LABORATORY MANUAL IN PHYSICS

WAUCHOPE

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IN

PHYSICS

BY

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PREFACE

This manual has been prepared to meet the modern demand on the part of high school instructors of Physics for a set of experiments which will connect the laboratory work more closely with the everyday experiences of the student.

To send the pupil into the laboratory to "Determine the Magnitude and Point of Application of the Resultant of Two Parallel Forces Acting in the Same Direction," "Determine the Coefficient of Linear Expansion of a Metallic Rod," or "Find the Focal Length of a Convex Lens," is to give him a task in which he has very little interest. Laboratory exercises should be motivating. They should be based on problems which arise naturally from daily observations and which can only be solved by laboratory experiments. Moreover, the natural method of reasoning employed by the student of high school age is from the particular to the general. It is better, then, to use the laboratory to solve such problems as finding where a load should be placed on a pole between a man and a boy so that each will carry his share, or the amount of expansion of a steel bridge on a hot summer day, or the reason for wearing convex glasses to correct far-sightedness. This method of treatment gives interest and significance to the work and also teaches the pupils the laws of Physics in a much more efficient way without requiring special or elaborate apparatus.

An effort has been made to eliminate "busy work" and to offer only those laboratory exercises which are really worth while as teaching principles of Physics and in which the student can "see some use." Additional experiments of a practical nature, making use of commercial forms of apparatus, thoroughly provide for a full year's work.

The questions and problems introduced in the "Discussion" under each experiment constitute an important feature so often neglected in connection with laboratory work, and serve to illuminate the meaning and widen the range of association of the principles involved. Many more questions of a like nature will suggest themselves to the student and teacher. This discussion should follow the experiment immediately and not be delayed until it can be taken up in the class room.

The manual is arranged by topics and experiments primarily to accompany Mann and Twiss' *Physics*, but can, of course, be used with any text. To facilitate a wider range of selection by the instructor, a number of additional experiments have been outlined under Appendix I.

The author wishes to express the highest appreciation of the assistance given by Dr. C. R. Mann in the preparation of the manual. Grateful acknowledgment is also made for helpful suggestions received from many high school instructors.

J. A. WAUCHOPE.

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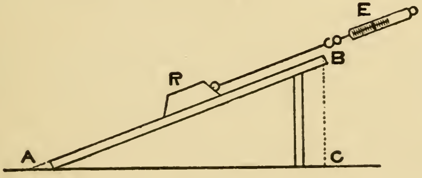
EXPERIMENT No. 1

PART I

Question.—Does it require more work to slide a cake of ice up an inclined plane than to lift it vertically to the top of the plane?

Apparatus.—Inclined plane; block of iron weighing several pounds; spring balance.

Remarks.—Work is expressed in *foot-pounds* and is determined by multiplying together the number of pounds of force and the number of feet of distance through which the force acts. One foot-pound = 1 pound × 1 foot.



Directions.—Find the weight of the block and the height *CB* of the plane. The product of these two will give the work done in lifting the block vertically. Now find the length *AB* of the plane and the force required to draw the block with uniform speed up the plane as indicated by the spring balance. The product of these two will give the work done in drawing the block up the plane. Call the weight of the block the *resistance* and the force exerted along the plane the *effort*, and record your results as follows:

Results.—

Resistance = ——— lb.
Effort = ——— lb.
Resistance $\times$ height of plane = ——— foot-pounds.
Effort $\times$ length of plane = ——— foot-pounds.

Discussion.—The work done on this machine, that is, effort $\times$ length, is known as the *input*. The work performed by the machine, that is, resistance $\times$ height, is known as the *output*. Which is greater, the *input*, or the *output*? What causes this difference?

PART II

Question.—What is the efficiency of the inclined plane used in this experiment? Would the use of a smoother surface on the incline make any difference in the efficiency of the machine?

Apparatus.—Same as Part I; glass plate.

Remarks.—By the efficiency of a machine is meant the ratio of the work gotten out of it to the work put into it; or,

$$\frac{\text{Output}}{\text{Input}} = \text{Efficiency}$$

Efficiency is expressed in per cent.

Directions.—Using the results obtained in Part I, calculate the efficiency of the inclined plane. Now substitute the glass plate for the wood surface. Obtain results as before and determine the efficiency. Record your results as follows:

Results.—

With wood surface: Efficiency $= \frac{\text{Output}}{\text{Input}} =$ ——— $=$ ——— %

With glass surface: Efficiency $= \frac{\text{Output}}{\text{Input}} =$ ——— $=$ ——— %

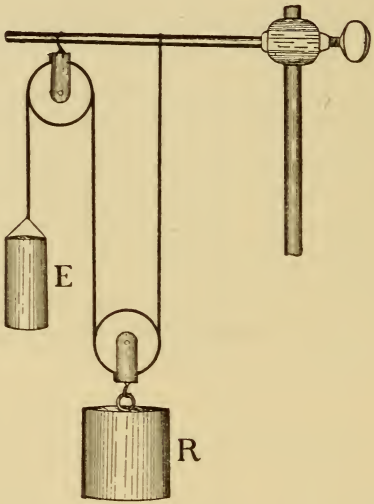
Discussion.—What causes the difference in efficiency in the two trials made? If the block is mounted on rollers or placed in a small car is the efficiency of the plane greater? What further improvement can you suggest to increase the efficiency of the plane? Can you make a plane with an efficiency of 100%? How and why? This is known as an *ideal* inclined plane. How may we find the relations between input and output for an ideal plane?

EXPERIMENT No. 2

Question.—Is more work required to pull a safe up to the third floor with pulleys than to carry it up by hand?

Apparatus.—Two pulleys, one fixed, the other movable; block of iron weighing several pounds; a pail; shot.

Directions.—Arrange the apparatus as shown in the diagram. Pour shot slowly into pail E until just enough is contained to raise the block with uniform speed. Making use of two yardsticks, measure how far the pail moves downward in order to raise the block one foot. Find the weight of the block, also of the pail of shot. The work done by the pail of shot in raising the block one foot is found by multiplying together the weight of the pail of shot in pounds



and the distance in feet through which it moves downward, and is expressed by *foot-pounds*. The work done in raising the block by hand through one foot is evidently the weight of the block in pounds multiplied by the distance of one foot. Call the weight of the block the *resistance* and the weight of the pail of shot the *effort* and record your results as follows:

Results.—

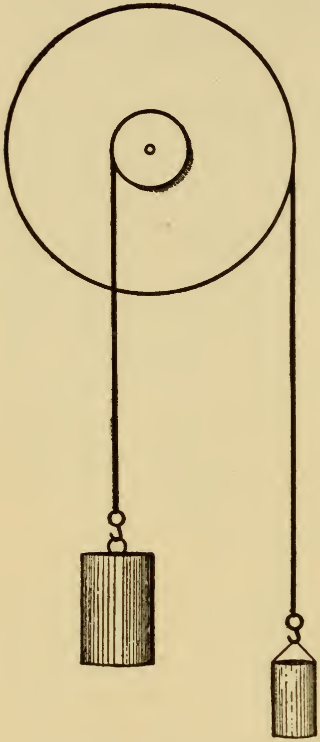
Resistance = ——— lbs.
Effort = ——— lbs.
Resistance × distance it was raised = ——— foot-pounds.
Effort × distance it moved downward = ——— foot-pounds.

Discussion.—The number of foot-pounds of work gotten out of this machine, that is, the product of the resistance by the distance it was raised, is known as the *output*. The number of foot-pounds of work done on the machine, that is, the product of the effort by the distance it moved downward, is known as the *input*. Which is greater, the output or the input? What causes this difference? What is the efficiency of the above arrangement of pulleys? To determine this, divide the output by the input, or,

$$\frac{\text{Output}}{\text{Input}} = \text{Efficiency}$$

Calculate the efficiency and express it in per cent. Is it necessary to measure the distances moved by the block and the pail in order to determine the efficiency? How could you improve the pulleys to make them more efficient? What is an ideal pulley? Of what use is it? Is it possible to make a real pulley with an efficiency of 100%? Why and how?

EXPERIMENT No. 3



Directions.— Repeat Experiment No. 2, using the wheel and axle device instead of the pulleys. Obtain results as in the preceding experiment and calculate the efficiency of the machine.

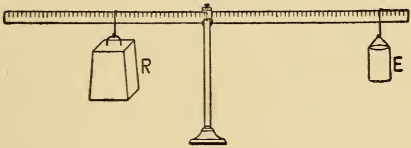
Discussion.—Is it necessary to measure the distances moved? Why? What else might we measure? How improve wheel and axle to get greater efficiency? Is the wheel and axle better than pulleys for raising water in buckets from a well? Why? Is a wheel and axle device ever used in moving houses? How? Have you ever seen one at work? Where?

EXPERIMENT No. 4

Question.— Does it require less work to lift a stone with a crow bar than to raise it directly by hand through the same height?

Apparatus.—Lever; iron block weighing several pounds; a pail; shot.

Remarks.—Work is expressed in *foot-pounds* and is determined by multiplying together the number of pounds of force used and the number of feet of space through which the force acts. One foot-pound = 1 pound × 1 foot.



Directions.—Find the weight of the block and calculate how much work it would take to raise it vertically by hand to a height of one-half of a foot. Now arrange the apparatus as shown in the diagram with the block suspended about a foot from the fulcrum and the pail near the end of the lever. Pour shot slowly into the pail until just enough is obtained to raise the block with uniform speed. Making use of two yardsticks, measure how far the pail moves downward in order to raise the block one-half of a foot. Weigh the pail of shot. The number of foot-pounds of work done by the pail of shot in raising the block one-half of a foot is the product of the weight of the pail by the distance it moved downward. Call the weight of the block the *resistance* and the weight of the pail of shot the *effort*, and record your results as follows:

Results.—

Resistance = ——— lbs.
Effort = ——— lbs.
Resistance × distance it was raised = ——— foot-pounds.
Effort × distance it was lowered = ——— foot-pounds.

Discussion.—You are now ready to answer the question: Does it take more work to raise a weight by hand or to lift it by means of a lever?

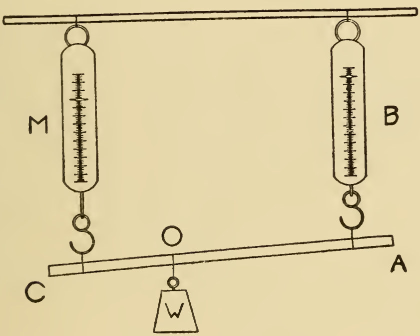
Calculate the efficiency of the machine used in this experiment, following directions given under Discussion, Experiment No. 2. Why is the efficiency of the lever greater than that of the inclined plane or pulleys used in Experiments 1 and 2?

Do we need to measure the distances moved through? Why? Can a lever be made with an efficiency of 100%? Why? Repeat the experiment with the fulcrum out of center, and note whether the efficiency of the lever ever seems to be greater than 1? Is it ever really so? Why? Why are levers useful, since efficiency is less than 1? Do you ever use levers? Where and how?

EXPERIMENT No. 5

Question.—If a boy can carry half as much as a man, how would you arrange a load on a pole between them so that each will carry his share?

Apparatus.—Two spring balances; rod; 10 kilogram weight.



Directions.—Arrange the apparatus as shown in the diagram, letting balance M represent the man and balance B the boy. Move the weight W along the rod until the reading of M is twice that of B. Take the readings of the balances. In reading the balances make correction for the weight of the rod; this can be done by temporarily removing the weight. Measure the distances AO and OC. Compute the value of the fractions $\frac{M}{B}$ and $\frac{AO}{OC}$.

Record your results in a table similar to the following:

Results.—

Force M	Force B	Distance AO	Distance OC	$M \div B$	$AO : OC$

Discussion.—How does the ratio of the two forces M and B compare with the inverse ratio of their distances from where the weight W is hung? State the relationship in the form of a proportion. The weight W holds the two forces M and B in equilibrium, and is known as their equilibrant. How does the equilibrant compare in value with the sum of the two parallel forces? Is any work done in this experiment? How? Do the readings of the balances change if you raise the apparatus uniformly upward or move it sideways?

If you invert the apparatus, letting the two balances hang down and the 10 kilograms act upward, what weights on the two will balance it? When you shovel coal, do you pull up with your left hand as hard as you push down with your right? Why?

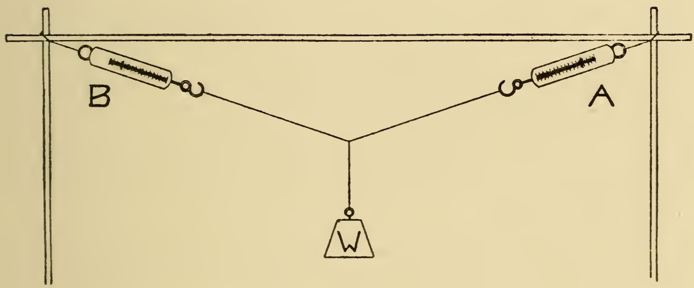
Problem.—Where must a load of 200 pounds be placed on a stick 10 feet long, if the boy who holds one end is to support 60 pounds?

EXPERIMENT No. 6

Question.—When a girl weighing a hundred pounds sits in a hammock, is the strain on each hook a hundred pounds, or is it more or less?

Does the amount the hammock sags affect the strain on the hooks?

Apparatus.—Two spring balances; weight of 20 or 25 pounds; cord.

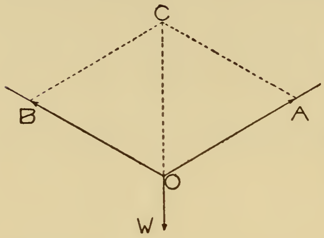


Directions.—Find the value of the weight in pounds and then arrange the apparatus as shown in the diagram. Take the readings of the balances *A* and *B*. Now lengthen the cord connecting *A* and *B* so that it will sag more, and again take the readings of the balances.

Results.—Tabulate your results obtained under the first and second trials, and answer the questions asked above.

Discussion.—The force *W* holds in equilibrium the two forces *A* and *B* and is known as their *equilibrant.*

Suppose in place of the two forces *A* and *B*, we substitute just one force to balance the force *W*; such a force would be known as the *resultant* of *A* and *B*.



To find this resultant, place a stiff piece of paper behind the juncture of the cords and get the exact directions of the forces *A*, *B*, and *W*. Now using a convenient scale (*e.g.* ¼ in. = 1 lb.), lay off on *OA*, *OB*, and *OW*, the values of *A*, *B*, and *W*, respectively. Complete the parallelogram as shown in the diagram and draw the diagonal *OC*. *OC* represents the resultant of *OA* and *OB*. Measure the diagonal and multiply its length by the scale number to find its numerical value.

How does the magnitude and direction of the resultant compare with the magnitude and direction of the equilibrant *W*?

What three forces are in equilibrium here? Do the lines that represent three forces in equilibrium form a triangle? If you knew the weight of the girl in the hammock, what measurements would you make on the hammock to find the pull on the ropes?

Is any work done by the forces in this experiment? Why?

Under what conditions will the tension on each rope be half the weight of the girl? Is it possible to stretch a rope so tight that it will be truly straight and horizontal? Why?

EXPERIMENT No. 7

Question.—Where will water pipes tend to burst first on account of water pressure, in the basement or at the top of the building?

What is the change in pressure per vertical foot?

Apparatus.—Pressure gauge.

Directions.—Find the pressure of the water on the different floors of the school building by attaching the gauge to taps indicated by the instructor. If, while you are performing this experiment, some one should draw water from a faucet, the pressure would be decreased in the pipes throughout the building; therefore leave the gauge attached at each tap for a minute and take the highest reading that you can get. Take, also, the vertical distances in feet between the taps.

Results.—Tabulate the results obtained, and calculate the change in pressure per vertical foot.

Discussion.—You can now answer the question as to where water pipes will tend to burst first.

How high could you run a water pipe in your city before reaching an elevation where there would be no pressure at all?

Does a stand pipe have to be constructed of the same strength from bottom to top? Why?

How is a dam constructed?

Why are railroad water tanks made flat and of large diameter instead of tall and of smaller diameter?

EXPERIMENT No. 8

Question.—How much does the air in the laboratory weigh?

Apparatus.—Meter stick; bottle with stopper, tubing and pinch-cock; air pump; c. c. graduate; large vessel of water.

Directions.—Measure the length, width, and height of the laboratory and calculate its volume in liters (1 liter = 1000 c. c.). To get the weight of a liter of the air in the laboratory proceed as follows. See that the bottle and tubing are perfectly dry inside. Place a little vaseline around tubing and stopper to make the bottle air-tight. Get the weight of the bottle with attachments in grams. Extract from the bottle as much air as possible and close the pinch-cock securely. Again weigh and calculate the weight of air removed.

Place the bottle with its connections completely under water, and open the pinch-cock allowing water to flow in and take the place of the air which was removed. With the end of the tube still under water, hold the bottle in a horizontal position on the surface of the water so that the water inside the bottle is on a level with the water in the vessel, and then close the pinch-cock. Why must the bottle be held in this position when the pinch-cock is closed? Measure the volume of the water in the bottle in cubic centimeters. This will, of course, be equivalent to the volume of the air which was extracted. Knowing the weight of air extracted in grams and its volume in cubic centimeters, calculate the weight of a liter of air.

Results.—Record all data obtained and calculations made, and express the weight of the air in the room in both kilograms and pounds.

Discussion.—Is the weight of the air in the laboratory the same at all times? Why?

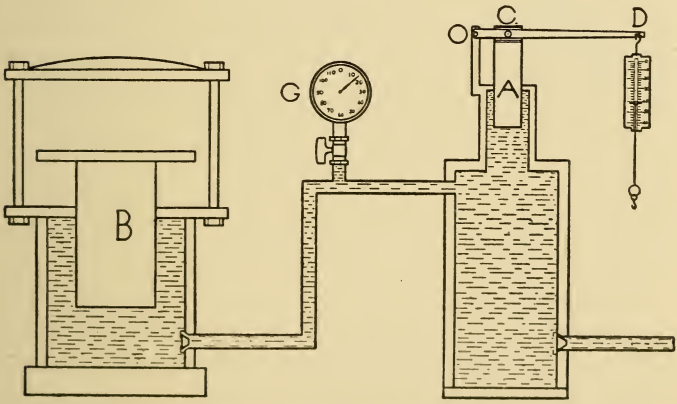
Why does not your body notice this great pressure of the air?

EXPERIMENT No. 9

Question.—If a force of 50 pounds is exerted at the handle of the hydraulic press in the laboratory what pressure is exerted by the large piston?

Apparatus.—Hydraulic press; spring balance; calipers.

PART I



Directions.—First calculate the downward pressure that is exerted by the piston *A* if a force of 50 pounds is applied to the handle *D*. To do this, measure carefully the lever arms *OC* and *OD* from centers of pivots at *O* and *C* and consult your text for a solution of problems in connection with levers of the second class.

Now caliper the pistons *A* and *B*, and calculate the areas of their ends. (Area = $\frac{1}{4} \pi D^2$). Determine the upward pressure exerted by the large piston *B* by applying the following law. *The force exerted by the small piston is to the force exerted by the large piston as the area of the small piston is to the area of the large piston.*

PART II

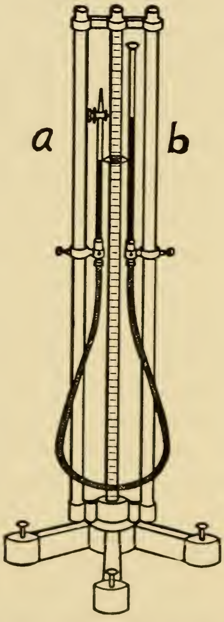
The results obtained in Part I by calculations from dimensions of the hydraulic machine are theoretical. Let us now find what pressure is obtained by the actual working of the machine. Place a block above the large piston to prevent it from moving upward. Pump water into the press until a pull of 50 pounds on the spring balance attached to the handle is necessary to force more water into the machine. The pressure exerted by the large piston is obtained by reading the gauge, *G*. If the gauge does not register the total pressure but reads "Pounds per square inch" or "Atmospheres" the total pressure in pounds can easily be computed.

Discussion.—What are the causes of the difference between the results obtained in Part I and Part II? Name the different places at which friction occurs. Do the weights of the lever and pistons have any effect on the actual results? If so, what is the effect of each? Is the actual pressure exerted upward by the large piston really quite the same as that indicated by the gauge? Why? Explain why the pressure exerted by the hydraulic press is multiplied to such an extent. Consult a reference book for a discussion of Pascal's Law relative to liquid pressure.

Name other appliances in which the principle of the hydraulic machine is made use of.

EXPERIMENT No. 10

Question.—If the gas company were to double the pressure on the tank supplying the mains, what effect would it have on the volume of the confined gas?



Apparatus.—Boyle's apparatus; mercury; illuminating gas; barometer.

Directions.—In the apparatus shown in the diagram the tube *a* is filled with illuminating gas. Move the tube *b* until the mercury stands at the same level in both tubes. Evidently the only pressure now on the confined gas is that of the atmosphere, since the two mercury columns balance each other. How much is this atmospheric pressure? To determine this read the barometer. The barometer shows what length of mercury column is balanced by the atmosphere.

Record the volume of the confined gas. This volume may be expressed in inches (or centimeters) since the diameter of the tube *a* is the same throughout. Also record the pressure upon the gas as indicated by the barometer. This pressure is expressed in so many inches (or centimeters) of mercury.

Now double the pressure upon the gas by raising the tube *b* until the difference in level between the columns of mercury is equal to the reading of the barometer. The pressure on the confined gas is now two atmospheres. Record this together with the volume of the gas.

Results.—Tabulate in a neat form data obtained.

Discussion.—What effect has doubling the pressure upon the volume of the confined gas?

While performing this experiment would the results be effected if the temperature of the room changed materially? Why?

Robert Boyle first discovered this relationship between pressure and volume of gas which you have just proved, and other physicists have shown that it holds good for all gases. Consult your text book for a statement of Boyle's Law.

Problem.—The air in the air dome of a fire engine pump is at atmospheric pressure when the pump is not working. Suppose when the pump is working, the air in the dome is reduced to one-fourth of its original volume, what pressure does it exert? (One atmosphere = 15 lb. per sq. in.)

EXPERIMENT No. 11

Question.—Which weighs the more; a wooden bridge containing 500 cubic feet of spruce, or an iron bridge containing 100 cubic feet of iron?

Apparatus.—Rectangular blocks of spruce and iron.

Directions.—First find the density of spruce and of iron. By density is meant the weight of a unit volume. One way of expressing it is in grams per cubic centimeter. Measure the length, breadth, and thickness of the blocks and compute their volumes in cubic centimeters. Also find their weights in grams. Calculate the weight of one cubic centimeter of each block. Since one cubic centimeter of water weighs one gram, and one cubic foot of water weighs 62.5 pounds, you can readily compute the weight of a cubic foot of spruce and of iron.

Results.—

	Length	Breadth	Thickness	Volume	Weight	Density
Spruce						
Iron						

Weight 1 cu. ft. iron =
Weight 1 cu. ft. spruce =
Weight of spruce bridge =
Weight of iron bridge =

Discussion.—Can the Cubans make rafts of ebony? Why? Why are fishing bobbers made of cork? Why is lead placed in the keel of a boat?

Problem.—Thomas Edison was recently presented with a cube of copper one foot on each edge. Could he carry it? Compute the weight.

EXPERIMENT No. 12

Question.—What is the specific gravity of the milk and cream obtained from your milkman? How do your results compare with those obtained by others of your class?

Apparatus.—Milk; cream; specific gravity bottle.

Directions.—The specific gravity of milk means its weight divided by the weight of an equal volume of water. Weigh the empty bottle when perfectly dry. Fill the bottle half way up the neck with water, drop in the stopper, and allow the hole in the stopper to become filled with water. Dry the outside of the bottle and again weigh to find the weight of the water. In the same way find the weight of the bottle full of milk; also full of cream.

Results.—Weight of water =
Weight of milk =
Weight of cream =
Specific gravity of milk =
Specific gravity of cream =
Results obtained by other
members of class: Milk =
Cream =

Discussion.—

Why does cream rise to the top of milk?

How does a cream separator work?

In which can you float more easily, salt or fresh water? Why?

How are submarines made to rise or sink?

EXPERIMENT No. 13

Question.—Does the lead sinker on your fishing line pull on the line more when it is out of the water than when it is in the water? If so, how much more? Use results obtained for finding the specific gravity of lead.

Apparatus.—Piece of lead; balance; vessel of water.

Directions.—Suspend the piece of lead from the left side of the balance by means of fine thread and find its weight. Now hang the piece of lead in water and find its weight in water. Compute its loss of weight in water.

How can these results be used to find the specific gravity of lead? By specific gravity of a substance is meant *its weight divided by the weight of an equal volume of water.* The piece of lead, of course, displaces its own volume of water, and the weight of this water displaced, as Archimedes first discovered, is equal to the loss of weight of the lead in water. Therefore, if you know the weight of the piece of lead in air and its loss of weight in water you can find the specific gravity of lead.

$$\text{Specific gravity} = \frac{\text{Weight in air}}{\text{Loss of weight in water}}$$

Results.—

Weight of lead in air	=
Weight of lead in water	=
Loss of weight of lead in water	=
Specific gravity of lead	=

Discussion.—How would you perform an experiment to prove Archimedes' principle that *a body immersed in water is buoyed up by a force equal to the weight of the water displaced*?

Problem.—If you can just float in water with your nose out what is your volume?

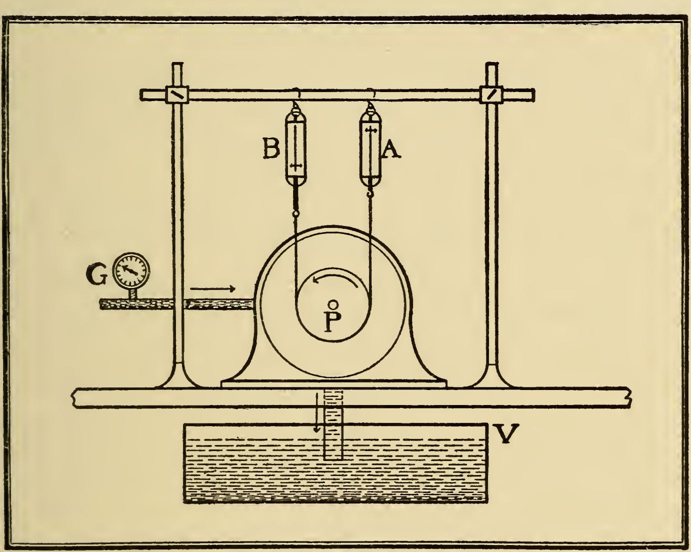
EXPERIMENT No. 14

Question.—What is the efficiency of the water motor in the laboratory?

Apparatus.—Water motor; pressure gauge; two spring balances; brake belt; speed indicator.

Directions.—To obtain the work put into the motor it will be necessary to get the pressure of the water in pounds per square inch by means of the gauge *G* connected to the supply pipe, also the quantity of water in cubic inches flowing through the motor in a given time and caught in the vessel *V*.

To obtain the work gotten out of the motor it is necessary to make use of a brake consisting of two spring balances *A* and *B* and a friction belt passing under the pulley *P*. Raise the rod supporting the balances until the motor slows down to its ordinary working speed. If the motor rotates in the direction indicated by the arrow the belt will pull harder on *B* than on *A*. The difference between the readings of the balances measures the pounds pull of the motor on the belt.



One student should take care of the speed indicator; a second student, the balances; and a third, the gauge and flow of water.

Before starting the motor disconnect the belt from the balance *A*. When the motor has reached full speed replace the belt on balance *A*. At the word "Go" from the student watching the speed indicator, place the empty vessel *V* under the outlet and let run for a short time, say two minutes. Note the number of revolutions, and during the entire time observe the balances and gauge in order to get their average readings. Determine the volume of the water in cubic inches. The *input*, or work done on the motor, is called *fluid work* and depends upon the pressure of the water and the volume of flow.

$$\text{Fluid work} = \text{Pressure} \times \text{volume}$$

Since the pressure is in pounds per square inch and the volume in cubic inches, the volume must be divided by 12 (1 ft. = 12 in.) in order to obtain the work expressed in foot-pounds. Therefore

$$\text{Input} = \text{Pressure (lb. per sq. in.)} \times \frac{\text{(volume cu. in.)}}{12}$$

The *output*, or work done by the motor is equal to the pounds pull on the belt multiplied by the distance through which this pull acts. During one revolution this pull acts through a distance equal to the circumference of the pulley. With a pair of calipers measure the diameter of the pulley and calculate the circumference in feet. The circumference multiplied by the number of revolutions gives the total number of feet through which the pull acts. The product of the pounds pull by the distance in feet gives the output of the motor in foot-pounds.

Determine the efficiency of the motor.

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}}$$

Results.—

Input:

Pressure of water =

Volume of water =

Work put into motor =

Output:

Pounds pull $(B-A)$	=
Circumference of pulley	=
Number of revolutions	=
Total distance	=
Work done by motor	=
Efficiency	=

Discussion.—To what is the loss in a water motor due? Is the pressure of the water at the outlet the same as at the inlet? Where does the loss in pressure occur?

Instead of expressing the input or output in foot-pounds of work, we may express them in the form of mechanical power, or foot-pounds of work per second. And so the efficiency may be expressed as the ratio of power output to power input, or

$$\text{Efficiency} = \frac{\text{Power output}}{\text{Power input}}$$

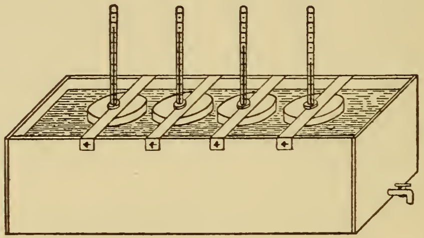
Since the work in and work out were performed in the same time the ratio of powers is equal to the ratio of works. In speaking of the output of a motor which term is usually applied, "foot-pounds of work" or "power"?

Calculate the delivered horse-power of the motor from results obtained (1 horse-power = 550 foot-pounds per second).

EXPERIMENT No. 15

Question.—Which makes the best lining for a fireless cooker; an air space, excelsior, felt, or mineral wool?

Apparatus.—Four calorimeters, or tin cans, with covers; four thermometers; excelsior; felt; mineral wool; pan with clamps.



Directions.—First heat a large kettle of water. While the water is coming to a boil, pack one can with excelsior, one with felt, and one with mineral wool. The fourth can is used with just the air in it. Arrange a thermometer in each can with the bulb in the center of the can and the stem passing through the hole in the cover. Clamp the cans in the pan as shown in the diagram. Now pour boiling water into the pan until the cans are about three-fourths submerged, being careful not to get any water in the cans. Let stand until ten minutes before the close of the laboratory period; then take the readings of the thermometers. Remove the cans, being careful not to let them tip over in the water, and empty the pan.

Results.—Record the final temperatures and arrange the different substances in the order of their conductivity.

Discussion.—Why do storm windows keep a house warmer? Why are steam pipes often covered with asbestos? Why does a thermos bottle retain the heat longer than a fireless cooker? Why is a wool blanket warmer than a cotton blanket of the same weight?

Name a dozen poor conductors of heat; a dozen good conductors.

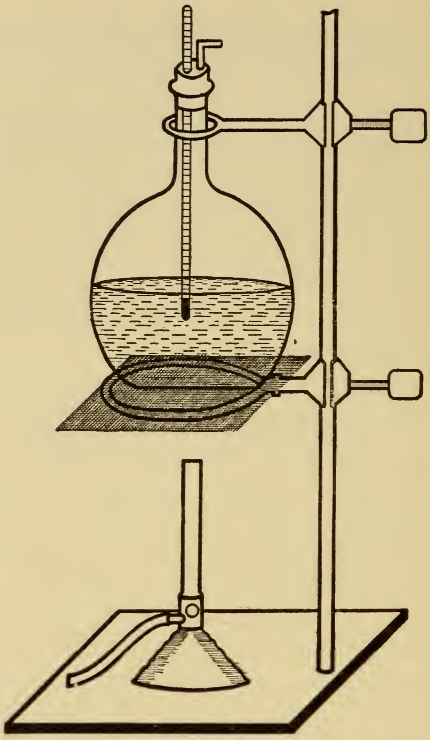
EXPERIMENT No. 16

Question.—In a kettle of boiling water, which is hotter, the water or the steam above the water?

At what temperature does water boil in your locality?

Apparatus.—Glass flask; thermometer reading to tenths; two-hole rubber stopper; bent glass tube.

Directions.—Be very careful with the thermometer used in this experiment as it is of a higher grade than is ordinarily employed in the laboratory. Arrange the apparatus as shown in the diagram with the bulb of the thermometer just beneath the surface of the water. When the water is boiling freely take the reading of the thermometer, estimating to tenths of degrees. Boil the water faster or slower and see what difference it makes in the boiling point. Now raise the thermometer above the water and take the temperature of the steam.



Results.—Temperature of boiling water =
Temperature of steam =
Elevation of (your locality) =

Discussion.—Will water boil at the same temperature on the top of a high mountain as it will at the level of the sea? Why?

When boiling vegetables will they get done any sooner by boiling the water faster?

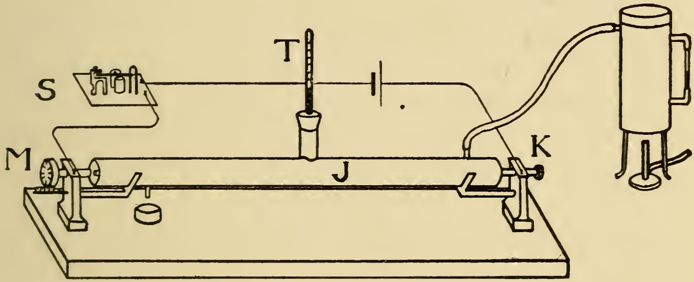
Which do you think is a better way to cook vegetables, in boiling water or in steam? Why?

EXPERIMENT No. 17

Problem.—How much does an iron bridge 100 feet long change in length if the range in temperature is from 40° C. in summer to –40° C. in winter?

Remarks.—In order to work this problem, it will be necessary to first find the fraction of its length which a piece of iron expands on being heated 1° C.

Apparatus.—Expansion frame; iron rod; boiler; thermometer; telegraph sounder; one cell.



Directions.—Measure the length of the iron rod in centimeters and place it in the steam jacket *J* shown in the diagram. Push the thermometer *T* down until it touches the rod, being careful not to break the thermometer. Connect the telegraph sounder *S* and the cell in series with the frame. See that the iron rod rests firmly against the back stop *K*. If the micrometer screw *M* is turned up until it touches the iron rod, the electric circuit will be completed and the sounder will click. (*Caution.*—Turn up the micrometer carefully so that only sufficient contact is made to cause the sounder to click; otherwise you will strain the instrument.) Note that the micrometer reads in hundredths of millimeters. Adjust K so that the micrometer will stand at zero when the sounder clicks. After this adjustment do not allow the jacket to turn, otherwise it will affect the reading of the micrometer. Now turn back the micrometer so that it will be out of the way when the rod expands. Take the reading of the thermometer which will give the temperature of the cold rod. Pass steam through the jacket and continue to heat the rod a half minute after the thermometer has ceased to rise. Take the temperature of the hot rod. Now turn the micrometer until the sounder clicks. Note by the micrometer how much the rod expanded.

Results.—Fraction of its length which iron rod expanded $= \dfrac{\text{amount of expansion}}{\text{length when cold}} =$

This divided by the change in temperature gives the fraction of its length which the iron rod expanded for a change of 1° C. Express this result in the form of a decimal. This result is known as the *coefficient of linear expansion* of iron.

The iron bridge will expand this fraction of its length for a change of 1° C. Calculate how much it will expand for the change of temperature given in the problem.

Discussion.—In building a railway, why are spaces left between the rails?

Why are steam boilers put together with red-hot rivets?

Why do telegraph wires "sing" more in winter than in summer?

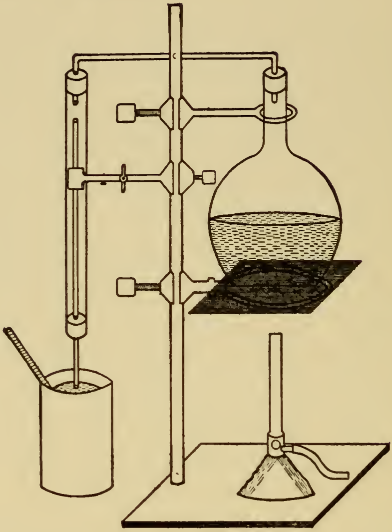
EXPERIMENT No. 18

Question.—If a liter (1 kilogram) of water at 20° C. in an open kettle takes ten minutes to come to a boil, how long will it have to boil to change it all into vapor?

Remarks.—*The amount of heat required to raise the temperature of* 1 *gram of water* 1° *C.* is taken as the unit of heat and is called the *calorie.* Evidently to bring the kilogram of water to the boiling point, 100° C., requires 1000 grams × (100° − 20°) = 80,000 calories. In other words 80,000 calories of heat were given up by the flame to the water in ten minutes. In order to find how long it will take to change the boiling water into steam it will be necessary first to determine by experiment how many calories are required to change 1 gram of boiling water into steam.

Apparatus.—Flask with water trap attached; calorimeter; thermometer.

Directions.—Have the flask about one-half full of water and start it to heating. Empty the water trap if it contains much water. Weigh the calorimeter and put into it exactly 500 grams of cold water. Take the temperature of the water. Place a screen between the boiler and the calorimeter to prevent heat from the flame reaching the calorimeter. When steam is given off freely from the boiler introduce sufficient steam into the water to raise its temperature to about 35° C., at the same time constantly stirring the water with the thermometer. Before turning off the burner, remove the calorimeter, stir, and take the final temperature. Again weigh to find the amount of steam condensed in the water.



a. The number of calories of heat taken up by the cold water is evidently the weight of the water (500 gm.) multiplied by its rise in temperature. Part of this heat was given up by the steam in being condensed and part by the condensed steam in being lowered to the final temperature.

b. The number of calories of heat given up by the steam after it was condensed is equal to the weight of the steam multiplied by its fall in temperature.

Subtracting *b* from *a* we have the amount of heat given up by the steam in being condensed. This divided by the weight of the steam gives the amount of heat given up by 1 gm. of steam in being condensed.

Results.—

Weight of cold water =
Amount of heat taken up by water (a) =
Weight of steam =
Amount of heat given up
to water by condensed steam (b) =
Amount of heat given up
by steam in being condensed $(a-b)$ =
Amount of heat given up by 1
gm. of steam in being condensed =

Discussion.—The result just obtained is of course the same as the amount of heat required to change one gram of boiling water into steam. This is known as the *Heat of Vaporization of Water*. You can now estimate how long it will take to entirely vaporize the liter of water referred to in the above problem.

Explain how a steam heating plant operates.

Why are burns from steam more painful and injurious than those from boiling water?

In hot dry atmospheres, like that of Mexico, water is cooled by placing it in porous earthenware jars or canvas bags. Explain.

EXPERIMENT No. 19

Question.—What is the temperature at which dew will form today? Compare your result with those obtained by other students on other days.

Apparatus.—Thermometer; calorimeter; ice; water.

Directions.—Place about two inches of water in the calorimeter. Add finely crushed ice to the water, a very little at a time, stirring continually with the thermometer. Watch closely for the first appearance of moisture on the calorimeter. Since the breath contains more moisture than the air of the room, be very careful not to breathe against the vessel. When the dew first appears, take the reading of the thermometer. Try several times, wiping off the dew, adding a little warm water, and then more ice. The object is to find the highest temperature at which there is the slightest appearance of moisture.

Results.—Tabulate the temperature and date together with results gotten by other students.

Discussion.—The temperature at which the water vapor in the atmosphere becomes saturated and begins to condense is known as the *dew point.* Is the dew point in winter higher or lower than in summer? What is frost? Do "Jack Frost's pictures" appear on the outside or inside of windows? Why? Do they appear more frequently when it is very cold? Why? On the kitchen windows, or those of the bedroom? In heated houses or cold sheds? Why?

EXPERIMENT No. 20

Question.—Will a vessel of water come to a boil sooner when the cover is left on than it will when the cover is off? Why?

PART I

Apparatus.—Two-quart pail with loose cover, or a teakettle; plate burner; thermometer.

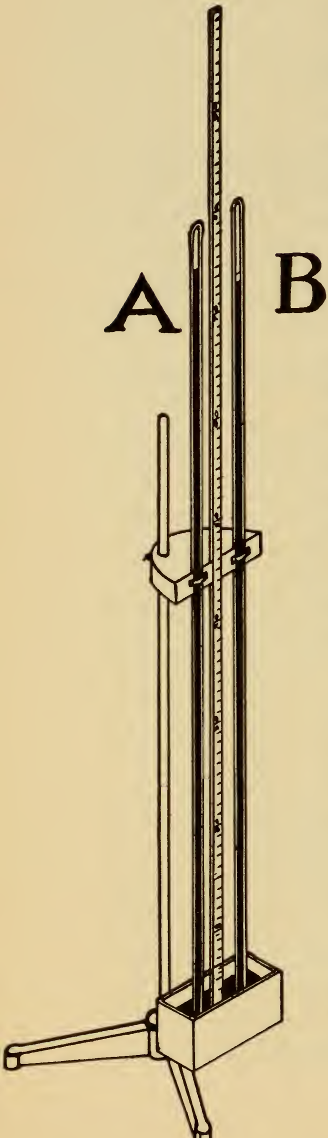
Directions.—Put a given amount of water, say a quart or a liter, at a given temperature into the vessel, and, leaving off the cover, note the time necessary to bring the water to a boil. Repeat the experiment with the cover on, having all other conditions the same.

Results.—Tabulate your results for both cases as to amount and temperature of water and time consumed.

PART II

Apparatus.—Two barometer tubes; mercury; cup; pointed bent tube with rubber bulb attached.

Directions.—With the assistance of the instructor fill the tubes with mercury and invert in the cup of mercury. Note that the mercury stands at the same level in both tubes. What holds the mercury up in the tubes? Introduce a little water into the tube *B*, being careful not to let in any air, and note the



difference in the heights of the mercury in the two tubes. The reason the mercury falls in the tube *B* is because the water evaporates until the upper part of the tube is filled with saturated water vapor, exerting a downward pressure on the mercury.

Now raise the temperature of the water by holding a gas flame within an inch of the tube. (*Caution.*—Do not let the flame touch the glass.) Does this cause more water to evaporate? How do you know? Would you conclude that for a given temperature a given amount of water will evaporate in order to produce saturation in the upper part of the tube, and that when saturation is reached evaporation will cease?

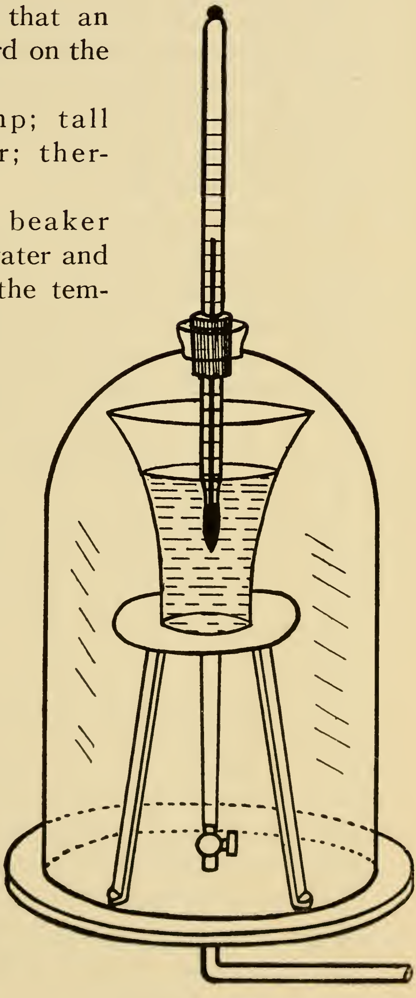
Discussion.—You are familiar with the fact that when water evaporates from the hand, the hand is cooled. You are now ready to explain fully the effect produced by leaving off the lid of a kettle while the water is coming to a boil.

If a kettle boiled long enough to saturate all of the air in the room, would further evaporation take place from the kettle?

EXPERIMENT No. 21

Question.—Why is it that an egg cannot be boiled hard on the top of a high mountain?

Apparatus.—Air pump; tall receiver; glass beaker; thermometer.



Directions.—Fill the beaker about one-third full of water and bring to a boil. Note the temperature of the boiling water. Transfer the beaker to the air pump and arrange the apparatus as shown in the diagram, with the thermometer passing through a stopper in the top of the receiver and the bulb of the thermometer in the water. Be very careful not to break the thermometer. Extract air until the water begins to boil. Note the temperature, also the reading of the pressure gauge attached to the pump. Repeat the operation every minute or so until a half dozen or more results have been obtained.

Results.—Tabulate your results showing the varying temperatures and pressures at which the water boils. Calculate the change in pressure necessary to produce a change of 1° C. in the boiling point of water.

Discussion.—How would you devise a cooking utensil that would boil eggs on top of a high mountain?

When an engine boiler gives way, why does the water sometimes change instantaneously into steam with great violence?

Problem.—On the top of Pike's Peak the barometer stands commonly at 17.79 inches. At what temperature does the water boil?

EXPERIMENT No. 22

Problem.—How much ice is needed to cool a liter of water at 40° C. to 5° C.? Test it and compute the heat of fusion of ice.

Apparatus.—Calorimeter or tin can; ice; thermometer.

Directions.—Weigh the dry calorimeter. Put into it 1 liter (1 kilogram) of water heated to a little above 40° C. When the water reaches 40° drop in two good sized handfuls of cracked dry ice. Stir continually with the thermometer. When the temperature reaches 5°, quickly remove the remaining ice. Weigh again to obtain the amount of ice intrduced.

The heat unit in the metric system is the *gram-calorie*, *i.e.*, the amount of heat required to raise the temperature of 1 gram of water 1° C. The number of gram-calories required to melt 1 gram of ice is known as the *heat of fusion* of ice.

Results.—Calculate the number of gram-calories given up by the 1000 grams of water in cooling from 40° to 5°. This heat was evidently used, first, to melt the ice, and then to raise the temperature of the ice water from 0° to 5°. Calculate the heat required to raise the ice water to 5° by multiplying the weight of the ice (or ice water) by 5. Subtracting this from the amount of heat given up by the liter of water leaves the amount of heat required to melt the ice. This divided by the weight of the ice gives the number of gram-calories of heat required to melt 1 gram of ice; that is, the heat of fusion of ice.

Discussion.—Explain why a large lake that freezes over in winter prolongs the spring in the locality. Explain the action of an ice cream freezer.

Why do farmers sometimes place tubs of water in cellars to prevent vegetables from freezing?

EXPERIMENT No. 23

Question.—How much heat is absorbed by an aluminum kettle having the temperature of the room when it is filled with water at 60° C? Test it and compute the specific heat of aluminum.

Apparatus.—Aluminum kettle; thermometer; vessel in which to heat water.

Directions.—Weigh the aluminum kettle in grams. Note the temperature of the room and set the kettle in a place where it will retain this temperature. Heat sufficient water in another vessel to about 60° C. Take the temperature of the water. The next step must be made quickly. Pour enough of the water into the aluminum kettle to almost fill it, and stirring with the thermometer, quickly note the final temperature, which is of course the temperature of the kettle. Again weigh to obtain the amount of water used.

By the *specific heat* of aluminum is meant the amount of heat required to raise the temperature of 1 gram of aluminum 1° C. The amount of heat given up by 1 gram of water in cooling 1° C. is taken as the unit of heat, and is known as a *gram-calorie.*

Results.—The weight of the water multiplied by its fall of temperature is equal to the number of gram-calories which it gives up to the aluminum kettle. Dividing this by the rise in temperature of the kettle will give the gram-calories required to raise the temperature of the kettle 1°. From which you can determine the amount of heat required to raise 1 gram of aluminum 1°; which is the specific heat of aluminum.

Discussion.—Examine a table of specific heats and compare the specific heat of other substances with that of water. Why do hot water plants produce such even temperatures?

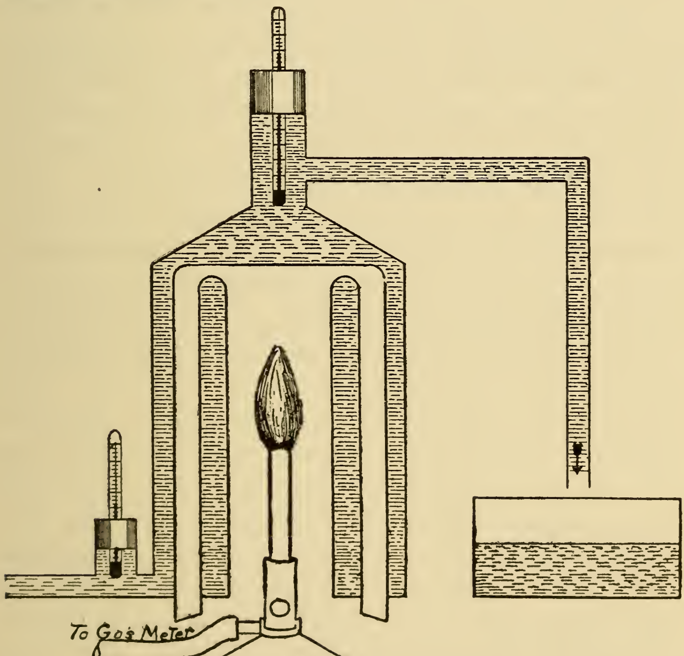
Why do inland towns have a greater range of temperature than sea coast towns?

Why is a hot water bottle better than a hot stove lid to keep your feet warm for the night?

EXPERIMENT No. 24

Question.—How much heat is produced by the combustion of one cubic foot of the gas supplied by your local gas company?

Apparatus.—Gas meter; water jacket; two thermometers (Fahrenheit); Bunsen burner; vessel in which to catch water.



Directions.—As shown in the diagram, water flows in at the bottom of the water jacket and out at the top. The hot gases from the burner pass through tubes surrounded by water and give up their heat to the water before passing out at the bottom of the apparatus. Thermometers placed at the bottom and top of the water jacket indicate the change in temperature of the water. By measuring the amount of water flowing through and its rise in temperature while one cubic foot of gas is consumed, the heat of combustion of the gas may be determined.

Light the burner. To produce the best results do not have the flame too high, and adjust the burner so as to give it more air than usual, making the flame rustle when it burns. Place the burner under the calorimeter, turn on the water and let the apparatus run until the thermometers remain stationary. Now place the vessel *V* under the outlet and at the same time note the reading of the gas meter. Let run until exactly one cubic foot of gas has been consumed and at the same time shut off the water. Careful observation should be made of the thermometers during the experiment to obtain their average readings. Take the weight or measure of the water passed through in pounds. Calculate the amount of heat taken up by the water, bearing in mind that 1 B. T. U. is the amount of heat that will raise the temperature of 1 pound of water 1° F. The result is the heat of combustion of 1 cubic foot of the gas supplied to the laboratory.

Results.— Rise in temperature of water =

Weight of water =

Heat of combustion per cubic foot =

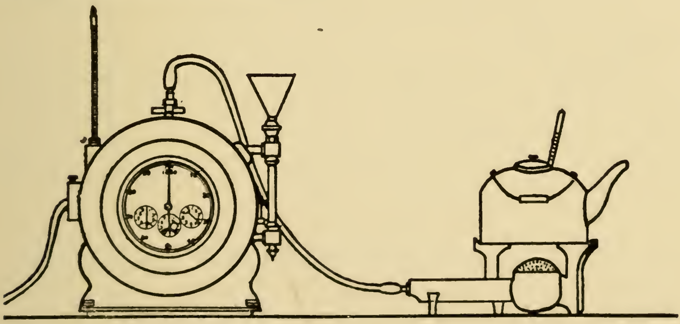
Discussion.—How much does your local company charge for gas per thousand feet (*i.e.*, cubic feet)? Calculate how much it costs you to heat 6 pints (*i.e.*, 6 pounds) of water from 40° F. to the boiling point if you use a burner and teakettle having a combined efficiency of 52 per cent.

The heat of combustion of coal may be found by burning it in a suitably constructed water-jacket. For average coal it is 15,000 B. T. U. per pound. If the furnace in your house burns 100 pounds of coal a day how many B. T. U. are liberated in the house if the furnace has an efficiency of 50 per cent.

EXPERIMENT No. 25

Question.—What is the thermal efficiency of an ordinary teakettle?

Apparatus.—Bunsen burner; teakettle; gas meter; Fahrenheit thermometer.



Directions.—Put into the teakettle 4 pounds of water, noting the temperature of the water. Heat this over the same gas burner used in Experiment No. 24 until 1 cubic foot of gas is consumed. Again take the temperature of the water.

Results.—Calculate the number of B. T. U. taken up by the water. (For definition of B. T. U. see the text book.) The number of B. T. U. supplied by the combustion of the cubic foot of gas has already been determined in Experiment No. 24.

You can calculate the efficiency of the kettle, which is the ratio of the useful heat got out to the total heat put in; or

$$\text{Thermal Efficiency} = \frac{\text{Heat out (B. T. U.)}}{\text{Heat in (B. T. U.)}} = \text{——}\%$$

Discussion.—Can you think of a way of increasing the efficiency of a teakettle? Would a teakettle with a highly polished bottom be more efficient than one with a smoked bottom? Why?

If you wished to heat 3 quarts of water, which would be more efficient, to use a 4-quart or an 8-quart kettle? Why?

Problem.—An engine with its boiler consumes 192 pounds of coal per hour and develops 96 horse-power. What is its efficiency? (1 B. T. U. = 778 foot-pounds. Heat of combustion of coal = 15,500 B. T. U. per pound.)

EXPERIMENT No. 26

Question.—Does a cell lose its strength if continuously connected? Test a dry cell; a gravity cell. Which form is better for door bells? Which for telegraph lines?

Apparatus.—Dry cell; gravity cell; galvanometer.

Directions.—Connect the dry cell to the galvanometer and take readings every two minutes for ten minutes. Test the gravity cell in the same way. Examine the construction of a gravity cell, also the half of a dry cell sawed lengthwise. The dry cell is not really "dry" but is kept moist by a solution of sal ammoniac. Note how it is sealed at the top in order to keep the cell moist. Consult your text book for a discussion of *polarization*.

Results.—

	Reading of Galvanometer					
	0 min.	2 min.	4 min.	6 min.	8 min.	10 min.
Dry cell						
Gravity cell						

Discussion.—Do either of the cells become polarized? Which is suited for "open circuit" work such as ringing door bells or running gas engines? Which for "closed circuit" work such as telegraphing?

Why not use the gravity cell for all kinds of work?

EXPERIMENT No. 27

Question.—What is the nature of the field about a magnet?

Apparatus.—Two bar magnets; iron filings; blue-print paper; plate of glass.

Directions.—Place on the table a bar magnet, and over this a plate of glass. Sift fine iron filings evenly on the plate, being careful not to use too many filings. Holding one corner of the plate, tap it gently with a pencil until the magnetic lines of force are well defined. Lift up the plate vertically from the magnet and place beneath it a piece of blue-print paper. Expose this to the sunlight about 20 seconds, then quickly place it in the sink and rinse thoroughly. When dry, bind it in your notebook. Repeat the experiment with two like poles separated about two inches with the magnets lying in the same straight line. Again, with two unlike poles.

Discussion.—Are the lines about a bar magnet uniformly distributed or are there crowded places? What is the cause of this?

Are the poles immediately at the ends of the bar?

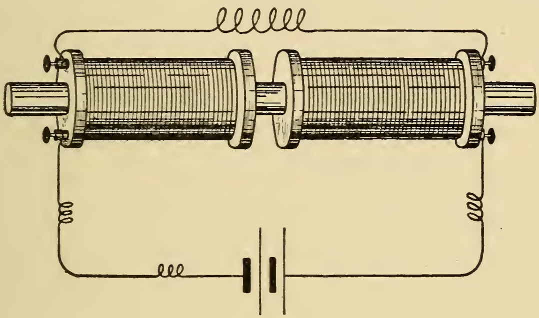
Do the lines cross each other or do they merge into one another?

Which poles placed near each other show magnetic attraction? Which magnetic repulsion?

EXPERIMENT No. 28

Question.—What determines the strength of an electro-magnet?

Apparatus.—Soft iron rod; two spools of magnet wire; tacks; two cells; compass.



Directions.—Slip one of the spools of wire over the rod and connect to one of the cells. See how many tacks end to end you can get to hang on the end of the rod. In the same way try two spools connected with one cell and again two spools with two cells. (*Caution.*—When the two spools are used they must be placed on the rod in such a way that the current will pass around the rod in the same direction through both.)

Test a coil of wire without the iron core and see if it possesses any magnetism. If it will not attract tacks, test it with a magnetic needle.

Using a magnet needle, test the electro-magnet for polarity.

Discussion.—What effect has increasing the number of turns of wire on the strength of the electro-magnet? Does doubling the number of turns double the strength?

What effect has increasing the strength of the current? Is the magnetic strength proportioned to the current strength?

Examine an electric bell and explain how it operates.

Name some other instruments that make use of electro-magnets.

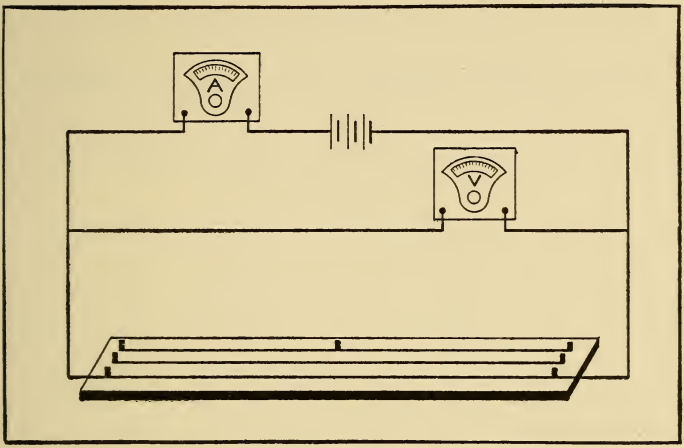
EXPERIMENT No. 29

Question.—What effect has the length, diameter, or material of a conductor upon its electrical resistance?

Apparatus.—Frame containing 100 centimeters of No. 30 copper, 100 centimeters of No. 30 German silver, 100 centimeters of No. 24 German silver, and 50 centimeters of No. 30 German silver; ammeter; voltmeter; one storage cell or two dry cells; wire gauge.

Directions.—Connect the ammeter in series and the voltmeter in parallel with the 100 centimeters of No. 30 German silver wire as shown in the diagram. The ammeter gives the current in amperes passing through the wire, and the voltmeter gives the fall of potential in volts. Read the amperes and volts to tenths. Be careful to leave the battery connected only long enough to take the readings of the meters in order not to decrease the strength of the battery. Calculate the resistance of the wire in ohms. By Ohm's Law:

$$\text{Ohms} = \frac{\text{Volts}}{\text{Amperes}}$$



In like manner determine the resistance of 50 centimeters of the German silver No. 30 and compare it with the resistance of 100 centimeters of the same wire to show the effect of length.

To show the effect of diameter, determine the resistance of 100 centimeters of German silver No. 24 and compare it with the resistance of 100 centimeters of No. 30 German silver. See the wire table in the Appendix for the diameters of the wires.

To show the effect of material determine the resistance of 100 centimeters of copper No. 30 and compare it with the resistance of the same size and length of German silver.

Results.—

Material	Length	Diameter	Volts	Amperes	Resistance

Discussion.—State the relation existing between the length of a wire and its resistance.

State the relation existing between the diameter of a wire and its resistance.

The resistance of German silver is how many times that of copper?

Why are heavy copper cables used in the construction of trolley wires?

Of what material would you make a resistance coil for cutting down the current?

Could the filament of an incandescent lamp be made of copper? Why?

EXPERIMENT No. 30

Question.—How can the electromotive force of a battery be increased?

Apparatus.—Several dry cells; gravity cell; voltmeter.

Remarks.— By the electromotive force of a battery is meant the force which the battery is able to exert in moving an electric current through a conductor. The volt is the unit of electromotive force. A cell having an E. M. F. of one volt can drive a current of one ampere through a conductor having a resistance of one ohm. The voltmeter is an instrument so constructed as to measure the electromotive force of a cell or battery.

Directions.—Connect the voltmeter to one of the dry cells to see how much electromotive force it exerts. Now connect two cells in series and test with the voltmeter. Again with three cells in series. What effect has the size of a cell on its electromotive force? Test a dry cell of different size. Does a different kind of cell produce a different electromotive force? Test a gravity cell.

Results.—

E. M. F. of one dry cell =
E. M. F. of two dry cells in series =
E. M. F. of three dry cells in series =
E. M. F. of dry cell of different size =
E. M. F. of gravity cell =

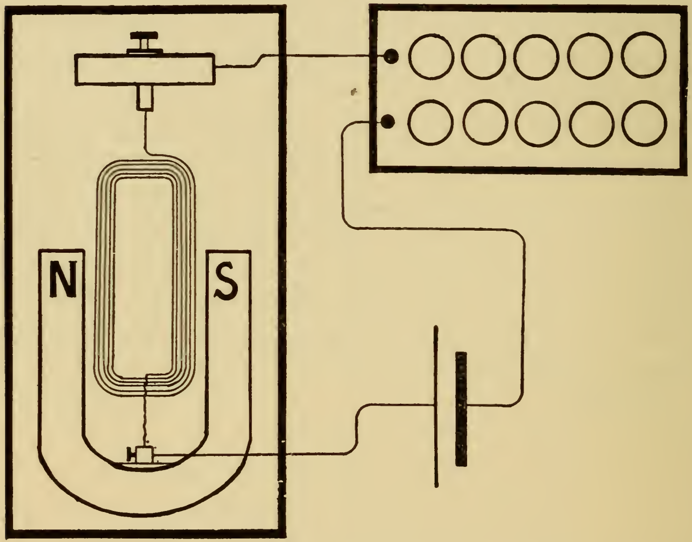
Discussion.—Just as two locomotives can pull or push twice as heavy a train as one locomotive, so two cells in series can push twice as much current as one cell through the same resistance.

If you test an electric bell, one dry cell will be found sufficient to ring it. Why, then, in the construction of some bell circuits, is it found necessary to use several cells in series?

EXPERIMENT No. 31

Question.—What makes an electric motor go?

Apparatus.—D'Arsonval galvanometer; cell; resistance box.



Directions.—Note that the galvanometer as shown in the diagram consists of a permanent horseshoe magnet, between the poles of which is suspended a coil of wire. Connect the wires leading from the cell to the terminals of the coil of the galvanometer, introducing between the cell and the galvanometer a resistance of 500 or 1000 ohms depending upon the sensibility of the galvanometer. Why does the coil move in the direction it does and then come to rest in a certain position? You have already learned that when an electric current is passed through a coil of wire, the coil becomes a magnet with one of its faces a north pole and the other a south pole. So the moving coil of the galvanometer becomes an electromagnet and its poles are attracted by the unlike poles of the permanent horseshoe magnet. The coil takes up a position with its north pole next to the south pole of the permanent magnet.

Change the connections of the wires leading from the cell so as to reverse the direction of current in the coil. Explain the motion and final position of the coil.

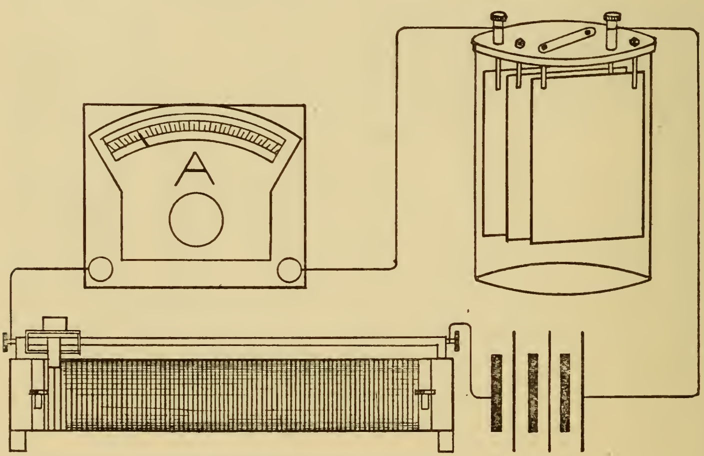
When the coil is set in motion it does not stop after making a half turn, but, on account of its inertia, its poles move past the unlike poles of the horseshoe magnet. Then the coil is stopped and brought back by the magnetic force and the twisting force of the ribbon by which the coil is suspended. If we could do away with the twisting force of the suspending ribbon could we produce a continual motion of rotation by reversing the current each half turn? Explain.

Discussion.—The moving coil of an electric motor is mounted on a shaft so that continual motion of rotation is possible. The current is brought into this by means of an arrangement which changes the direction of the current every half turn. Examine a toy motor and apply the principles learned in this experiment.

EXPERIMENT No. 32

Question.—In electro-plating with copper, how long will it take one ampere of current to deposit one gram of copper?

Apparatus.—Copper plating bath with two loss plates and one gain plate; ammeter; rheostat; several cells.



Directions.—Arrange the apparatus as shown in the diagram. (*Caution.*—Do not pass any current through the apparatus until the instructor has seen the connections). The rheostat is a coil of resistance wire for regulating the amount of current and keeping it constant. In electro-plating, the metal is always deposited on the negative pole. Pass the current through the apparatus in such a direction that copper will be deposited on the middle or gain plate. Remove the middle plate, rinse in water, dry over a gas flame, and weigh carefully to thousandths of a gram. Return the coil to the solution, turn on the current, and note the time and the reading of the ammeter. Keep the reading of the ammeter constant by means of the rheostat. Let run for an even number of minutes, say 20; then remove the gain plate, rinse and dry it very carefully so as not to remove any of the copper, and again weigh.

From data obtained calculate how long it would take one ampere to deposit one gram of copper.

Results.—

Weight of copper deposited =
Time of deposit =
Number of amperes =
Time one ampere will deposit one gram =

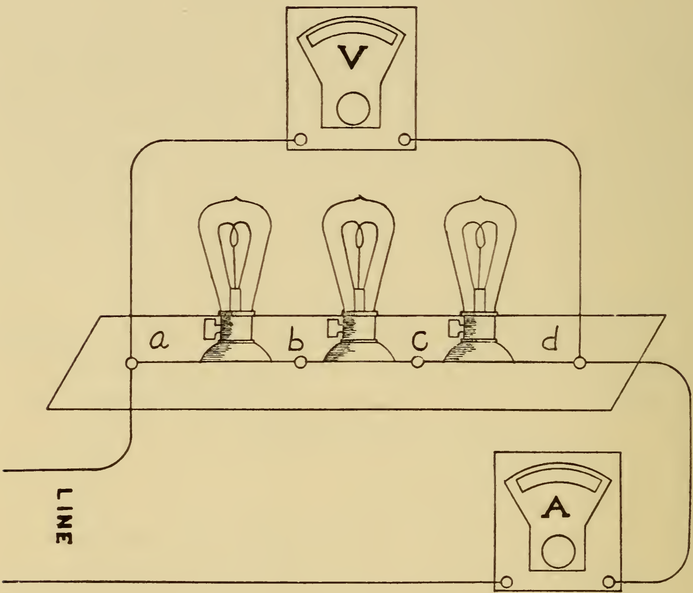
Discussion.— If you had weighed the two loss plates at the beginning and end of the experiment you would have found that they had lost in weight just as much as the small plate gained. Thus the electro-plating solution maintains its strength. What would happen if you reversed the current while electro-plating?

Problem.—In the copper refining plant at Great Falls, Montana, 90 tons of copper are deposited per day (24 hours). What strength current is used?

EXPERIMENT No. 33

Question.—What is meant by "Fall of Potential?"

Apparatus.—110-volt current; three electric lamps; voltmeter.



Directions.—Pass the current through the three lamps connected in series as shown in the diagram. It requires electrical pressure to force the current through the lamps. This pressure is measured by the voltmeter. Connect the terminals of the voltmeter to *a* and *d* to obtain the volts pressure required to drive the current through all three lamps. In like manner find the difference of electrical pressure between *a* and *c* for two lamps, and between *a* and *b* for one lamp.

Results.—

Volts pressure required for three lamps =
Volts pressure required for two lamps =
Volts pressure required for one lamp =

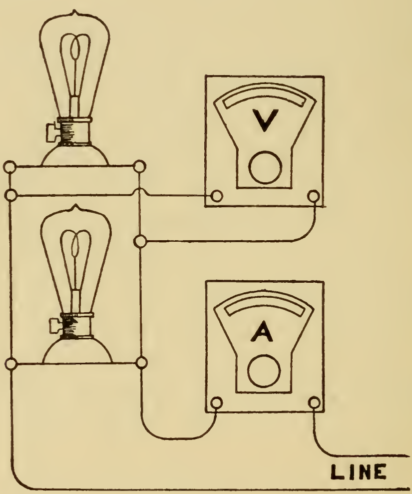
Discussion.—*Potential* is only another expression for electrical pressure. *Difference of Potential* means difference of electrical pressure, and *Fall of Potential* means fall of electrical pressure. A voltmeter is used to measure the potential difference between any two points in an electrical circuit, just as pressure gauges are used to measure the difference in water pressure between any two points of a water pipe. The further away from the pumping station the greater the fall of pressure of the water in pounds per square inch, due to the resistance of the pipes. So the further the electric current goes in a conductor the greater the fall of potential in volts, due to the electrical resistance of the conductor. The greater the resistance the greater the fall of potential. Do the lamps used in this experiment all have the same amount of resistance? Why do not the lamps give light in this experiment?

EXPERIMENT No. 34

Question.—How much current is required to light an ordinary 16-candlepower carbon filament lamp? A 32-candlepower?

What is the potential difference between the terminals of the lamp? Calculate the resistance of each.

Apparatus.--110-volt circuit; 16-candlepower and 32-candlepower lamps; voltmeter; ammeter.



Directions.— Connect the ammeter in series and the voltmeter in parallel with the lamp as shown in the diagram. (*Caution.*—Do not turn on the current without first showing the connections to the instructor). The ammeter will give the current in amperes passing through the lamp, while the voltmeter will give the potential difference in volts between the terminals of the lamp. While testing one of the lamps have the other turned off.

Since a potential difference of 1 volt will drive a current of 1 ampere through a resistance of 1 ohm, the resistance of the lamp in ohms can be calculated by making use of Ohm's Law:

$$\text{Amperes} = \frac{\text{Volts}}{\text{Ohms}} \text{ or}$$

$$\text{Ohms} = \text{Volts} \div \text{amperes}$$

Results.—

Candlepower of Lamp	Current	Potential Difference	Resistance

Discussion.—Examine the construction of the above lamps and note why one should have a higher resistance than the other.

A street car running on a 550-volt circuit is to be lighted by twenty 110-volt 16-candlepower lamps. Make a diagram showing how these lamps should be connected.

EXPERIMENT No. 35

Question.—Why is it better to connect house electric lamps in parallel? Find the resistance of two lamps in parallel and compare it with the resistance of one lamp found in the preceding experiment. Also the resistance of four lamps in parallel.

Apparatus.—Four 16-candlepower lamps; 110-volt circuit; voltmeter; ammeter.

Directions.—Connect the ammeter in series with two of the lamps, the lamps being in parallel, and connect the voltmeter across their terminals as shown in the diagram of the preceding experiment. (*Caution.*—Show connections to instructor before turning on the current.) Note the current in amperes passing through the lamps, also the potential difference in volts between the terminals of the lamps. In like manner test four lamps in parallel.

Calculate the resistance of each combination of lamps by Ohm's Law as explained in Experiment No. 34.

Results.—

	Current	Voltage	Resistance
One lamp			
Two in parallel			
Four in parallel			

Discussion.—What is the effect of connecting lamps in parallel? Why is it advantageous to have house lamps connected in this way?

Make a diagram showing how you would run the wires for a house of four rooms, each room having two lights.

EXPERIMENT No. 36

Question.—How many watts of power are required to light an arc lamp?

Apparatus.—Arc lamp; voltmeter; ammeter.

Directions.—Connect the ammeter in series and the voltmeter in parallel with the arc lamp. (*Caution.*—Do not turn on the current until connections have been shown to the instructor. As soon as the lamp burns steadily as shown by the meters, note the amount of amperage and voltage required for the lamp.

$$\text{Watts} = \text{Volts} \times \text{amperes}$$

Calculate the number of watts of power required to operate the lamp.

Results.—

Current strength =
Electromotive force =
Electrical power =

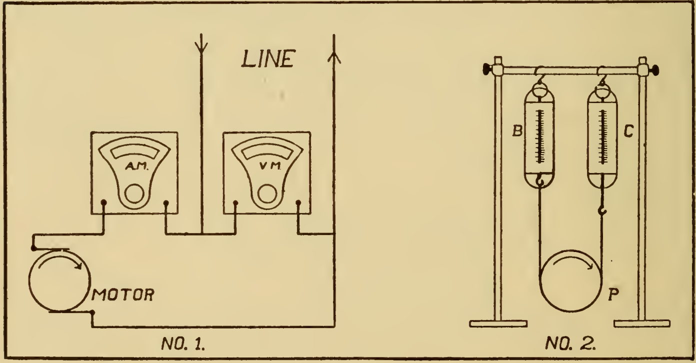
Discussion.—Just as water power depends upon water pressure and the quantity of water flowing per second, so electrical power depends upon electrical pressure and the quantity of electricity flowing per second. The unit of electrical pressure is the volt, and the unit of quantity of electricity per second is the ampere. Electrical power, therefore, is equal to amperes multiplied by volts. The unit of electrical power is the watt. One ampere flowing under a pressure of one volt is equivalent to one watt.

Consult a reference for an explanation of the construction and operation of the arc lamp.

EXPERIMENT No. 37

Question.—What is the efficiency of the electric motor in the laboratory? That is, what per cent of the electrical power put into the motor is gotten out of it in the form of mechanical power?

Apparatus.—Motor; ammeter; voltmeter; two spring balances; brake belt; speed indicator; watch.



Directions.—To obtain the number of watts electrical power put into the motor, connect the ammeter in series and the voltmeter in parallel with the motor as shown in Diagram No. 1.

To obtain the mechanical power gotten out of the motor make use of the brake shown in Diagram No. 2, consisting of two spring balances *B* and *C* and a friction belt passing under the pulley *P*. Raise the rod supporting the balances until the pointers of *B* and *C* stand about midway on the scales. If the motor rotates in the direction indicated by the arrow there will evidently be more pull on balance *C* than on balance *B*. The difference between the readings of the balances gives the pounds pull on the face of the pulley.

One student should read the ammeter and voltmeter; a second student, the balances; and a third, the speed indicator and watch.

Before starting the motor, disconnect the belt from the balance *B*. Throw in the switch and move the lever of the starting resistance slowly to the off position. When the motor has come to speed replace the belt on the balance *B*. Note the number of revolutions made in one minute, and during the entire time observe the balances and the ammeter and voltmeter in order to get their average readings.

Calculate the *input* of electrical power. Amperes multiplied by volts equal watts. To what is this equivalent in horse-power?

(1 horse-power = 746 watts)

Calculate the *output* of mechanical power. The number of foot-pounds of work done during the one minute is the measure of the output. The pounds pull on the friction belt is evidently the difference between the readings of the two balances. During one revolution of the motor this pounds pull acts through a distance equal to the circumference of the pulley. With a pair of calipers measure the diameter of the pulley and calculate the circumference in feet. The foot-pounds of work done by the motor during one revolution is therefore equal to the pounds pull multiplied by the circumference of the pulley. The foot-pounds of work per minute done by the motor is evidently equal to the work done during one revolution multiplied by the number of revolutions made in one minute. To what is this equivalent in horse-power? (1 horse-power = 33,000 foot-pounds per minute).

Calculate the efficiency of the motor. You have already learned that the efficiency of a machine is equal to the ratio of the output to the input.

Results.—

Input:

- Volts =
- Amperes =
- Watts =
- Horse-power =

Output:

- Reading of balance *B* =
- Reading of balance *C* =
- Pounds pull =
- Diameter of pulley =
- Circumference of pulley =
- Foot-pounds during one revolution =

Number of revolutions per minute =
Foot-pounds per minute =
Horse-power =

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}} =$$

Discussion.—How does the efficiency of an electric motor compare with that of a water motor? (Experiment No. 14.)

To what are the losses in an electric motor due? Is there any friction due to the atmosphere? If you place a thermometer on the field or armature windings before and after a run you will find that there is a rise in temperature. What is the cause of this?

Can we run a 4-horse-power motor with a 4-horse-power dynamo? Why?

Problem.—An electric motor delivers 10 horse-power. If it has an efficiency of 90 per cent how many amperes are required to run it on a 110-volt circuit?

EXPERIMENT No. 38

Question.—How much heat is radiated per second by a 110-volt 16-candlepower lamp? Is there any definite relation between the amount of heat produced and the electrical power required to run the lamp?

Apparatus.—Calorimeter; 16-candlepower lamp; voltmeter; ammeter; Fahrenheit thermometer.

Directions.—Connect the ammeter in series and the voltmeter in parallel with the lamp. (*Caution.*—Show the connections to the instructor before turning on the current.) Place in the calorimeter one pound of water. The water should be as cold as can be drawn from the faucet. Take the temperature of the water, leaving the thermometer in the calorimeter. Immediately place the lamp in the water and note the time. The lamp should be held so that the brass base is just above the surface of the water. Let run for ten or fifteen minutes. The meters should have uniform readings throughout the experiment. Remove the lamp, quickly stir the water with the thermometer, and take the final temperature.

Bearing in mind that one B. T. U. is the amount of heat required to raise the temperature of one pound of water 1° F., calculate the number of B. T. U. given out by the lamp during the time of the experiment. How many B. T. U. per second? Knowing the number of watts (amperes × volts) required to produce this amount of heat per second, you can calculate the number of watts required to produce 1 B. T. U. per second.

Results.— Weight of water =
Rise in temperature =
Number of seconds =
Total number of B. T. U. =
B. T. U. per second =
Watts (amperes × volts) =
Watts for 1 B. T. U. per second =

Problems.—One B. T. U. per second is equivalent to what horse-power?

How many watts of power are required to run an electric heater that furnishes 820 B. T. U. an hour?

EXPERIMENT No. 39

Question.—Why do different sized organ pipes or tuning-forks emit different pitched tones?

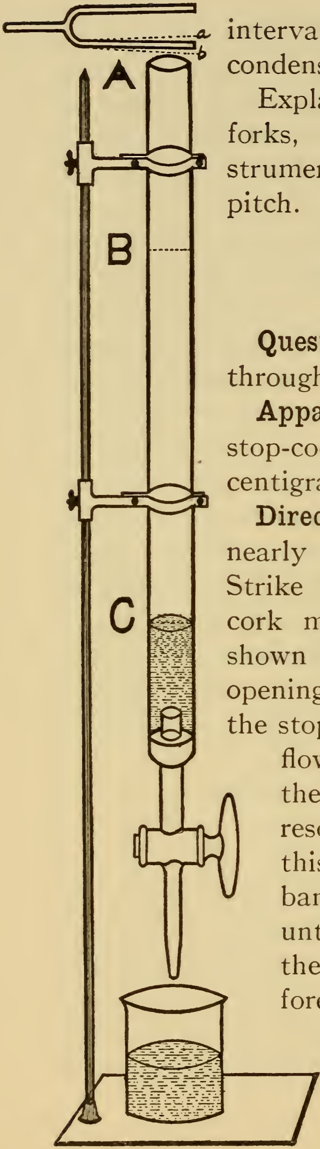
Apparatus.—Rotator; speed indicator; siren disk; tuning-fork; blow-pipe; watch.

Directions.—Place on the shaft of the rotator the siren disk. Using the blow-pipe, force a continuous blast of air through one of the rows of holes of the disk. Cause the rotator to revolve at such a speed that a sound is produced of the same pitch as the tuning-fork. By means of the speed indicator note the number of revolutions of the disk in one minute. Calculate the number of revolutions per second. Count the number of holes in the row used and multiply by the number of revolutions per second. This will give the number of holes passing by the blow-pipe in one second, or the number of puffs of air per second. Since the disk and tuning-fork produce the same tone, the number of puffs per second equals the vibration frequency of the tuning-fork.

Results.—

Number of revolutions per minute =
Number of holes in row =
Number of puffs per second =

Discussion.—When the tuning-fork vibrates, it periodically condenses the air in front of the prong once during each vibration, causing so many condensations per second. Similarly, when the air is blown through the row of holes of the disk, these holes being equal distances apart, the air is cut up at regular



intervals into just so many puffs or condensations per second.

Explain why different sized tuning-forks, organ pipes, or other musical instruments produce tones of different pitch.

EXPERIMENT No. 40

Question.—How fast does sound travel through the air?

Apparatus.—Glass tube fitted with stop-cock; tuning-fork of known pitch; centigrade thermometer.

Directions.—Close the stop-cock and nearly fill the glass tube with water. Strike the tuning-fork with a rubber or cork mallet and hold in the position shown in the diagram as near to the opening of the tube as possible. Open the stop-cock a little and let the water flow until a point *B* is found where the sound of the tuning-fork is best resonated by the air column. Mark this point *B* with a thread or rubber band. Now let the water flow again until another point *C* is found where the tuning-fork is resonated as before. The points *B* and *C* should be well fixed by a second or third trial if necessary. Measure the length BC in centimeters. This length BC is one-half of the length of a sound wave produced in the air by this particular tuning-fork.

Explanation.—When the tuning-fork moves from a to b a condensation of air is produced. When the water stands at B, this condensation moves down the tube to B and back to A in time to join the prong in its upward movement from b to a, thereby increasing the sound. That is, while the tuning-fork is making one-half of a vibration (ab), one-half of a wave-length is formed (A to B and back to A). Therefore AB is one-fourth of a wave-length. Again, when the water stands at C the prong makes three half-vibrations beginning at a, while the condensation runs down the tube and back. Therefore AC is three-fourths of a wave-length or BC is one-half a wave-length. $2BC = 1$ wave-length. The number stamped on the tuning-fork represents the number of vibrations or wave-lengths made by it in one second. Multiplying, you have the distance sound travels in air in one second.

The colder the air the slower sound travels. There is a variation of 60 centimeters for each degree centigrade. How fast would sound travel at 0° C.? Take the temperature of the air in the tube, and calculate the velocity at 0° C.

Results.—Length of air column BC =
Length of sound wave =
Number of vibrations of fork =
Velocity of sound at ——— C. =
Velocity of sound at 0° C. =

Discussion.—If you had used a different pitched tuning-fork the velocity of sound would have been found to be the same. If you had used a tuning-fork having twice the vibration frequency, what length would the air column have to be in order to resonate it?

Give examples of musical instruments that make use of resonating air chambers.

EXPERIMENT No. 41

Question.—What effect has varying the length of the string upon the pitch of the tone produced?

What effect has tension?

Apparatus.—Sonometer; set of tuning-forks; two steel wires of same diameter.

Directions.—To show the effect of length, tune one of the wires on the sonometer to the C-fork (256 vibrations per second). Measure the length of the string. Now shorten the string to one-half its original length by means of the movable bridge. Find a tuning-fork which makes the same number of vibrations per second. Record this number and the length of the string.

To show the effect of tension, tune one of the wires to the C-fork, the other to the fork an octave higher. Record the vibration frequencies and tensions of the wires.

Results.—

Effect of Length		Effect of Tension	
Length	No. of Vibrations	Tension	No. of Vibrations

Discussion.—Do you find that *the pitch of a wire is proportional to its length?* Which wires in a piano give the notes of highest pitch? Of what use are the frets on a banjo?

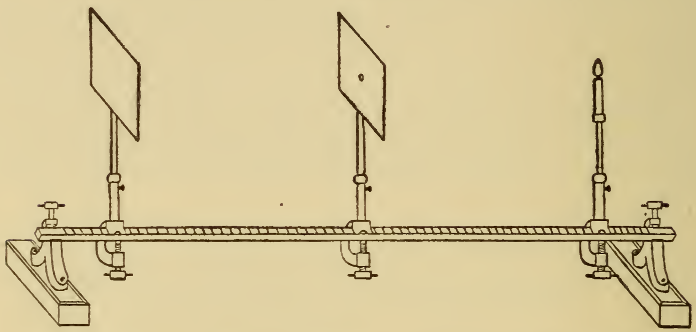
Extract the square-roots of the tension in the above results and note whether *the vibration frequency of a wire is proportioned to the square-root of its length.* How is a piano tuned?

Why was it necessary to have the wires of the same diameter in this experiment?

EXPERIMENT No. 42

Question.—Of what use is the pupil of the eye?

Apparatus.—Dark room; optical bench; gas jet or candle; screen; piece of card-board.



Directions.—Arrange the apparatus as shown in the diagram, with the gas jet, turned flatwise, at one end and the screen at the other. Make a hole in a piece of card-board with the point of the pencil and mount it between the flame and the screen. Observe the image of the flame on the screen. Account for its being inverted. Move the card-board back and forth and account for the varying size of the image. Make a diagram of rays of light leaving the upper and lower parts of the flame passing through the aperture and striking against the screen.

Gradually enlarge the hole in the card-board until it is an inch or so in diameter and note the effect on the image. Explain the cause of this effect.

Discussion.—Explain the use of the pupil of the eye. If the lens of the eye were removed, as is sometimes done, without injuring the other parts, would you be able to see anything?

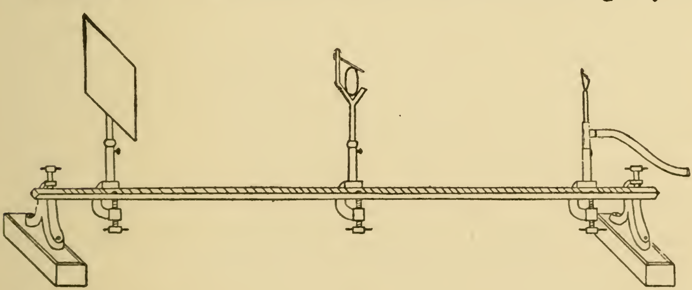
When the oculist introduces atropine intc the eye to enlarge the pupil, objects are then seen indistinctly. Why? Have a fellow student look toward the light, then away from it, and note the change in the size of the pupil. Why does the eye make this accommodation?

When you are taking a photograph in the bright sunshine why should you use a small aperture of the camera?

EXPERIMENT No. 43

Question.—Why is the vision of a far-sighted person corrected by the use of convex lenses? Test lenses of different convexity for their focal length.

Apparatus.—Dark room; optical bench; two lenses of different convexities; concave lens; screen; gas jet.



Directions.— Arrange the gas jet, lens, and screen on the optical bench as shown in the diagram. Adjust the flame and screen until positions are found equidistant from the lens, and at the same time a distinct image is formed on the screen of the same size as the object. Measure the distance from the lens to the screen. Half this distance is the focal length of the lens. Test the other lens of different convexity in the same manner.

Test a concave lens in the same way. Are the rays of light brought to a focus or do they diverge?

Results.—Record the focal lengths of the lenses.

Discussion.—What effect has a convex lens upon the rays of light? Is it the lens of greater convexity that has the greater converging power?

The lens of the eye is a double convex lens. In a far-sighted person this lens does not converge the rays sufficiently to produce a clear image on the retina of the eye. Explain the defect of the lens, and why a convex lens is used to correct the vision.

What is the defect of the eye of a near-sighted person and why does a concave lens correct it?

EXPERIMENT No. 44

Question.—How can the magnifying power of a telescope be determined?

Apparatus.—Telescope; optical bench or sunlight.

Directions.—Place on the blackboard a horizontal scale in inches, making the division marks very clear. At a distance of ten or fifteen feet, place the telescope and carefully focus it upon the scale. Determine how many divisions of the scale as seen by one eye without the use of the telescope will just cover one division as seen through the telescope at the same time by the other. This will give the magnifying power. It may take some time to accustom the eyes to use the instrument in this way and to adjust it so that one scale will be seen superposed on the other.

Remove the lenses from the telescope, being careful not to injure them in any way, and find their focal lengths by means of the optical bench as explained in the preceding experiment; or, the focal length may be found by the sunlight. Focus the parallel rays of the sun on a screen, being careful that the lens is perpendicular to the rays. The distance from the lens to the screen is the focal length. It has been shown that the magnifying power is equal to the focal length of the object-glass divided by the focal length of the eye-piece. Find the magnifying power in this way and compare the result with that obtained in the first part of the experiment.

Results.—

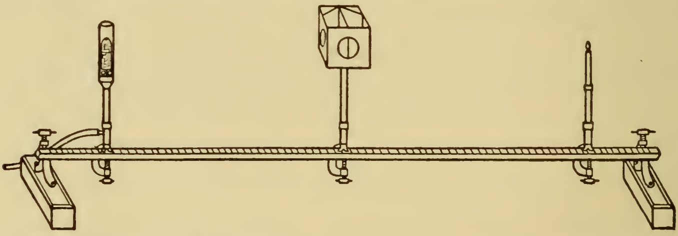
Magnifying power by scale comparison =
Focal length of object-glass (F) =
Focal length of eye-piece (f) =
Magnifying power = $F \div f$ =

Discussion.—Consult your text book or a reference for a description of the astronomical telescope. Construct a diagram tracing the rays of light through the lenses to the eye.

EXPERIMENT No. 45

Question.—What is the candlepower of an ordinary gas jet? Of a Welsbach burner?

Apparatus.— Dark room; optical bench; photometer; standard candle; gas jet; Welsbach burner.



Directions.—Place the standard candle at one end of the optical bench, the gas jet turned flatwise at the other end, and the photometer between the two. The candle should be kept trimmed so that the flame will be as near 3 c. m. long as possible. Note the oiled translucent spot in the center of the photometer screen. By looking into the mirrors placed at an angle of 45° to the screen, the observer can determine whether one side of the screen is illuminated more than the other. Move the screen until it is equally illuminated on both sides; that is, when the distinction between the oiled spot and the rest of the screen almost wholly disappears. Measure the distances from the screen to the candle and from the screen to the gas jet.

The gas jet must have more than one candlepower since it produces at a greater distance than the candle the same illumination. It has been shown that *when two lights illuminate an object equally, their candlepowers are proportional to the squares of their distances from the object.* In other words, if the gas jet were twice as far away as the candle it would have 4-candlepower; 3 times as far, 9-candlepower; 4 times as far, 16-candlepower; etc. Therefore, to find the candle-power of the gas jet, divide its distance from the screen by the distance of the candle from the screen and square the quotient.

In like manner find the candlepower of the Welsbach burner.

Results.—

Distance of candle (d) =

Distance of gas-jet (D) =

Candlepower of gas-jet = $\left(\frac{D^2}{d}\right)$ =

Distance of Welsbach burner =

Candlepower of Welsbach burner =

Discussion.—Why does a Welsbach burner give more light than an ordinary gas-jet? Does it use as much gas? Which will give more illumination, a candle at a distance of one foot or a 16-candlepower lamp at a distance of four feet?

EXPERIMENT No. 46

Question.—What is the efficiency of a carbon filament lamp? Of a Tungsten lamp?

Apparatus.—Optical bench; photometer; standard candle; carbon filament and tungsten lamps; ammeter; voltmeter.

Directions.—The efficiency of an electric lamp is measured by the number of watts per candlepower required to run the lamp; the less the number of watts per candlepower the higher its efficiency. Let us see which has a higher efficiency; the carbon filament lamp, or the tungsten lamp.

Find the candlepower of each lamp according to directions given in Experiment No. 45. Also find the number of watts required for the lamp by the method given in Experiment No. 36. Calculate the number of watts per candlepower.

Results.—

I. Carbon filament lamp

Distance of lamp from screen =
Distance of candle from screen =
Candle-power of lamp =
Amperes =
Volts =
Watts =
Watts per candlepower =

II. Tungsten lamp
(Same data)

Discussion.—Which has a higher efficiency, the carbon filament or the tungsten?

The consumer is charged for electric lighting so much per kilowatt-hour. A kilowatt equals 1000 watts. A kilowatt-hour is the electrical work done in 1 hour at the rate of 1 kilowatt. Suppose you wish to light a house with twenty 32-candlepower lamps and burn all of them on an average of 4 hours a day. If electricity costs 10 cents per kilowatt-hour what will be the difference in cost per month (30 days) by using tungsten lamps instead of carbon filament lamps?

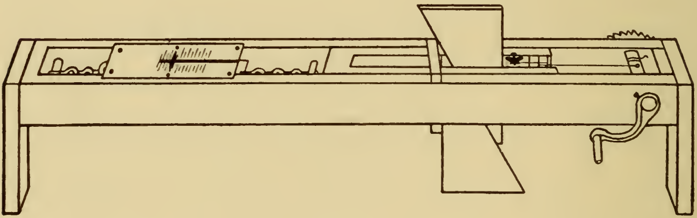
APPENDIX I

EXPERIMENT A

Question.—Does the use of dye in coloring thread black affect its strength?

Test the breaking-strength of black and white cotton thread of the same size and make.

Apparatus.—Tensile machine; white and black thread, of same number, as coarse as can be obtained, and of same make.



Directions.—Arrange the wedges of the instrument as shown in the diagram with one supported on the table and the other resting in the slot. Pass one end of the thread to be tested through the hole in the crank-shaft, and turn the crank so that the thread will wind itself several times around the shaft. Pass the other end of the thread once around the horizontal post of the sliding frame and then clamp under the binding screw. With the left hand, keep a slight pressure on the upper wedge so that it will fill the slot as the sliding frame moves forward. By turning the crank, increase the tension on the thread until it breaks.

Test each kind of thread five or six times in order to get its average breaking-strength.

Results.—

Average breaking-strength of white thread =

Average breaking-strength of black thread =

Discussion.—Does the use of dye affect the strength of the thread? What kind of material is used for making the strongest fishing lines? Of what are tent ropes made?

Piano wires are made of what material? Why? Why do the lead cables used by telephone companies have to be suspended every foot or so from an iron cable? Of what material are suspension bridges constructed?

EXPERIMENT B

Question.—Why will an auger bit stand a certain amount of twisting without changing its shape? Is there any definite relation between the twisting force and the amount of distortion?

Apparatus.—Torsion frame with grooved wheel marked in degrees and vernier attachment; scale pan and weights; iron or steel rod.

Directions.—Thoroughly clamp the rod in the frame. See that the zero of the vernier is just opposite the zero on the wheel when no weight hangs from the wheel. Place weights in the pan until the total weight, including the weight of the pan, equals 500 grams, and note the amount of torsion in degrees. Read to tenths of degrees by means of the vernier. If the zero of the vernier does not come exactly opposite a mark on the wheel, look along the vernier until you find two marks that come exactly in a line. The number of the line on the vernier, counting from zero, will give the number of tenths of degrees. Remove the weight and note whether the scale returns to zero. In like manner, take readings for 1000, and 2000 grams.

Results.—

Twisting Force	500 gm.	1000 gm.	2000 gm.
Distortion			

Discussion.—What relation exists between the amount of distortion and the force applied? Is the rod permanently distorted? What name is given to this property of matter which causes the rod to return to its original shape? Is the frame of a bicycle in use subject to twisting forces? May the twisting force sometimes be great enough to permanently distort the frame? Is there then an elastic limit to steel? Name some substances that have a lower elastic limit than steel.

EXPERIMENT C

Question.—Why does a pendulum clock always have some means for adjusting the length of the pendulum?

Is there any definite relation between the length of a pendulum and the time of its vibration?

Apparatus.—Pendulum support; thread; iron ball; watch.

Directions.—Fasten to the support a pendulum one hundred centimeters long. The length of the pendulum should be measured carefully from the point of support to the center of the bob. By amplitude of vibration is meant the distance the bob is drawn to one side from the vertical. Using a small amplitude, count the number of single vibrations made by the pendulum during one minute. Repeat the operation, shortening the pendulum to seventy-five centimeters, and again to fifty centimeters.

Results.—

Length of Pendulum	Number of Vibrations in One Minute	Time of One Vibration

Discussion.— Is the time of vibration of a pendulum proportional to its length; that is, if we double the length, is the time of vibration twice as long? Suppose you extract the square-root of the length of the pendulum in each of the above cases. Do you find that the time of vibration of a pendulum is proportional to the square-root of its length?

What force causes the pendulum to return each time to the middle point of its swing? Is this a constant force? Would a pendulum clock be possible if the force were not constant? Why?

If you move a pendulum clock into a very warm room will it gain or lose time? Why?

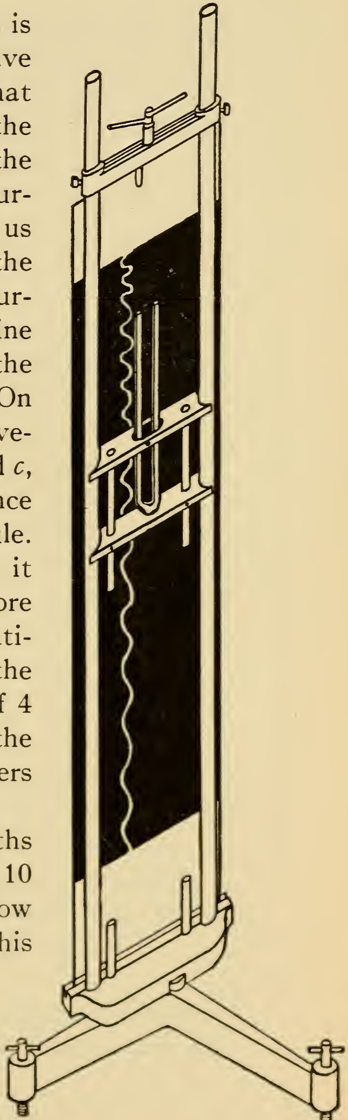
Will a pendulum clock gain or lose time if you take it to the top of a high mountain? Why? To the sea level? To the equator? To the north pole?

EXPERIMENT D

Question.—A man falling off a tower 200 feet high will strike the earth with what velocity?

Apparatus.—Acceleration apparatus using a tuning-fork for the falling body.

Directions.—Note the mechanism at the top of the apparatus for holding the tuning-fork. Place the tuning-fork in position, and hang from its projecting shank a plumb bob, adjusting the leveling screws in the base of the instrument so that the fork will fall vertically. By turning the lever, the tuning-fork is released and at the same time is set in vibration. As the fork descends it traces a wavy line on the smoked glass. Stamped on the fork is the number of vibrations it makes per second. The distance the fork falls during one vibration is measured by the length of the wave made during that period. Note that the wave-lengths get longer, the further the fork descends, that is, the greater the distance passed over during one vibration of the fork. Let us now find the velocity with which the fork is moving at certain points during its fall. Through the wavy line draw a line, 10 centimeters from the starting point and letter it *a*. On each side of *a* mark off two wave-lengths and letter these points *b* and *c*, respectively. Measure the distance *bc* with a pair of dividers and rule. The fork moved from *b* to *c* while it was making 4 vibrations. Therefore the velocity of the fork at *a* in centimeters per second is equal to the distance *bc*, divided by the time of 4 vibrations. In like manner find the velocity of the fork at 40 centimeters from the starting point.



Count the number of wave-lengths from the starting point to the 10 centimeter mark, and calculate how long it took for the fork to fall this distance. How much did the fork change its velocity during this time? How much would the fork change its velocity during 1 second? In like manner calculate how long it took for the fork to fall from the 10 centimeter mark to the 40 centimeter mark, and how much it changed its velocity during this time; consequently how much it would change its velocity during 1 second.

From the results obtained we conclude that the rate of change of velocity (*i.e.*, the acceleration) of a falling body is uniform. You have found the acceleration in centimeters per second. What is this equal to in feet per second?

Results.—

Velocity of fork at 10-centimeter mark	=
Time required to fall 10 centimeters	=
Acceleration during this time	=
Acceleration for 1 second	=
Velocity of fork at 40-centimeter mark	=
Time required to fall from 10-centimeter to 40-centimeter mark	=
Acceleration during this time	=
Acceleration for 1 second	=

Discussion.—From results obtained you will note that the velocity of the fork is equal to the acceleration multiplied by the time it has been falling, or

$$v = a\ t \qquad (1)$$

Also, that the velocity is equal to twice the distance divided by the time, or

$$V = \frac{2\ s}{t} \qquad (2)$$

Multiplying equation (1) by equation (2) we have $V^2 = 2\,a\,s$, or $V = \sqrt{2\,a\,s}$

Using this formula, you can work the problem given at the beginning of the experiment.

Give other illustrations of accelerated motion besides that of a falling body.

When water is poured from a pitcher, why is the stream thinner at the bottom?

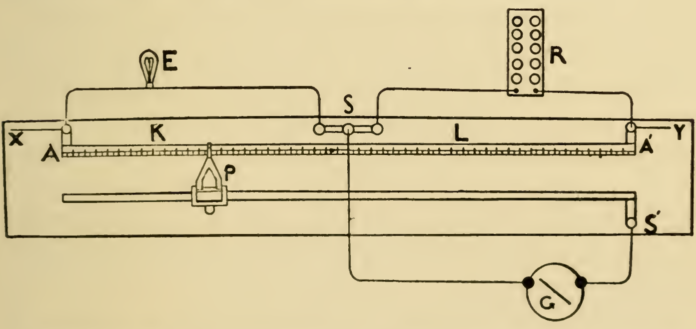
Does a bullet fired vertically upward return to the earth with the same velocity with which it left the gun? Why?

A paper bag full of water dropped from an upper story is dangerous to the passerby, while the water is not dangerous if poured from the bag. Why?

EXPERIMENT E

Question.—What is the resistance of a 16-candle-power carbon filament lamp when cold?

Apparatus.—Wheatstone's bridge; galvanometer; resistance box; electric lamp; one or two cells.



Directions.—Connect the apparatus as shown in the diagram. *X* and *Y* are wires leading to the battery; AA', a high resistance wire one meter long, stretched on a meter-stick; G, a galvanometer; E, the lamp to be tested; R, a resistance box; P, a sliding piece, for making contact with the wire, and electrically connected to S', a broad bar having practically no resistance.

Trace the direction the current takes when P is raised. It enters X (say) and is divided into two parts at A, one of which goes through E and R, and the other from A to A' where the two branches join and return to the battery through Y.

The principle of the Wheatstone bridge is this; since the current divides at A and is united again at A', the fall of potential along the two branches is the same. If P is in such a position that a current passes through the galvanometer, the fall of potential from A to S is not the same as the fall of potential from A to S'. But when there is no flow through the galvanometer, the fall of potential from A to S is the same as from A to S'. Or, in other words, the fall of potential in E is equal to the fall of potential in K, and the fall of potential in R is equal to the fall of potential in L. Since this is true,

$$\frac{E}{R}=\frac{K}{L}$$

Knowing the values of R, K, and L, found by the experiment, the value of E, the resistance of the lamp, can be determined.

Introduce a resistance of 200 ohms in R. Move P along the wire AA' until a point is found where no current passes through the galvanometer. Measure the lengths of the divisions of the wire, *K* and *L*. Compute the resistance of the lamp.

Results.—

Length of wire, *K* =
Length of wire, *L* =
Resistance, *R* =
Resistance of lamp =

Discussion.—Why should the wire *AA′* be of the same diameter throughout?

Examine a 32-candlepower carbon filament lamp. Is the filament of a different length or diameter than that of the 16-candlepower? Why is this difference made? Examine a tungsten, or tantalum lamp, and give the reason for using a filament of such a length and diameter.

EXPERIMENT F

Question.—Upon what does the voltage of a dynamo depend?

Apparatus.—Dynamo belted to motor; speed regulator for motor; rheostat; voltmeter.

Directions.—Start the motor and bring it to its highest speed by gradually moving the arm of the speed regulator to the off position. Close the circuit which excites the field of the dynamo. Connect the voltmeter to the brushes of the dynamo and test its voltage. Now change the speed of the dynamo armature by changing the speed of the motor and note the effect on the voltage.

The armature rotates in a magnetic field produced by the current flowing through the field windings. What effect will changing the strength of the field have upon the voltage set up in the armature? Place a rheostat in series with the field coils so as to lessen the amount of current going to the field. Note the effect on the voltage by introducing more or less resistance in the rheostat.

Discussion.—The voltage set up in the armature is caused by the coils of wire on the armature cutting the lines of magnetic force passing between the north and south poles of the field magnet. The greater the number of lines of force cut per second, the higher the voltage. Therefore, if we were to increase the number of turns of wire on the armature, what effect would be produced on the voltage?

Explain the effect of changing the speed of the armature.

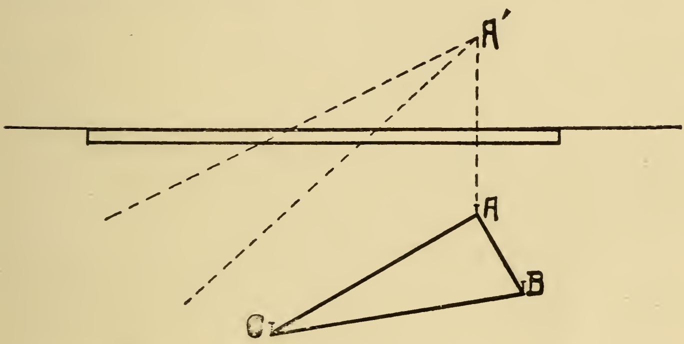
Explain the effect of changing the strength of the magnetic field. How would you change the field windings so as to increase the magnetic strength of the field?

If you wished to construct a dynamo having a very high voltage would you wind the armature with large or small wire? Why?

EXPERIMENT G

Question.—Why is the image in a plane mirror reversed?

Apparatus.—Rectangular mirror attached to block; cardboard; pin; rule.



Directions.—Write your name on a piece of paper, hold it in front of the mirror and note the image formed. Is it reversed? Let us locate the image formed by the mirror of some simple object such as a triangle and see the reason for its being reversed.

Draw a straight line through the middle of the card-board and place on it the reflecting or back surface of the mirror. In front of the mirror, and to one side as shown in the diagram, draw a triangle, *ABC*. The image of the triangle can be located by locating the images of its vertices, *A*, *B*, and *C*. Stick a pin vertically in the card-board at *A*. To the left of the triangle lay a rule on the card-board and sight along its edge to the image of the pin. Draw a line to indicate this direction. The image of A must lie somewhere in the line produced. Move the rule to one side and again locate by a line the direction in which the image is seen. The intersection of these two lines produced must be the location of the image of A. Letter this point of intersection A'. In like manner locate B' and C'. Connect A', B', and C'.

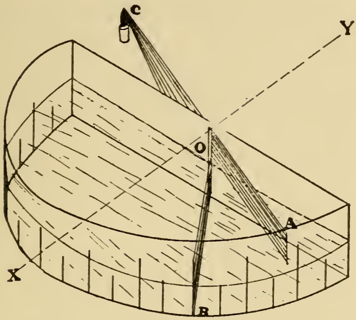
Discussion.—Does the location of $A'B'C'$ explain why the image formed by a plane mirror is reversed? Is a photograph of yourself the same as your image in a mirror? Has the image a fixed position no matter from what position you view it in front of the mirror? Connect A and A'; B and B'; C and C'. How does the distance of the image from the mirror compare with the distance of the object? When you approach a full-length mirror, what does your image do?

EXPERIMENT H

Question.—When looking at a pond of water at an angle, why does its depth appear less than it really is?

Apparatus.—Semi-circular glass vessel, the plane side being opaque with a vertical slit in the center through which light may pass, the half-circle being transparent and graduated in degrees; candle; compass.

Directions.—Fill the vessel one-third full of water and place the lighted candle in the position shown in the diagram. The incident beam of light CO will pass through the slit O. The part of the beam above the water will not be refracted and will pass in a straight line to A. The part striking the water will be



refracted and will go to *B*. Take the readings of *A* and *B* in degrees, counting from *X*, the zero of the scale.

With compass, rule, and sharp pencil, lay off on a page of your notebook an accurate reproduction of the half-circle and the lines *CO*, *OA*, and *OB*. Draw the line *XY* perpendicular to the plane side of the vessel at *O*. The angle *COY* is known as the *angle of incidence*. The angle *BOX* is known as the *angle of refraction*. The angle *AOB* is known as the *angle of deviation*. By reading *A* to get the measurement of angle *AOX* we get the measurement of angle *COY*. Why?

Make another trial with the candle nearer to *Y*, and still another with the candle at *Y*.

Results.—

	1st Trial	2nd Trial	3rd Trial
Angle of Incidence			
Angle of Refraction			
Angle of Deviation			

Discussion.—When light strikes the surface of water at an angle is it refracted? In what direction is the light wave bent, toward, or away from a line perpendicular to the surface? Which has a greater density, air or water? Do you think light moves more slowly in water than in air? Does this give you a reason for the fact that the light wave is bent the way it is when it enters water on a slant?

When light passes from water into air which way is it bent, toward or away from the normal? Make a diagram showing why a pond viewed slantwise seems to have less depth than it really has. Why do we see the sun before it is actually "up?" What is the cause of the twilight after sunset? Why does a "burning glass" bring light to a focus?

Why is a diamond such a brilliant stone?

APPENDIX II

TABLE I

Densities in Grams per Cubic Centimeters

SOLIDS	
Aluminum	2.56– 2.80
Amber	1.06– 1.11
Basswood	.32– .59
Birch	.51– .71
Brass	8.20– 8.60
Cedar	.49– .57
Copper	8.80– 8.95
Cork	.18– .24
Ebony	1.11– 1.33
Spruce	.48– .70
Gold	19.26–19.34
Hickory	.60– .93
Ice	.88– .92
Iron	7.03– 7.90
Lead	11.36–11.40
Limestone	2.46– 2.86
Mahogany	.56– .85
Maple	.62– .75
Oak	.60– .90
Pine	.46– .59
Silver	10.42–10.57

LIQUIDS	
Alcohol (95%)	.820
Ether	.736
Mercury	13.596
Naphtha, wood	.810–.848
Naphtha, petroleum	.665
Oil, linseed	.940
Oil, olive	.915
Oil, turpentine	.870
Water	1.000
Water, sea	1.026

GASES AT 0° C. AND 76 CM. PRESSURE	
Air	.001293
Carbon dioxide	.001977
Hydrogen	.000896
Nitrogen	.001256
Oxygen	.001430

TABLE II

Specific Heats

Air	.237
Aluminum	.218
Brass	.086
Copper	.093
Hydrogen	3.409
Ice	.505
Iron	.113
Lead	.031
Mercury	.033
Silver	.056
Water	1.000

TABLE III

Diameter of Wire, Brown and Sharpe's U. S. Standard Gauge

Gauge Number	Diameter Inches	Diameter Millimeters	Gauge Number	Diameter Inches	Diameter Millimeters
0000	.4600	11.684	17	.0453	1.1495
000	.4096	10.405	18	.0403	1.0237
00	.3648	9.266	19	.0354	0.9116
0	.3249	8.251	20	.0320	0.8168
1	.2893	7.348	21	.0285	0.7249
2	.2576	6.543	22	.0253	0.6438
3	.2294	5.827	23	.0226	0.5733
4	.2043	5.189	24	.0201	0.5106
5	.1819	4.621	25	.0179	0.4545
6	.1620	4.115	26	.0159	0.4049
7	.1443	3.665	27	.0142	0.3606
8	.1285	3.264	28	.0126	0.3211
9	.1144	2.906	29	.0113	0.2859
10	.1014	2.588	30	.0100	0.2546
11	.0907	2.305	31	.0089	0.2268
12	.0808	2.053	32	.0079	0.2019
13	.0720	1.828	33	.0071	0.1798
14	.0641	1.628	34	.0063	0.1601
15	.0571	1.450	35	.0056	0.1426
16	.0508	1.2908	36	.0050	0.1270

TABLE IV

Useful Data

$\pi = 3.1416$

Area of circle $= \pi R^2$.

1 in. = 2.54 cm.

1 meter = 39.37 in.

1 oz. avoirdupois = 28.35 gm.

1 kgm. = 2.2 lb.

1 liter = 2.11 pints.

1 cu. cm. water weighs 1 gm.

1 liter water weighs 1 kgm., or 2.2 lb.

1 gal. = 231 cu. in.

1 gal. water weighs 8.35 lb.

1 cu. ft. water weighs 62.5 lb.

1 cu. ft. air at 0° C. weighs .080728 lb.

1 H. P. = 33,000 ft. lb. per min.

1 H. P. = 746 watts.

1 B. T. U. = 252 gram calories.

1 B. T. U. = 778 foot-pounds.

1 B. T. U. per second = 1055 watts.