the light to the photometer, and d_2 being the distance from the candle to the photometer. The candle power of the light is figured by the use of the formula

$$C = B \times \frac{d_1}{d_2}.$$

Using the 15 watt tungsten bulb as the standard, the process is repeated as outlined for a 25 watt and 50 watt tungsten bulb.

Comparative Cost. A photometer box is listed in most catalogues at prices of two dollars or over. Lamp sockets are listed at one dollar and fifty cents or more. Candle supports are listed at prices ranging from ten cents to fifty cents. Screen holders or card supports would cost at least ten cents each at most scientific supply houses. The apparatus described in this experiment should not cost over fifty-five cents complete, with the exception of the bulbs.

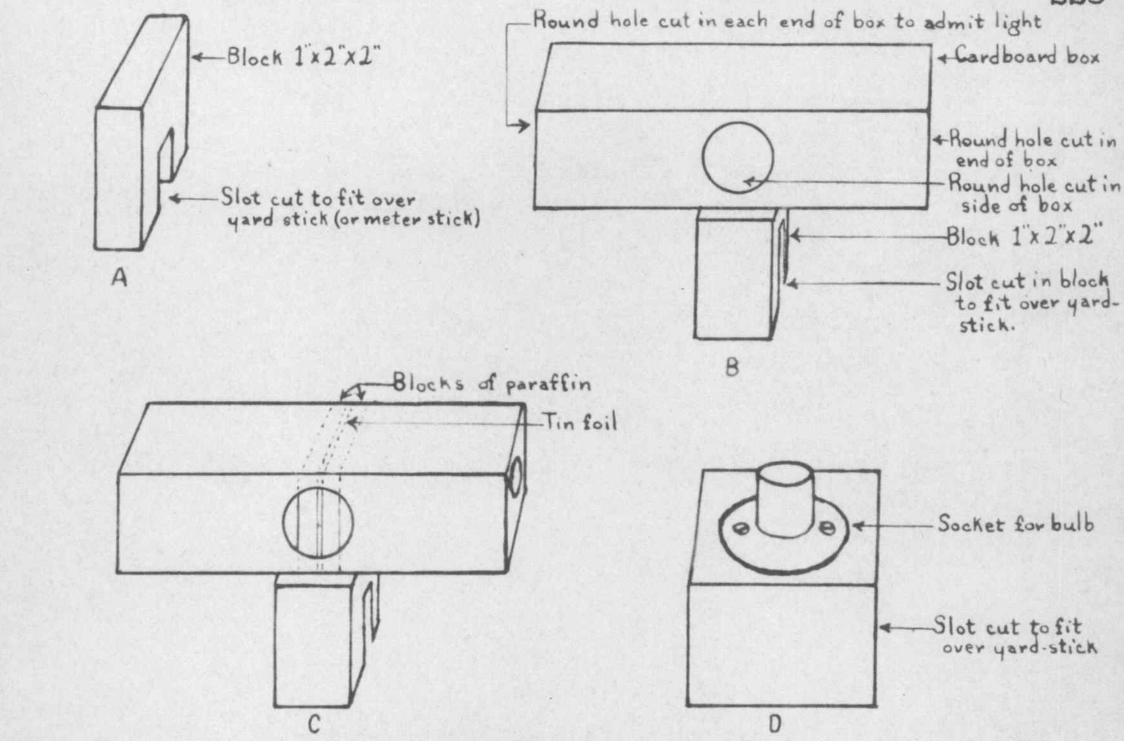

Figure 106 Construction of a Joly Photometer

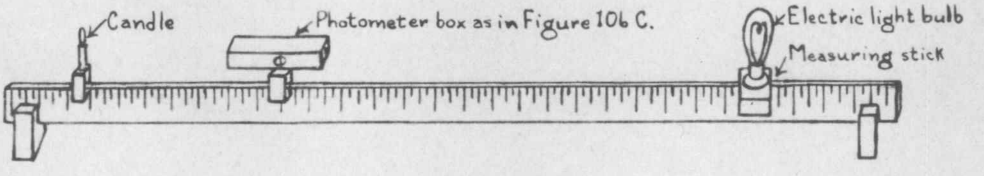

Figure 107 Measurement of Candlepower by Means of a Photometer

Experiment 57.

Focal Length of Lenses

Purpose. To locate the principle focus and to find the focal length of a converging lens.

Materials Required. Meter stick, five 1" x 2" x 2" blocks, strip of tin about $\frac{1}{2}$" x 6", candle, piece of cardboard, and lens.

Construction of the Apparatus. Slots are sawed in the blocks so that the blocks fit over the yard stick as shown in Figure 108 A. A strip of tin is fastened to one of the blocks by means of small nails and the ends are bent up so that they will press tightly against the sides of the lens as in Figure 108 B. A slot is sawed in the top of another one of the blocks as shown in Figure 108 C, to receive a square of cardboard.

Procedure. The yard stick or meter stick is fastened in an upright position by means of two of the blocks described in Figure 108 A. The lens and lens mount are then fitted to the yard stick at about the middle. The cardboard and cardboard holder are fitted to one end of the yard stick as shown in Figure 109. The lens and stick are pointed toward the sun. The lens is moved back and forth on the yard stick until the image of the sun is as small as possible. The screen is now at the principle focus of the lens. The focal length is measured and recorded. The apparatus is placed near the back of the room and the lens is pointed at some distant object, such as a house or tree, through an open window. The lens is adjusted in position until a sharp inverted image is formed on the screen is now at the principle focus and the focal length is recorded.

Comparative Cost. Lens and mirror supports, screen holder or cardboard holder, candle holders and supports for the meter stick all cost about ten cents each whereas the materials required for this experiment would not cost over five cents, exclusive of the lens.

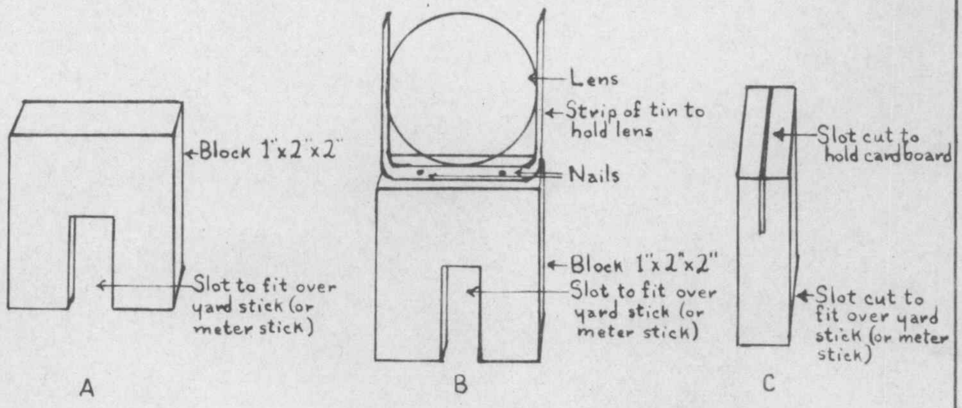

Figure 108 Construction of Parts for an Optical Bench

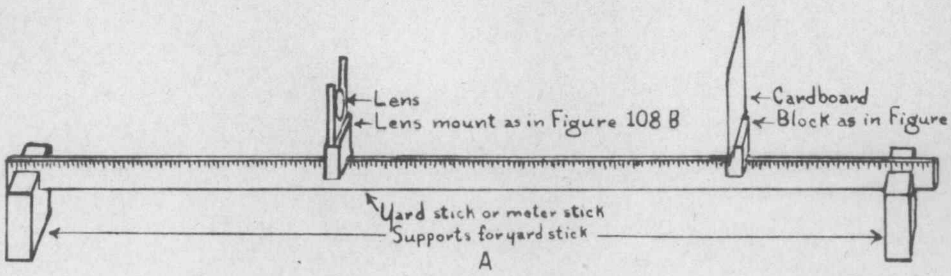

Figure 109 Focal Length of a Lens

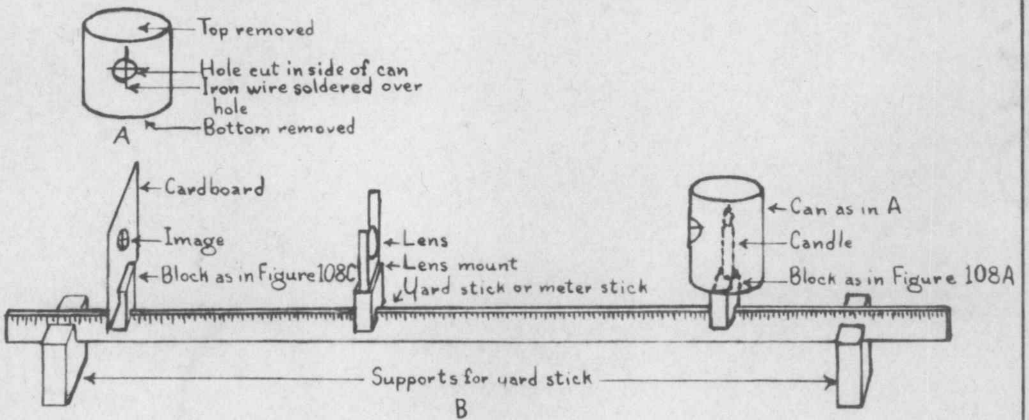

Figure 110 Image Formation with Lenses

Experiment 58.

Image Formation with Lenses

<u>Purpose</u>. To study the kind, size and position of various images formed by the double convex lens.

<u>Materials Required</u>. Five blocks 1" x 2" x 2", meter stick or yard stick, strip of tin $\frac{1}{2}$" x 6", lens, candle, cardboard, coffee can, short piece of stove pipe wire and solder.

<u>Construction of the Apparatus</u>. Directions for constructing the apparatus used in this experiment were given in Experiment 57, except for the object which is made from a coffee can. Both ends are removed and a hole about 1" in diameter is made in one side of the can. Small iron wires are soldered over the hole as shown in Figure 110 A. This apparatus is fastened to the candle block as shown in Figure 110 B.

<u>Procedure</u>. The focal length of a double convex lens is found as in Experiment 57. The lens is placed in the center of the meter stick with the screen facing the dark part of the room. On the other side of the lens at a distance of one focal length a chalk mark is made and labeled F. At a distance of two focal lengths another chalk mark is made and labeled 2F. A lighted candle is used as the source and cross wires as the object. The object is placed as far away as possible from the lens

or at the other end of the room. This distance is called infinity. The screen is moved until a sharp image is obtained, and a description of the image is given as to kind (real or virtual), size (larger or smaller) and position (erect or inverted). The object is moved closer to the lens foot by foot until the object is three focal lengths from the lens, the screen being adjusted for a sharp focus each time and a description of the image recorded as before. The observations are repeated for a distance of two focal lengths and for a distance between one and two focal lengths. The object is placed one focal length from the lens and the results are noted; less than one focal length from the lens and the results noted.

Comparative Cost. The same apparatus is used for this experiment as was used in Experiment 57, and the comparative cost was taken up in the same experiment.

Experiment 59.

Image Formation in Curved Mirrors

Purpose. To study the kind, size and position of various images formed by curved mirrors.

Materials Required. Four supports for yard stick as described in Figure 108 A, two card supports as described in Figure 108 C, two yard sticks, two squares of cardboard about 6" square with a window cut in one of the squares as shown in Figure 111, a candle, 2" x 6" x 8" block, convex and concave shaving mirrors.

Construction of the Apparatus. The apparatus required in this experiment has been described in the preceding experiments. (See Experiment 57)

Procedure. A transluscent screen (cardboard with a design in the window), is placed on the yard stick at some distance from a concave mirror which has previously been fastened to the 2" x 6" x 8" block, and a candle is placed behind the screen. Another yard stick is placed on supports and placed at an angle with the first yard stick also pointed towards the mirror as shown in Figure 111. A piece of cardboard is placed in another holder and placed on the second yard stick. The cardboard is moved back and forth on the yard stick until the image formed by the transluscent screen and candle forms the most distinct image. The distance of each screen from the mirror, whether the image is larger or smaller than the object and whether the image is erect or inverted is recorded. The same data is recorded for two more positions. The concave mirror is replaced by the convex mirror and the same data recorded as for the concave mirror.

Comparative Cost. The apparatus used in this experiment has been described in previous experiments with the exception of the concave and convex mirrors which may be secured from the ten-cent store.

Experiment 60.

Optical Instruments; The Compound Microscope.

Purpose. To study the construction and the magnifying power of the compound microscope.

Materials Required. Two yard stick supports as shown in Figure 108 A, two lens supports as shown in Figure 108 B, two card supports as shown in Figure 108 C, two cards about 12" square (graph paper pasted on one of the cards as seen in Figure 112), two lenses and yard stick.

Construction of the Apparatus. There is no apparatus required for this experiment which has not already been described.

Procedure. The focal length of two lenses is found by the method used in Experiment 57. The apparatus is arranged as shown in Figure 112, and the objective lens placed further than its focal length from the cardboard with the graph paper on it. This distance is recorded. A piece of stiff cardboard is placed on the meter stick at the point where the clearest image of the graph paper is formed. The position of the cardboard is recorded. The second lens (the eye piece) is placed on the other side of the cardboard. This lens is moved until a small circle drawn on the side of the cardboard facing the eye piece shows the greatest magnification. The cardboard is removed and the image of the graph paper is observed. The position of the eye piece may be changed slightly in order to focus clearer. The position of the eye piece is recorded and the magnifying power is computed. The image is described.

Comparative Cost. The apparatus required in this experiment has been previously described and consequently has already been compared with commercial apparatus.

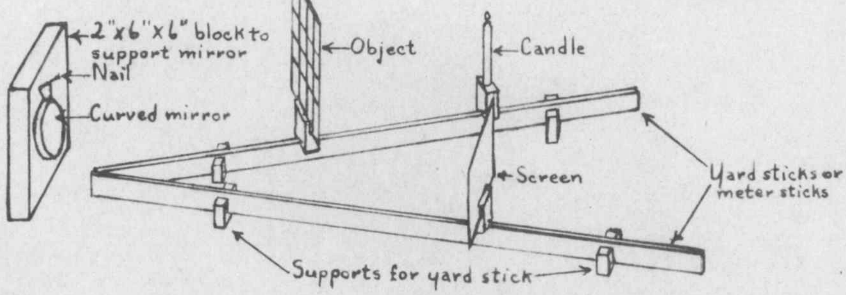

Figure 111 Image Formation in Curved Mirrors

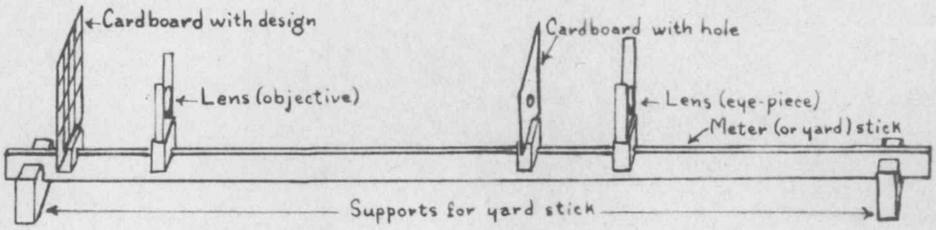

Figure 112 Optical Instruments - The Compound Microscope

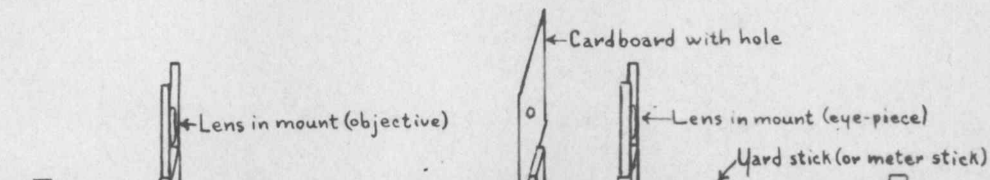

Figure 113 Optical Instruments - The Telescope

Experiment 61.

Optical Instruments;
The Telescope

<u>Purpose</u>. To study the construction and magnifying power of a telescope.

<u>Materials Required</u>. Two yard stick supports as shown in Figure 108 A, two lens supports as described in Figure 108 B, one card support as described in Figure 108 C, yard stick, cardboard about 6" square and two lenses.

<u>Construction of the Apparatus</u>. The apparatus required for this experiment has been described in Experiment 57.

<u>Procedure</u>. The focal length of both lenses is found as in Experiment 57. A lens of long focal length is mounted near one end of the yard stick, to serve as an objective. A cardboard is placed in a position behind the lens on a yard stick in such a position that a clear image of some distant object is seen on it. The other lens (the eye piece) is mounted on the other side of the cardboard and moved backward and forward until a small circle on the surface of the cardboard is seen with the greatest magnification. The cardboard is then removed and the distant object is viewed through the telescope. The eye piece may be moved slightly to make a clearer image. A large cardboard with two heavy black lines about 5" or 6" apart is placed on the opposite wall of the room. The

lines are observed through the telescope with one eye while the other eye looks directly at the cardboard. Another student places lines on the cardboard to coincide with those seen through the telescope. Several trials are made. The distance is measured between each group of lines and the magnifying power of the instrument is computed. The magnifying power so computed is compared with that found from a comparison of the focal lengths of lenses.

Comparative Cost. The apparatus required in this experiment has been described in previous experiments.

INVISIBLE RADIATIONS

Experiment 62.

The Three Element Vacuum Tube

Purpose. To study the three element vacuum tube.

Materials Required. Vacuum tube (201 A), galvanometer, variable resistance rheostat, two knife switches, 6 volt battery, 45 to 90 volt B battery, one dry cell or C battery.

Construction of the Apparatus. No additional apparatus is needed for this experiment except for the vacuum tube and the batteries. The vacuum tube may be secured from any radio shop (it is entirely possible that they would be glad to donate weak tubes which would serve for this experiment but would not be useful in a radio).

Procedure. The apparatus is connected as shown in Figure 115, using the entire 90 volt battery in the plate circuit. All switches are left open and the galvanometer is read (the galvanometer should be shunted until it is determined whether it will carry the current). The switch in the filament circuit (S 1) is closed, the rheostat being adjusted so that about half the resistance is used. The switch S 3 is closed and the galvanometer is read. The resistance is reduced so that the filament current is increased and the galvanometer is again read. S 3 is opened. The B battery is changed to its lower value (45 volts), S 3 is closed and the galvanometer is read. Again S 3 is opened. The 90 volt B battery is connected with the plate circuit, with the terminals reversed so that the negative is connected with the plate. S 3 is closed again and the galvanometer is read in the plate circuit. S 3 is again opened. The B battery is connected as it was originally. S 3 and S 2 are both closed and the galvanometer is read. Both switches are opened. The connections of the C battery are reversed so that the negative terminal is connected to the grid. The switches are closed and the galvanometer is read. All switches are opened.

Comparative Cost. All of the apparatus with the exception of the tube and batteries is compared with commercial apparatus in preceding experiments.

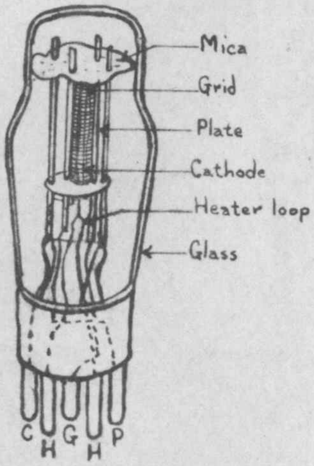

Figure 114 The Three Element Vacuum Tube

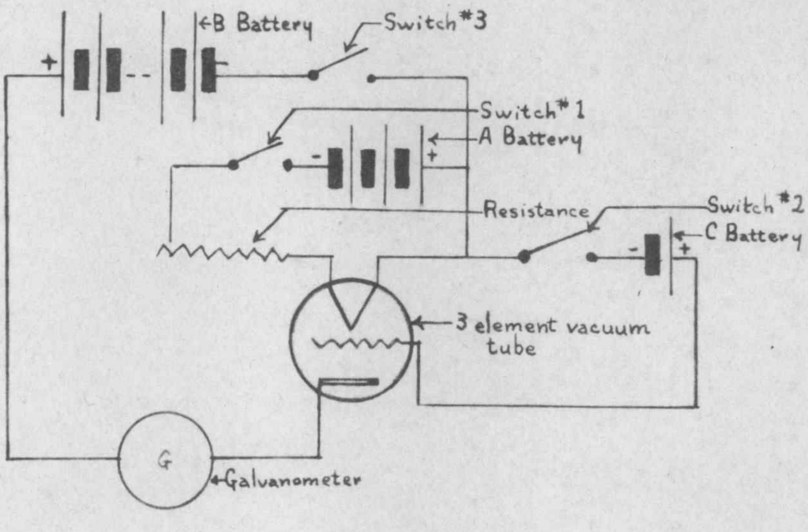

Figure 115 A Study of the Three Element Vacuum Tube

CHAPTER V.

SUMMARY AND CONCLUSIONS

SUMMARY

The purpose of this study is to suggest ways of equipping for a complete course in high-school physics at a minimum cost by having each laboratory group of students construct their own apparatus.

The study is divided into two parts: (1) an analysis of available workbooks to determine the experiments considered essential for a complete course in high-school physics; and (2) an analysis of the experiments to determine the apparatus needed and to describe the method of constructing this equipment at the least possible cost. The experiments selected were then organized in the following five stages: (1) a statement of the purpose of the experiment, (2) a list of the materials required, (3) a description of the construction of the apparatus required to perform the experiment, (4) a description of the procedure followed in performing the experiment and (5) comparative data on the costs of apparatus made in the laboratory to similar apparatus purchased from manufacturers of scientific equipment.

About sixty-two experiments are considered essential in a high-school physics course. These were found to distribute themselves as follows: three in Measurements, eight in Properties of Fluids, five in Force and Motion, seventeen in Work and Heat, sixteen in Magnetism and Electricity, four in Wave Transmission and Sound, eight in Light, and one in Invisible Radiations.

It was found that all of the material required in teaching a complete course in high-school physics was available and that all of the apparatus required could easily be constructed by the students themselves. The cost of all the apparatus required, if it was kept intact for each experiment, was about twelve dollars and fifty cents as compared to a cost of one hundred and thirty-five dollars for similar apparatus purchased from scientific apparatus manufacturers for about one tenth of the cost of the commercial apparatus. However, in most cases it would probably be desirable for the apparatus to be dismantled and the wire and other materials used on other experiments. The experiments may also be assigned in such a manner that each group may have a different experiment for any given laboratory period thus making a few pieces of apparatus do for a class of 25 to 30 students. If this is done, the apparatus and materials for a class of 25 to 30 students should not cost over twenty dollars.

A number of pieces of apparatus and useful materials may be obtained from sources indicated in the first part of Chapter Four for little or no cost, both for demonstration and experimental purposes.

CONCLUSIONS

The data presented in this study are believed to warrant the following conclusions:

(1) Laboratory work is essential in a course in high-school physics.

(2) Lack of apparatus in a high school need not be a hindrance to the teaching of physics. Suitable equipment may be constructed for as little as fifteen dollars, or about one tenth of the cost of commercial apparatus.

(3) High school students can construct physics apparatus and enjoy doing it. The students, according to most authorities, really learn more about the principles of physics by construction and use of their "flivver apparatus", than by the use of high priced commercial apparatus. Many authors maintain that students pay too much attention to accuracy and lose sight of the principles involved when the have fine scientific apparatus.

(4) The construction of apparatus gives the students some useful experience in the form of carry-over, for instance the simple wiring involved in constructing the apparatus might enable them to repair plugs and fixtures in the home.

BIBLIOGRAPHY

Periodicals

1. Adams, J. M., "An Impulse Apparatus for the Second Law of Motion", School Science and Mathematics, 14:520-521, June, 1914.

2. Adams, J. M., "A Quantitative Test of the Conservation of Angular Momentum", School Science and Mathematics, 32:893-895, November, 1932.

3. Akeley, L. E., "An Acceleration Apparatus", School Science and Mathematics, 9:478-480, May, 1909.

4. Andrews, R. C., "An Acceleration Apparatus", School Science and Mathematics, 17:334-335, April, 1917.

5. Arthur, J. M., "A Simple Reflecting Galvanometer", School Science and Mathematics, 11:544-545, June, 1911.

6. Austin, R. O., "A Steam Trap for Latent Heat of Vaporization", School Science and Mathematics, 9:477-478, May, 1909.

7. Bail, P. M., "Selling Physics and Chemistry", School Science and Mathematics, 30:195-197, February, 1930.

8. Bailey, James, "Geissler Tubes from Electric Light Bulbs", School Science and Mathematics, 10:639-640, October, 1910.

9. Baldwin, R. R., "A Water Filtration Plant Model", School Science and Mathematics, 38:454-456, April, 1938.

10. Bean, W. D., "An Apparatus for Concurring Forces", School Science and Mathematics, 8:48, January, 1908.

11. Beltz, H. D., "Gas and Electric Furnaces for Physics Laboratory Work", School Science and Mathematics, 10:639-640, October, 1910.

12. Black, N. H., "Better Demonstrations in Physics", School Science and Mathematics, 30:366-373, April, 1930.

13. Blank, E. E., "Experiments in Microscopy, Demonstrating the Brownian Movement and Cottrell Precipitate", School Science and Mathematics, 32:281-283, March, 1932.

14. Bloxam, H. L., "What About the Monocycle?", School Science and Mathematics, 33:104-106, January, 1933.

15. Bowen, C. F., "Charge and Discharge of Condensers, Illustrated by Means of an Easily Constructed Mechanical Model", School Science and Mathematics, 12:486-489, June, 1912.

16. Bowie, R. M., "A Laboratory Apparatus for the Determination of the Acceleration of a Freely Falling Body", School Science and Mathematics, 32:870-874, November, 1932.

17. Brown, H. B., "To Remodel an Old Style Air Pump", School Science and Mathematics, 8:322-324, April, 1908.

18. Brown, H. E., and others, "A Project in Physics", Science Education, 18:42-45, February, 1934.

19. Bucknell, F. T., "An Apparatus for Determining the Coefficient of Linear Expansion of a Metal Tube", School Science and Mathematics, 7:493-495, June, 1907.

20. Carman, A. P., "A Projection of the Guinea and Feather Experiment", School Science and Mathematics, 13:421-422, May, 1913.

21. Chase, H. L., "Another Fuse Device", School Science and Mathematics, 17:120-128, February, 1917.

22. Chloe, H. J., "The Coefficient of Expansion of Air", School Science and Mathematics, 10:742-743, November, 1910.

23. Cohn, B. E., "Improved New Methods (Elementary) for Determination of Heat of Vaporization", School Science and Mathematics, 29:878-880, November, 1929.

24. Derge, G. J., "Spheroidal State", School Science and Mathematics, 31:1098-1099, December, 1931.

25. Dwight, C. H., "A Home-made Galvanometer", School Science and Mathematics, 21:270-271, November, 1921.

26. Edwards, R. L., "Spark Recording of Lissajous Figures in Elementary Physics Laboratory", School Science and Mathematics, 30:909-910, November, 1930.

27. Eisman, Louis, and Joseph, Alexander, "A Striking Demonstration of the Principle of the Repulsion Motor", The Science Classroom, January, 1939.

28. Farr, W. H., "A Switchboard for Electrical Testing", School Science and Mathematics, 19:537-542, June, 1919.

29. Farwell, H. W., "An Elementary Optical Bench", School Science and Mathematics, 16:488-493, June, 1916.

30. Fitch, Phillip, "The Cartesian Diver", School Science and Mathematics, 11:543-544, June, 1911.

31. Getman, F. H., "A Simple Form of Polariscope", School Science and Mathematics, 7:484-485, June, 1907.

32. Gibson, Del, "An Acceleration Apparatus", School Science and Mathematics, 12:11-12, January, 1912.

33. Gorton, F. R., "An Inexpensive Apparatus Illustrating the Hydrostatic Paradox", School Science and Mathematics, 9:26, January, 1909.

34. Gorton, F. R., "A Method of Projecting and Blending Colors", School Science and Mathematics, 10:509-510, June, 1910.

35. Gorton, F. R., "A Method of Superimposing Colors", School Science and Mathematics, 10:592, October, 1910.

36. Gorton, F. R., "A Simple Apparatus for Index of Refraction", School Science and Mathematics, 8:287-288, April, 1908.

37. Gorton, F. R., "A Student Self Filling Barometer", School Science and Mathematics, 12:490-491, June, 1912.

38. Greer, W., "Amateur Telescope Making as a Project in High School Physics", School Science and Mathematics, 34:76-79, June, 1934.

39. Hall, C. M., "A Linear Expansion Apparatus", School Science and Mathematics, 8:415-416, May, 1908.

40. Hammond, P. F., "An Atwood Machine", School Science and Mathematics, 12:498-502, June, 1912.

41. Harrington, E. R., "How to Increase Laboratory Equipment", School Science and Mathematics, 36:39-41, January, 1936.

42. Hartsough, R. C., "A Boyle's Law Apparatus", School Science and Mathematics, 18:349-350, April, 1918.

43. Haupt, E. J., "An Annotated Bibliography of Contributions to School Science and Mathematics Describing Inexpensive Home-made Physics Apparatus", School Science and Mathematics, 29:763-769, October, 1929.

44. Hobbs, G. M., "A New Centripetal Force Apparatus", School Science and Mathematics, 31:41-44, January, 1931.

45. Hornbeck, J. W., "A Laboratory Experiment on Random Forces", School Science and Mathematics, 29:749-751, October, 1929.

46. Hyde, G. H., "Home-made Apparatus for the Physics Class", Science Education, 15:159-174, March, 1931.

47. Hyde, P. C., "A Convenient Lamp Bank", School Science and Mathematics, 18:632-633, October, 1918.

48. Kazmarek, F. A., "The Lemon Cell", The Science Classroom, May, 1925.

49. Kelley, R. W., "A Useful Pendulum and Simple Wireless Method for the Velocity of Sound", School Science and Mathematics, 14:306-311, April, 1914.

50. Kemp, J. G., "A Simple Effectual Boyle's and Charles' Law Apparatus", School Science and Mathematics, 17:825-826, December, 1917.

51. Kennon, W. L., "A Boyle's Law Apparatus of Improved Design", School Science and Mathematics, 29;375-379, April, 1929.

52. Kennon, W. L., "A Force Table with New Features", School Science and Mathematics, 29:838-839, November, 1929.

53. Kennon, W. L., "A Rational Inertia Apparatus of New Design", School Science and Mathematics, 28:940-945, December, 1928.

54. Kiebler, E. W., and Curtis, F. D., "A Study of the Content of the Laboratory Course in High School Physics", School Science and Mathematics, 29:980-985, December, 1929.

55. Kiplinger, C. C., "A Simple Barometer", School Science and Mathematics, 14:568-570, June, 1914.

56. Klopsteg, P. E., "A New Design of Electromagnet Energized with Thermoelectric Current", School Science and Mathematics, 29:256-258, May, 1929.

57. Knipp, C. T., "A Convenient Form of Singing Tube", School Science and Mathematics, 20:787-788, December, 1920.

58. Kremer, J. B., "An Apparatus for an Experiment in Moments", School Science and Mathematics, 14:404-409, May, 1914.

59. Kremer, J. B., "A Pyrometer for Laboratory Use", School Science and Mathematics, 14:47-51, January, 1914.

60. Krenerick, H. C., "A Camera and Object Holder", School Science and Mathematics, 8:656-658, November, 1908.

61. Krenerick, H. D., "An Inexpensive Wireless Set", School Science and Mathematics, 13:301-302, April, 1913.

62. Kruglak, H., "A Cartesian Diver Designed by Pupils", School Science and Mathematics, 38:141-142, February, 1938.

63. Le Sourd, H. W., "Another Convection Experiment", School Science and Mathematics, 31:454, April, 1931.

64. Le Sourd, H. W., "Convection", School Science and Mathematics, 31:304, March, 1931.

65. Little, N. C., "An Old Experiment in New Dress", School Science and Mathematics, 33:333-337, April, 1935.

66. Longacre, A., "A Demonstration of the Inverse Square Law", School Science and Mathematics, 35:621, June, 1935.

67. MacNeil, W. K., "Physics Demonstrations on the Commencement Program", School Science and Mathematics, 35:911-914, December, 1935.

68. Mahoney, J. J., "A New Total Reflection Demonstration", School Science and Mathematics, 35:577, June, 1935.

69. Martin, M. J., "Two Laboratory Experiments and the Equilibrium of Torques", School Science and Mathematics, 30:635-636, June, 1936.

70. Masson, L. T., "A Density Ball", School Science and Mathematics, 34:365, June, 1934.

71. Meister, Morris, "A Microprojector", Science Classroom, January, 1939.

72. Meister, Morris, "Self Starters in the Science Class", Science Classroom, December, 1938.

73. Meister, Morris, "Simple Apparatus, - Difficult Ideas", Science Classroom, January, 1939.

74. Meister, Morris, "Some Unusual Experiments", Science Classroom, February, 1939.

75. Meister, Morris, "Visualizing the Air Stream Surrounding a Wing in Demonstrating 'Lift'", Science Classroom, January, 1939.

76. Minor, R. S., "A Momentum Balance", School Science and Mathematics, 12:137-140, February, 1912.

77. Moelk, J. W., "A Physics Display Case", School Science and Mathematics, 36:592-593, June, 1936.

78. Morse, H. L. E., "An Experiment to Show the Physics of a Hammer Drawing a Nail", School Science and Mathematics, 13:416-418, May, 1913.

79. Mumper, W. N., "An Experiment Involving Archimedes' Principle", School Science and Mathematics, 9:297-298, March, 1909.

80. Nichols, H. M., "A Device for Testing Electrical Wiring", School Science and Mathematics, 10:639, October, 1910.

81. Osmund, T., "Free Fall Machine (or Acceleration Apparatus for Measuring G)", School Science and Mathematics, 20:602-607, October, 1920.

82. Packard, J. C., "A Water Barometer", School Science and Mathematics, 15:480-481, June, 1915.

83. Parker, W. M., "An Apparatus to Determine the Acceleration of Freely Falling Bodies", School Science and Mathematics, 12:562-563, October, 1912.

84. Peple, G. A., and Robeson, F. L., "A New Torquemeter", <u>School Science and Mathematics</u>, 29:526-528, May, 1929.

85. Pershing, A. V., "An Easy Method of Exhibiting Interference Fringes with Ordinary High School Apparatus", <u>School Science and Mathematics</u>, 34:841-842, November, 1934.

86. Phillips, T. D., "A Simple Resonance Spring", <u>School Science and Mathematics</u>, 33:551, May, 1933.

87. Pinkus, L. F., "Movable Diagrams", <u>Science Education</u>, 20:167-168, October, 1936.

88. Platzer, W. H., "A Combination Desk and Demonstration Table", <u>School Science and Mathematics</u>, 38:971, December, 1938.

89. Prensky, S. D., "Practical Experiments in Radio with the Laboratory Vacuum Tube Unit", <u>School Science and Mathematics</u>, 33:832-838, November, 1933.

90. Pyle, W. R., "The Apparatus for a Dip Needle", <u>School Science and Mathematics</u>, 7:466-467, June, 1907.

91. Rendtorff, E. J., "A Useful Type of Air Thermometer", <u>School Science and Mathematics</u>, 8:684-686, November, 1908.

92. Rendtorff, E. J., "Boyle's Law Apparatus", <u>School Science and Mathematics</u>, 11:16-17, January, 1911.

93. Schilling, H. K., and Sickhoff, D., "New Laws of Motion Apparatus", <u>School Science and Mathematics</u>, 34:34-38, January, 1934.

94. Scoville, J. W., "A Simple Apparatus to Illustrate the Path of a Projectile", <u>School Science and Mathematics</u>, 12:194, March, 1912.

95. Sinclair, J. F., "A Dissected Siphon", <u>School Science and Mathematics</u>, 11:416, May, 1911.

96. Smith, N. F., "Convenient Gasometer", School Science and Mathematics, 12:376, May, 1912.

97. Smith, N. F., "Experiments with Vibrating Strings and Rods", School Science and Mathematics, 23:75-76, January, 1923.

98. Starr, O. L., "A Projectile Experiment", School Science and Mathematics, 33:956-958, December, 1933.

99. Starr, O. L., "A New Surface Tension Experiment", School Science and Mathematics, 34:511-513, May, 1934.

100. Stewart, A. W., "A Cartesian Diver", Science Education, 15:183-184, March, 1931.

101. Stirton, W. E. "Group Individual Project in Refraction", Science Education, 20:164-167, October, 1936.

102. Teike, H., "A Simple Demonstration of Color Mixture, School Science and Mathematics, 11:542-543, June, 1911.

103. Thompson, G. E., "A Roof Truss for the Laboratory", School Science and Mathematics, 17:824-825, December, 1917.

104. Trytten, M. H., "An Experiment in Torques for an Elementary Laboratory", School Science and Mathematics, 34:823-824, November, 1934.

105. Unseld, G. P., "A Resistance Experiment for the High School Class", School Science and Mathematics, 31:387, April, 1931.

106. Upham, H. A., "A Falling Body Apparatus", School Science and Mathematics, 15:210-212, March, 1915.

107. Van De Water, F., "A Unique Modification of Helmholtz's Screen Experiment", School Science and Mathematics, 31:994-995, November, 1931.

108. Van Dyke, F. C., "A Foot Apparatus", School Science and Mathematics, 8:34-36, January, 1908.

109. Vestal, C. L., "An Atwood Machine", School Science and Mathematics, 11:129-132, February, 1911.

110. Vestal, C. L., "A Wall Form of Bending Apparatus", School Science and Mathematics, 11:413-415, May, 1911.

111. Waggoner, C. W., and Hake, J. W., "A Simple Gas Meter for Use with the Junker Calorimeter for Testing Service Meters", School Science and Mathematics, 15:571-576, October, 1915.

112. Whitmore, B. S., "In a Sound Studio: An Auditorium Program by the Physics Class", School Science and Mathematics, 37:273-280, March, 1937.

113. Williams, S. R., "A Convenient Form of a Liquid Rheostat", School Science and Mathematics, 12:489-490, June, 1912.

114. Wilson, R. G., and Kunerth, W., "An Experiment with Polarized Light", School Science and Mathematics, 34:613-617, June, 1934.

115. Wooten, B. A., "Project Work in Undergraduate Physics", Science Education, 16:404-406, October, 1932.

Books on Construction of Apparatus

116. Adlam, G. H. J., The Science Masters' Book, John Murray, Albemarle Street W., London, England, 1931.

117. Duckworth, E. H. and Harries, R., The Laboratory Workshop, G. Bell and Sons, Ltd., London, England, 1933.

118. Lynde, C. J., Science Experiences with Home Equipment, International Text Book Company, Scranton, Pennsylvania, 1937.

119. Lynde, C. J., Science Experiences with Inexpensive Equipment, International Text-book Company, Scranton, Pennsylvania, 1939.

Workbooks

120. Black, N. H., and Weaver, E. C., Laboratory Experiments and Workbook to Black and Davis' "Elementary Practical Physics", New York City, The Macmillan Company, 1938.

121. Cook, S. C., and Davis, J. C., A Combined Laboratory Manual and Workbook in Physics, New York and Chicago, Metzger-Bush and Company, 1936.

122. Cushing, B. L., A Laboratory Guide and Workbook, New York, Ginn and Company, 1937.

123. Fletcher, C. L., and Lehman, S., Laboratory Manual for Unified Physics, New York, McGraw-Hill Book Company, 1938.

124. Fuller, R. W., and Brownlee, R. B., and Baker, D. L., Laboratory Exercises in Physics, Boston, Allyn and Bacon, 1932.

125. Good, Frederick F., Laboratory Projects in Physics, New York, The Macmillan Company, 1920.

126. Henderson, W. D., Physics Guide and Laboratory Exercises, New York, Lyons and Carnahan, 1936.

127. Millikan, R. A., and Gale, H. G., A Laboratory Course in Physics, Boston, New York, Ginn and Company, 1906.

128. Packard, J. C., Everyday Physics--A Laboratory Manual, Boston, New York, Ginn and Company, 1917.

129. Powers, S. R., and Brown, H. E., Workbook in Physics, Boston, Allyn and Bacon, 1932.

130. Turner, H. F., Workbook and Laboratory Manual in Physics, New York City, College Entrance Book Company, Incorporated, 1937.

APPENDIX

In addition to the experiments, demonstrations and projects referred to in the bibliography, the writer wishes to call attention to additional experiments, projects and demonstrations which may be available to the readers. These references are listed below:

Experiments

FLUIDS

Archimedes' Principle,	An Experiment Establishing Archimedes' Principle, School Science and Mathematics, 3:21-22.
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Index of Refraction,	A Simple Way to Determine the Index of Refraction of Light, G. B. Masslich, School Science and Mathematics, 5:266-267.
" " "	An Index Meter, J. S. Gibson, School Science and Mathematics, 1:150-152.
" " "	The Use of Glass Blocks in Refraction, H. Garrett, School Science and Mathematics, 5:359-362.

Optics,	<u>An Optical Experiment for the Elementary Laboratory</u>, S. C. Gladden, American Physics Teacher, 5:211.
"	<u>Some Elementary Laboratory Experiments in Heat and Optics,</u> W. W. Hanson and R. D. Richtmeyer, American Physics Teacher, 5:168-171.
"	<u>Some Simple Experiments in Optical Resolution</u>, W. M. Roberds, American Physics Teacher, August, 1937.

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