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LABORATORY MANUAL OF PHYSICS

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A LABORATORY MANUAL OF PHYSICS

BY

HENRY C. CHESTON, PHILIP R. DEAN
AND CHARLES E. TIMMERMAN

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MAN. PHYSICS.
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PREFACE

THE reason for adding this book to the large number of laboratory manuals is that those now in use either contain too much matter to be successfully covered by a pupil in one year, or elaborate the principles chosen without regard to economy in time.

In a large number of schools physics occurs in the course for but one year, and is given four or, at most, five periods per week. If of these five periods two are given to individual laboratory work, not more than fifty experiments can be performed, and these must be made so comprehensive as to afford a broad basis for class teaching.

We believe that little theory should be taught, the fundamental principles of which the pupil is not familiar with from personal investigation and subsequent reflection. In each experiment, after the data required have been collected by careful observation, each pupil should be expected to draw from these facts some general principle relevant to the declared object of the experiment. The pupils are not expected to discover Nature's laws, but their minds are directed in a certain definite channel to the conception of the general principle which the data at command indicate to be true. This constitutes the life of science teaching.

Difficulty will frequently be experienced in getting the pupils to write their conclusions in complete sentences.

For the formation of distinct concept this must invariably be required. We are confident that if the pupils are required to draw the inferences asked for in each experiment and the correction of the note-books by the teacher is not a perfunctory process, but is done with an eye single to the development of this logical faculty in the pupils, the training is more thorough than could possibly be obtained in any other way in the same time.

This manual contains all of the experiments, sometimes in condensed form, which are required by the College Entrance Board of the Middle States and Maryland, by Harvard University, and by the New York Board of Regents. Of these experiments it is expected that at least thirty-five will be performed by the individual pupil and that a record of them will be preserved in a note-book.

HENRY C. CHESTON.
PHILIP R. DEAN.
CHARLES E. TIMMERMAN.

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EXPERIMENT I

Object. — *To find the volume of a regular solid.*

Apparatus. — A rectangular block of wood; a cylinder of wood; a half-meter stick and two draughtsman's triangles.

Directions. — I. Measure the lengths of the twelve edges of the block.

To measure the length of an edge of the block, place the scale or measuring stick upon the block so that the graduations

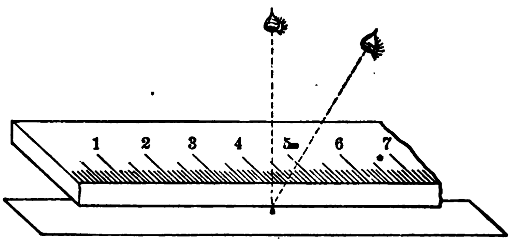

FIG. 1. — Wrong method.

are close to the edge to be measured. Do not use the graduations at the end of the stick, as it may be worn.

Read the marks on the scale at both ends of the edge and record them under Observations, being careful not to allow the scale to move until both readings have been taken. Estimate to tenths of the smallest division of the scale for each reading.

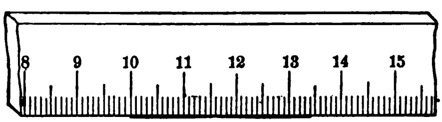

FIG. 2. — Right method.

(The left end reading is 9.98 cm.. and the right end reading is 13.42 cm. The length of the line is the difference of the readings, or 3.44 cm.)

Find the volume of the block from the average values of length, width, and thickness.

Enter observations as indicated below.

	Observations	1	2	3	4
Length	Scale reading, right end				
	Scale reading, left end				
	Length				
	Average length				
Width	Scale reading, right end				
	Scale reading, left end				
	Width				
	Average width				
Thickness	Scale reading, right end				
	Scale reading, left end				
	Thickness				
	Average thickness				
Volume of block					

II. Arrange apparatus as shown in Figure 3, having the triangles pressing against the half-meter stick and just touching

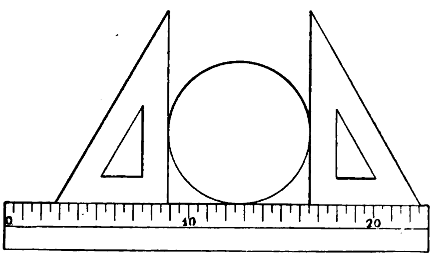

Fig. 3.

the cylinder. Take readings of four diameters of each circular face and eight readings for altitude.

Calculate the volume of the cylinder.

Observations.		1	2	3	4
Base 1st	Readings on scale, right end .				
	Readings on scale, left end . .				
	Diameter				
2d	Reading on scale, right end. .				
	Reading on scale, left end . .				
	Diameter				
	Average diameter				

		1	2	3	4	5	6	7	8
Altitude	Reading right end .								
	Reading left end. .								
	Altitude								
	Average altitude. .								
	Volume of cylinder.								

EXPERIMENT II

Object. — *To find the volume of an irregular solid.*

Apparatus. — A lump of lead or of iron; string; a graduated cylinder.

Directions. — Partly fill the cylinder with water. Owing to capillarity, the surface appears concave, as in Figure 4. Read the volume of the water, always sighting along the bottom of the curved surface. Estimate to tenths of the smallest division.

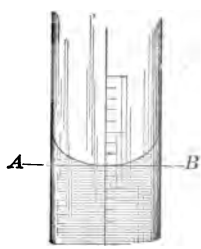

Fig. 4.

Wipe the solid carefully, and then immerse it as in Figure 5. Read the volume again, and calculate from these two readings the volume of the solid.

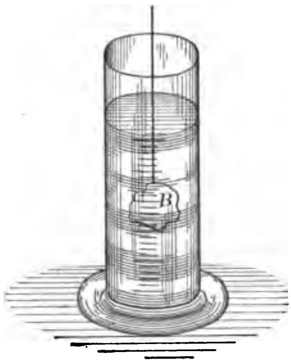

FIG. 5.

Beginning with a different quantity of water in the cylinder, make a second and a third set of readings. Wipe the solid each time before immersion.

Calculate the average volume of the submerged solid in cubic centimeters, stating, if possible, the degree of accuracy thus: volume of solid = —— c.c. ± —— c.c.

OBSERVATIONS	1	2	3
Reading of graduate before submerging solid,			
Reading of graduate after submerging solid .			
Volume of solid			
Average volume of solid			

Conclusions. — Explain why the method used gives the volume of the submerged solid.

EXPERIMENT III

Object. — *To determine the mass per unit volume (or density) of a solid.*

Apparatus. — A platform balance; a set of metric weights; and the solids of Experiments I and II.

Directions. — Move the slider *D* to the zero of the scale and set the balance to swinging slightly. If the pointer *P* moves equal distances on each side of the middle point of its scale, the balance is adjusted. If not, adjust the balance by means of the nuts on the screw thread S.

Test the sensitiveness of the balance by moving the slider one small division of its scale to see if the pointer still moves equal distances for each side of the middle point.

Place the solid whose mass is to be found upon the left pan of the balance and upon the right pan sufficient metric weights, beginning with the largest of the set, until, when the balance is swinging, the pointer moves equal distances on each side of the middle point of its scale. If this cannot be effected by the weights of the set alone, move the slider D along its scale until a balance is produced. Record the sum of the weights on the right pan and the reading of slider D as the mass of the solid.

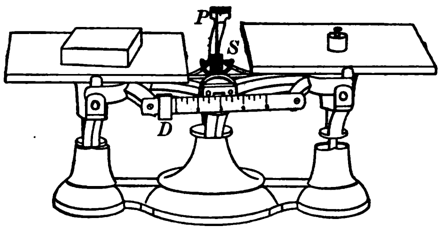

FIG. 6.

Interchange the positions of solid and weights and find the mass of solid when placed upon the right pan. Record the difference of the weights on left pan and the reading of slider as the mass of the solid.

Calculate the average mass.

Record the volumes of the solids as found in Experiments I and II.

Calculate the number of grams per cubic centimeter of volume of each solid.

OBSERVATIONS	WOOD	LEAD
Weights on right pan		
Weights on left pan		
Average mass		
Volume of solid		
Calculated mass per unit volume		

Conclusions. — Why was the mass determined the second time with the position of the solid and weights reversed?

Why should the reading of slider *D* be considered as minus when the weights are on the left pan?

EXPERIMENT IV

Object. — *To study the gravity pressure of liquids.*

Apparatus. — A jar of water; a pressure gauge; a half-meter stick.

Directions. — Open pinchcock at *C* for a moment, to bring the colored liquid in the arms of the U-tube to the same level. Turn the mouth of the thistle tube *E* upward. Read on the half-meter stick the position of the rubber membrane over the thistle tube; also the position of the top of the liquid in arms *A* and *B*.

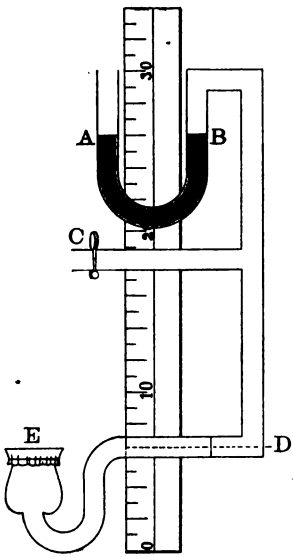

FIG. 7.

Be sure that the jar contains water that has stood some time in the room so that it is at the same temperature as the air. If the water in the jar has been recently drawn from the faucet, lower the gauge into the water for a few minutes, and then raise it and open the cock *C* to allow the air in the gauge to be at the same temperature as the water and also to bring liquid in *A* and *B* to same level.

Lower the gauge until the mouth *E* of the thistle tube is 3 cm. below the surface of the water in the jar. Read the levels on the half-meter stick of the liquid in *A* and *B*, also of the surface of the water in the jar. Raise the gauge from the water and note if the liquids in *A* and *B* come to the same level; if not, discard the reading. Readjust the level by opening cock *C* and repeat. Make a similar test after each reading. Then lower the tube *E* to 6 cm. below the water surface and take the readings as before. Finally, lower E to 9, 12, and 15 cm. below taking readings.

Now raise the gauge and turn the mouth of tube *E* downward. Lower the gauge to 6 and 12 cm. successively below the water surface as before and take the readings. Again raise the gauge and turn the thistle tube so that *E* faces sidewise, and repeat as above at 6 and at 12 cm.

Observations	Direction *E* faces	Position of *D*	Position of Water Surface	Position of Liquid in *A*	Position of Liquid in *B*	Depth of *E* below Water Surface	Difference of Levels of *A* and *B*
1							
2							
3							
4							
5							
6							
7							
8							
9							

Conclusions. — Plot on cross-section paper the curve showing the variation of pressure with the depth of liquid, marking the depths along the horizontal axis and the indicated pressure along the vertical axis.

What do your results prove about liquid pressure?

EXPERIMENT V

Object. — *To find the relation between the loss of weight of a body placed in a liquid, and the weight of liquid it displaces.*

Apparatus. — A cylinder which will sink in water; a cylinder which will float in water; an overflow can; a tumbler; a platform balance and metric weights.

Directions. — I. Adjust the balance. Weigh the sinking body in air and then find its weight while submerged in water in the manner shown in Figure 9. Place the overflow can upon a level surface. Pour water into it until it flows from the spout. Catch this water in the tumbler and, when the water ceases to flow, throw the water in the tumbler away. Then hold the empty tumbler under the spout, carefully submerge the solid in the water in the can, and catch all of the water that flows out. Do not disturb the can in any way. Weigh the tumbler and the water which the solid displaced. Weigh the tumbler empty. Calculate the loss of weight of the solid in water and the weight of water it displaced.

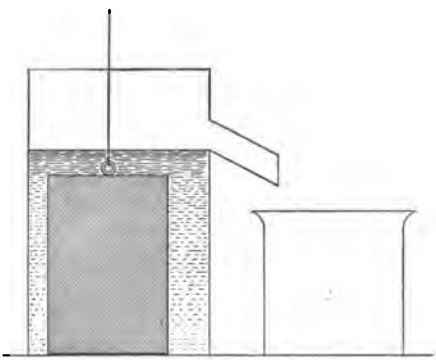

FIG. 8.

II. Repeat the foregoing with the floating solid except that, when the solid is placed in water, it must be allowed to float, that is, sink just as far as its weight pulls it under.

Observations	I. Sinking Solid	II. Floating Solid
Weight of solid in air		
Weight of solid in water		
Loss of weight in water		
Weight of empty tumbler		
Weight of tumbler and displaced water .		
Weight of displaced water		

Conclusions.—Infer from observations the relation sought both for any sinking solid and for any floating solid in any liquid.

From results of Experiment IV, explain why a solid weighs less in a liquid.

EXPERIMENT VI

Object.—*To determine the specific gravity of a solid that will sink in water.*

Apparatus.—Lumps of coal, lead, and iron; a jar of water; thread; a platform balance and weights.

Directions.—Adjust the balance. Find the weight in air and in water of the lumps of coal, lead, and iron. From these weights calculate the specific gravity of each.

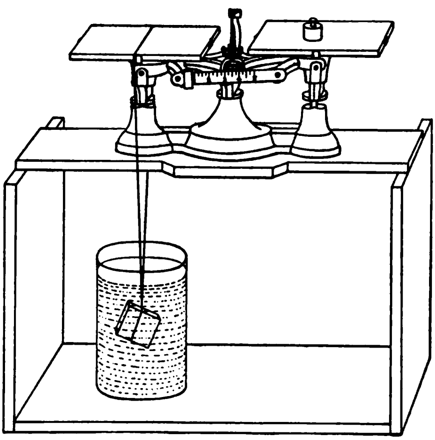

Fig. 9.

Definition. — Specific gravity is the number which expresses the number of times the *weight* of a substance is as great as the *weight* of an equal volume of water.

Observations	Coal	Lead	Iron
Weight in air			
Weight in water			
Calculated weight of an equal volume of water			
Calculated specific gravity			

Conclusions. — How do the conclusions of Experiment V aid you in finding the specific gravity of a sinking solid?

Show clearly that the number you recorded as the specific gravity of coal or lead is in accordance with the above definition.

EXPERIMENT VII

Object. — *To find the specific gravity of a body that will float in water.*

First Method

Apparatus. — A wooden block; a sinker; a platform balance and weights; a vessel of water.

Directions. — Adjust the balance. Weigh the sinker in air and then when suspended in water. Weigh the block in air. Then attach the sinker closely to the under side of the block and weigh both together in water. Calculate the loss of weight of the combined mass in water and the loss of weight of the sinker alone. From these calculate the weight of water displaced by the submerged block. Then calculate the specific gravity of the block.

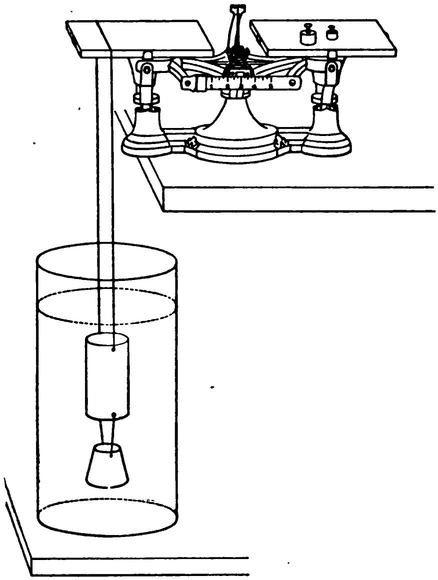

FIG. 10.

OBSERVATIONS	
Weight of sinker in air	
Weight of sinker in water	
Weight of block in air	
Weight of block and sinker together in water	
Calculated weight of water of same volume as block	
Calculated specific gravity of wood	

SECOND METHOD

Apparatus.— A cylinder of wood about 1 cm. in diameter and 20 cm. long; a clamp and guides to make it float upright in water; a jar of water; a half-meter stick.

Directions. — Measure the length of the cylinder, then float it upright in water by means of the clamp and guides, and measure the length of cylinder above the water surface. Repeat, having the other end uppermost.

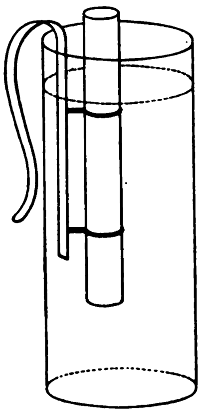

FIG. 11.

Calculate the average length under water, and divide this length by the entire length of the rod. The quotient is the specific gravity of the wood.

OBSERVATIONS	1	2
Length of wooden cylinder		
Length of cylinder above water		
Calculated length of cylinder under water		
Average specific gravity of wood		

Conclusions. — Explain both of these methods, showing why the results obtained must be the specific gravities sought.

EXPERIMENT VIII

Object. — *To find the specific gravity of a liquid.*

First Method

Apparatus. — A small wide-mouthed bottle with glass stopper; a jar of alcohol; a platform balance and weights.

Directions. — Adjust the balance. Weigh the bottle when it is empty and dry. Fill it with alcohol, being careful that no bubbles remain in the bottle, and weigh again. Pour the alcohol back into the large jar of alcohol, dry the small bottle, and then fill it with water. Weigh again. Calculate the weights of alcohol and of water the bottle contained, and from these weights calculate the specific gravity of alcohol.

Observations	
Weight of empty bottle	
Weight of bottle filled with water	
Weight of bottle filled with alcohol	
Calculated weight of water in bottle	
Calculated weight of alcohol in bottle	
Calculated specific gravity of alcohol	

Second Method

Apparatus. — A lump of lead or other sinking solid; a small jar; alcohol; a platform balance and weights.

Directions. — Weigh the solid in air and then when it is submerged in alcohol. Wipe the solid dry and weigh it in water. Calculate the loss of weight of the solid both in alcohol and in water, and from these find the specific gravity of alcohol.

Observations	
Weight of solid in air	
Weight of solid in alcohol	
Weight of solid in water	
Calculated loss of weight in alcohol	
Calculated loss of weight in water	
Calculated specific gravity of alcohol	

Conclusions. — Explain both methods, showing especially how the conclusions of Experiment V apply to the determination of specific gravity in II.

EXPERIMENT IX

Object. — *To find the specific gravity of a liquid.*

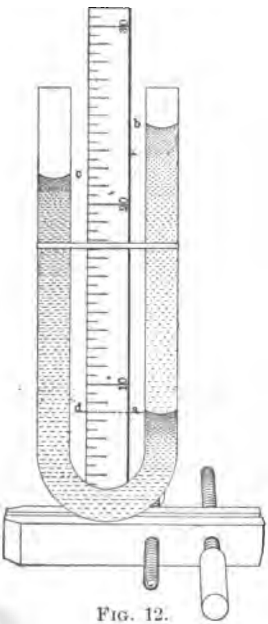

FIG. 12.

First Method

Apparatus. — A glass U-tube with arms about 30 cm. long mounted vertically in front of a metric scale; kerosene and water.

Directions. — Pour water into the U-tube till each arm is about half full. Then pour kerosene into one arm until the surface of separation of the two liquids is about 1 cm. above the bend of the tube. Take readings on the scale, first, of surface of separation of water and kerosene *a*; second, of upper surface of kerosene *b*; and third, of upper surface of water *c*.

Change the quantity of kerosene in the arm *b* several times, and repeat readings.

Calculate the length of the kerosene column *ab* and the length of the water column *cd* above the level of the surface of separation. From the two lengths calculate the specific gravity of kerosene.

Observations	1	2	3
Reading on metric scale of surface of separation *a*			
Reading on metric scale of surface of kerosene *b*			
Reading on metric scale of surface of water *c*			
Calculated length of kerosene column *ab* . .			
Calculated length of water column *cd* . . .			
Calculated specific gravity of kerosene . .			
Average specific gravity of kerosene . . .			

Second Method

Apparatus. — A glass Y-tube; two pieces of glass tubing about one meter long; two tumblers; short connecting rubber tubes; two meter sticks; pinchcock; wooden clamp; rubber bands; kerosene and water.

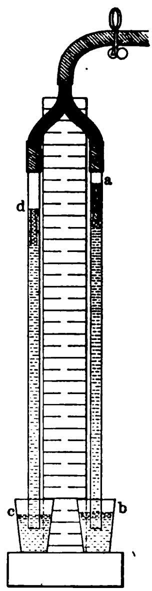

Fig. 13.

Directions. — Set up apparatus as shown in Figure 13. Partly fill one tumbler with kerosene and the other with water. Place one end of the inverted Y-tube in each liquid and suck enough air from the upper part of the tube to bring the upper kerosene surface to 5 cm. from rubber tube connection *r*. Close the upper rubber tube with pinchcock. Take the readings of surface of kerosene *b* in the tumbler, of surface of kerosene *a* in the tube, of surface of water *c* in the tumbler, of surface of water *d* in tube. Calculate the length of kerosene column *ba*, and the length of water column *cd*.

From these two lengths calculate the specific gravity of kerosene.

Repeat readings several times, changing the heights of the liquids in the tubes by opening the pinchcock for a moment.

Observations	1	2	3
Reading on the meter stick of kerosene surface *b*			
Reading on the meter stick of kerosene surface *a*			
Reading on the meter stick of water surface *c*			
Reading on the meter stick of water surface *d*			
Calculated length of kerosene column *ab* . .			
Calculated length of water column *cd* . . .			
Calculated specific gravity of kerosene . .			
Average specific gravity of kerosene . . .			

Conclusions. — Explain both methods, stating what supports the two columns of liquid and why we use the lengths above the surface of separation in I, and above the surfaces of liquid in tumblers in II.

EXPERIMENT X

Object. — *To find the specific gravity of air.*

Apparatus. — A simple air pump; a two-liter bottle with stopper, tubing, and pinchcock; a large vessel of water; a cubic centimeter graduate; a platform balance and weights.

Directions. — Adjust stopper and tubing with vaseline so that it will be air tight. Weigh the bottle with all attachments. Connect the rubber tube with the exhaust nozzle of the pump and pump out the air, making at least 50 strokes. With the pinchcock, clamp the rubber tube near the bottle, disconnect from the pump and again weigh the bottle and all attachments. Calculate the weight of the air removed.

Insert the clamped end of the tube under the water in the large vessel and loosen the pinchcock. (This water should have been standing in the room for several hours to acquire the temperature of the air.) Gradually lower the bottle mouth downward into the water until the level of the water in it, as it runs in, shall be the same as that outside in the large vessel.

When the water ceases flowing into the bottle, clamp the pinchcock again, and remove the bottle, placing it upon the table. Remove the stopper and tubing, and measure with the graduate the water now in the bottle.

Calculate the number of cubic centimeters of air which you removed.

Using the weight of the air removed and the weight of the same volume of water, calculate the specific gravity of air.

Observations	
Weight of bottle and attachments before exhausting air . . .	
Weight of bottle and attachments after exhausting air . . .	
Calculated weight of air removed	
Number of cubic centimeters of water that ran into bottle . .	
Weight of water of same volume as removed air	
Calculated specific gravity of air	

Conclusions. — Explain your results. Why was it necessary to hold the bottle so that the level of the water in it was the same as that in the vessel outside? Why should the water used be of the same temperature as the air?

EXPERIMENT XI

Object. — *To determine from the mercurial barometer the atmospheric pressure upon unit surface.*

Apparatus. — A glass tube more than 80 cm. long, closed at one end; a similar tube about 50 cm. long; a small dish; a platform balance and weights; a beaker; a meter stick; a bottle of mercury.

Directions. — Nearly fill the smaller tube with mercury, close the open end with forefinger and tip the tube, causing a large air bubble to pass the entire length of the tube to catch and remove smaller bubbles from the side of the tube. Then completely fill the tube with mercury. Half fill the dish with mercury, and, closing the open end of the tube with your finger, invert the tube, placing the open end under the mercury in the dish; remove your finger and bring the tube to a vertical position.

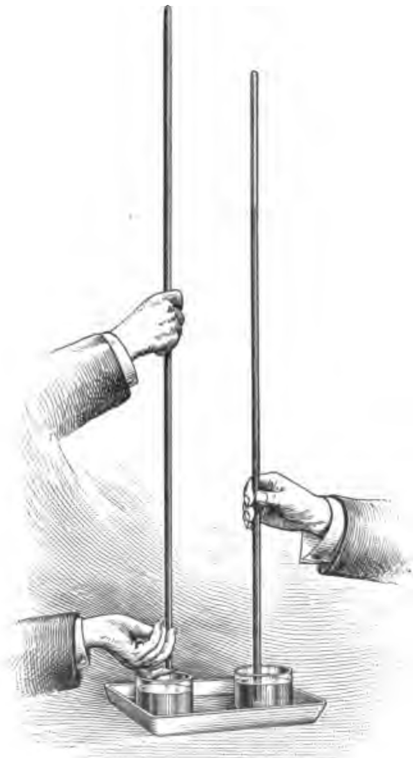

FIG. 14.

Repeat with the longer tube. Measure the height of the column of mercury remaining in the longer tube above the level of the mercury in the dish. Then raise the tube so that the open end is just below the surface of the mercury in the dish, close the end with your finger and remove the tube and contained mercury. Pour this mercury carefully into the beaker and weigh it. Weigh the beaker empty, and calculate the weight of the column of mercury whose height you measured.

Measure the inside diameter of the tube and calculate its cross section. From the weight of the mercury and the cross section of tube calculate the weight of a column of mercury of the same height but of unit section.

Observations	
Height of mercury in tube above mercury in dish	
Weight of empty beaker	
Weight of beaker and mercury which was in tube	
Calculated weight of mercury supported in tube	
Inside diameter of tube	
Calculated cross section of inside of tube	
Calculated weight of mercury column same height but unit section	

Conclusions. — What supported the mercury in the tubes? Why, in first case, did the tube remain filled? Why, in second case, did only part of the mercury in the tube remain? What determines the height of mercury which remains in the tube?

According to the principle of transmission of pressure by fluids, what must be the section of a tube of uniform diameter in which the weight of the column of mercury supported would equal the atmospheric pressure upon unit surface?

EXPERIMENT XII

Object. — *To find the relation between the volume of a certain mass of air and the pressure upon it.*

Apparatus. — Two glass tubes, one able to be closed at one end with stopcock or metal cap, connected by rubber tubing and partly filled with mercury. The tubes are mounted in an upright position in front of a metric scale.

Directions. — Open the stopcock *S* or adjust the height of the tubes *A* and *B* so that the mercury will stand at the same level in each. Read the barometer. If the tube *A* is graduated, read the volume of the inclosed air and take readings of the scale at the surface of the mercury in *A* and in *B*. (If the tube *A* is not graduated, note the scale readings at the top of tube *A*, the surface of mercury in *A*, and in *B*.) Find the length of the air column in *A* and the difference of level of the mercury columns. Close the stopcock *S* and raise the open tube or lower the closed tube to bring the mercury to different heights in the two arms. Take altogether five sets of readings. Determine from the height of the barometer and the difference of level of the mercury in *A* and *B* the total pressure upon the air in the closed tube. If the tube *A* is not graduated and is of uniform section, the volume of the air column will be proportional to its length, and the length may be used as a measure of the volume. Calculate the product of each volume and its corresponding pressure.

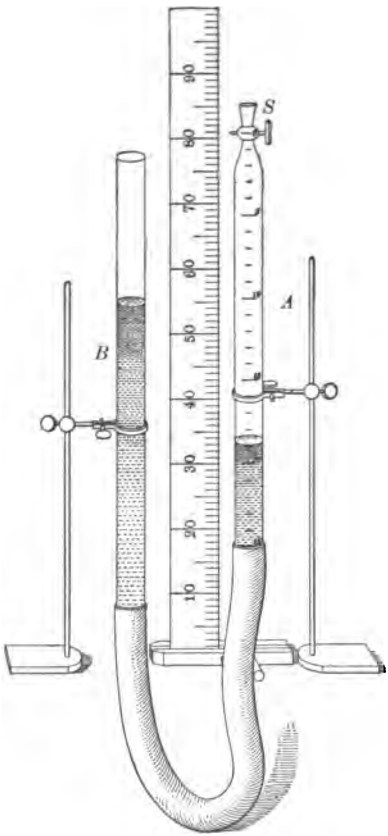

FIG. 15.

Plot results upon cross-section paper, measuring volumes along the horizontal axis and the pressures along the vertical.

Observations	1	2	3	4	5
Barometer reading . . .					
Top of closed tube . . .					
Top of mercury in closed tube					
Top of mercury in open tube					
(Volume or calculated length of air column) .					
Calculated difference of level of mercury . .					
Calculated total pressure in centimeters of mercury					
Calculated product of volume and pressure . .					

Conclusions. — Compare the products *VP* obtained, and state what change in the volume of a gas must accompany any change of pressure.

EXPERIMENT XIII

Object. — *To compare masses by the acceleration produced by equal forces.*

Apparatus. — A universal pulley and clamp; a rubber cord; two small cars; some pieces of sheet lead.

Directions. — Clamp the pulley to the edge of the table, set the sheave so that it will revolve in a horizontal plane, pass the rubber cord around the sheave, and attach its ends to the cars. Mark a line on the table six or eight inches from the pulley, load each car with the pieces of lead and draw the cars away from the pulley, which by moving distributes the tension so that it is equal on both sides. Release the cars at the same time and observe which car crosses the line first. Stop the

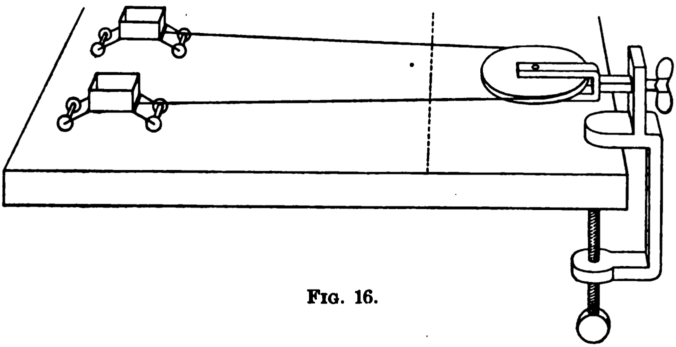

FIG. 16.

cars before they strike the pulley. Increase the load of the car which crossed the line first until upon repeated trials the two cars cross the line together.

Weigh each loaded car when this last result is obtained.

OBSERVATIONS	1	2	3	4
Weight of first loaded car . . .				
Weight of second loaded car which received the same acceleration .				

Conclusions. — What relation exists between two masses when the same force imparts to them equal accelerations?

Force $= ma$, where m equals the mass of the body and a equals its acceleration. Show how your observations prove this equation. Since the cars were at the same distance from the pulley, and crossed the line together, they have travelled equal distances in equal times. Prove the accelerations equal. Apply the equation, $S = \frac{1}{2} at^2$.

EXPERIMENT XIV

Object. — *To find the errors in a spring balance (or dynamometer).*

Apparatus. — A spring balance with a fixed zero and a pointer; a box of weights; an iron stand, and clamp.

Directions. — Support the balance vertically with the iron stand and take the reading with no weight attached to the hook. Then attach, successively 50 g., 100 g., 150 g., etc., until the limit of the scale is reached, and read each time the balance. Find the correction for each reading in order that the reading may be the same as the attached weight. If the reading of the balance is more than the attached weight, the correction is *minus;* if less, the correction is *plus.*

Plot results on cross-section paper, using the axis of abscissas or horizontal axis, for the attached weights and the axes of ordinates, or vertical axis, for the correction. Plus corrections are represented by distances *above* axes of abscissas; and minus corrections, distances *below.*

Hold the balance in a horizontal position and read the position of the pointer. The plus correction obtained must be added to all balance readings when used hereafter in a horizontal position.

OBSERVATIONS	ATTACHED WEIGHT	READING OF BALANCE	CORRECTION
a. Balance vertical			
b. Balance horizontal . . .			

EXPERIMENT XV

Object. — *To determine the conditions of equilibrium of three parallel forces.*

First Method

Apparatus. — Three dynamometers; a meter stick; three clamps; cord.

Directions. — Adjust each dynamometer so that there shall be no error for the zero reading when pulling horizontally. Attach two of the dynamometers to the meter stick, each 2 cm. from one end so that they shall be 96 cm. apart. Fasten with cord these dynamometers to the table top by the clamps so that they shall pull in a parallel direction.

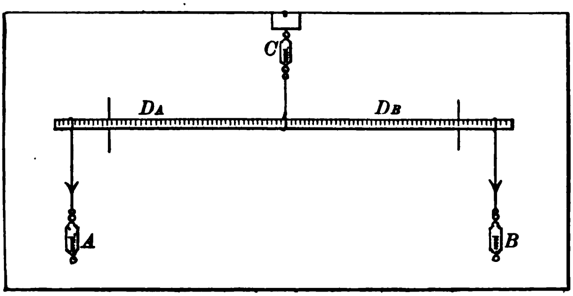

Fig. 17.

Fasten the third dynamometer to the opposite side of the table so that it shall pull parallel to the first two. Attach its hook at the 50 cm. mark, adjusting the meter stick till it is at right angles to the lines of force and the single dynamometer pulls about 10 lb. Read the three dynamometers *A*, *B*, and *C*.

Move the third dynamometer to the 34 cm. mark and read dynamometers again. Finally move it to the 74 cm. mark and take readings.

Observations	Direction of Forces	Dynamometer Readings	Points of Application of Forces	Calculated Distance from Force C
1 { A				
B				
C				
2 { A				
B				
C				
3 { A				
B				
C				

Conclusions.—In what relative directions must three parallel forces act upon a body to keep it at rest? What relation exists between the magnitudes of forces A, B, and C? What relation exists between forces A and B and their distances D_A and D_B from the force C?

State a general law in the form of a proportion deduced from your answer to the last question.

Second Method

Apparatus.—Two dynamometers; meter stick; cord; an iron weight.

Directions.—Suspend the two dynamometers from two hooks 96 cm. apart in the wooden frame above the table. Suspend the meter stick from the hooks of the dynamometer by cord attached 2 cm. from each end of the stick. Record the pulls on dynamometers A and B, due to the weight of the meter stick, and allow for this in subsequent data.

Hang the iron weight by a hook at the 50 cm. mark and adjust the cord till the stick is horizontal. Record the pulls on dynamometers *A* and *B*. Move the iron weight to the 34 cm. mark and read the dynamometers. Finally, move the iron

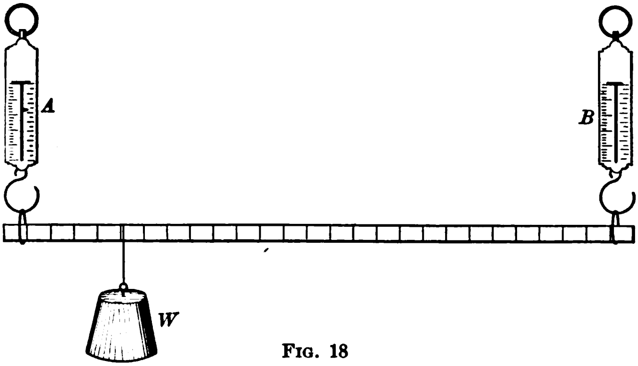

FIG. 18

weight to the 74 cm. mark and read the dynamometers. Remove the iron weight from the stick and the stick from the dynamometers, and weigh the iron weight successively on each dynamometer. Record its average weight as force *C*.

OBSERVATIONS		DIRECTION OF FORCES	BALANCE READINGS	POINTS OF APPLICATION OF FORCES	CALCULATED DISTANCE FROM FORCE *C*	ALLOWANCE FOR WEIGHT OF STICK	FORCES (CORRECTED BALANCE READINGS)
1	*A*						
	B						
	C						
2	*A*						
	B						
	C						
3	*A*						
	B						
	C						

Answer the questions at the end of the first method.

EXPERIMENT XVI

Object. — *To find the relation between the moments of two forces acting upon a lever.*

Apparatus. — A half-meter stick pivoted at its middle point and balanced by a wire rider; a box of metric weights; thread; a dynamometer.

Directions. — Hang a 200 g. weight at the 15 cm. mark and determine where a 100 g. weight must be applied to balance it. Repeat, using 120 g. and 150 g., successively, in place of the 100 g. weight. Apply a 100 g. weight at the 45 cm. mark and apply an upward force with the dynamometer at the 35 cm. mark.

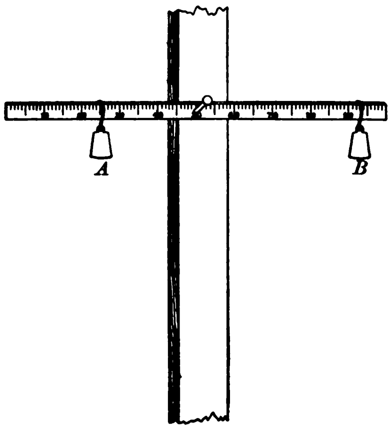

FIG. 19.

Calculate the distances from each force to the fulcrum. Calculate the moment of each force about the fulcrum.

Definition. — The moment of a force is its tendency to produce rotation about some point or line as axis, and its value is obtained by multiplying the magnitude of the force by the perpendicular distance from the axis to the line of action of the force. Moments are positive (+) when clockwise, and negative (−) when counter clockwise. Distances measured to the right of the center of moments are +, to the left −. A + force is one in such a direction that if applied at a + distance will have a + moment.

Observations	1	2	3	4
Position of fulcrum				
Position of force *A*				
Position of force *B*				
Magnitude of force *A*				
Magnitude of force *B*				
Calculated distance of *A* from fulcrum				
Calculated distance of *B* from fulcrum				
Calculated moment of *A* about fulcrum				
Calculated moment of *B* about fulcrum				

Conclusions. — Compare the moments of the two forces about the fulcrum. If two forces act upon a lever and it is in equilibrium, what relation must exist between their moments about the fulcrum?

What is the pressure upon the fulcrum? Must the two forces be equal to produce equilibrium? Discuss.

EXPERIMENT XVII

Object. — *To determine the conditions of equilibrium of more than three parallel forces.*

First Method

Apparatus.—Five dynamometers; a meter stick; five clamps; cord.

Directions. — Adjust each dynamometer so that there shall be no error for the zero reading when pulling horizontally. Attach three dynamometers on one side of the meter stick to the 2 cm., 34 cm., and 98 cm. marks, respectively. Fasten the clamps to the edge of the table and the dynamometers to the clamps so that the forces shall be parallel. On the other side attach the remaining two dynamometers to the 18 cm. mark and the 66 cm. mark, respectively.

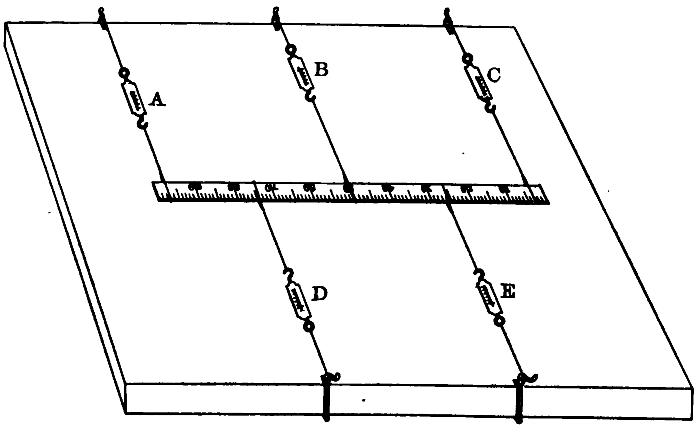

FIG. 20.

Adjust the dynamometers so that all shall pull parallel and at right angles to the meter stick, making the largest force about 12 lbs.

Calculate the moments of each force about (1) the 0 cm. mark, (2) the 66 cm. mark. Find the algebraic sum of the forces, and also the sum of the moments. In taking the 0 cm. mark as the center of moments, the distances of the forces from it will be all positive or all negative according as the 0 mark is at your left or right. If the 0 mark is at your left, the forces pulling the stick towards you are positive, those pulling it away from you are negative. Determine if any force considered + in (1) becomes − when the 66 cm. mark is the center of moments. Infer from your results the sum of the moments about any other point of the rod.

Observations		A	B	C	D	E
Direction of forces						
Dynamometer readings						
Points of application						
Using 0 cm. as the center of moments.	Distance from center of moments					
	Moments of forces					
	Algebraic sum of forces					
	Algebraic sum of moments					
Using 66 cm. as the center of moments.	Distance from center of moments					
	Moments of forces					
	Algebraic sum of forces					
	Algebraic sum of moments					

Conclusions. — When an object acted on by any number of parallel forces is at rest, what is the relation of the forces? What is the relation of the moments about any point as an axis?

Second Method

Apparatus. — Three dynamometers; two iron weights; a meter stick; cord.

Directions. — Support the meter stick by cords attached to the hooks of the dynamometers and applied at the stick at the 2 cm., 34 cm., and 98 cm. marks, respectively. Determine the allowance to be made on each dynamometer for the weight of the stick. Hang one iron weight at the 18 cm. mark and the other at the 66 cm. mark, and record readings of the dynamometers. Weigh the iron weights on each dynamometer and record their average weights as forces *D* and *E*. Calculate the moments of each force about (1) the 0 cm. mark, (2) about the 66 cm. mark.

Find the algebraic sum of the forces and also of the moments.

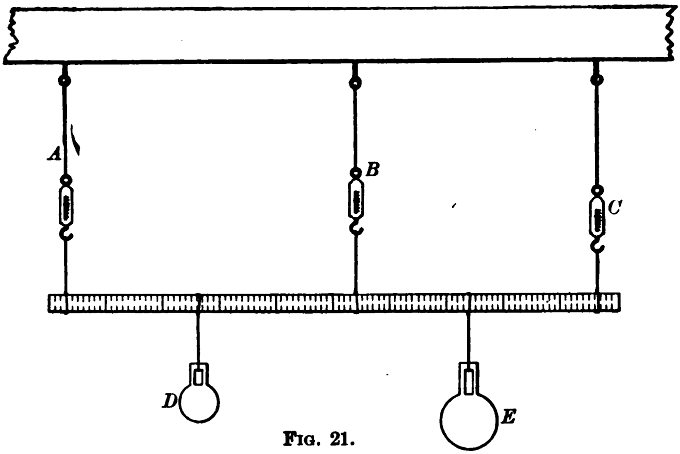

FIG. 21.

OBSERVATIONS		A	B	C	D	E
Direction of forces						
Dynamometer readings						
Points of application						
Allowance for weight of stick						
Forces (corrected dynamometer readings)						
Using 0 cm. as the center of moments.	Distance from center of moments					
	Moments of forces					
	Algebraic sum of forces					
	Algebraic sum of moments					
Using 66 cm. as the center of moments.	Distance from center of moments					
	Moments of forces					
	Algebraic sum of forces					
	Algebraic sum of moments					

Answer the questions asked at the end of the first method.

EXPERIMENT XVIII

Object. — *To find the conditions of equilibrium of four forces acting at right angles and applied at different points in a plane.*

Apparatus. — A square board with 49 holes placed 2 inches apart and numbered consecutively; four marbles; four clamps; four dynamometers; four pegs; cord.

Directions. — Support the board in the middle of the table. Place pegs in four different holes and attach the hooks of the dynamometers to the pegs with cord. Pull on dynamometers

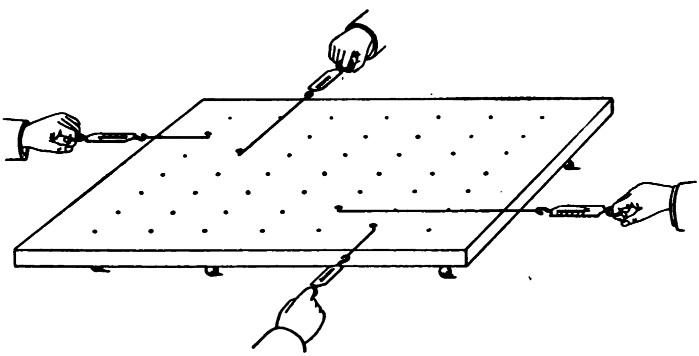

Fig. 22.

in directions N., E., S., and W., and fasten them to clamps attached to the edge of the table. The dynamometers must be so adjusted that any slight displacement of the board will cause it to be brought back to its first position.

Read forces, points of application, and directions.

Calculate the moments of all forces about any three points. Find the algebraic sum of the moments about each point.

Observations	A	B	C	D
Forces				
Points of application				
Direction of forces				
Distance from center of moments, 1st point				
Distance from center of moments, 2d point				
Distance from center of moments, 3d point				
Moments of forces, 1st point				
Moments of forces, 2d point				
Moments of forces, 3d point				
Sum of moments, 1st point				
Sum of moments, 2d point				
Sum of moments, 3d point				

Conclusions. — Compare the forces acting parallel to each other. What is the sum of the moments about any point of the body ?

EXPERIMENT XIX

Object. — *To prove that a lever acts as if its mass were collected at one point; viz., its center of gravity.*

Apparatus. — Meter stick; wooden clamp; a triangular wooden prism; platform balance and weights.

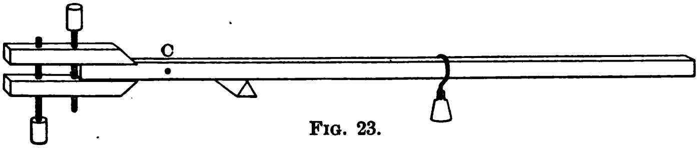

FIG. 23.

Directions. — Fasten the clamp to the meter stick as shown in Figure 23. To find the center of gravity of the meter stick and clamp, balance the stick upon the prism as a fulcrum.

Record the reading on the meter stick above the supporting edge of the prism.

Hang a 200 g. weight near the free end of the meter stick and balance again upon the fulcrum. Read the position of the weight and of the fulcrum.

Calculate the distance of the weight from the fulcrum and also the distance of the center of gravity (found above) from the fulcrum. Calculate the moments of the 200 g. weight about the fulcrum. Weigh the stick and clamp and calculate the moment about the fulcrum of this weight, considering it as acting at the center of gravity.

OBSERVATIONS	
Weight of stick and clamp	
Position of center of gravity	
Position of 200 g. weight	
Position of fulcrum (2d time)	
Calculated distance from fulcrum of 200 g. weight	
Calculated distance from fulcrum of center of gravity . . .	
Calculated moment about fulcrum of 200 g. weight	
Calculated moment about fulcrum of weighted stick	

Conclusions. — What does the equality of moments prove? Explain why the first position of the fulcrum determines the center of gravity of the stick.

EXPERIMENT XX

Object. — *To determine the mechanical advantage of various arrangements of pulleys.*

Apparatus. — Two single pulleys; two double pulleys; a dynamometer; stout cord; an iron weight.

Directions. — Suspend the block of a single pulley from the support above the table as in diagram (1). Pass a cord over the sheave of the pulley and hang the iron weight from one end of it. Attach the dynamometer to the other end of the cord and pull so as to raise the weight slowly and steadily. Read the dynamometer while the weight is rising. Then allow the weight to descend slowly at the same speed, observing the reading of the dynamometer. Take the average of these two readings as the force *F* to balance weight, *W*, thus eliminating the amount of force needed to overcome the fric-

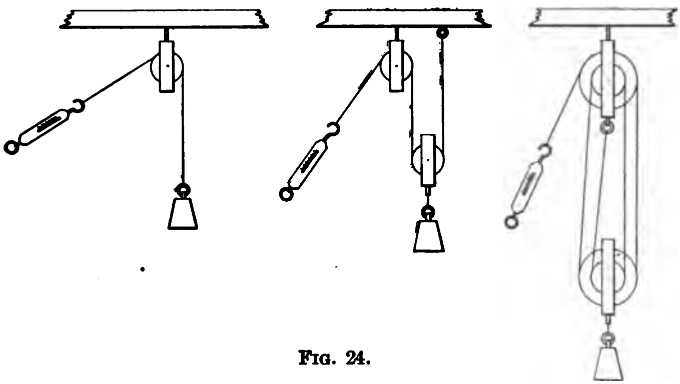

FIG. 24.

tion of the pulley. (The pulley in this arrangement is called a single fixed pulley.) Find how far *F* moves to raise *W* one foot.

Arrange the two single pulleys as in diagram (2) and find as before the average value of force *F* to balance the weight, *W*. Again find how far the force moves to raise the weight one foot.

Repeat with the two double pulleys arranged as in diagram (3). Weigh the movable pulley and iron weight in each of the last two cases and call the joint weight, *W*.

Definition.—When by a machine a force of one pound overcomes a resistance of *a* pounds, the *mechanical advantage* of the machine is called a *gain of force* of *a*. ($R \div F = a$.)

When a force moving one foot causes a resistance to move *a* feet, the *mechanical advantage* is called a *gain of speed* of *a*. (*R* speed ÷ *F* speed = *a*.)

Observations	1	2	3
Arrangement of pulleys			
Weight lifted			
F + friction			
F − friction			
Average value of F			
Distance F moves			
Distance W moves			
Work done by F			
Work done upon W			

Conclusions. — State the mechanical advantage of each of the three arrangements of pulleys used. Explain why in (2) and (3) the force can support a weight as many times as great as itself as you observe it to be. Explain also the relative speeds. Compare work done by *F* with the work done upon *W*.

EXPERIMENT XXI

Object. — *To find the conditions of equilibrium of three concurrent forces in one plane. (Parallelogram of forces.)*

First Method

Apparatus. — Three dynamometers; a half-meter stick; three clamps; cord.

Directions. — Arrange apparatus on top of table as shown in Figure 25, the balances being held in desired position by cords fastened to the clamps at the edge of the table. Make each angle 120°. Read each dynamometer. Place a notebook page under the cords with the point *l* at the center of the page.

Mark two points directly beneath each of the three cords. Through these pairs of points draw the three lines which represent in direction the three forces. Using a scale as 1 cm. equivalent to 1 lb., make each line as many centimeters long as there are pounds of force in its direction. Then the lines represent the forces both in magnitude and direction.

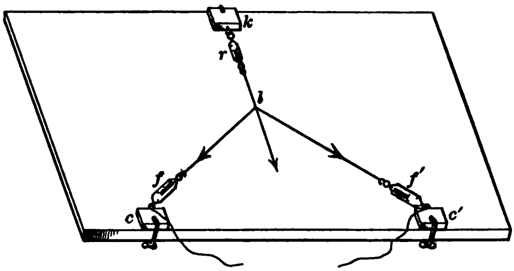

Fig. 25.

Upon any two of these lines as sides construct a parallelogram and draw the diagonal passing through *l*.

On the scale used, how great a force does this diagonal represent? Compare it with the third force both in magnitude and in direction, remembering that the directions of forces are from the point *l*, and not toward it.

Construct second and third parallelograms, using other pairs of forces.

Change the position of the clamps so as to make the angle between *f* and *f′* 90°; take readings, and construct the parallelograms. Repeat with the angle between *f* and *f′* 60°.

Observations	1	2	3
Reading of dynamometer *f*			
Reading of dynamometer *f′*			
Reading of dynamometer *r*			
Angle between *f* and *f′*			
Angle between *f* and *r*			
Angle between *f′* and *r*			
Length of diagonal (case *f* and *f′*)			
Length of diagonal (case *f* and *r*)			
Length of diagonal (case *f′* and *r*)			

Conclusions. — State what relation must exist between the magnitudes and directions of three concurrent forces that they may be in equilibrium.

Second Method

Apparatus. — Two dynamometers; an iron weight; a half-meter stick; cord.

Directions. — Suspend the two dynamometers from two hooks in the crossbar of the upright supports at the table. Tie together the ends of three pieces of cord and fasten the free ends of two cords to the hooks of the dynamometers, and to the third attach the iron weight.

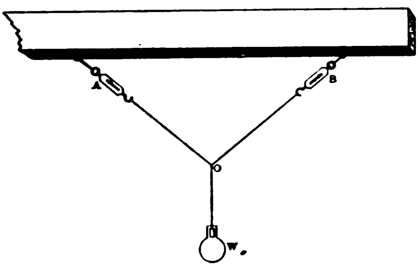

Fig. 26.

Take the readings of each dynamometer *A* and *B*. Then place a page of your notebook in a vertical position back of the cords and mark two points at least 10 cm. apart directly back of each of the three cords. Connect each pair of points and extend the three lines until they meet. These three lines will then indicate the directions of the three forces acting upon the point *O*. Remove the cords and weigh the iron weight on each dynamometer and record its average weight as force *C*.

Now to make the three lines drawn represent these three forces in magnitude, as well as in direction, use a scale of 1 cm. equivalent to 1 lb. and lay off on each line from the point of intersection as many centimeters as there are pounds of force in that direction.

Using any two of these forces as adjacent sides, construct a parallelogram and draw the diagonal which passes through point *O*.

Measure the length of the diagonal and note its direction. On the scale used how great a force does the diagonal represent? Compare it with the third force both in magnitude and direction, remembering that the directions of the forces are from the point *o*, not toward it.

By changing the lengths of the cords attached to the dynamometers other sets of readings can be obtained.

Observations	1	2	3
Reading of dynamometer *A*			
Reading of dynamometer *B*			
Weight of iron ball on dynamometer *A* . .			
Weight of iron ball on dynamometer *B* . .			
Average weight of iron ball			
Angle between *A* and *B*			
Length of diagonal between *A* and *B* . . .			
Direction of diagonal between *A* and *B* . .			

Conclusions. — State what relation must exist between the magnitudes and directions of three concurrent forces that they may be in equilibrium.

EXPERIMENT XXII

Object. — *To determine the mechanical advantage and the law of the inclined plane.* (*a*) *When the force is parallel to the plane.* (*b*) *When the force is horizontal.*

Apparatus. — A board about 1 m. long; a supporting frame; a small car; a dynamometer; an iron weight.

Directions. — Support the board in an inclined position by means of the frame, making an angle of 30° with the horizontal. Attach the car by cord to the hook of the dynamometer; place the car upon the plane, and observe the forces necessary to pull it slowly up the plane, and also to allow it to descend slowly, while pulling in a direction parallel to the plane.

Then place the iron weight in the car and determine the forces to pull both car and weight up the plane and to allow them to descend. Calculate from these two sets of readings the force necessary to move the weight only. Measure the length of plane and its height.

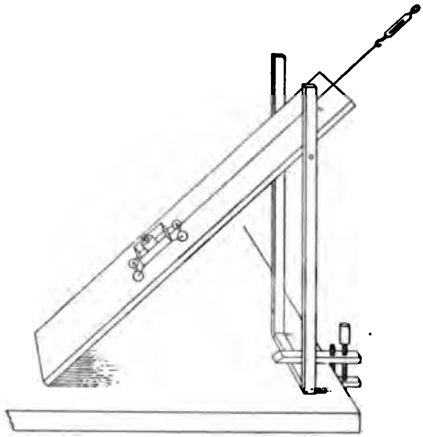

FIG. 27.

Repeat with the board inclined at an angle of 45°.

Then placing the cord in the slit cut lengthwise in the board, repeat the last case, pulling in a horizontal direction.

Measure the length of base as well as the height.

OBSERVATIONS	1	2	3	4
Angle of inclination (approximate)				
Force (ascending) for car alone . .				
Force (ascending) for car and weight				
Calculated force for weight only .				
Force (descending) for car alone .				
Force (descending) for car and weight				
Calculated force for weight only .				
Average value of force for weight only				
Direction of force				
Weight in the car.				
Dimensions of plane, length . . .				
Dimensions of plane, height . . .				
Dimensions of plane, base . . .				
Calculated work done by force in pulling the whole length of plane				
Calculated work done upon weight in raising it the entire height of plane				

Conclusions. — What is the mechanical advantage of an inclined plane whose length = l cm., height = h cm., and base = b cm., (1) when force is parallel to plane? (2) when force is horizontal?

What relation exists between the force and the weight and the dimensions of the plane, (1) when force is parallel to plane? (2) when force is horizontal?

How does increasing the angle of inclination affect the mechanical advantage of the plane?

Do you gain in work by using a machine? Discuss.

EXPERIMENT XXIII

Object. — *To find whether the amplitude of vibration and material of the bob affect the time of vibration of a simple pendulum.*

Apparatus. — A wooden and an iron ball; thread; an iron ring stand and clamp; a large cork stopper; a metronome, or a watch with a second-hand.

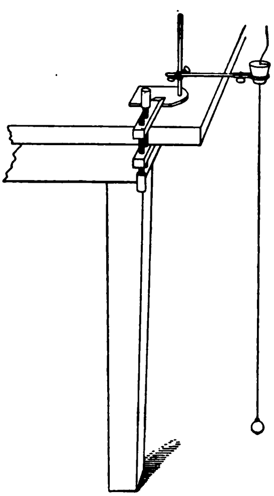

FIG. 28.

Directions. — Arrange the apparatus as shown in Figure 28 so that the pendulum shall strike nothing as it swings. Pass the thread through a slit in the stopper, and then tightly clamp it. The point of suspension, or the point about which the pendulum swings, will be where the thread enters the under side of the cork.

Adjust the pendulum to a length of 60 cm., measuring from the point of suspension to the center of the bob, and start it swinging through a total arc of 10°. To obtain an amplitude of 10°, draw the bob out until it is 5.2 cm. away from the vertical position; for 15°, 8.0 cm.; for 20°, 10.5 cm. Count the number of single vibrations it makes in a half minute, using the metronome to indicate the time.

Measure the length of the pendulum again. If it has changed, the experiment must be repeated.

Repeat, using an arc of 15°. Then repeat, using an arc of 20°.

Remove the bob used so far, and with the other ball as a bob perform the experiment again.

Observations

Material of Bob	Amplitude of Arc	Length of Pendulum at Beginning	Length of Pendulum at End	Number of Vibrations in One Half Minute

Conclusions. — What effect has a varying amplitude of arc upon the number of vibrations of a pendulum in a given time?

What effect has a change in the material of the bob upon the number of vibrations in a given time?

EXPERIMENT XXIV

Object. — *To find how the length of the simple pendulum affects the time of one vibration.*

Apparatus. — An iron ball; thread; an iron ring stand and clamp; a large cork stopper; a metronome, or a watch with a second-hand.

Directions. — Arrange the apparatus as shown in Figure 28. Adjust the length of the pendulum until it is exactly 100 cm. and start it swinging through a small arc.

Count the number of single vibrations in a half minute, the interval of time being indicated by the metronome. Use all the precautions suggested in Experiment XXIII. Calculate the time of one vibration from the number of vibrations made in half a minute. Adjust the length of the pendulum to 50 cm. and repeat. Then repeat, using successively 36 cm. and 25 cm. as the required lengths. Calculate in each case the square root of the length.

Observations

Length of Pendulum	Number of Vibrations in One Half Minute	Time of Each Vibration	Square Root of Length

Ratios

	Lengths	Square Root of Length	Number of Vibrations in One Half Minute	Time of One Vibration
1st : 2d				
1st : 3d				
1st : 4th				
3d : 4th				

Conclusions. — What is the relation between the length of a pendulum and its time of vibration? What is the relation between the length of a pendulum and its number of vibrations in a given time?

EXPERIMENT XXV

Object. — *To measure action and reaction in the collision of (a) two elastic bodies, (b) of two inelastic bodies.*

Apparatus. — Two ivory balls of unequal mass; release blocks mounted upon a meter rod; supporting frame; supporting thread; some putty.

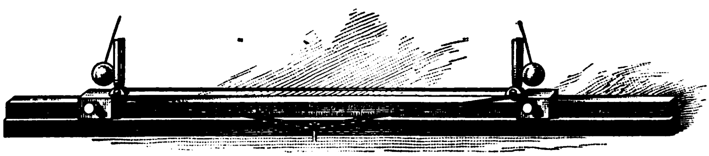

Fig. 29.

Directions. — Arrange the apparatus as shown in Figure 29, so that the balls just touch and have their centers at the same level. Read the position on meter rod directly below the centers of both balls. Draw the larger ball back 20 cm. and hold it in position by a release block. Release the ball and determine the position of the center of the smaller ball at the extreme point of its swing after collision. Repeat and determine the position of the center of the larger ball at the extreme point of its swing after collision. Repeat, drawing the ball back 30 cm. before releasing it.

Then leaving the larger ball at rest, draw the smaller ball back 30 cm. and hold it in position with a release block. Release it, and find as before the distance each ball swings after collision.

Draw both balls back in opposite directions unequal distances and hold them in position with the release blocks. Release both at the same instant and find the distance each goes after collision.

Place a band of putty around one ball and repeat the first case. Find the mass of each ball by weighing on a platform balance.

Take the distance each ball swings as representing its velocity; call distances to the right of position of rest positive; those to the left, negative.

Calculate the momentum (mass × velocity) of each ball before and after collision.

Calculate the momentum imparted to the struck ball and the change of momentum of the striking ball produced by the reaction of the struck ball.

Observations	1	2	3	4
Position of rest of { large ball . .				
Position of rest of { small ball . .				
Mass of { large ball				
Mass of { small ball				
Velocity before collision of { large ball . . .				
Velocity before collision of { small ball . . .				
Velocity after collision of { large ball				
Velocity after collision of { small ball . . .				
Calculated momentum before collision of { large ball .				
Calculated momentum before collision of { small ball .				
Calculated momentum after collision of { large ball .				
Calculated momentum after collision of { small ball .				

Conclusions. — Compare the algebraic sum of the momenta before collision with that after collision.

Considering action and reaction as separate phases of one phenomenon, how great must the imparted momentum representing the action be, as compared with the imparted momentum representing the reaction, in order that the sum of the momenta before collision should bear the observed relation to the sum of the momenta after collision?

EXPERIMENT XXVI

Object. — *To find the coefficient of friction for two given surfaces.*

Apparatus. — A board with a smooth surface; a cherry block 10 cm. × 10 cm. × 4 cm.; a dynamometer.

Directions. — Weigh the block. Tie a cord about it and attach it to the hook of the dynamometer. Place the board in a horizontal position and lay the block with one of its square faces resting upon the board. Place 100 g. on the block and, holding the dynamometer and cord horizontal, draw the board

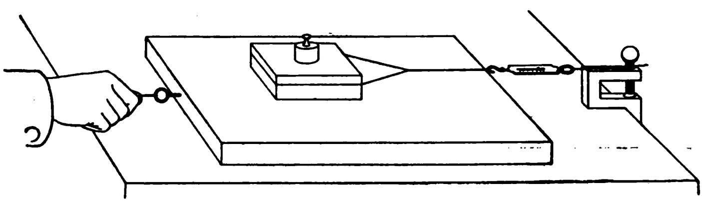

FIG. 30.

slowly and steadily under the block. Observe the reading of the dynamometer, neglecting the reading at the start, which is greater than the sliding friction. Repeat several times and take the average reading as the value of the friction. Repeat the experiment with 200, 300, 400, and 500 g. successively placed on the block.

Finally repeat the experiment with the block resting upon one of its smaller faces and with 200 g. and 500 g. successively placed upon it.

Observations	Weight of Block	Weight placed upon Block	Area of Rubbing Surface	Friction, or Reading of Dynamometer

Conclusions. — The coefficient of friction is $\frac{F}{P}$, where $F =$ the friction and P the pressure between the two surfaces, which here equals the sum of the weight of the block and that placed upon it.

From the value of $\frac{F}{P}$ in each case state how a change in the load affects the coefficient of friction; also how a change in area of rubbing surface affects the coefficient of friction.

EXPERIMENT XXVII

Object. — *To determine the effect of a varying load upon the coefficient of friction for two given surfaces.*

Apparatus. — A board with a smooth surface; a wooden box with two wooden runners glued to its bottom; a wooden clamp and a half-meter stick; a box of weights.

Directions. — Incline the board until the empty box slides slowly and with uniform speed down the plane after being started by the hand. Measure the height h of the inclined plane and the length of base b.

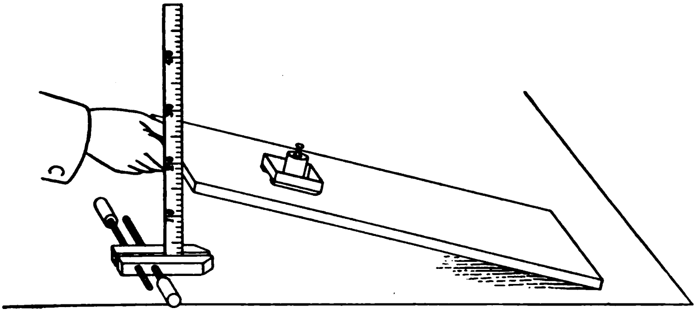

FIG. 31.

Place 100 g. in the box and repeat the experiment. Increase the load to 200 g. and repeat.

OBSERVATIONS	LOAD IN BOX	HEIGHT OF PLANE	LENGTH OF BASE	COEFFICIENT OF FRICTION $\frac{h}{b}$

Conclusions. — The coefficient of friction equals $\frac{F}{P}$, where $F =$ the force required to make the body slide, and P is the pressure perpendicular to the surface.

In the parallelogram of forces drawn in Figure 32 show that from similar triangles the force WK : pressure WF : : height of plane AC : length of base BC.

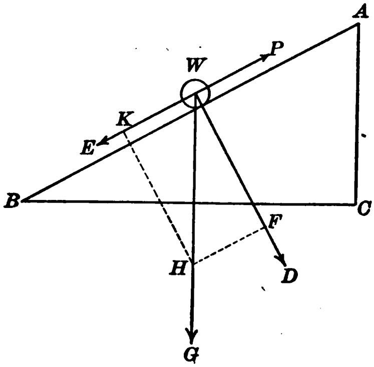

FIG. 32.

Therefore $\frac{F}{P} = \frac{AC}{BC} =$ coefficient of friction.

What effect has changing the load upon the coefficient of friction?

EXPERIMENT XXVIII

Object. — *To determine the breaking strength of a wire and to compare the strengths of various wires.*

Apparatus. — Testing machine; 30 lb. dynamometer; assorted wire.

Directions. — Wind one end of a piece of No. 30 brass wire around the end of frame back of the wedge as shown in Figure 33, and fasten the other end to the axle of the ratchet. Insert the wedge as shown, set the pawl to engage the ratchet, and slowly turn the handle until the wire breaks. Read the dynamometer. Repeat the experiment with a fresh piece of wire and take the average of the two readings as the breaking strength of the wire used. Find the diameter of the wire from the table in the appendix and calculate its cross section.

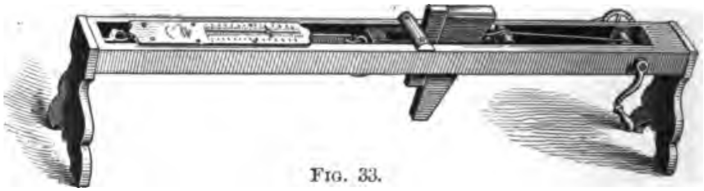

FIG. 33.

Find in the same way the breaking strength of No. 28 brass wire, No. 30 iron wire, No. 30 steel wire, and No. 30 copper wire.

OBSERVATIONS

KIND OF WIRE	DIAMETER OF WIRE	READING OF DYNAMOMETER	BREAKING STRENGTH OF SECTION=1 SQ. CM.

Conclusions. — When the material is the same, what relation exists between the force needed to break a wire and its diameter? From the force used to break the first wire calculate what force would break a brass wire of 1 sq. cm. cross section.

EXPERIMENT XXIX

Object. — *To investigate the elasticity of wires by stretching.*

Apparatus. — Brass, iron, and steel wire, No. 30; a dynamometer; a clamp; a meter stick.

Directions. — Attach one end of a piece of wire more than a meter long to a clamp fastened to the edge of the table and the other end to the hook of the dynamometer. Fasten a paper pointer on the wire near the hook of the dynamometer and note its position on the meter stick lying upon the table under the wire. Stretch the wire with a force of ½ lb., note the position of the pointer and then release the wire, noting again its zero position. Determine the amount of temporary stretching and the permanent stretching. When the wire begins to stretch permanently, its limit of elasticity has been passed. Repeat the experiment with the same wire, increasing the force ½ lb. each time and obtaining a zero reading by releasing the wire after each increase until the wire breaks. Perform the same experiment with the other wires. Soften a piece of brass wire by passing it through a gas flame several times and perform the experiment with it as with the others.

Observations	1	2	3	4
Kind of wire				
Diameter of wire				
Zero reading				
Stretching force				
Reading of pointer				
Amount of temporary stretching .				
Amount of permanent stretching .				

Conclusions. — What relation exists between the amount of stretching and the stretching force? How is the limit of elasticity affected by softening the wire?

EXPERIMENT XXX

Object. — *To determine the effect of varying load and varying dimensions upon the amount of bending of a beam.*

Apparatus. — Two pine sticks over a meter long and 1¼ cm. thick, one 1¼ cm. wide, the other 2½ cm. wide; two triangular supports; a scale pan and supporting cords; a micrometer screw caliper; two small brass screws; a box of weights.

Directions. — Screw a small brass screw into the middle of each rod. Support the rod $1\frac{1}{4}$ cm. wide upon the triangular prisms so that the distance between the supporting edges is one meter. Place the micrometer caliper into position and support the scale pan from the rod as shown in Figure 34.

With no load on the pan take a reading of the micrometer when brought into contact with the brass screw in the beam.

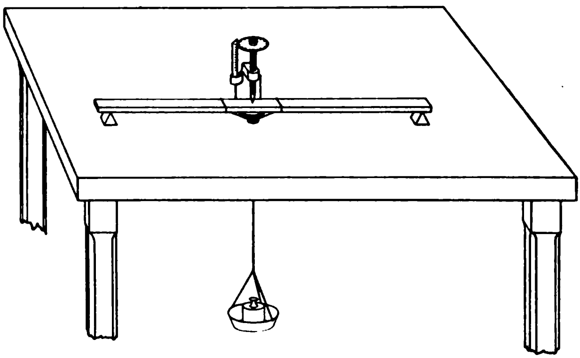

FIG. 34.

Then place 100 g. in the pan, bring micrometer screw into contact with brass screw, and again take reading. Take similar readings, using 200 g., 300 g., 400 g., and 500 g. successively.

Move the supporting edges until they are successively 80 cm. and 60 cm. apart and take readings with a load of 200 g.

Use the rod $2\frac{1}{2}$ cm. wide with a load of 200 g. and distance between supports 1 m.

Turn this rod around so that it acts as a beam $1\frac{1}{4}$ cm. wide, $2\frac{1}{2}$ cm. thick, and 1 m. long. Take readings with a load of 500 g.

OBSERVATIONS

Length of Beam	Width of Beam	Thickness of Beam	Load on Beam	Micrometer Readings		Amount of Bending
				With no Load	With Load	

Conclusions. — The dimensions of a beam being constant, what relation exists between load and amount of bending? The load, width, and thickness of beam being constant, what relation exists between length of beam and amount of bending? Similarly, what relation between amount of bending and the width of the beam, everything else being the same?

Finally state relation between bending and thickness of beam.

The formula expressing these relations is: bending $= \frac{CWl^3}{wt^3}$, where C is a constant depending upon material, W is the load, l the length, w the width, and t the thickness of the beam.

EXPERIMENT XXXI

Object. — *To determine the relation of amount of twisting of a rod, the twisting moment, the length, and the diameter of the rod.*

Apparatus. — Two rods, one $\frac{3}{4}$ in. diameter, the other $\frac{1}{2}$ in. diameter; base lever shown in Figure 35; two dynamometers; table clamp, steel rod and clamp, cord; card graduated in degrees.

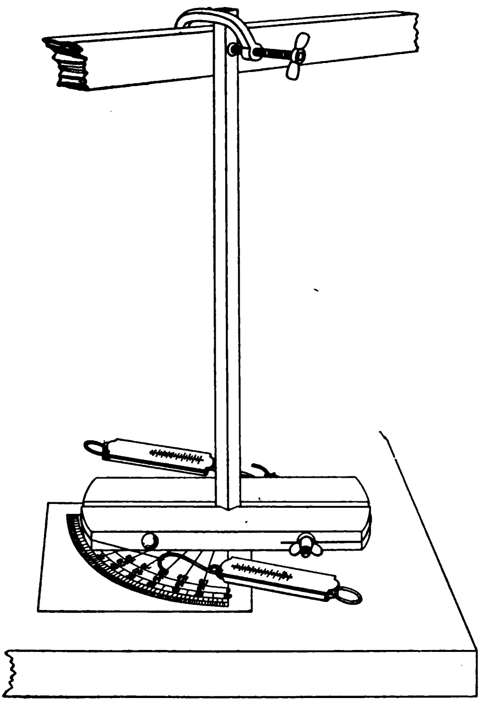

FIG. 35.

Directions. — Arrange the apparatus as shown in Figure 35. Adjust the clamp so that the length of rod twisted is 30 in. Read the zero position of base lever on the graduated circle. Apply a force of 1 lb. at each dynamometer and read position of base lever. Increase the force to 5 lb. by a gradual increase of 1 lb., each time observing the position of base lever after each increase. Decrease the length of the part of the rod twisted to 20 in., and repeat.

Perform a similar experiment with the other rod.

Observations	1	2	3	4
Length of rod				
Diameter of rod				
Twisting force				
Zero position of lever				
Position while twisted				
Amount of twist				

Conclusions. — Determine the relation between the amount of twist and the twisting moment, dimensions being same. Determine relation between amount of twist and length of rod, force and diameter being the same.

Determine relation between amount of twist and the diameter, the force and length being the same.

EXPERIMENT XXXII

Object. — *To find the number of vibrations per second of a tuning fork.*

Apparatus. — A tuning fork (C) with framework and supported pendulum as in Figure 36; a bass viol bow well rosined; a watch or metronome; a piece of smoked glass.

Directions. — Adjust one fork prong and pendulum tip with bristles or wire fastened on by wax so that each bristle shall just graze the smoked glass as it is drawn underneath. Arrange it so that when the fork and the pendulum are set vibrating together the bristles may be as near together as possible without touching.

Count the number of vibrations of the pendulum in one half minute. Being careful not to change the length of the pendulum, set it to vibrating with a fair amplitude and at the same time start the fork vibrating by drawing the bow across it quickly. While both are vibrating, draw the blackened glass on its wooden frame along under the two in a direction at right angles to their line of vibration. (A little practice, using a string, perhaps will enable the experimenter to secure a result showing a complete pendulum vibration and clear fork vibra-

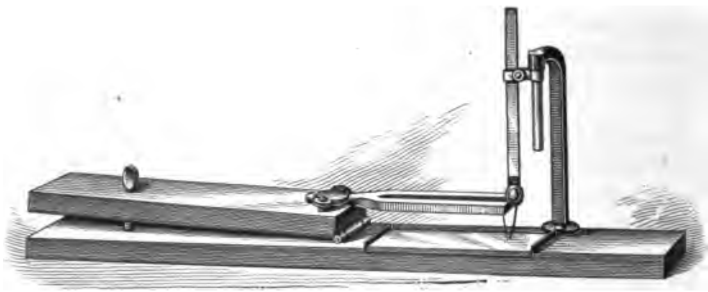

FIG. 36.

tions.) Remove the glass and count carefully the number of fork vibrations as recorded to one complete pendulum vibration. Calculate the number of fork vibrations to one minute. Calculate the number of fork vibrations to one second.

OBSERVATIONS	1	2	3	4
Number of vibrations of pendulum per half minute				
Number of vibrations of tuning fork to one vibration of pendulum . .				
Calculated number of vibrations of fork per half minute				
Calculated number of vibrations of fork per second				

Conclusions. — Explain how the curve was traced upon the glass and why the line should be curved. Explain how the number of vibrations per second is obtained.

EXPERIMENT XXXIII

Object. — *To determine the ratio between the length of a resonating column of air and the wave length of the sound it reënforces.*

Apparatus. — Two glass cylinders about 40 cm. high, one about 3 cm. diameter and the other about 6 cm.; eight tuning forks; a thermometer; a jar of water and a siphon.

Directions. — Set fork C 256 in vibration and hold it over the mouth of the narrower cylinder as shown in Figure 37; adjust the length of the air column in the cylinder till the sound is

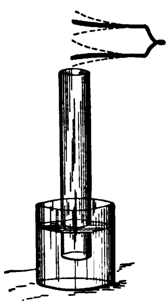

FIG. 37.

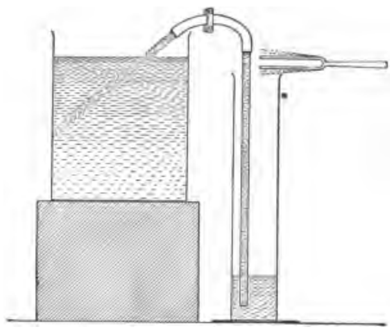

FIG. 38.

most strongly reënforced. Measure the length of the air column. Repeat, using the wider cylinder as in Figure 38 and obtain the length of the resonating column. From these two measurements determine what fraction of the diameter should be added to the length of the air column to give the true length.

Adjust the jar of water and siphon so that water can be run into the wider cylinder at will, and determine the resonating column for each of the tuning forks in succession, shortening the air column by allowing water quietly to flow into the jar. Determine the temperature of the air in the jar and add to the velocity of sound in air at 0° C. (332. m.) the product of the temperature and 0.6 m., which is the increase in velocity of sound in air per degree rise in temperature.

Divide the velocity of sound in air by the vibration frequency of each fork to find the wave length of each. Find the ratio of this wave length to the length of resonating column for the same fork after being corrected for diameter.

Observations	1	2	3	4
Vibration frequency of fork . . .				
Diameter of cylinder				
Length of resonating air column .				
Calculated correction for diameter.				
Corrected resonating column . . .				
Temperature of air in jar				
Velocity of sound in air at temperature of jar				
Wave length of sound				
Ratio of wave length to resonating column				

Conclusions. — What relation exists between vibration frequency of forks and the lengths of resonating columns? Explain why the ratio between wave length and resonating air column should be as determined.

EXPERIMENT XXXIV

Object. — *To find the effect of changes in length, tension, and thickness of a stretched wire on its vibration frequency.*

Apparatus. — A sonometer with arrangement for recording tension on the wire; wooden prism for bridges; piano wire, sizes 28 and 22; a meter stick; tuning forks C, E, G, C′.

Directions. — I. Stretch one string with a force of 10 lb. Adjust the bridge until the note emitted when the string is plucked is in unison with that of the lower C tuning fork. (If the student has not a good ear, he may be helped by adjusting so as to avoid beats.) Measure the length of that part of the string which was vibrating. Keeping the tension the same, carefully move the prism, shortening the length of the vibrating part until it is in unison successively with E, G, and C′ fork. Measure each length.

Repeat, using a constant tension of 15 lb. and the other string. Infer the law as to length of the vibrating string.

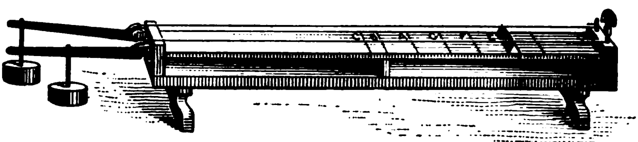

FIG. 39.

II. Stretch one string with a force of about 4 lb. and adjusting the length so that it shall vibrate in unison with low C, read the tension exactly. Without changing the length, change the tension successively until notes have been produced vibrating in unison with E, G, and C′, respectively; measure each tension. Repeat, using the other wire and beginning with 12 lb. tension. Extract the square roots of the tensions and infer the law as to tension.

III. Stretch both strings, one (No. 22) being twice the diameter of the other (No. 28) with 10 lb. tension for each. Adjust the length of the coarser wire until its note is C, and adjusting the other to the same length, determine what tone is emitted. Try the same with E, G, and C′ and infer the law as to diameters. The relation between the tone and the diameter of the string may also be determined by finding the lengths of the strings which give the same tone. Compare the ratio of the diameters with the inverse ratio of these lengths.

OBSERVATIONS

Tone Emitted	Length of String	Diameter of String	Tension of String	Square Root of Tension

Conclusions. — What relation exists between the length of a string and the pitch of the tone it emits? What relation exists between the pitch and the tension of the string? What relation exists between the diameters of two strings of the same length and tension and the two tones emitted?

EXPERIMENT XXXV

Object. — *To determine whether the two fixed points on a centigrade thermometer are properly marked.*

Apparatus. — A centigrade thermometer; a funnel; a tumbler; a ring stand; a glass flask with side neck, or a boiler; wire gauze; a Bunsen burner.

Directions. — I. To test the Freezing Point.

Place the funnel in a large ring on the retort stand with tumbler under it: fill with finely cracked ice. Put the thermometer into the ice, making sure that the ice surrounds the bulb closely and that the mercury does not come above the ice. Leave the thermometer in for about five minutes, or until the mercury has been stationary several minutes, and read the position of the mercury in the thermometer, estimating to tenths of the smallest division.

II. To test the Boiling Point.

Partly fill the boiler with water and put the thermometer through the perforated stopper so that 100° mark is a little above it. Then place the stopper in the boiler, taking care that the bulb does not touch the water. Stop up with a cork the lower outlet. Apply heat until a steady flow of steam has come from the upper outlet tube for about five minutes. Read the position of the mercury, estimating again to tenths of the smallest division. Read the barometer. Stop all outlet tubes for about half a minute and note the effect on the temperature of the steam.

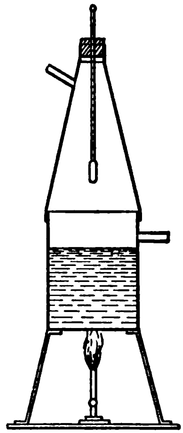

FIG. 40.

A correct centigrade thermometer registers 100° in steam when the barometer reading is 760 mm. By experiment it is found that a change of barometer reading of 27 mm. produces a similar change of 1° C. in the temperature at which steam is formed: thus each millimeter of change of barometer reading changes the boiling point by $\frac{1}{27}$ of 1° C.

From the barometer reading calculate the true boiling point for the present atmospheric pressure. The melting point of ice is practically constant for small changes of pressure.

OBSERVATIONS	
Reading of thermometer in melting ice	
Reading of thermometer in steam under atmospheric pressure .	
Reading of thermometer in steam under increased pressure .	
Reading of barometer	
Calculated reading of a true thermometer in steam under the observed barometric pressure	
Calculated error of boiling point of thermometer No. — . . .	

Conclusions. — What is the error in your thermometer for the melting point and what for the boiling point? What correction, plus or minus, must be made in the readings of your thermometer for boiling point and what for freezing point to obtain the correct temperature? What does the changing temperature, when the outlets of the boiler are closed, indicate?

EXPERIMENT XXXVI

Object. — *To find the coefficient of linear expansion of brass.*

Apparatus. — A copper boiler; a Bunsen burner; rubber tubing; linear expansion apparatus; glass tumbler; thermometer No. —; a meter stick.

Directions. — Fill the boiler half full of water, and, having no connection made with the jacket, heat with the Bunsen burner nearly to boiling. Meanwhile measure the length of the brass rod including the steel tips and then adjust the apparatus as in diagram, taking pains that the steel tips on the end of the

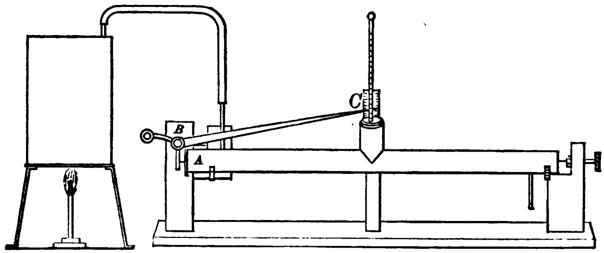

FIG. 41.

rod shall touch lightly the brass knob at the right hand and the short arm of the pointer on the other end. That portion of the pointer near the scale should be near the top of it: this may be accomplished by using the screw at the right hand end.

Measure the short arm of the pointer from the steel point *A* to the fulcrum *B* of the lever, and the long arm of the pointer from left hand edge *C* of the scale to the fulcrum. Take readings of the thermometer and of the pointer on the scale. (To do this accurately sight with the eye so that the pointer covers its image in the mirror.)

Then being very careful not to disturb the apparatus, connect the jacket with the boiler so as to pass steam through the jacket. Do this until the thermometer has been stationary for several minutes and take readings of the thermometer and of the pointer.

Calculate the distance the pointer has moved, and from this, and the ratio of the arms of the lever, calculate the total expansion of the rod. Then calculate the expansion of the rod per degree change of temperature, and finally, the number of centimeters that one centimeter of the rod increased in length per change of temperature of 1° C. This last number is called the coefficient of linear expansion.

Observations	1	2	3	4
Length of brass rod				
Length of long arm of lever . . .				
Length of short arm of lever . . .				
Reading of pointer before heating .				
Temperature before heating . . .				
Reading of pointer after heating .				
Temperature after heating . . .				
Total expansion of rod				
Expansion per degree				
Expansion per centimeter per 1° .				

Conclusions. — Show how you know that the rod expanded. Explain how you determined just how much it expanded, stating clearly the relation between the distance, the end of the rod moved in expanding, and the distance the point *C* of the lever moved.

Explain how, from the total expansion, the expansion of 1 cm. of brass when its temperature is raised 1° C. is found.

EXPERIMENT XXXVII

Object. — *To find the coefficient of expansion of air (a) when the pressure is constant, (b) when the volume is constant.*

Apparatus. — Two glass tubes of small bore connected by rubber tube, one tube closed at one end, containing dry air and a column of mercury; a tubulated ice tray; a steam jacket; a boiler and Bunsen burner; some ice; a half-meter stick.

Directions. — Place the tube in a horizontal position in the ice tray so that the air column is completely surrounded by ice. After several minutes measure from open end of tube to the inner end of mercury column. Remove the tube from the tray, lay it in a horizontal position, and measure its entire length. Calculate the length of the air column at 0° C.

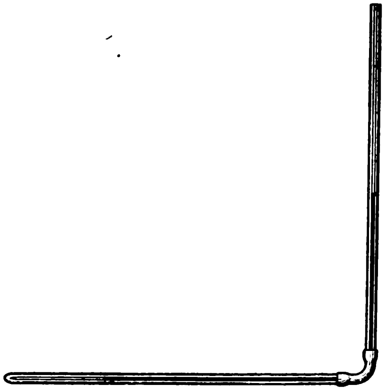

FIG. 42.

Place the tube in a horizontal position in the steam jacket so that the air column will be completely surrounded by steam. After steam has been passing freely through the jacket for several minutes, measure from the open end of the tube to the inner end of the mercury column.

Calculate the length of the air column at the temperature of steam. Read the barometer and calculate the temperature of steam at the time of the experiment.

Find the total expansion for the given rise of temperature, then the expansion per degree rise of temperature, and finally the expansion per unit volume (the length represents the volume) per degree rise of temperature.

To obtain the second coefficient, lay the tube again in a horizontal position in the ice tray and after several minutes mark with a rubber band, or a string tied around the tube, the inner end of the mercury column. Then place the tube in the steam jacket and after the steam has been passing freely around it for several minutes raise the outer arm of the connected tubes until the inner end of the column of mercury is at the point marked. The air column then has the same volume as in the ice. Measure the height of the mercury in each arm above the table and find the difference of level. Read the height of the barometer.

Find the total increase of pressure for the given change of temperature, then the increase per degree change of temperature, and, finally, the increase of each centimeter of the pressure at 0° C. per degree change of temperature.

Observations	
(*a*) Length of tube	
Length from open end of tube to inner end of mercury .	
Length of air column	
Temperature in ice	
Temperature in steam	
Total expansion of air column	
Expansion per 1° change of temperature	
Expansion per unit volume per 1°	
(*b*) Height of barometer	
Pressure of air while in ice	
Height of mercury in open arm	
Height of mercury in closed arm	
Difference of level of mercury when volume is same and air is in steam	
Pressure of air while in steam	
Temperature of steam	
Total increase of pressure	
Increase of pressure per 1°	
Increase per centimeter of pressure at 0° C. per 1° change of temperature	

Conclusions. — State the sources of error in this experiment. Compare the two coefficients and explain. Why can we use the length of the air column to represent the volume?

EXPERIMENT XXXVIII

Object. — *To study the result of mixing together a known quantity of hot water at a known temperature and a known quantity of colder water at a known temperature.*

Apparatus. — Platform balance and weights; calorimeter; beaker; thermometer No. —; hot and cold water.

Directions. — Weigh the dry calorimeter. Put into it about 150 g. of wáter at a temperature of about 60° C. Nearly fill a 250 cc. beaker with cold water at a temperature of about 10° C. Weigh accurately the calorimeter and hot water. Take the temperature of the cold water, stirring well, then of the hot water, and immediately pour the cold into the hot water in the calorimeter. Stir quickly with the thermometer and take the temperature of the mixture within a half a minute. Then weigh accurately the calorimeter and the mixture. Calculate the weight of the hot and of the cold water used, and the rise or fall of temperature of each. Calculate the number of calories of heat given up by the hot and gained by the cold water. Repeat the experiment, using different quantities of hot and of cold water.

Definition. — A calorie is the quantity of heat liberated or absorbed by a gram of water when its temperature is changed 1° C. Therefore, if 1 gram of water changes in temperature 2° C. two calories are liberated or absorbed, which would also be the quantity of heat involved if 2 grams of water change 1° C. in temperature. If 25 grams of water change 12° C. in temperature the quantity of heat lost or gained is 25×12 or 300 calories, or if m grams of water change in temperature $t°$ the quantity of heat involved is mt calories.

Observations	1	2	3	4
Weight of calorimeter				
Weight of calorimeter and hot water				
Weight of calorimeter and mixture				
Temperature of the cold water				
Temperature of the hot water				
Temperature of the mixture				
Calculated weight of the hot water				
Calculated weight of the cold water				
Calculated fall of temperature of hot water				
Calculated rise in temperature of cold water				
Number calories of heat liberated by cooling of hot water				
Number calories absorbed by warming of cold water				

Conclusions. — When two quantities of water of different temperatures are mixed together, compare the quantities of heat exchanged.

Upon what will the temperature of the mixture depend? Compare the masses of water and the changes of temperature. Account for the slight inequality between the calculated number of calories absorbed and calories liberated.

EXPERIMENT XXXIX

Object. — *To determine the thermal capacity of a calorimeter, i.e. the number of calories absorbed or liberated in changing the temperature of the calorimeter 1° C.*

Apparatus. — A calorimeter; a beaker; a thermometer; hot water.

Directions. — Weigh the dry calorimeter. Pour into the beaker about 200 g. of water at a temperature of about 60° C.

Take the temperature of the room, which will be the temperature of the calorimeter. Then take the temperature of the hot water, and immediately pour it into the calorimeter. Stir thoroughly, and take the temperature within a half minute. Weigh the calorimeter and water. Calculate the weight of water poured into the calorimeter, the fall of temperature of the water, and the rise in temperature of the calorimeter.

Calculate the number of calories liberated by the water. State the number of calories gained by the calorimeter. Divide this number by the rise of temperature to obtain the number of calories required to heat the calorimeter 1° C.

Observations	1	2
Weight of calorimeter		
Weight of calorimeter and water		
Temperature of calorimeter		
Temperature of hot water		
Temperature of calorimeter and water		
Fall of temperature of water.		
Rise of temperature of calorimeter		
Calories liberated by water		
Calories gained by calorimeter		
Calories gained by calorimeter in heating 1° C. . . .		

EXPERIMENT XL

Object. — *To determine the specific heat of a solid.*

Apparatus. — A calorimeter; a copper dipper; a boiler; a stirring rod; a thermometer; lead shot or copper punchings.

Directions. — Half fill the boiler with water and place the dipper containing about 200 g. of lead or copper in the top of the boiler. Heat to about 95° C., keeping the dipper covered. Meanwhile weigh the empty calorimeter and then weigh in it about 200 g. of water previously cooled by ice. Take the temperature of the cold water. Stir the shot thoroughly, take its temperature, and then quickly pour it into the cold water in the calorimeter. Stir the mixture thoroughly and take its temperature. Weigh the calorimeter and its contents and calculate the weight of shot used. Calculate the number of calories of heat gained by the water and the calorimeter.

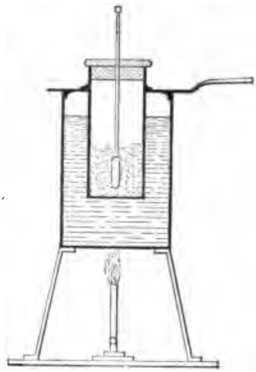

FIG. 43.

From the law of the exchange of heat, state the number of calories of heat lost by the lead shot. Calculate from the total number of calories lost and the fall of temperature of the shot when mixed with the cold water, how many calories the shot lost in cooling 1° C. From this number and the number of grams of shot used, calculate the number of calories given out by 1 g. of lead in cooling 1° C. This last quantity is the specific heat of lead.

OBSERVATIONS	1	2
Weight of empty calorimeter		
Weight of calorimeter and cool water		
Weight of cool water		
Temperature of lead shot		
Temperature of cool water		
Temperature after mixing		
Weight of calorimeter, water, and shot		
Calculated weight of shot		
Calculated calories gained		
Total calories lost by shot		
Calories lost by shot in cooling 1°		
Calories lost by 1 g. lead in cooling 1°		

Conclusions.—Explain how the final result above was obtained and state the sources of error in determining it.

EXPERIMENT XLI

Object. — *To determine the number of calories of heat required to melt 1 g. of ice at 0° without any change of temperature (heat of fusion).*

Apparatus. — Cracked ice; a calorimeter; hot water; a balance and weights; and a centigrade thermometer, No. —.

Directions. — Weigh the empty calorimeter, and weigh in it about 200 g. of hot water at about 80° C. Wipe dry about 75 g. of ice broken into a number of pieces.

Obtain the temperature of the hot water and immediately begin putting in the ice, piece by piece, until it is all melted, when the temperature of the water should be noted. Weigh the calorimeter and its contents and calculate the weight of the ice put into it.

Calculate the number of calories of heat lost by the hot water and the calorimeter. State the amount of heat absorbed during the melting and subsequent warming of the melted ice. Calculate separately the heat absorbed in raising the temperature of the melted ice. Now find the heat absorbed in melting only. Finally calculate the calories required to melt 1 g. of ice.

Observations	1	2	3	4
Weight of calorimeter				
Weight of calorimeter and hot water				
Weight of hot water				
Temperature of water before putting in ice				
Temperature of water after ice melted				
Weight of calorimeter and contents				
Calculated weight of ice				
Calories lost by hot water				
Calories absorbed by melted ice in warming				
Calories absorbed during process of melting				
Calories to melt 1 g. of ice . . .				

Conclusions.— Explain the different steps in the above process and state the sources of error.

EXPERIMENT XLII

Object. — *To determine the number of calories liberated in condensing 1 g. of steam at 100° C. to water at 100° (heat of vaporization).*

Apparatus. — A boiler, calorimeter, a steam separator, thermometer, cold water, rubber tubing.

Directions.—Half fill the boiler with water and start heating. Weigh the calorimeter and then pour into it about 300 g. of water at less than 10° C. Weigh the calorimeter and cold water. Take the temperature of the water. Pass steam into the water,

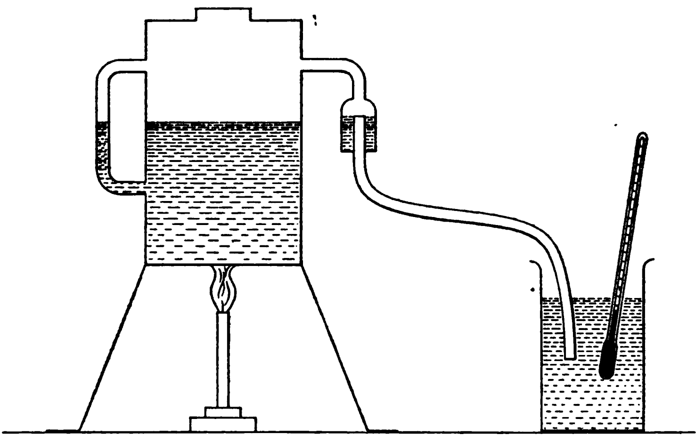

FIG. 44.

connecting the separator between the boiler and calorimeter. Stir the water constantly and watch the temperature. When the temperature reaches 30° C. stop the supply of steam. Take the temperature accurately and then weigh the calorimeter and mixture.

Calculate the number of grams of steam condensed. Calculate the number of calories of heat gained by the cold water and the calorimeter; also the number of calories liberated by the condensed steam in cooling from 100° to the temperature of the mixture. From the above values find the number of calories liberated in condensing the steam and the number liberated in condensing 1 g. of steam without changing its temperature.

Observations	1	2
Weight of calorimeter		
Weight of calorimeter and cold water		
Weight of calorimeter and mixture		
Temperature of cold water		
Temperature of mixture		
Weight of cold water		
Weight of steam		
Rise in temperature of cold water		
Fall in temperature of steam		
Calories gained by cold water and calorimeter . . .		
Calories liberated in cooling condensed steam . . .		
Calories liberated in condensing steam		
Calories liberated in condensing 1 g. of steam . . .		

Conclusions. — Explain how the result is obtained.

EXPERIMENT XLIII

Object. — *To determine the dew-point.*

Apparatus. — A polished calorimeter; a thermometer No. —; ice or snow; a beaker.

Directions. — Note the temperature of the room. Pour water of a temperature about 15° C. into the calorimeter to the depth of one inch. From the beaker pour in slowly ice water, carefully stirring with the thermometer. Continue this until a mist first appears on the outside of the calorimeter. Read the thermometer. Allow the temperature of the water in the

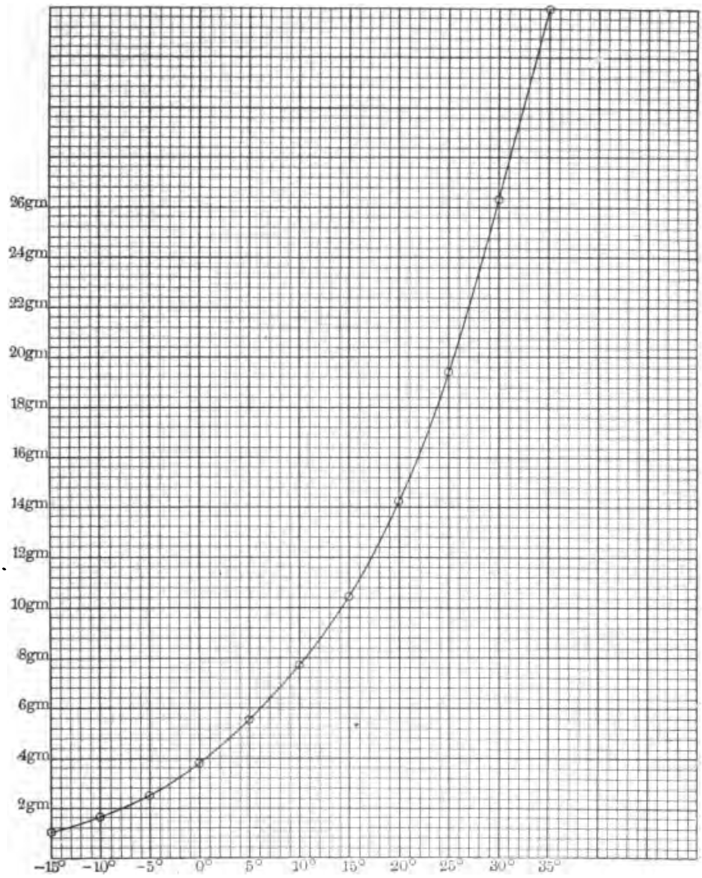

FIG. 45.

calorimeter to rise gradually without disturbance and read the thermometer when the mist begins to disappear. The average of these two temperatures is to be taken as the dew-point.

Cautions. — Do not allow the moist hand or breath to come in contact with the calorimeter during the experiment. Take pains to obtain a good light on the calorimeter, that the mist may be distinctly seen when it first appears.

From the saturation curve (Fig. 45) which shows the weight of water vapor necessary to saturate one kilogram of air at different temperatures, note the weight of water vapor actually present in the atmosphere, and the weight of water vapor necessary at the room temperature to saturate the air. From these calculate the relative humidity, which is the ratio of the first of these weights to the second.

Observations	1	2
Temperature of room		
Temperature when mist first appears		
Temperature when mist begins to disappear		
Calculated dew-point		
Calculated relative humidity		

Conclusions. — What is meant by saturated air? What does the curve show as to the relation between the temperature and the amount of water vapor necessary to saturate the air? Why does dew form, and why does it disappear?

EXPERIMENT XLIV

Object. — *To investigate the law of intensity of illumination and to determine the candle power of a lamp.*

Apparatus. — Five candles; a Bunsen photometer and a lamp.

Directions. — I. Light the candles and place four of them at one end of the photometer and the one remaining candle at the other end. Move the screen at such a point that the translucent spot appears as bright as the rest of the screen.

Read the positions of the screen and the sources of light on the photometer bar. Extinguish one of the four candles and repeat, finding the positions at which three and one candles respectively illuminate the screen equally. Extinguish one of

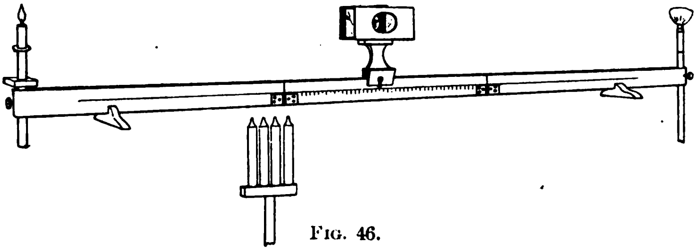

FIG. 46.

the three candles and repeat. Find the ratio of the number of candles on both sides of the screen, also the ratio of their distances from the screen and the ratio of the squares of these distances.

From the above ratios deduce the law of the intensity of illumination.

OBSERVATIONS	1	2	3	4
Number of lighted candles at left end				
Number of lighted candles at right end				
Position of candles at left end . .				
Position of candles at right end . .				
Position of screen				
Calculated distance from screen to candles at left end				
Calculated distance from screen to candles at right end				
Calculated square of distance from screen to candles at left end . .				
Calculated square of distance from screen to candles at right end. .				
Ratio of number of candles at ends of bar				
Ratio of squares of distances from screen				

Directions. — II. Repeat the experiment using the lamp and one candle as the sources of light. Calculate the candle power of the lamp.

Observations	1	2	3	4
Position of candle				
Position of lamp				
Position of screen				
Calculated distance between candle and screen				
Calculated distance between lamp and screen				
Calculated square of distance between candle and screen . . .				
Calculated square of distance between lamp and screen				
Ratio of squares of these distances .				
Candle power of lamp				

Conclusions. — Show how by means of the law of intensity of illumination, the candle power of the lamp was found.

EXPERIMENT XLV

Object. — *To determine the location and size of an image seen in a plane mirror.*

Apparatus. — A plane mirror fastened to one side of a wooden block; paper; a pin; a half-meter stick; a protractor.

Directions. — Draw a line on the sheet of paper connecting the middle points of the long sides. Place the reflecting surface of the mirror over this line in a vertical position. In front of the mirror draw a scalene triangle as shown in Figure 47, having no point nearer than 6 cm. to the mirror and the distance between two of its vertices at least 10 cm.

Set up a pin in a vertical position at one of the vertices (A) of the triangle. Lay the half-meter stick upon the paper, and sighting along one edge, point the stick in such a direction that

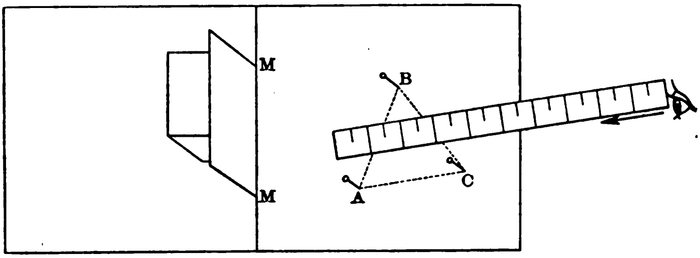

FIG. 47.

a line drawn along its edge, if produced back of the mirror, would pass through the *image* of pin A. Draw this line along the edge of the stick. Sight along the stick from a different position and obtain a second line which, if produced, would pass through the image of pin A. Have a large angle between the lines sighting at the one image.

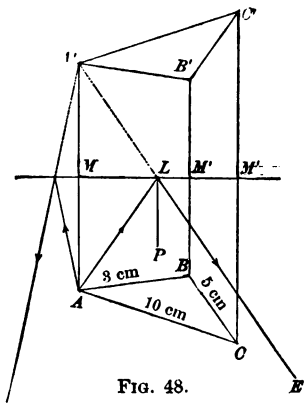

FIG. 48.

Set up the pin at a second vertex B and sight at its image from two different positions. Repeat for the point C. Remove the mirror and extend the first two lines till they meet. Mark the point of meeting A', which is the image of A. Extend the second and third pairs of lines and make their points of meeting B' and C'.

Connect A', B', and C'. This triangle is the image of the triangle ABC. Measure each of its sides. Connect A with A', B with B', and C with C'. Measure the distances AM and $A'M$ of A and A' from the mirror line. Also, measure BM', $B'M$; and CM'' and $C'M''$.

Measure the angles which AA', BB', and CC', respectively, make with the mirror line. From the point, L, where the first line drawn in this experiment crosses the mirror line, draw a line to A' and also draw a perpendicular, LP, to the mirror line at this point. The first line drawn is a reflected ray. Measure the angle ELP which it makes with the perpendicular to the mirror. The line drawn from A to this point on mirror line is the corresponding incident ray. Measure the angle ALP which the incident ray makes with the perpendicular to the mirror.

Observations	
Lengths of AB, BC, and AC	
Lengths of $A'B'$, $B'C'$, and $A'C'$	
Distance from mirror to A	
Distance from mirror to A'	
Distance from mirror to B	
Distance from mirror to B'	
Distance from mirror to C	
Distance from mirror to C'	
Angle between AA' and mirror	
Angle between BB' and mirror	
Angle between CC' and mirror	
Angle of incidence ALP	
Angle of reflection ELP	

Conclusions. — How do object and image compare in size? Is there any inversion of image? If so, what kind? Given the position of an object in front of a plane mirror, how could you locate its image without sighting it? Infer the law of reflection of light from the observed angles of incidence and reflection.

Infer the position of a vertical object placed upon the edge of a horizontal mirror. In what does it differ from the image seen in a vertical mirror? Explain the use of a mirror in Exp. XXXVI.

EXPERIMENT XLVI

Object. — *To find the position of a real and of a virtual image formed by a concave cylindrical mirror.*

Apparatus. — A concave cylindrical mirror; a sheet of paper; a half-meter stick; a pin.

Directions. — Set the mirror near the middle of the paper. Draw a line AOB along the base of the reflecting surface. Remove the mirror. Draw a line ADB, connecting the ends of the first line drawn. Erect a perpendicular ODC at its middle point. On this perpendicular ODC, perpendicular to it and $1\frac{1}{2}$ cm. from the center of the mirror draw a line PM, extending 1 cm. each side of the median line. Set up a pin at P and replace the mirror.

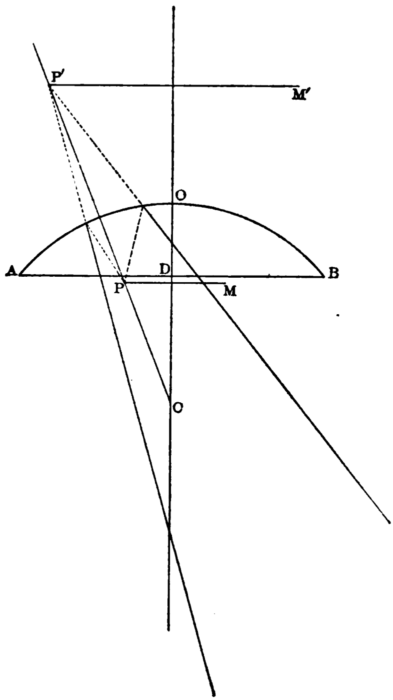

FIG. 49.

Sighting along the stick place it so that one edge of it points at the image of P. Draw a line along this edge; then from a different position sight again at the same image. Have the sighting lines pass near the center of the mirror to avoid the error due to spherical aberration. Place the pin at M, and sight at its image from two different positions. Remove the mirror and produce the two lines drawn when sighting at the image of P until they intersect. This point P' is the image of P. Do the same for the other lines, sighting at the image of $M(M')$. Connect the two points of the image. Measure the distances along OC from the line PM to the mirror and from $P'M'$ to the mirror. (Distances measured behind the mirror are negative.) Measure the length of PM and of $P'M'$. Calculate the reciprocals of the distances of the object and of the image from the mirror and find their algebraic sum. Find the center of the circle of which AOB is a part of the circumference, measure its radius, and find its reciprocal.

Repeat, placing the mirror on another paper near one end and draw a line 2 cm. long perpendicular to the median line and 4 cm. from the mirror. Again repeat, having the object line 4 cm. long and 10 cm. from the mirror.

Observations	1	2	3
Distance of object from mirror (Do) . . .			
Distance of image from mirror (Di) . . .			
Radius of curvature (R)			
Reciprocal of Do $\left(\frac{1}{Do}\right)$.			
Reciprocal of Di $\left(\frac{1}{Di}\right)$			
Sum of reciprocals $\left(\frac{1}{Do}+\frac{1}{Di}\right)$			
Reciprocal of R $\left(\frac{1}{R}\right)$			
Size of object			
Size of image			
Kind of image			

Conclusions. — State the relation between the reciprocals of the distances from the mirror of an object and its image and the reciprocal of the radius of curvature. State the relation between the sizes of the object and of its image and their distances from the mirror.

EXPERIMENT XLVII

Object. — *To locate images formed by a convex cylindrical mirror.*

Apparatus. — A convex mirror; a sheet of paper; a half-meter stick; a pin.

Directions. — In the same manner as in the experiment with the concave mirror, locate the image of the object line *AB* when its distance from the mirror is successively 1.5 cm., 4 cm., and 10 cm.

Observations. — Use the same form as in Experiment XLVI.

Conclusions. — Make a general statement as to kind, size, and position of the images formed by a convex mirror.

EXPERIMENT XLVIII

Object. — *To determine the index of refraction from air to glass.*

Apparatus. — A rectangular block of glass; two pins; a draughtsman's triangle; a half-meter stick; a sheet of paper.

Directions. — Place the block of glass in the middle of the paper and trace with pencil the perimeter of its base. Draw a line making an angle of 45° with one face of the glass and set up the two pins on this line, 5 cm. apart.

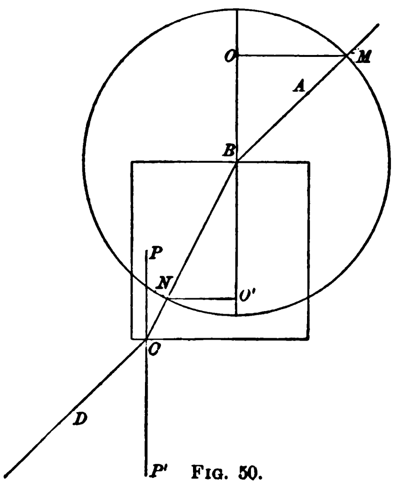

FIG. 50.

Looking through the glass, place the rubber triangle so that one edge seems to be in the same straight line as the two pins. Draw a line along this edge on the paper. Remove the glass and extend this line to the base line of the glass block. Connect the two points, *B* and *C*, where these lines meet the faces of the glass.

Erect two perpendiculars *OO′* and *PP′* to the two faces of the glass at the points *B* and *C*. About *B* as a center draw a circle of about 5 cm. radius. From the point *M*, where this circle cuts the line *AB*, draw the line *MO* perpendicular to *OB*. Likewise, from the point *N*, where the same circle cuts *BC* produced, draw the line *NO′* perpendicular to *BO′*.

Measure the perpendicular *MO* in the angle of incidence *MBO*, and also the perpendicular *NO′* in the angle of refraction *O′BN*. Divide the first perpendicular by the second. The quotient is the index of refraction from air to glass.

With the point *C* as a center make the same construction to obtain the index of refraction from glass to air.

Observations	1	2
Length of perpendicular in first angle of incidence .		
Length of perpendicular in first angle of refraction .		
Calculated index of refraction from air to glass . .		
Length of perpendicular in second angle of incidence		
Length of perpendicular in second angle of refraction		
Calculated index of refraction from glass to air . .		

Conclusions. — What does this experiment show as to the direction in which light travels? How is a ray of light affected on (1) entering a denser medium, (2) entering a rarer medium? Compare the two indices obtained and discuss.

When the faces of the glass at which the light enters and emerges are parallel how do the directions of the incident and emergent rays compare?

EXPERIMENT XLIX

Object. — *To trace the path of a ray of light through a prism, and to find the index of refraction of light from air to glass.*

Apparatus. — A triangular glass prism; two pins; a draughtsman's triangle; a sheet of paper; a protractor; a half-meter stick.

Directions. — Place the prism on one of its triangular faces, near the middle of the paper. Trace its perimeter on the paper. Through *P*, the middle of one of its sides, draw a line *NP*, perpendicular to that face. To the same point, draw a line *AP*, making an angle of 45° with this line and towards the thickest part of the prism. Set up the two pins on this line. Place one edge of the triangle so that, looking through

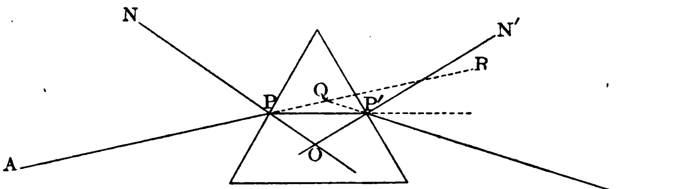

FIG. 51.

the prism, it appears to be in the same straight line as the two pins. Draw a line along this edge of the triangle and produce it until it reaches the prism at *P′*. Draw a line connecting *P* and *P′*, and produce it about 5 cm. each side of the prism. Through *P′* draw a line *P′N′* perpendicular to that face of the prism. Measure the angles of incidence and refraction, *APN* and *OPP′*, and the angle of deviation *P′QR*.

To find the index of refraction, take from the table in the Appendix the sines of the angles of incidence and of refraction and divide the first by the second.

With the point *P′* as center make the same construction to obtain a second determination of the index of refraction.

OBSERVATIONS

ANGLES	MAGNITUDE IN DEGREES	SINES
Incidence (1)		
Refraction (1)		
Incidence (2)		
Refraction (2)		
Deviation		
Index from air to glass		
Index from glass to air		

Conclusions. — What is the direction of the bending of the ray? How do the indices show the relative velocities of light in air and in glass?

EXPERIMENT L

Object. — *To determine the index of refraction from water to air.*

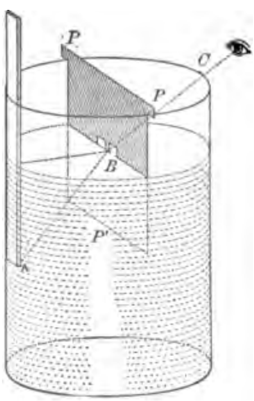

FIG. 52.

Apparatus. — A battery jar; a metal partition, shown in Figure 52, to fit the jar; a small 30 cm. ruler.

Directions. — Place the metal partition across the middle of the top of the jar and pour into the jar enough water so that when the ruler is placed under the water about two-thirds its length the surface of the water will be about 1 mm. from the tooth in the lower edge of the partition.

Looking in the direction of the diameter of the jar, which is perpendicular to the metal partition, insert the ruler in the water until its lower edge seems to be in same straight line as the tooth of the partition and the edge of the jar nearest your eye.

Read the length of the ruler below the edge of the jar. Measure the distance from edge of the jar to the water surface. Measure the distance of the partition from the edge of the jar over which you sighted and also its distance from the ruler on the other side of the jar.

Make a full size diagram of the jar, marking the position of the partition, the end of the ruler, the water surface, and the edge nearest your eye.

Draw a line *AB* from the end of the ruler to the tooth of the partition to mark the path of the ray in the water. Draw a line from *B* to *C* to mark the path of the ray in the air after emerging from the water. Draw the perpendicular *PBP'* to the surface of the water at the point of refraction *B*.

Measure the angle of incidence *ABP'* and the angle of refraction *CBP*.

From the table in Appendix find the sines of these angles and divide the sine of the angle of incidence by the sine of the angle of refraction. The quotient is the index of refraction from water to air.

EXPERIMENT LI

Object. — *To find the relation between any pair of conjugate focal distances and the principal focal distance of a converging lens.*

First Method

Apparatus. — A double convex lens; lens holder; screen; screen holder; a source of light; a screen with rectangular opening in which are two cross wires; a meter stick.

Directions. — Place the light behind the screen with the cross wires. Place the lens in the lens holder and put it on the meter stick. Place the screen holder on the stick behind it. Place the end of the meter stick against the screen with the cross wires and the second screen 75 cm. from it. Move the lens along the stick until a sharp image of the cross wires is formed upon the second screen. Read the positions of screen and lens and measure the height of the image. Then move the lens until a second position is found which gives a sharp

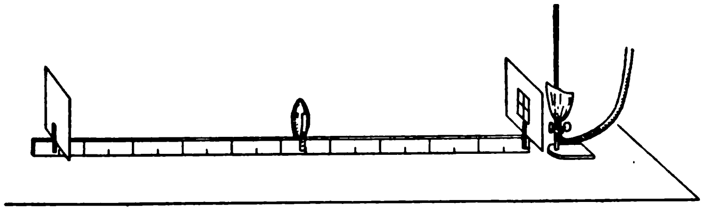

FIG. 53.

image. Move the screen to the 65 cm. mark and again find two positions of the lens at which sharp images are formed. Move the screen to the 50 cm. mark and repeat.

To get the principal focal length, focus on some very distant object, as a roof or chimney, and get a sharp image of it. Read the positions of lens and screen.

OBSERVATIONS	1	2	3	4	5	6
Position of object						
Position of lens						
Position of screen						
Distance from lens to object, Do						
Distance from lens to image, Di						
Reciprocal of object distance, $\frac{1}{Do}$						
Reciprocal of image distance, $\frac{1}{Di}$						
Sum of reciprocals, $\left(\frac{1}{Do}+\frac{1}{Di}\right)$						
Focal length of lens						
Reciprocal of focal length . .						
Size of image						
Size of object						

Definition. — *Conjugate foci are two points so related that if the object be placed at one the image will be formed at the other.*

Conclusions. — What is the relation between the reciprocals of any pair of conjugate focal distances and the reciprocal of the principal focal distance? What is the relation between the sizes of object and image and their distances from the lens? How do you explain the fact that, for a given distance between object and screen, you found sharp images with two positions of the lens?

Second Method

Apparatus. — A double convex lens; a lens holder; two long pins; two ordinary pins; two strips of paper each 10 by 50 cm.; two thumb tacks.

Directions. — Place the strips of paper end to end and fasten to the table with the thumb tacks. Draw a median line parallel with the long sides. Ten centimeters from one end of this median erect a perpendicular 5 cm. long to it, extending 2.5 cm. on each side of the median. Mark the ends of this perpendicular *A* and *B* and set up an ordinary pin at each end.

Support the lens in a vertical position 50 cm. from line *AB* and with its center over the median line. Place a piece of colored paper on the head of pin *A* to distinguish it, and, looking through the lens, set up a long pin so as to coincide with the position of the *image* of *A*. To do this, place the long pin so that it hides the image when you are looking steadily at it from one position, then move your head to the left or right; if the image *appears* to move to the left or right of the long pin then the image is farther from your eye than the long pin. Move the long pin farther from your eye and repeat the above until upon moving your head to the left or right the long pin continues to hide the image of *A*. The long pin is then where the image is formed. If, in the first operation, the image appears to move to the right of the long pin when you move your head to the left, then the image is nearer your eye than the long pin and the pin must therefore be moved nearer your eye to locate exactly the image.

In the same manner locate the image of *B* with the second long pin. Measure the distance along the median line of the image *A'B'* from the lens. Measure the size of the image, *i.e.* the length of the line *A'B'*.

Place the lens 25 cm. from the object *AB*, and find the image *A'B'* again.

Finally, place the lens 8 cm. from the line *AB* and locate the image *A'B'*. In this third case the image will be found on the same side of the lens as *AB*. In locating this image look at the long pin *over* the lens, at the same time observing the image of *A through* the lens. Otherwise, locate the image just as before. Find the principal focal length of the lens as described in the first method.

Observations	1	2	3	4	5	6
Distance from lens to object, *Do*						
Distance from lens to image, *Di*						
Reciprocal of object distance, $\frac{1}{Do}$						
Reciprocal of image distance, $\frac{1}{Di}$						
Sum of reciprocals $\left(\frac{1}{Do}+\frac{1}{Di}\right)$						
Focal length of lens, *F* . .						
Reciprocal of focal length, $\frac{1}{F}$						
Size of image						
Size of object						

Conclusions. — State the same relations asked for in the first method.

EXPERIMENT LII

Object. — *To investigate the properties of magnets.*

Apparatus. — Two bar magnets; bottle of iron filings; a sewing needle; a wooden support and clamp; a short piece of soft iron; manila paper; bits of various substances as copper, zinc, brass, lead, wood, iron, steel, glass, and rubber.

Directions. — 1. Bring one end of a bar magnet near each of the various substances given.

2. Lay the bar magnet upon the manila paper and scatter iron filings over it; then pick the magnet up, turning it over to allow the filings to drop off, if they will. Note the distribution of the filings.

3. Support the bar magnet by a thread so that it is horizontal, and fasten the thread to the wooden support. Note the direction of the magnet when it comes to rest. Repeat with the other magnet. Mark like pointing ends.

4. Suspend one magnet in a horizontal position and hold each end of the other magnet successively near each end of suspended magnet. Note the action of like pointing ends, also that of unlike pointing ends.

5. Hold one end of the sewing needle near some iron filings; then rub the needle throughout its entire length with the N end of the magnet about ten times *in one direction* only, say from the eye to the point. Then hold one end of the needle near iron filings. Suspend the needle with thread in a horizontal position and note the direction of the end last touched by the magnet. Compare this direction with that in which the end of the bar magnet with which the needle was rubbed would point if freely suspended in a horizontal position.

6. Lay the magnetized needle in iron filings and note the distribution of the filings; then break the needle into two equal parts and test similarly each part. Suspend horizontally one piece and with the other piece test the polarity of the four ends.

7. Wrap a bar magnet in paper and bring one end near iron filings.

8. Bring one end of the piece of soft iron near iron filings. Then holding one end of a bar magnet *near* one end of the soft iron, again place the other end of soft iron near iron filings. Finally, note what happens when the bar magnet is removed.

Observations. — State fully everything observed in each of the eight parts of the experiment.

Conclusions. — Is magnetic attraction a universal or a specific force? How is magnetism distributed in a bar magnet? What are the properties of freely suspended magnets? State the law of action of magnet poles. Why does the end of needle last touched, point in the direction observed? What does the broken magnetized needle indicate as to the condition of the particles of a magnet? Part 7 illustrates magnetic transparency as a property of paper. Is air magnetically transparent? How do you know this? Part 8 illustrates magnetization by induction. What do your observations indicate as regards the magnetic retaining power of soft iron? What magnetic pole of the soft iron is nearest the inducing pole of the bar magnet? How do you know this? Infer why magnets attract soft iron or steel.

EXPERIMENT LIII

Object. — *To map magnetic fields by means of iron filings.*

Apparatus. — Two bar magnets; a wide mouth bottle; iron filings; cheese cloth; heavy paper; two half-meter sticks.

Directions. — Place a bar magnet upon the table, place a sheet of heavy paper over it, using the half-meter sticks to support it. Put iron filings into the bottle and cover the mouth with the

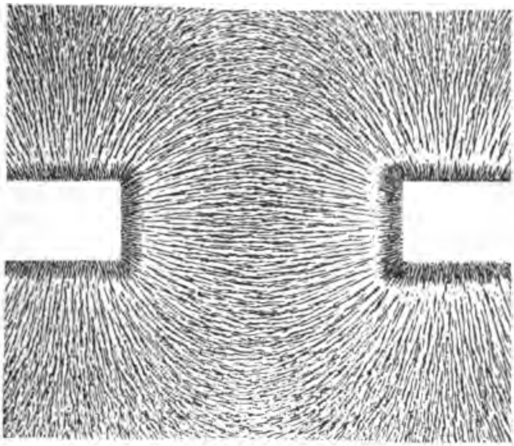

FIG. 54.

cloth. Sprinkle the filings *lightly* over the paper, tapping slightly to assist the arrangement of the filings. Draw in your notebook the outline of the field as formed on the paper.

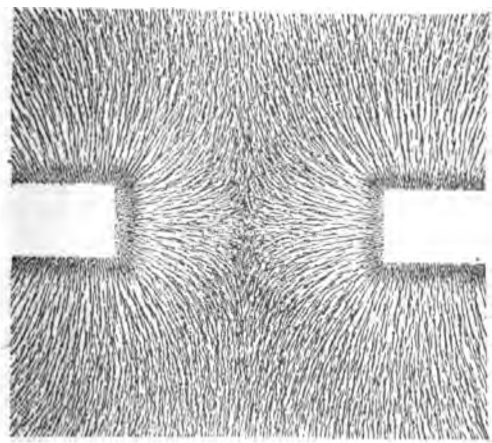

FIG. 55.

In the same manner determine the magnetic fields of the following:—

1. Two bar magnets in the same line with unlike poles near each other (about 3 cm. apart).

2. Two bar magnets in same line with like poles near each other (3 cm. apart).

3. Two bar magnets alongside of each other, parallel and about 3 cm. apart, having like poles adjacent.

4. Same as three, but with *unlike* poles adjacent.

5. Two magnets at right angles, something like a letter T, but not in contact.

Observations.—Make diagrams of each of the foregoing fields.

Conclusions.—Why do the filings arrange themselves along lines? Why are the lines curved? Do any two lines intersect? Explain. What properties of the lines of force are illustrated in (1) the space between unlike poles, (2) the space between like poles?

EXPERIMENT LIV

Object.—*To find the form of the magnetic field about a bar magnet.*

Apparatus.—A bar magnet; a magnetic compass; paper.

Directions.—Place the paper upon the table and in the upper right hand corner mark the direction of the earth's magnetic force as determined from the compass. Do not change the position of the paper after marking this direction. Place the bar magnet in the middle of the paper pointing N and S and with its N pole toward the north; trace its perimeter and mark the position of its North seeking pole. Bring the compass close to the magnet and move it until its needle points directly to one corner of the magnet. Mark by a dot the direction of the end of the needle farthest from the magnet. Move the compass until that end which pointed to the magnet now points to the dot made and again mark the direction of the other end by a second dot. Continue moving and marking direction of the compass until the edge of the paper or the magnet is again reached. Join the consecutive dots by a line and indicate by an arrowhead the direction of the N-end of the compass when placed on this line. Mark off centimeter spaces along the magnet from the first point and, starting with the compass pointing to each of these in turn, trace out other lines. Start a line from the middle of each end. Upon a second paper place the magnet with its S-end pointing toward the north and repeat the experiment.

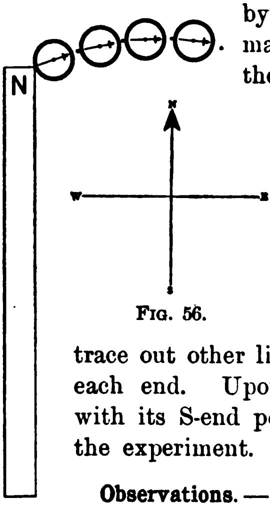

Fig. 56.

Fig. 57.

Observations. — Preserve the paper obtained showing the compass directions at the various points about a bar magnet.

Conclusions. — What do these lines joining the dots represent, and why? Compare the two fields as mapped, and determine if they show any influence from the earth's magnetic field. How? In what respect is this method less advantageous than that of the iron filings? In what more advantageous?

EXPERIMENT LV

Object. — *To determine the chemical action in a simple voltaic cell.*

Apparatus. — A strip of ordinary commercial zinc; a narrow strip of copper; a tumbler containing some dilute sulphuric acid (H_2SO_4); a strip of amalgamated zinc; connecting wires; a wire connector; a magnetic compass; a voltmeter.

Directions. — Place the strip of commercial zinc alone in the acid. Then place the copper strip alone in the acid. Place both zinc and copper strips in the acid but not in contact nor with wires connected. Finally, connect the wires. Repeat the foregoing with amalgamated zinc instead of the commercial zinc.

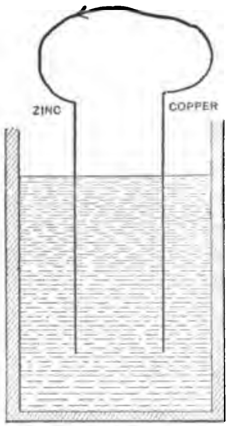

FIG. 58.

Arrange a portion of the wire connecting the zinc and copper while in the acid so that it has a northerly and southerly direction, and hold the magnetic compass over and near the wire.

Connect the copper strip with the + terminal of the voltmeter and the zinc strip with the − terminal. Place the strips in acid and read the voltmeter every half minute until you have at least five readings, being careful meanwhile not to disturb the cell.

Observations. — State carefully everything observed. Note what change in phenomena results from using amalgamated zinc instead of commercial zinc; also from connecting and disconnecting the strips. Record the effect on the magnetic compass and the voltmeter readings.

Conclusions. — The evolution of gas in the liquid is an evidence of chemical action. The gas is hydrogen and comes from the sulphuric acid (H_2SO_4) which is decomposed; the zinc combines with the sulphur (S) and oxygen (O_4) of the acid, forming a white soluble salt, zinc sulphate ($ZnSO_4$). The action is expressed by the equation: $Zn + H_2SO_4 = H_2 + ZnSO_4$. The action on zinc when it is not connected with the copper is called local action. How is this remedied? How is the chemical action in the cell influenced by connecting the copper and zinc terminals?

The decreasing electromotive force of a simple cell when in closed circuit for several minutes is a defect called polarization. The remedy for this will be shown in the next experiment.

EXPERIMENT LVI

Object. — *To study the two-fluid cell and the tangent galvanometer.*

Apparatus. — A glass jar; a porous cup; a strip of amalgamated zinc; a strip of copper 10 cm. square; a bottle of dilute sulphuric acid (H_2SO_4); a bottle of copper sulphate ($CuSO_4$) solution; a voltmeter; a tangent galvanometer consisting of a coil of 15 turns of insulated wire mounted on a wooden base with a small magnetic needle supported in the center of the coil.

Directions. — I. Half fill the glass jar with copper sulphate solution. Bend the copper strip in semicylindrical shape and place it in the solution. Half fill the porous cup with dilute H_2SO_4, and place the amalgamated strip in the acid; then set the porous cup in the glass jar. Note if there is any local action. Then connect the copper strip with the + terminal of the voltmeter, and the zinc with the — terminal. Take five readings of voltmeter at intervals of $\frac{1}{2}$ minute.

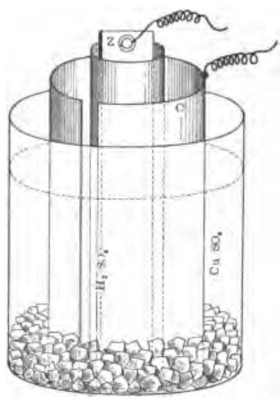

FIG. 59.

II. Adjust the galvanometer by putting the coil in such position that its plane is in a north and south direction, the coil will then be parallel with the magnetic needle at its center. Turn the compass case around until the zero of the scale is directly beneath the N end of the needle.

Now connect the copper and zinc of the two-fluid cell at such terminals of the galvanometer coil that the electric current will pass five times around the needle. Record the deflection of the N end of the needle. Repeat, using successively 10 and 15 turns of the galvanometer coil.

Observations	1	2	3	4
I. Reading of voltmeter				
II. Reading of tangent galvanometer Number of turns of coils used . .				

Conclusions. — What is the difference in the construction of a simple cell and this cell? What difference in the action of the two cells is noticed when the circuits are closed? What, then, do you conclude was the cause of the decreasing e.m.f. of the simple cell, and why the e.m.f. of this cell does not vary? What is the effect of increasing the number of turns of a galvanometer coil, the current being practically constant? What does the deflection of the magnetic needle indicate as to a magnetic field inside the coil?

EXPERIMENT LVII

Object. — *To determine the relation between the directions of an electric current and of the lines of magnetic force about it.*

Apparatus. — A wire traversed by an electric current; a sheet of manila paper; a magnetic compass.

Directions. — Fasten the manila paper by two pins to the table, and draw on it a north and south line parallel to the compass needle, also an east and west line bisecting the NS line. Place the compass with its center over the point of intersection of these two lines. Determine from your instructor the direction of the current in the wire, and hold a portion of the wire *over* the compass and parallel to the NS line in such a way that the current in that portion is moving from south to north. Record the magnitude and direction of the deflection of the N end of compass needle. Then hold the wire under the compass and parallel to the NS line, and record deflection. Repeat with the wire reversed so that the current flows from north to south.

Then hold the wire successively over and under the compass and parallel with the east and west line, so that the current

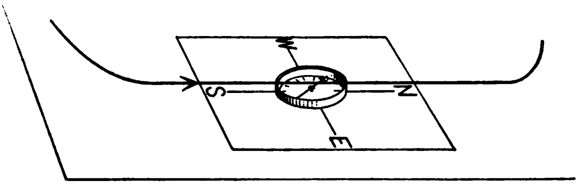

FIG. 60.

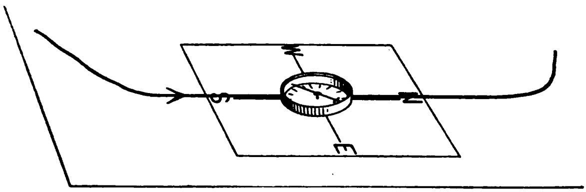

FIG. 61.

flows from west to east. Repeat with current flowing from east to west.

Support the compass in a horizontal position about 20 cm. above the table. Hold a portion of the wire vertical and in front of the N end of the compass needle so that the current flows down in front of it. Repeat with the current flowing up. Make diagrams showing the direction of current and deflection for each case.

OBSERVATIONS

POSITION OF WIRE RELATIVE TO COMPASS	DIRECTION OF CURRENT	DIRECTION OF DEFLECTION OF N END OF NEEDLE	MAGNITUDE OF DEFLECTION

Conclusions. — Represent the current as flowing in your right hand toward the fingers. If the palm faces the compass toward what part of the hand does the N end of needle deflect? Let the direction of the *progressive* motion of a right-handed screw represent the current direction. Compare the direction of the *rotary* motion of the screw with the direction of the lines of magnetic force surrounding the wire traversed by a current.

EXPERIMENT LVIII

Object. — *To indicate the conditions upon which the electromotive force of a cell depends.*

Apparatus. — Two strips each of carbon, copper, lead, iron and zinc; four tumblers; dilute sulphuric acid, dilute hydrochloric acid, sal-ammoniac solution, and salt solution; a Daniell, a gravity, a Bunsen, and a dry cell; a voltmeter; wires.

Directions. — Connect a carbon strip with the + terminal, and a zinc strip with the – terminal of the voltmeter, and place them successively in each of the four liquids, noting the readings. Connect the strips in pairs with the terminals of the voltmeter, using dilute H_2SO_4 as the electrolyte. Each substance in the list of strips given is electropositive to those following it. The + strip should in every case be connected with the + terminal of the voltmeter. Connect the terminals of each cell with the voltmeter, and note in each case the reading, which is approximately the electromotive force of the cell.

Observations

	Exciting Liquid	E.M.F.
Carbon and zinc in	H_2SO_4	
	HCl	
	Sal. ammon.	
	Salt water	

E.M.F. IN H_2SO_4

	CARBON	COPPER	LEAD	IRON	ZINC
Carbon					
Copper					
Lead					
Iron					
Zinc					

NAME OF CELL	ELEMENTS	LIQUIDS	E.M.F.

Conclusions. — Infer the conditions necessary for the production of an e.m.f.

EXPERIMENT LIX

Object. — *To determine upon what the strength of current in an electric circuit depends.*

Apparatus. — A voltmeter; an ammeter; a gravity cell; a Bunsen cell; a storage cell; a rheostat; connecting wires.

Directions. — Connect the terminals of each cell with the voltmeter to determine the e.m.f. of each. Then connect each cell in series with the ammeter and the rheostat, as shown in Figure 62, connecting the + pole of the cell with the + terminal of the ammeter. Introduce, by means of the rheostat, 1 and 5 ohms resistance successively into the electric circuit and note the current strength indicated by the ammeter.

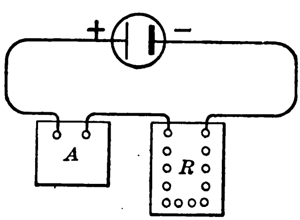

FIG. 62.

Observations

Name of Cell	Gravity		Bunsen		Storage	
E.M.F.						
Ext. R	1 ohm	5 ohms	1 ohm	5 ohms	1 ohm	5 ohms
Current						

Conclusions. — When the external resistance is the same, compare e.m.fs. and current strengths. When the e.m.f. is the same, compare resistances and current strengths.

EXPERIMENT LX

Object. — *To determine what arrangement of cells will give the strongest current for a given external resistance.*

Apparatus. — Three cells; a volt-ammeter; a rheostat; connecting wires.

Directions. — By means of the voltmeter find the e.m.f. (1) of a single cell, (2) of three cells connected in parallel (Fig. 63), (3) of three cells connected in series (Fig. 64).

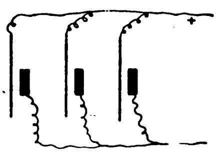

Fig. 63.

Fig. 64.

Then connect in circuit with the ammeter and the rheostat (1) a single cell, (2) three cells connected in parallel, (3) three cells connected in series. Determine from the ammeter the current strength in each case (1) when .2 ohm is the rheostat resistance, (2) when 10 ohms is the rheostat resistance.

Observations	1	2	3	4	5	6
Number of cells						
How arranged						
Electromotive force						
External resistance						
Current strength						

Conclusions. — When the external resistance is small, which arrangement of cells is best? Which, when the resistance is large? How does connecting cells in parallel affect the e.m.f.? How in series?

What must be the reason, since e.m.fs. are the same, that three cells in parallel give a much stronger current than one cell in the first case? Why is it not true in the second case? What must be the reason, since the e.m.f. in series is increased, that three cells in series when external resistance is small give so nearly the same current as one cell? Apply Ohm's law.

EXPERIMENT LXI

Object. — *To study the electro-magnet.*

Apparatus. — An iron rod; insulated copper wire over 1 m. long; small iron nails; a magnetic compass; an ammeter; 110 volt current regulated by a lamp board.

Directions. — Wind twenty turns of wire in a single layer about the iron rod near one end, leaving 1 cm. of rod projecting. Pass the current of one lamp through the wire and hold the one centimeter of projecting rod in the small nails. Raise the rod and count the number of nails lifted. Cut off the current and count the number of nails remaining on the iron rod.

Double the current in the wire by introducing a second lamp in parallel with the first, and repeat the above. Again double the current by using four lamps in parallel, and repeat. Increase the number of turns of wire about the rod to forty, and repeat.

Determine by means of the compass the N and S poles of the electro-magnet, and knowing the direction of current in the wire determine whether it passes clockwise or counter clockwise about the N pole as you face the pole, also about the S pole.

Observations	1	2	3	4	5	6
Number of turns of wire used						
Current strength						
Number of nails lifted . . .						
Direction of current about N pole						
Direction of current about S pole						

Conclusions. — What relation exists between the lifting power of an electro-magnet and the number of amperes of current circulating in its coil? What relation between lifting power and the number of turns? How long does an electro-magnet exert magnetic force? How could you determine the direction of current after locating the poles of an electro-magnet? Would a steel rod act the same as the iron rod? Why?

Refer back to the first experiment with a galvanometer and explain the effect of increasing the number of turns of galvanometer coil.

EXPERIMENT LXII

Object. — *To calibrate a tangent galvanometer by comparison with an ammeter.*

Apparatus. — A storage cell; a tangent galvanometer; an ammeter; a current reverser; connecting wires; a rheostat.

Directions. — Connect, as shown in Figure 65, the cell in series with the rheostat, ammeter, and current reverser. Connect the galvanometer with the reverser so that the current may be reversed in the coil. Adjust the galvanometer coil so that it is in the magnetic meridian and the needle is at the zero of the scale. Then close the circuit through the galvanometer and introduce sufficient resistance in the rheostat to make the deflection 5°. Reverse the current in the galvanometer, and if the

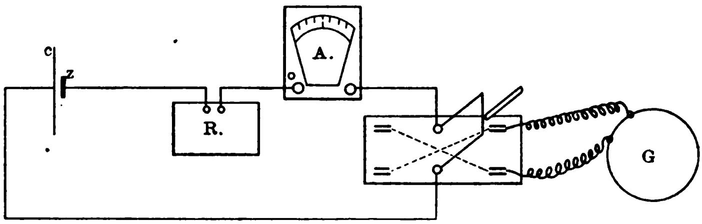

FIG. 65.

deflection is not 5°, open the circuit and readjust the coil. When you get the same deflections on both sides, read the ammeter. Then reduce the rheostat resistance until the deflection is 15°. Reverse the current in the galvanometer, and if the deflection is 15°, again read the ammeter. Repeat for every 10° up to 65°.

Plot your results on cross-section paper, laying off the amperes on the horizontal axis, and the tangents of the deflections on the vertical axis.

OBSERVATIONS

AMPERES	READING OF GALVANOMETER		TANGENT OF AVERAGE DEFLECTION
	FIRST DEFLECTION	REVERSED DEFLECTION	

Conclusions. — What does your plotted curve indicate as the relation between the tangents of the deflections, and the current measured in amperes?

EXPERIMENT LXIII

Object. — *To determine the internal resistance of a cell.*

Apparatus. — An ammeter; a rheostat; a Daniell cell; a gravity cell; a dry cell.

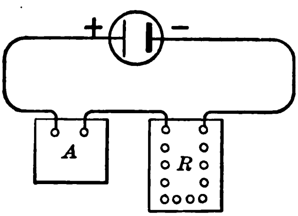

FIG. 66.

Directions. — Connect the Daniell cell in series with the ammeter and the rheostat as shown in Figure 66. Adjust the rheostat until the ammeter reads ½ ampere, and observe the resistance in the rheostat. Then increase the resistance until the reading of the ammeter is exactly one half as much as before, or ¼ ampere, and note the rheostat resistance. Repeat, selecting different current values but cutting it down one half each time. Perform the same experiment with the other cells.

OBSERVATIONS

NAME OF CELL	CURRENT STRENGTH	RHEOSTAT RESISTANCE	CALCULATED CELL RESISTANCE

Conclusions. — From Ohm's law $C = \frac{E}{R + r}$. In each case of reducing the value of C one half, the same cell is used, therefore the value of E is unchanged. For the same cell the value of r is constant for a short time. What relation, then, must exist between the values of $R + r$ in each of the cases, *i.e.* before and after reducing the current? What relation exists between the *increase* in the resistance and the original value of $R + r$?

Let R = original external resistance, r = resistance of cell, x = added resistance to reduce current one half; then $r = x - R$. Deduce this formula. Calculate the value of r for each cell used from the formula obtained.

EXPERIMENT LXIV

Object. — *To determine, by the method of substitution, the resistances of several wires, and from them the relation between the resistance of a wire and its length and diameter.*

Apparatus. — A tangent galvanometer; German silver wires of varying lengths and diameters; a storage cell; a current reverser; a rheostat and a single pole double throw switch.

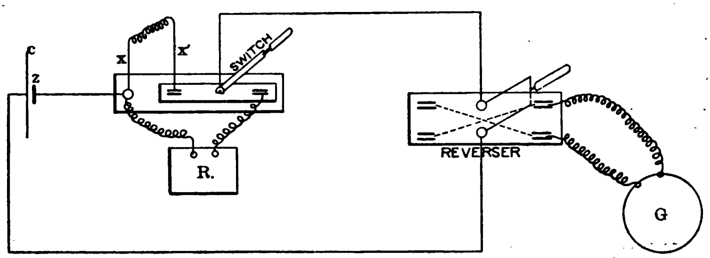

FIG. 67.

Directions. — Connect the apparatus as shown in Figure 67. Adjust the galvanometer coil in the magnetic meridian and the needle at the zero of the scale. Place the blade of the switch so that the current will pass through the German silver wire xx', and then throw the current into the galvanometer by means of the current reverser. Read the deflection, reverse the current and read again. Place the blade of the switch so that the current passes through the rheostat in place of the wire xx', and introduce sufficient resistance in the rheostat to produce the same deflection as before. Note the resistance of the rheostat.

Repeat the experiment with a German silver wire of the same diameter as the first, but twice as long. Finally, repeat the experiment with a German silver wire of the same length as the first but of different diameter.

OBSERVATIONS

KIND OF WIRE	LENGTH OF WIRE	DIAMETER OF WIRE	RESISTANCE OF WIRE	DEFLECTION OF GALVANOMETER	

Conclusions. — Since the deflection was the same with the wire xx' and the rheostat resistance, what must be the resistance of each wire used? Determine the relation between resistance and length of wire. Determine the relation between the resistance of a wire and the square of its diameter.

EXPERIMENT LXV

Object. — *To determine the relative value of the electric potential at various points in a wire traversed by an electric current.*

Apparatus. — A No. 30 platinoid wire over 1 m. long; several cells of high e.m.f.; an ammeter; a voltmeter.

Directions. — Connect the cells arranged in series with the ammeter and the platinoid wire *MN* (Fig. 68), so that the current flows from *M* to *N*. Connect the point *M* also with the + terminal of the voltmeter. The end *S* of the wire connected with the − terminal of the voltmeter is to be placed in

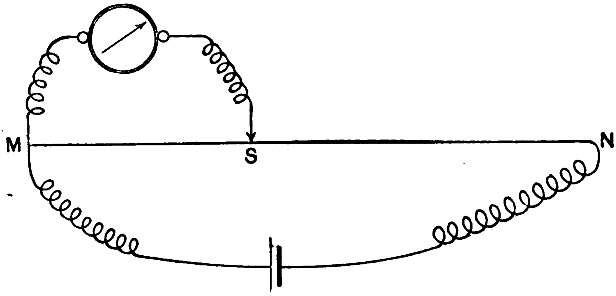

FIG. 68.

contact with the wire at various points and readings taken of both voltmeter and ammeter. Place the end *S* first at *N*, then at the middle point of wire *MN*, then at a point one quarter of *MN* distant from *M*, finally at some other point, say .6 of *MN* distant from *M*.

OBSERVATIONS	1	2	3	4
Length *MS* along *MN*				
Reading of voltmeter				
Reading of ammeter				

Conclusions. — How does the difference of potential between *M* and *N* compare with the difference of potential between *M* and *S* when *S* is between *M* and *N*? What change in electric potential takes place as you move along the wire in direction of the current? Is this change uniform? How do you know?

If part of the wire *MN* were thicker than the rest of it, would the change in potential in 10 cm. of this part be the same as in

10 cm. of the other part? How does Ohm's law aid you in answering this question? Does the ammeter indicate a change in current strength? Why?

EXPERIMENT LXVI

Object. — *To determine by Wheatstone's bridge the specific resistance of copper, i.e. the resistance of a copper wire 1 ft. long, 1 mil in diameter.*

Apparatus. — A Wheatstone's bridge; a sensitive galvanoscope; a dry cell; two rheostats; a piece of insulated copper wire No. 30; connecting wires.

Directions. — Connect the cell at points C and C', the galvanoscope at K and K', one rheostat at r_1, the other rheostat at r_2. Introduce in one rheostat 2 ohms resistance and in the other 3 ohms resistance; then make the contact at K' at such a point in the wire AA' that the galvanoscope indicates no difference of electric potential between the points K and K'; *i.e.* the needle is at zero. Compare the ratio of the lengths of wire l_3 and l_4 with the ratio of resistances introduced at r_1 and r_2. After you have determined the relation among these four parts of the bridge, disconnect the rheostat from r_2 and substitute for it the piece of copper wire whose resistance is to be found.

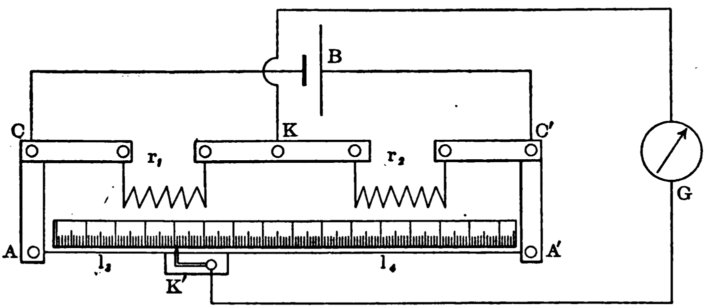

FIG. 69.

Introduce ½ ohm resistance in rheostat at r_1 and move the contact K' along the wire AA' until a point is found which is of the same potential as K, *i.e.* when the needle is at zero. By means of the relation found in first part of the experiment, determine the resistance of the copper wire used.

Find the length of the wire in feet and, with a wire gauge, its diameter in mils. Calculate the resistance of a copper wire 1 ft. long, 1 mil in diameter, by means of the formula $R = kl \div d^2$, where k is the specific resistance sought, l is the length in feet, and d the diameter in mils, and R is the resistance of the given piece of copper wire.

Observations	
I	
Reading of point K'	
Resistance at r_1	
Resistance at r_2	
Length l_3	
Length l_4	
II	
Reading of K'	
Resistance at r_1	
Length l_3	
Length l_4	
Calculated resistance r_2	
Length of wire at r_2	
Diameter of wire at r_2	
Specific resistance of copper	

Conclusions. — A Wheatstone's bridge is a divided circuit; the current enters at C' (say), part going by r_2Kr_1 to C, the other part through the wire stretched along the meter stick to A, and from C the reunited current goes back to the cell. Explain from what we have learned of the fall of potential in a wire, why, when K and K' are of equal potential, the resistance r_1 : resistance $r_2 :: l_3 : l_4$.

The same thing can be proved from Ohm's law, $E = CR$.

EXPERIMENT LXVII

Object. — *To determine the joint resistance of two conductors connected in parallel.*

Apparatus. — A Wheatstone's bridge; three rheostats; a galvanoscope; a Daniell cell.

Directions. — Connect one rheostat at r_1 and two rheostats *in parallel* at r_2. Connect the cell at A and A' and the galvanoscope at K and K'. Introduce 1 ohm in rheostat R_1, and 1 and

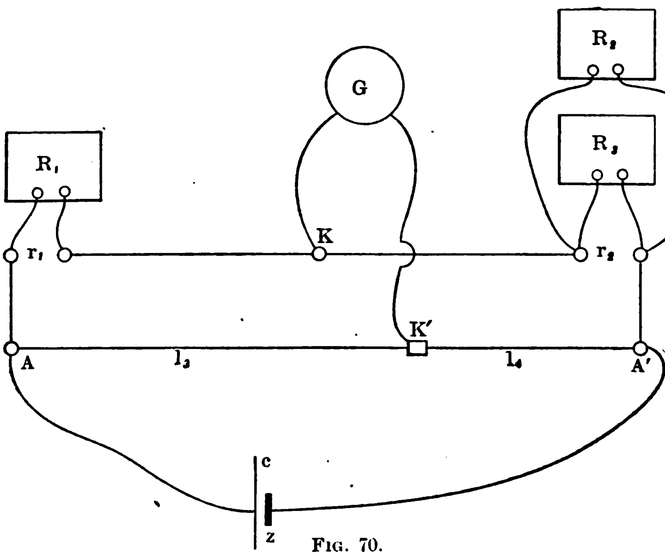

FIG. 70.

2 ohms, respectively, in the two rheostats R_2 and R_3 connected at r_2. Find the point on wire AA' which has same potential as K, and calculate the joint resistance of 1 ohm and 2 ohms connected in parallel.

Repeat with R_2 and R_3 equal to 2 ohms and 3 ohms, 2 ohms and 2 ohms, 3 ohms and 5 ohms, successively.

OBSERVATIONS

RESISTANCE R_1	R_2	R_3	LOCATION OF POINT K^1	DISTANCE		CALCULATED JOINT RESISTANCE OF R_2 AND R_3
				l_3	l_4	

Conclusions. — The *conductance* of a wire whose *resistance* is 2 ohms is one half that of a wire whose resistance is 1 ohm. Since a wire whose resistance is 2 ohms has a conductance of $\frac{1}{2}$, the resistance is the *reciprocal* of the conductance. The joint *conductance* of two wires in parallel whose resistances are 10 ohms and 20 ohms, respectively, is the sum of their separate conductances, or $\frac{1}{10} + \frac{1}{20} = \frac{3}{20}$, which means that the two wires conduct $\frac{3}{20}$ as well as a wire whose resistance is 1 ohm. Therefore, the resistance of the two wires whose conductance is $\frac{3}{20}$ must be $\frac{20}{3}$ or $6\frac{2}{3}$ ohms.

Compare your determinations of the several joint resistances with the values obtained theoretically as stated above.

EXPERIMENT LXVIII

Object. — *To determine the manner of division of a current in parallel conductors.*

Apparatus. — Three ammeters; two rheostats; a storage cell.

Directions. — Connect the apparatus as shown in Figure 71, R_2 and A_2 being in parallel with R_3 and A_3, and the total current passing through A_1.

Introduce 1 ohm in R_2 and 2 ohms in R_3. Read all three ammeters. Change resistances in R_2 and R_3 to 2 and 3 ohms, respectively, and repeat. Make $R_2 = 1$ ohm and $R_3 = 9$ ohms and take readings.

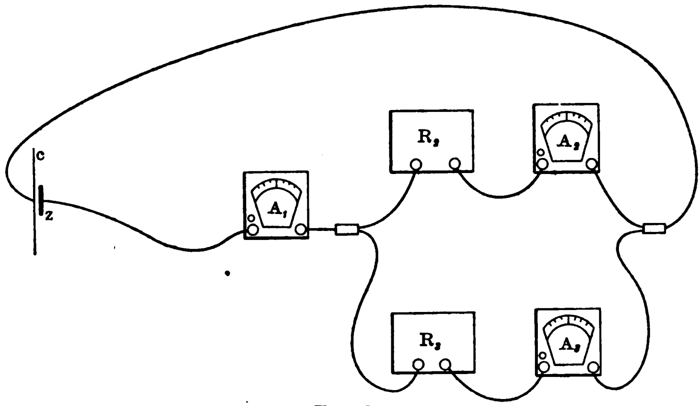

FIG. 71.

OBSERVATIONS

CURRENT			RESISTANCE	
A_1 Main Circuit	A_2 1st Branch	A_3 2d Branch	R_2 1st Branch	R_3 2d Branch

Conclusions. — Find the relation between the current in the branches of a divided circuit and the resistances of those branches. If you wished to pass only one tenth of the total current through a certain conductor, what should be the resistance of the *shunt* to that conductor?

EXPERIMENT LXIX

Object. — *To find the temperature coefficient of resistance.*

Apparatus. — Wheatstone's bridge; a galvanoscope; a rheostat; a cell, a boiler, and a copper dipper; coils of wire wound on grooved rubber core (copper and German silver); some ice; a thermometer.

Directions. — Connect the ends W and W' of the coil of copper wire at r_2 on bridge, insert thermometer within the rubber core, and immerse it in water cooled to nearly 0° C. in the dipper. Find the location of K', the point of equipotential with K, and calculate the resistance of the coil of wire at the observed temperature. Heat water in the boiler to boiling, place the dipper with the coil and boiling water in it inside the boiler, and find the resistance of the coil at the temperature of the water. Note the temperatures each time at the instant the point K' is determined. Repeat with G. S. wire.

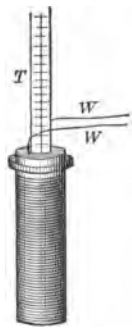

FIG. 72.

Find the increase of resistance for each. Calculate the increase per 1° rise in temperature. Finally, calculate the increase per ohm of the resistance at 0° per 1° rise in temperature. This last result is the temperature coefficient of resistance of the given material.

OBSERVATIONS	1	2	3	4
Kind of wire				
Temperature of wire				
Location of K'				
Distance l_3				
Distance l_4				
Rheostat resistance r_1				
Calculated resistance of coil of wire r_2				

Conclusions. — Compare the temperature coefficients of a pure metal and of an alloy.

EXPERIMENT LXX

Object. — *To investigate the construction and action (a) of an electric bell. (b) of an electric telegraph.*

Apparatus. — An electric bell; a telegraph sounder and key; a dry cell.

Directions. — (1) Connect the dry cell with the terminals of the bell, hold your hand on the gong to deaden the sound, or unscrew the gong, and trace the path of the current through the bell, determining why the clapper vibrates continuously so long as the circuit is closed. Make a diagram of the bell, showing its essential parts.

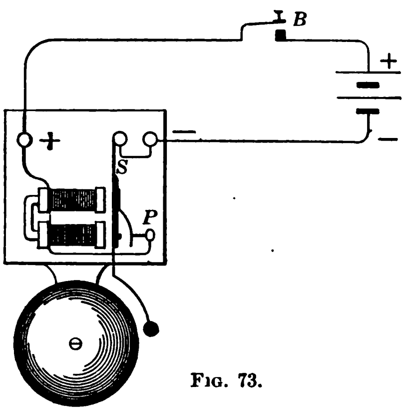

FIG. 73.

(2) Connect the dry cell to the binding posts of the telegraph instrument, press down the key, then (1) after a short interval of time release the key, (2) hold the key down for a longer interval, thus illustrating the formation of the dots and dashes of the Morse telegraphic code.

Trace the path of the current through both sounder and key, determining the cause of the vibration of the lever of the sounder. Make a diagram of both instruments, showing the essential parts.

Observations. — State fully the action of both instruments.

Conclusions. — With the aid of the diagrams, explain the action observed.

State what connections would be necessary to convert the electric bell into a stroke bell, such as the fire alarm bell, in which the gong is struck by the clapper but once each time the circuit is closed.

EXPERIMENT LXXI

Object. — *To investigate induced currents.*

Apparatus. — Two coils of wire about 15 cm. high and of such relative size that one may be placed within the other — the outer coil is wound upon a wooden bobbin, the inner is wound upon an iron core; a sensitive galvanoscope; a strong steel bar magnet; several cells of low resistance.

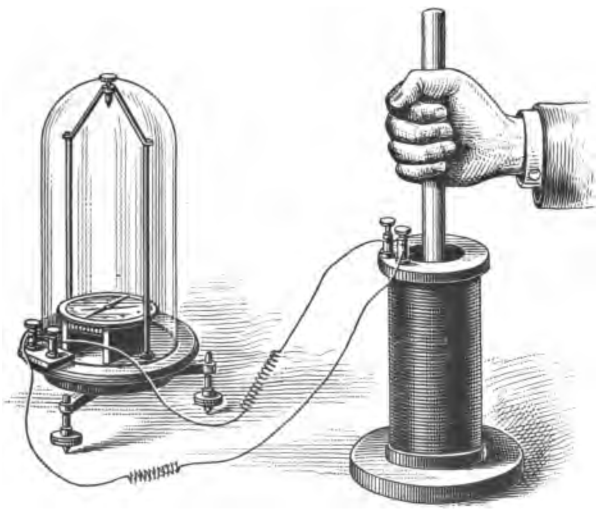

FIG. 74.

Directions. — Connect the larger coil with the galvanoscope and quickly thrust into the coil the N. end of the strong bar magnet. Note the magnitude, direction, and duration of the deflection of the galvanoscope needle. When the needle has come to rest, quickly withdraw the N end of bar magnet from the coil. Note the throw of the needle as before. Repeat the experiment with the S pole and note throw of galvanoscope needle when the S pole is (1) thrust into the coil, (2) withdrawn from the coil. Determine what must be the direction of current in the coil, as it appears when facing the end resting upon the table, to produce the observed deflection in each case.

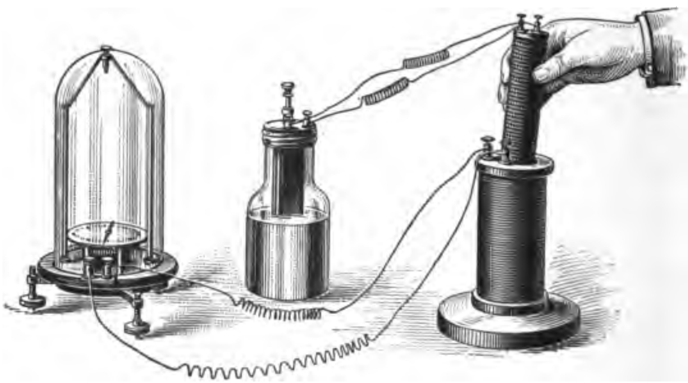

FIG. 75.

Connect the smaller coil of wire with the cells joined in series and quickly thrust it into the coil connected with the galvanoscope. Note the throw of the needle. Then quickly withdraw the inner coil and note the throw of the needle. Determine from the manner of the connection with the cells what is the direction of the current in the inner coil as it appears when you face the end thrust into the outer coil.

Then place the one coil again within the other, and when the needle is at rest cut off the current from the inner coil. Observe the throw as before. When the needle has come to rest, complete the circuit again through the inner coil, and observe the throw of the needle.

Observations	1	2	3	4	5	6	7	8
Inductor used								
Motion or change of inductor .								
Direction of deflection								
Magnitude of deflection								
Duration of deflection								
Direction of inducing current .								
Direction of induced current . .								

Conclusions. — This experiment shows that when lines of magnetic force are cut by a closed conductor an e.m.f. is generated. Upon what does the magnitude of the e.m.f. depend? Upon what the direction? Why is the e.m.f. not permanent? What is the source of the electric energy?

EXPERIMENT LXXII

Object. — *To study the action of a dynamo.*

Apparatus. — A dynamo; an ammeter; a voltmeter; a rheostat.

Directions. — Study separately the construction, position, and mutual connection of the various parts; viz., field magnet, armature, commutator, and brushes. Make a diagram showing what you observe on these points.

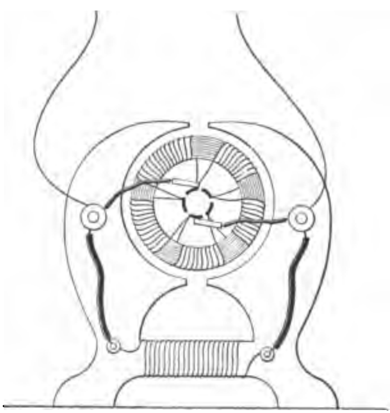

Fig. 76.

Connect the terminals of the dynamo with the voltmeter, revolve the armature at high speed, and note the maximum e.m.f. generated.

Disconnect the field coil from the circuit and revolve the armature again at high speed.

Introduce a rheostat into the field coil circuit and determine the e.m.f. generated when different resistances are introduced by means of the rheostat.

Vary the speed of revolution of the armature and note the e.m.fs. generated.

Remove the rheostat from the field coil circuit, connect the field coil in shunt with external circuit, and connect the rheostat and ammeter in series with each other but in parallel with the voltmeter. Introduce 100 ohms in rheostat, revolve the armature at maximum speed, and read both voltmeter and ammeter. Repeat with rheostat resistance 50, 25, and 10 ohms respectively.

Observations

E.M.F. generated, or D.P. of Dynamo Terminals	Increase of Field Resistance	External Resistance	Speed of Armature	Current Obtained

Conclusions. — Remembering that you have proved in a previous experiment the possibility of generating e.m.f. by moving a conductor *across* magnetic lines of force, show that the dynamo applies this principle.

Explain the generation of e.m.f. when the field coil was disconnected from the circuit.

How is the strength of the field magnet affected by increasing the resistance in the field coil circuit? State the relation of the e.m.f. generated to the strength of field. State the relation between speed of revolution of armature and e.m.f. generated. State the relation between the difference of potential of the dynamo terminals and the resistance of the external circuit. Upon what does the current strength depend? Prove your answer by your observations.

EXPERIMENT LXXIII

Object. — *To explain the rotation of the armature of an electric motor.*

Apparatus. — A small dynamo; a magnetic compass; six cells of low resistance, or 110 volt current regulated by a lamp board.

Directions. — Pass a current of several amperes through the armature alone and determine with the compass the location of the magnetic poles in it. Then pass the current alone through the coil of field magnet and determine the location of the magnetic poles.

Make a simple diagram of field magnet and armature, mark the poles where you located them, and determine what should be the result of the mutual action of these four poles.

Then pass the current simultaneously through both armature and field coil, increasing gradually the current supply until the rotation is produced.

Observations. — State everything observed as to location of poles, and direction of rotation.

Conclusions. — Compare the result with what you expected it to be. Compare the direction of rotation of the armature with the direction in which you would turn it to *produce* a current running in the same direction as the one used here. Why does the armature revolve?

APPENDIX

MENSURATION FORMULÆ

Area of triangle = $\frac{1}{2}$ base × altitude.

Area of circle = $\frac{\pi D^2}{4}$ or πr^2.

Circumference of circle = $2\pi r$ or πD.
Surface of sphere = $4\pi r^2$.
Volume of sphere = $\frac{4}{3}\pi r^3$.
Volume of prism or cylinder = area of base × altitude.
To convert inches into centimeters: inches × 2.54 = centimeters.
To convert centimeters into inches: centimeters ÷ 2.54 = inches.
To convert grams into pounds: grams ÷ 453.6 = pounds.
To convert pounds into grams: pounds × 453.6 = grams.

B. AND S. WIRE GAUGE

No. of Wire	Diameter		No. of Wire	Diameter		No. of Wire	Diameter	
	Mils	Mm.		Mils	Mm.		Mils	Mm.
1	289.3	7.35	**10**	101.9	2.58	**19**	35.4	1.91
2	257.6	6.55	**11**	90.7	2.36	**20**	32.0	0.82
3	229.4	5.83	**12**	80.8	2.04	**21**	28.5	0.72
4	204.3	5.19	**13**	72.0	1.82	**22**	25.3	0.65
5	181.9	4.72	**14**	64.1	1.63	**23**	22.6	0.59
6	162.0	4.11	**15**	57.1	1.45	**24**	20.1	0.50
7	144.3	3.67	**16**	50.8	1.29	**25**	17.9	0.45
8	128.5	3.28	**17**	45.3	1.18	**28**	12.7	0.33
9	114.4	2.91	**18**	40.3	1.01	**30**	10.0	0.25

PHYSICAL CONSTANTS

	Specific Gravity	Coefficient Expansion	Specific Heat	Index Refraction	Specific Resistance (a) 1 meter long, 1 mm. diam. at 0°; (b) 1 ft. long, 1 mil diam.	
					(a)	(b)
Aluminum	2.7	.00002	.21			
Brass	8.5	.000019	.09			
Copper	8.8	.000017	.093		.021	10.0
Cork	.24					
Diamond	3.5	•		2.47		
German silver	8.5	.00002			.269	128.1
Glass (crown)	2.5	.000009	.19	1.52		
Glass (flint)	3.6			1.65		
Gold	19.3	.000012	.03			
Ice	.9		.5	1.31		
Iron (cast)	7.2	.000012	.113			
Iron (wrought)	7.7				.125	59.5
Lead	11.3	.000028	.031		.253	120.6
Marble	2.7					
Oak	.8					
Paraffine	.9					
Pine	.5					
Platinum	21.4	.000009	.03		.116	55.2
Quartz	2.6			1.54		
Silver	10.4	.000019	.05		.019	9.0
Steel (tempered)	7.8	.000013				
Tin	7.3	.000019	.05			
Zinc	7.1	.00003	.09			
Acid, sulphuric	1.84	.00059	.34	1.43		
Alcohol	.81	.00106	.59	1.36		
Kerosene	.78	.0012	.39	1.49		
Mercury	13.6	.00018	.034			
Water (4°)	1.00		1.000	1.33		
Air	.00129	.00367	.237	1.0003		
Hydrogen	.000089	.00367	3.409	1.00014		
Carbon dioxide	.00197	.00367	.216	1.00045		

TABLE OF SINES AND TANGENTS

Angle	Sine	Tangent	Angle	Sine	Tangent	Angle	Sine	Tangent
0°	0.000	0.000	31°	0.515	0.601	62°	0.883	1.881
1	0.017	0.017	32	0.530	0.625	63	0.891	1.963
2	0.035	0.035	33	0.545	0.649	64	0.899	2.050
3	0.052	0.052	34	0.559	0.675	65	0.906	2.145
4	0.070	0.070	35	0.574	0.700	66	0.914	2.246
5	0.087	0.087	36	0.588	0.727	67	0.921	2.356
6	0.105	0.105	37	0.602	0.754	68	0.927	2.475
7	0.122	0.123	38	0.616	0.781	69	0.934	2.605
8	0.139	0.141	39	0.629	0.810	70	0.940	2.747
9	0.156	0.158	40	0.643	0.839	71	0.946	2.904
10	0.174	0.176	41	0.656	0.869	72	0.951	3.078
11	0.191	0.194	42	0.669	0.900	73	0.956	3.271
12	0.208	0.213	43	0.682	0.933	74	0.961	3.487
13	0.225	0.231	44	0.695	0.966	75	0.966	3.732
14	0.242	0.249	45	0.707	1.000	76	0.970	4.011
15	0.259	0.268	46	0.719	1.036	77	0.974	4.331
16	0.276	0.287	47	0.731	1.072	78	0.978	4.705
17	0.292	0.306	48	0.743	1.111	79	0.982	5.145
18	0.309	0.325	49	0.755	1.150	80	0.985	5.671
19	0.326	0.344	50	0.766	1.192	81	0.988	6.314
20	0.342	0.364	51	0.777	1.235	82	0.990	7.115
21	0.358	0.384	52	0.788	1.280	83	0.993	8.144
22	0.375	0.404	53	0.799	1.327	84	0.995	9.514
23	0.391	0.424	54	0.809	1.376	85	0.996	11.43
24	0.407	0.445	55	0.819	1.428	86	0.998	14.30
25	0.423	0.466	56	0.829	1.483	87	0.999	19.08
26	0.438	0.488	57	0.839	1.540	88	0.999	28.64
27	0.454	0.510	58	0.848	1.600	89	1.000	57.29
28	0.469	0.532	59	0.857	1 664	90	1.000	∞
29	0.485	0.554	60	0.866	1.732			
30	0.500	0.577	61	0.875	1.804			