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MICHIGAN STATE NORMAL COLLEGE.

A LIST OF ELEMENTARY QUANTITATIVE EXPERIMENTS IN PHYSICS.

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Prefatory Note.

The Physical Laboratory Practice of this institution is mainly a course in the measurement of *particular quantities*, and in general rests upon and reënforces the principles and laws of physics established by demonstration or class experiment. It is given in four courses.

1. The first course consists of simple dictated exercises accompanying our *Elementary* (or Grammar-School) *Physics*. For this work no manual is used.

2. The table work accompanying and forming an integral part of *Physics I* and *Physics II* for which *Part I* of this pamphlet is used as a manual. It is based on the "collective" system, so called.

3. A special laboratory course, called *Physical Laboratory Practice*, established especially for the benefit of those who have had a year of work in physics in some good high school but with inadequate practical application. Such students take a portion of the work in *Part I* and such additional experiments in *Part II* as they are able to perform in the assigned time. Students who have had *Physics I* and *Physics II* with us will pass directly to *Part II* and work an assigned selection of these exercises according to their needs. *Part II* follows the "separate" system. It is essentially a teachers' course and has to do with the *laboratory method* in science, or how to select, set up, test, repair, care for and use apparatus.

4. A course in *Advanced Laboratory Practice*, accompanying or following *Advanced Physics*. For this course a separate manual is used.

The *Exercises* at the end of *Part I* are carried forward along with the table work.

Hints and Cautions.

1. Make these hints a part of the directions for every experiment. Because they are not repeated continually do not the less have them in mind and observe them.

2. In general with every experiment you are to *observe, and record what you observe.* Make this formula a part of the directions in all your work. Observe accurately, under the most favorable conditions, and, if necessary, observe repeatedly. Press the piece that you are using up to the highest limit of its performance. Make the record at the time of observation; record each observation separately, and not a mere average; and carry out upon your notes all calculations required to give the result called for.

3. With regard to notes, the teacher should see *those taken at the time of performing the experiment.* Let them be legible, complete in themselves so as to need no explanation, and thoroughly good examples of punctuation, paragraphing, and of manuscript work in general. Where possible, record your observations *in a tabular form,* with proper title, and headings for the columns.

4. While a full written description of the piece is in general unnecessary, there should always be a *figure* of the piece with *descriptive list.* Usually it is best to add *dimensions* of the piece, so that as a teacher you can procure or construct the piece from your notes. In general a perspective view is not the most useful, but rather a plan, section, or simple *sketch* of the piece, *showing working parts.* Begin by reading the experiment and all hints and cautions referred to. Write the *number* of the experiment and leave a space for a *title,* which you should *fill in after the experiment is performed.* Perform the steps, as numbered in the exercise, in succession, recording the results as you go forward and numbering the steps of the work as in the exercise. Often a step as numbered simply calls for some adjustment of a piece, or some work not yielding a numerical result. Then record, "Did as required;" "See figure;" "See table below," etc. These notes if written in ink and in good literary form are all you need to make, though they may be copied at your rooms for greater excellence of form, provided the teacher confirms them at the time. Calculations may also be performed outside the laboratory hour. Reduce all fractions to decimals before recording and retain in the record and in all calculatious founded upon it only so many places as you have a right to. See Sabine.

5. Work *separately and without consultation or communication* with other members of the class. The teacher is there on purpose to assist you and he wishes to know where you have difficulty and how you yourself do the work. In some cases pupils will be purposely set to assist each other, but do not carry this habit into other problems.

6. In *reading scales* secure a good light and favorable conditions. Use a hand magnifier if necessary. You should always have one with you. See Worthington, p. 15–20, or Allen, p. 60–64.

7. In using wire, thread, silk, etc., be careful about entangling or snarling it. *Work from the free end*, and *leave only one free end* in all material wound on bobbins, spools, etc. Be careful to fasten the free end so that the coils will not loosen or unwind.

8. There is no excuse for *wasting or fouling mercury*. Wipe out with a clean cloth or thin paper all vessels before pouring mercury into them. Avoid spilling by special care at critical points, but work over the mercury tray or mercury table so that if any is spilled it may be saved. The stock of mercury should not diminish much during the year. A special stock will be kept for amalgamating zinc; use this for no other purpose. In amalgamating avoid excess; a single drop will usually suffice for one operation if it is properly done. See Shaw, p. 237.—You will be taught how to clean mercury; or see P. Ahrendt, etc.—Avoid using mercury in the presence of articles of gold, as rings, watches, etc.

9. Be careful about *slopping* or spilling liquids, *staining* with acids or corrosive substances, etc. Also about *marring*, *marking*, *scratching*, or otherwise defacing the furniture or apparatus. It would occasion no loss of time or energy if you should manipulate so carefully that you should *never* spill a drop of any liquid or mar any of the pieces. Simply see that the drip-cup is placed under all burettes; mix, pour, and stir corrosive liquids over the sink; hold a zinc or other battery element over an empty tumbler when you raise it from the cell; etc., etc. The accuracy of your work can be very well measured by your habits of manipulation.

10. A special point is made of matches. Take them as needed from the match-safes and in no case have or leave piles of them here and there in the laboratory. See that they are well quenched before throwing into waste boxes.

11. It is very important that the material and apparatus for any experiment or series of experiments be kept together and be properly restored to the box or case designed for them after every use. When an experiment is assigned you, look over the material for the experiment and see that it is all present and in order. If not, report promptly to the teacher in charge. At the close of the hour, or earlier if the experiment is completed, restore in perfect order to the box or case.

12. Report to the teacher at once any injury, breakage, or accident to apparatus or material. No special charge is made for the natural wear of apparatus or for injuries sustained by pieces assigned for use and properly used, *provided such injury is promptly reported.* Do not use a piece if it is evident that such use will be attended with any risk, either to the piece, or yourself, or to any material.

13. This paragraph may be referred to for a large number of special hints and cautions, usually alluded to in the exercise or set forth more fully in the references, and upon the carefnl observance of which the excellence of your work will mainly depend; such as precautions concerning index error, zero error, parallax, "back-lash" of screw, capillarity and refraction in reading liquid columns, and estimating scale-divisions to tenths. Also for precautions concerning straining a screw, using the same part of a screw continually, leaving a pinch-cock on a rubber hose when not in use, leaving the zinc of a simple cell in acid after using, or unnecessarily during use, and concerning heating, drying, and cleaning glass articles, etc., etc.

14. Do not meddle with the adjustment of fine pieces without special directions by the teacher; *e. g.* the adjustments of a balance. Do not take the standard barometers from their hooks, or readjust the prisms of the best spectroscope, or change the reticle of the transit, or dissect the objective of a microscope, etc., etc.

15. References are given to practical manuals concerning care in handling, accuracy in observing, and skill in manipulating: also to tables, formulas, etc. Use the references for these purposes *and not for matter to incorporate into your note books.* In general *copy nothing* from any text or reference book, but hold your notes closely to *records of personal observations* and deductions directly from these observations.

The reference books are not to be taken from the laboratory except in special cases and then by permission. Do not use the books to write on, for blocking, etc., but guard them from injury of all kinds.

Reference is so frequently made to the following books that they may conveniently be known by abbreviations.

Adams, Physical Laboratory Manual, designated by .... A.
Allen, Laboratory Physics .... Al.
Ames & Bliss, Laboratory Manual .... A. & B.
Arey, Experimental Physics .... Ar.
Ayrton, Practical Electricity .... Ayr.
Barker, Advanced Course in Physics .... B.
Chute, Practical Physics .... C.
Everett, Units and Physical Constants .... E.
Frick, Physical Technics .... F.
Glazebrook & Shaw, Practical Physics .... G. & S.

Gage, Manual and Note-Book	G.
Gage, Elements of Physics	G.
Hall & Bergen, Text-Book of Physics	H. & B.
Kohlrausch, Physical Measurements	K.
Loewy, Experimental Physics	Lo.
Lupton, Tables	L.
Mayer, Sound	M.
Mayer and *Barnard*, Light	M. & B.
Pickering, Physical Manipulation	P.
Stewart & Gee, Practical Physics	S. & G.
Stewart & Gee, Practical Physics for Schools	S. & G.
Sabine, Laboratory Course in Physics	S.
Shaw, Physics by Experiment	Sh.
Whiting, Physical Measurement	W.
Whiting, Tables	W.
Worthington, Physical Laboratory Practice	Wor.
Wright, Light and Lantern Work	Wr.
Woodhull, First Course in Science	Wo.

E. A. S.

NORMAL LABORATORIES, August, 1898.

Part I.

Experiments Accompanying Physics I and Physics II.

I.

Materials.—Metric scale divided in mm.; English scale divided in inches and hundredths; dividers with pencil point.

Experiment.—1. Draw a fine straight horizontal line, three or four inches long as may happen, and near each end and crossing it at right angles draw a fine line about an eighth of an inch long. Call the left hand intersection A and the right hand intersection B. Follow this order hereafter.

2. Measure this line as accurately as you can in inches and hundredths, using all precautions indicated in Expt. III. Make as many measurements as you choose but record only the average of them all.

3. Measure the same line in cm. and decimal of a cm., and hence calculate the value of one cm. in inches. Record as below.

(Figure.)

The line AB is..inches long.
The line AB is..cm. long.
∴ one cm. by my measurement is..............................inches.
But the true value of the cm. is..............................inches.
Difference between these values..............................inches.
Per cent. of my error upon the true value..............................

II.

Materials.—As in I.

Experiment.—Repeat I in full except draw a longer line and calculate the value of the inch in cm. Record as above.

IIa.

Materials.—A meter stick with millimeter divisions; a yard-stick divided in inches and fractions of an inch; rubber bands or clamps.

Experiment.—1. Clamp the two sticks together so that the graduated faces shall be in the same plane and the graduated edges adjacent, and so that some division on one scale *near* the end (not *at* the end) shall exactly coïncide with some division on the other scale. Mark this division with a pencil. Find two other divisions at least 20 inches from the former that exactly coïncide. Mark these also. "Read" and tabulate these divisions on both scales in inches and decimal, and cm. and decimal.

2. Slide one scale along the other a few divisions and repeat. If the second pair of divisions do not coïncide take some division on the yardstick and estimate the fraction of a mm. which would give coïncidence. In all cases read at least to half millimeters.

3. Repeat once or twice more.

4. Tabulate as below and calculate the number of cm. per inch.

CENTIMETERS IN ONE INCH.

		First Mark.	Second Mark.	Interval.	Cm. in 1 in.
First Trial	Inch Rule	----------	----------	----------	----------
	Cm. Rule	----------	----------	----------	----------
Second Trial	Inch Rule	----------	----------	----------	----------
	Cm. Rule	----------	----------	----------	----------

Average cm. in 1 in.------------

III.

Materials.—As in I.

Experiment.—Upon an indefinite line AB construct (geometrically) a rectangle ABCD and measure its adjacent sides in inches and in cm. Then calculate the area in sq. in. and sq. cm. and the value of one sq. cm. in sq. in. Record as below. Retain only as many decimal places in the result as you have a right to. Leave all points of construction.

AB by my measurement is------------------------------------in. long.
AD " ------------------------------------in. long.
AB " ------------------------------------cm. long.
AD " ------------------------------------cm. long.
∴. the area of ABCD is--sq. in.
∴. the area of ABCD is--sq. cm.
By my measurement 1 sq. cm.---------------------------------sq. in.
But the true value of 1 sq. cm.--------------------------------sq. in.
Difference between the values---
Per cent of my error upon the true value-------------------------------

HINTS CONCERNING LINEAR MEASURE.

Bring the graduated edge of the scale into actual contact with the line or edge to be measured.—Take precautions to make the beginning and end of the line or edge as nearly geometrical points as may be.—Do not use the end of the scale but some division near it, "reading" the two ends of the line and finding its length by subtraction.—In repeating begin at another scale division, and, in getting the length of a prism or cylinder, measure on different sides. Record all measurements of the same quantity if you wish to discuss their relative value, otherwise only the average. —Read at least to half millimeters and to twentieths of an inch (thirty-seconds or even sixty-fourths is easily practicable) but record decimally. See Allen, Ames, Worthington, etc., on Measurement.

IV.

Materials.—A rectangular wooden block No. ------; metric and English scales as in I.

Experiment.—1. Measure the length, breadth and thickness of the block in inches and hundredths. Follow directions for measurement as given. Repeat and average. Record averages.

2. Measure the dimensions in cm.

3. Calculate the volume of the block in cu. in.

4. Calculate the volume of the block in cu. cm.

5. Calculate the value of one cu. cm. in cu. in., and find error and per cent of error as heretofore.

V.

Materials.—A balance turning easily with 1 mg.; the marked zero being at the left division of the scale.

Experiment.—1. Read the "Directions" below for the care and use of a balance and in all work of this kind hereafter adhere closely to them. —Put the balance into action so carefully that the index will be disturbed by only a few scale-divisions. Record and "average" the number of scale-divisions (counted from the marked zero) for any *three* consecutive single vibrations of the index. Call this average "True Zero"; that is, the position of equilibrium of the index.

2. Repeat for another amplitude.

3. Repeat, taking the average of five consecutive swings.

4. Record the actual position at which the index comes to rest.

5. Average the above for the "True Rero" *for this time and position of the balance.* The word average above means the average of the middle swing with the average of all the others.—Why use an odd number of swings?

DIRECTIONS FOR WEIGHING.

1. Inspect the balance and set of weights and at once report any deficiency in material or performance.

2. Put nothing on the pans that may injure them. Be sure that the bottom of a glass vessel is clean before putting it on the pan. Weigh nothing in an open vessel that is giving off fumes. Clean, balanced filters may be placed in both pans if preferred.

3. Throw "out of action" when changing weights or moving riders; also when the weighing is completed. Do this slowly and not suddenly, and when the pointer is near zero.

4. Handle all weights with forceps. Never take them in the fingers, or lay them down anywhere except in the scale-pan or in their proper places in the box.

5. Close the door before making the final adjustment.

6. Determine the zero by the method of oscillations (as above) in all cases, and work from this and not the marked zero.

7. Count (*and record*) the weights as you put them on the pan and also as you take them off. Be sure of their denomination. Oral directions will be given for the order of weighing.

8. Do not change any of the adjustments of the balance.

VI.

Materials.—As in V; also wooden block of IV.

Experiment.—1. Place the block on the left scale pan and weigh and record the weight. Observe all precautions noted in V.

2. Place the block in the other pan and repeat. (Double weighing.)

3. Calculate the true weight of the block. (See note below.)

4. Calculate the density of the block. Give the formula.

5. Calculate the relative length of the arms of the balance.

Note.

Let l and r represent the lengths respectively of the left and right arms; W the true weight; and w and *w* the weights when the block is placed in the right and left pans respectively. Then, by the lever principle:

$$l\,W = r\,w,$$

and $$l\,w = r\,W.$$

Whence $$W = \sqrt{w\,w}.$$

and $$\frac{l}{r} = \sqrt{\frac{w}{w}}$$

VIa.

Materials.—A Balance No.______, sensitive to 1 mg.; set of metric weights; weight forceps.

Experiment.—1. Put the balance in action and find and record the true zero of the scale. See VI. Do not move the balance during the experiment.

2. Repeat until you can do this quickly and accurately, and hereafter begin weighing in this way.

3. Place the 1 cg. weight in the left scale-pan and read and record the average of three swings. See V.

4. Repeat with the 1 cg. weight in the right scale-pan.

5. Repeat with the 2 cg. weight in the right scale-pan.

6. Repeat with the 2 cg weight in the left scale-pan.

7. Average the last two, divide by 2, and record as the "sensitiveness of the balance without any load." Does this agree with the result of 3 and 4?

8. Make a diagram of the balance; and be sure you understand the principle of this experiment, and see how if you have, for instance, no 2 cg. or 5 mg. weight you could get along without them. How far will 1 mg. displace the index? 8 mg.? Upon what does the sensitiveness of a balance depend?

VIb.

Materials.—Balance and equipment; set of weights.

Experiment.—1. Suppose the 1 gram and the 10 gram weights of your set correct, and call the first "2" g. x, the second "2" g. y, and the 5 g. Z. Ascertain, by the method of oscillations, how much x exceeds y and express this by an equation.

2. Ascertain how much Z exceeds the 1 gram weight with x and y and express by an equation.

3. Ascertain how much the 10 gram weight exceeds the 1 gram with x, y, and Z, and express by an equation.

4. Solve for x, y, and Z.—How proceed if you knew the actual weight of the "1" gram and "10" gram weights instead of supposing them correct—as they are very nearly?

VII.

Materials.—As in V. Also a mm. scale; two rectangular blocks; and a bicycle ball.

Experiment.—1. Weigh the ball, using the method of oscillations, and record in grams and decimal.

2. Measure the diameter of the ball (oral cautions).

3. Calculate the volume of the ball in cu. cm.

4. Calculate the density of the ball.

VIII.

Materials.—A Jolly balance and equipment; set of weights.

Experiment.—1. Raise or lower the platform until the lower scale-pan is immersed in about half the depth of the water and level it until it swings clear of the glass. In all subsequent work keep it in this position by adjusting the platform.

2. Find the elongation of the spring in mm. for four or more weights placed in the upper scale-pan (say 4 g., 3 g., 2 g., 5 cg., 4 cg., 3 cg., etc.) and record in tabular form as below. Use the bead or the index to avoid parallax.

3. Sketch the apparatus.—What properties of matter and what principles are involved? Using the table below, how could you ascertain the weight of any object without having a set of weights? Is the extension per gram affected by the weight already in the pan?

JOLLY BALANCE.—SPRING A.

Weight.	Reading.	Extension.	Extension per Cg.	Cg. per 1 scale div
0	----------	----------	---------------	----------------
1 gram	----------	----------	---------------	----------------
2 "	----------	----------	---------------	----------------
	etc.	etc.	etc.	etc.

Average cg. indicated per scale division of extension.

IX.

Materials.—A Jolly balance and equipment; table of Experiment VIII; the bicycle ball of Experiment VII.

Experiment.—1. Find the weight of the ball in grams when placed in the upper scale-pan.

2. Also when placed in the lower pan. Make sure that there is no considerable amount of air adhering to the ball.

3. Calculate the loss of weight in water in grams and compare with the volume in cu. cm. See Experiment VII. Explain the relation.

X.

Materials.—A burette, capacity 25 cu. cm., graduated in tenths, mounted on stand, with glass stop-cock; funnel; water-bottle with pure water; two beakers.

Experiment.—1. Place a beaker below the jet; fill the burette above zero; turn the stop-cock gradually until single drops are delivered; draw down to exact zero. (Oral cautions.)

2. Pour contents of beaker back into water-bottle and run into the

beaker exactly 17.7 cu. cm. of water. Pour the same back into the burette and read and record.

3. Ascertain how many drops make 1 cu. cm. Record and average result of three trials.

4. Draw the piece.—How would you measure by means of a burette 11 grams of sulphuric acid of density 1.84 grams per cu. cm.?

XI.

Materials.—A cylindrical measuring glass to be used as a volumenometer; a cylindrical brass tube with means of suspension; other objects; water.

Experiment.—1. Partly fill the measuring glass, and by the method of displacement, ascertain the volume of the cylinder. Record both readings and their difference. (Caution.)

2. Change the amount of water and repeat.

3. Find in the same way the volume of the other objects, if time permits.

XII.

Materials.—Outside and inside calipers; steel scale divided in mm. and hundredths of an inch; the cylinder of XI.

Experiment.—1. By means of the calipers ascertain the outside and inside diameters of the cylinder. Take the mean of several readings. (Method and cautions.)

2. Measure the length of the cylinder.

3. Calculate the volume and compare with that found in XI.—Calculate the weight, the density being 8.4 g. per cu. cm.

XIII.

Materials.—Yard-stick; meter-stick; clamp; rubber band; watch or chronometer; set of iron weights.—Two students work together.

Experiment.—1. Clamp one end of the yard-stick to the table. Set the free end in vibration and see if you can count the single vibrations. If not, attach one or more weights by means of the rubber band to the free end until you can easily count them. With the meter stick measure the height of the free end above the floor when the stick is in equilibrium. Now depress the free end 1 cm. and release it at an exact second. Let one student count 20 single vibrations while the other gives the time interval. (The teacher will dictate a code of signals.) Tabulate amplitude, number of vibrations, and time of vibration.

2. Repeat for an amplitude of 3 or 4 cm.

3. Repeat for an amplitude of 6 cm.

4. Compare results and deduce law connecting amplitude and time of vibration. What forces act in the case? What kind of motion does each particle of the stick undergo? Explain the vibration. Explain the effect of the attached weight. Where is maximum velocity? Where maximum acceleration?

XIIIa.

Materials.—A torsion pendulum consisting of stem, platform, ring, bar, wire, clamp and hanger; block and circular scale; a watch or chronometer giving audible signals.

Experiment.—1. Raise the bar to the clamp and suspend it from the hanger. Bring the mark on the ring to face you and the zero of the scale exactly below this mark.

2. Rotate (without swinging) the pendulum through an arc of 20 degrees and count the number of single vibrations in ten minutes. Tabulate and calculate the time of one vibration. (Oral caution.)

(1) Repeat for an arc of 30 degrees.

(2) Repeat for an arc of 45 degrees.

(3) Repeat for an arc of 60 degrees.

3. Generalize the above; *i. e.* state how a change of amplitude (length of arc) affects the time.

4. Draw the piece.

XIV.

Materials.—As above.

Experiment.—Lower the bar upon the ring and repeat XIIIa in full. If there is any change account for it.

XV.

Materials.—A bicycle ball suspended by a silk filament; a foot measure and and a meter-stick; a watch or chronometer giving seconds. (Two students to work together, one to count seconds, the other, vibrations.)

Experiment.—1. Measure the length of the pendulum, calling the diameter of the ball 1.9 cm.

2. Place the foot measure below the ball, draw the ball aside 1 in.; release it at the beginning of a minute; count the number of vibrations in one minute, and calculate the time of one vibration. Tabulate.

3. Repeat, but draw the pendulum 2 in. from the vertical.

4. Repeat, but draw the pendulum 3 in. from the vertical. Generalize 2, 3, and 4.

5. Repeat 4 but let the pendulum swing for 10 minutes, and get the time to quarter seconds. Tabulate and calculate the value of g.

6. Draw the piece and name the parts. Discuss as in XIII, 4. What laws of the pendulum as developed in class demonstration are confirmed here?

XVI.

Materials.—As in the preceding; a crayon-box.

Experiment.—Raise the pendulum until it will swing just clear of the crayon-box; place the foot measure below the ball and repeat 5 in the preceding experiment.

XVII.

Materials.—A balance and equipment; set of weights; counterpoise for left pan and hanger; tumbler of distilled water; block of lead, the brass cylinder of 11, or other solid; silk thread.

Experiment.—1. Attach the thread to the solid, using only as much as is necessary for suspension; remove the left-hand pan and hanger and put the counterpoise in its place; find true zero; and suspend from the hook of the counterpoise and weigh the solid in air.

2. Bring the tumbler of water up under the suspended solid; see that it is well immersed in the water; free it from air bubbles and weigh in water. Why the difference? What does this difference express? Would flour or sand buoy the solid up in the same way? Upon what principle does the buoyant power of a true fluid finally depend?

3. Calculate the sp. gr. of the solid.

XVIII.

Materials.—As in XVII, and also a paraffined wooden block the sp. gr. of which is to be found.

Experiment.—1. Weigh the piece of wood.

2. Attach by the thread the piece of wood to the solid of XVII and weigh the two in water.

3. Taking the weight of the solid in air and in water from the preceding exercise, calculate the sp. gr. of the wood.—What would have been the order of procedure had you taken an unknown sinker? Is the weight of the sinker in air necessary? Explain *why* the procedure indicated gives the sp. gr.

XVIIIa.

Materials.—A picnometer; some shot or bits of wire; balance and weights; tissue paper or cloth for drying; funnel.

Experiment.—1. Dry and weigh the picnometer. (Oral directions.)

2. Fill about one-third full of the shot and weigh again.

3. Fill with water; get rid of air-bubbles (oral directions); insert the stopper; wipe dry, and weigh.

4. Compute the sp. gr. of the shot.—Would it have been as well to counterpoise the picnometer?

XIX.

Materials.—A picnometer; distilled water; alcohol; balance and weights; linen cloth; funnel.

Experiment.—1. Weigh or counterpoise the picnometer, which should be dry.

2. Fill with alcohol; press home the stopper, being careful that no bubble of air is left in the neck; wipe dry and weigh.

3. Pour the alcohol back into the bottle; rinse the picnometer two or three times with water, pouring rinsings into bottle labeled "Alcohol Waste"; fill completely with water; press home the stopper, wipe dry, and weigh.

4. Calculate the sp. gr. of the alcohol.—How correct for temperature? How would you proceed if you had a specific gravity flask of known weight and capacity?

XIXa.

Materials.—Balance and weights; an unknown liquid; a sinker made of a piece of thick glass rod drawn out into a hook.

Experiment.—1. Weigh the sinker in air.

2. Weigh in water, after counterpoising the pan and hanger as in XVII.

3. Weigh in the unknown liquid.

4. Calculate the sp. gr. of this liquid.—Is step 1 necessary? Explain the theory of this experiment.

XX.

Materials.—A Nicholson's hydrometer; a hydrometer jar; a set of weights; water; a solid of unknown sp. gr.; weight forceps.

Experiment.—1. Ascertain what weight placed in the pan will sink the hydrometer to the mark on the stem. Adjust very carefully, freeing the piece from air-bubbles, and preventing contact with the sides of the hydrometer jar.

2. Place the solid in the pan and find what additional weight is needed to bring the mark to the surface of the water.

3. Transfer the solid to the basket (below the cylinder of the hydrometer), free from bubbles, and ascertain what weight will sink the piece to the mark.

4. Calculate the sp. gr. of the solid.—Might the piece be used as a balance? How would it compare in delicacy with a Jolly balance? With the ordinary balance of your tables? How in "load"? How render delicate with large load?

XXI.

Materials.—A set of capillary tubes in a frame; capillary plates; a tin cup; alcohol; water; rubber bands; card-board.

Experiment.—1. Pour water into the cup (first cleaned and rinsed) and place the set of tubes vertically in the water. Observe the rise of the water in the tubes and compare with the apparent size of the bore of the tubes.—Draw carefully.

2. Put a narrow slip of card-board between the glass plates along one edge so as to keep these edges apart and with the rubber bands fasten them firmly together. Place the system in water so that the card-board slip shall be vertical, and observe the edge of water between the plates.—Draw carefully.

3. Repeat 1 with alcohol instead of water. Is the experiment quantitative? How could you make it so?

XXII.

Materials.—A hypsometer; a centigrade chemical thermometer passing through the stopper of the hypsometer; tumbler; distilled water; ice in small pieces; Bunsen burner.

Experiment.—1. See that there is water in the hypsometer; light the burner under it, and while the water is heating proceed to test the freezing point of the thermometer by stirring the ice in the tumbler of water until the temperature is stationary. (Oral cautions.) Read accurately and record the correction if any.

2. Warm (gradually) the thermometer bulb and finally bring it, with the attached stopper, iuto its place in the hypsometer. When the steam issues freely from the vent and the reading of the mercury column has become constant, record the reading as "boiling point." Repeat. (Oral cautions.)

XXIII.

Materials.—A Bunsen burner; copper boiler or hypsometer; watch; calorimeter; thermometer; supports.—Two students work together.

Experiment.—1. Take the temperature of the air at the beginning and end of 2 and record as average temperature of air.—Oral directions concerning the care and use of a thermometer.

2. Heat 250 cu. cm. or so of water to a temperaturs near boiling and pour into the calorimeter. While the water is heating, form a skeleton table, with proper headings, for the next step.

3. Take the temperature of the water in the calorimeter every half minute until you have 20 or so readings. Record these readings in a tabular form as the second column of a table of which the observed times form the first column. Calculate also a third column of *excesses* of the thermometer readings above the temperature of the surrounding air.

4. Construct upon coördinate paper a curve in which the numbers of the first column are abscissas and those in the third column are ordinates.

5. Discuss the curve.—Name some things that interrupt the heat exchanges according to the theory of the experiment.—The value of the work consists in this criticism of the conditions and in careful reading of thermometer at a given instant.

XXIV.

Materials.—As in XXIII, weight of calorimeter known.

Experiment.—1. Heat 50 cu. cm. of water to a temperature near *forty degrees* C, turn out the burner, take the temperature of the water carefully, and *at once* pour it into the calorimeter.

2. Stir the water in the calorimeter for a second or two with the thermometer and again carefully take its temperature.

3. Assuming that the final temperature of the calorimeter is the same as that of the water, and that the fall of temperature of the water is occasioned solely by heating the calorimeter, find the water equivalent of the calorimeter, *i. e.*, the number of heat units required to raise the calorimeter one degree.

4. Analyze the calculation fully.—Is it probable that some heat was lost by radiation? Might this amount have been found approximately by referring to XXIII?

XXV.

Materials.—As in XXIII; 500 grams of lead shot; a framed slate; a copper dipper.

Experiment.—1. Place 100 cu. cm. of water in the calorimeter and find its temperature. Set to one side where the temperature will not be affected.

2. Pour the 500 grams of lead shot into the dipper and heat in steam over the copper boiler. Stir the shot with the thermometer, noting the rise of temperature until it becomes stationery. Record this temperature.

3. Promptly, but without losing any of the shot or plashing the water, pour the shot into the calorimeter. Stir the mixed shot and water with the thermometer and note the temperature.

4. From the above data calculate the specific heat of lead. How could you allow for the cooling in operation 3? How for the heat lost to the calorimeter?

XXVI.

Materials.—A carefully selected thermometer with metal case in a favorable exposure.

Experiment.—Read carefully for 20 consecutive days at the hours of 7 A. M., 2 P. M., and 9 P. M.; average the readings for each day; and construct a curve upon coördinate paper in which the intervals of time shall be abscissas and these average temperatures shall be ordinates.

XXVII.

Materials.—A standard barometer with attached thermometer; Smithsonian "Instructions for Observers."

Experiment.—1. Set and read the barometer, at the same time of the day, once on each of the days of the preceding exercise, and tabulate the readings. Read also the attached thermometer, or take the temperatures from the preceding exercise.

2. Correct the readings for altitude 772 ft. and the observed temperature, by the tables in the Instructions (or other assigned reference), and tabulate.

3. Upon coördinate paper construct a curve in which the intervals of time shall be abscissas and the corrected readings ordinates.

XXVIII.

Materials.—A tuning-fork; a resonant jar; water.

Experiment.—1. Notice the letter on the fork and infer the number of vibrations of the fork from the table in your text-book.

2. "Pluck" the fork; hold it over the tube, and pour in water until the fundamental is reënforced most powerfully. Tie a string around the tube as a marker, and correct your first observation by repeated trials,

changing the position of the marker until you are satisfied with the result. Measure the length of the resonant tube; *i. e.* the column of air that most strongly reënforces the fundamental of the fork.

3. Correct for diameter by the rule of your book.

4. Calculate the length of the air wave.

5. Calculate the velocity of sound.—Explain in full the formula for 5 and the relation between the length of the tube and the length of the sound wave. What is the use of the water?

XXIX.

Materials.—A monochord with removable bridge; a tuning-fork.

Experiment.—1. Pluck the fork and the string and notice whether they are in unison. If not, bring them to unison by turning the key of the monochord. Measure, or notice on the scale, the length of the string.

2. Place the bridge under the string and move it until the tone that you recognize by ear as the fifth above that of the fork is produced. Pluck string and fork and make repeated trials. Find the length of the part of the string that rendered this tone.

3. Proceed in the same way for other intervals that you recognize by ear until if possible you have in tabular form the lengths of string of same size and tension for each tone of the scale.

XXX.

Materials.—A suspended magnetic needle; and pieces of steel, iron, copper, brass, "tin" plate, aluminum, wood and card-board.

Experiment.—1. Ascertain which of the above pieces are magnets, and label them.

2. Ascertain which are paramagnetic, and label.

3. Ascertain which are diamagnetic, and label.

XXXI.

Materials.—A bar magnet; a grooved board; a frame for supporting the magnet vertically; iron filings; wire gauze for sieve.

Experiment.—1. Place the magnet in the groove of the board and lay a smooth sheet of paper over the whole so that the system will be fairly stable and nearly horizontal. Sift the filings slowly and evenly over the paper, jarring (without moving laterally) the paper continually while the filings are accumulating. (Oral cautions.)

2. Sketch a few of the lines of filings carefully and complete the drawing afterward so as to show truly the lines of magnetic force quite quite out to the margin of the paper.

3. Get a good drawing of another section of the magnetic field by placing the magnet vertically in the frame and repeating 1.

XXXII.

Materials.—A deflection magnetometer and equipment, consisting of a base with leveling screws, box, windows, graduated circle; tube and suspension system, consisting of rod, clamp-screw, filament, hook, needle and mica vane; meter bar; carriage; and deflecting magnet.

Experiment.—1. Place the magnet at some distance; level until the ends of the vane read alike; and bring one end to zero. Do not hereafter disturb this adjustment.

2. Place the bar in the east and west slot ("A" position of Gauss); put the carriage on the bar east of the box so that the middle shall be 250 mm. from the middle of the needle, and place the magnet on the carriage. Read the deflection to half degrees. (To affect this adjustment, add half the breadth of the bar, half the length of the magnet, and the distance from the magnet to the box, which should together equal 250 mm.)

3. Turn the magnet end for end without moving the carriage and read the deflection.

4. Place the carriage on the bar west of the box and adjust the magnet so that its center shall be 250 mm. from the center of the needle. Carefully avoid displacing the box. Read the deflection.

5. Turn end for end and read.

6. Average the four readings as the *deflection of the needle*. Explain this deflection. To do this draw a *plan* of needle and magnet and name all the forces which act upon the needle. If the length of the needle is negligible in reference to the distance of the magnet from the needle, what pairs of forces will be equal? What would be the effect of bringing the magnet nearer? Of increasing its magnetism. Of increasing the earth's magnetism? When you know the magnitude and direction of the action of the magnet as a whole and of the earth as a whole, what principle comes in to determine the amount of deflection? See S. & G. "for Schools" (the Junior Course), p. 88, for an elementary discussion of the case.

7. If there is time get another set of deflections at another distance, say 184 mm.

XXXIII.

Materials.—The above used as a vibration magnetometer; a suspension system for the magnet of the above; a watch; a bar magnet.—Two students work together.

Experiment.—1. Level and orient as above. Place the bar magnet in the meridian north or south of the suspended magnet, a foot or so away, and then suddenly withdraw it and leave at some distance. This will usually set the magnet vibrating around the filament as an axis without swinging sideways. Repeat if necessary until you secure this result. Count the number of single vibrations in a given time in the same way as was done in pendulum work. Compute the time of one vibration.

2. Repeat for another time interval, say five min.

3. Repeat for another time interval.

4. Average the above averages of the time of one vibration. How is the piece like a torsion pendulum? How different? What would be the effect upon the time if the earth field were stronger? If the magnet were "stronger" with the same mass? If the mass were greater with the same strength of poles?

5. Place the bar magnet below the base in the magnetic meridian with the north pole turned toward the south and repeat 1. How is the time affected? Why?

XXXIV.

Materials.—Daniell cell, simple galvanometer, resistance box, connecting wires.

Experiment.—1. Set the battery in action by immersing the porous cup with the zinc plate in the jar of copper sulphate. Connect the wires with the battery, touch terminals to the tongue and describe the effect.

2. Join the battery with the galvanometer and describe the effect. Interchange the connections and describe the effect.

3. Trace the circuit in the direction the current is flowing and tell which way the north end of the needle turns for each direction of the current.

4. Join battery, galvanometer and resistance box in series; place the levers all on 0 (or have the plugs inserted), and record the reading of the needle. Reverse current and read again.

5. Put in 2 ohms, read and record.

6. " 5 " " "

7. " 8 " " "

8. " 10 " " "

9. Assuming that (r) equals 1 ohm and E. M. F. equals 1 volt, compute the current-strength in each of the above cases.

10. Tabulate all results and diagram the apparatus.

XXXV.

Materials.—Daniell cell, simple galvanometer, resistance box, reversing key, connecting wires, and coil.

Experiment.—1. Connect the cell with opposite posts on the reversing key, and join the coil and galvanometer to the remaining posts of the key. Read the needle, change the position of the plugs, and read again. What is the effect on the current?

2. After reading the needle carefully for both directions of the current, replace the coil by the resistance box and try to make the needle read the same as before by adjusting the resistance. What relation does this final resistance bear to that of the coil? Why?

3. Repeat 2 several times until a constant result is obtained.

4. Put in circuit both the coil and the resistance box with some small resistance (say 40 ohms). Remove the coil and find what added resistance will be required to produce the same deflection.

5. Put all results in tabular form and average those most nearly alike. Diagram the apparatus to show connections and direction of current.

6. If there is time, test the box as you did your set of weights; *i. e.*, try all resistances below the .5 ohm against the .5; all below 1 ohm against the 1 ohm, etc.

XXXVI.

Materials.—Battery, the parts of a tangent galvanometer, resistance box, current reverser and connecting wires, detector galvanometer.

Experiment.—1. Wind the wire upon the wooden ring, leaving the free ends long enough to lead down through the pillar and up through the holes in the base when the parts are put together.

2. Connect all the apparatus in series. Observe whether there is a deflection of the needle and also whether the reverser is connected properly.

3. Put in 0 resistance and read the deflection. Reverse and read again.

4. Put in 1 ohm and read. Reverse, etc.

5. Put in 2 ohms and read. Reverse, etc.

6. Put in 3 ohms and read. Reverse, etc.

7. Put in 4 ohms and read. Reverse, etc.

8. Put in 5 ohms and read. Reverse, etc.

9. Put in 7 ohms and read. Reverse, etc.

10. From these data find the resistance of the battery by the method discussed in class.

11. Using your detector galvanometer, find by the method of substitution the resistance of your tangent galvanometer coil.

XXXVII.

Materials.—A battery of several cells joined in series, tangent galvanometers for the whole class, current reverser, resistance box, wires and an ammeter.

Experiment.—1. Join the several cells in series with the ammeter, resistance box, reverser, and all the galvanometers.

2. Read the ammeter and let each student record the current strength with the corresponding deflection of the galvanometer. Reverse and read.

3. Reduce the current strength by adding resistance, *e. g.*, 3 ohms, 5 ohms, etc., each time reading the deflection both east and west and the strength of the current.

4. From the data thus found find the reduction factor of each galvanometer for one turn of wire. Formula dictated and explained in class.

XXXVIII.

Materials.—As in XXXIV; a bridge.

Experiment.—1. Find the resistance of the coil by the bridge method.

2. Also of the tangent galvanometer coil.

3. Also of the detector galvanometer coil.

XXXIX.

Materials.—A tumbler with dilute sulphuric acid; a block galvanometer; slips of copper, zinc, lead and iron; means of preventing slopping and dripping of acid.

Experiment.—1. Immerse the plates successively in the acid and observe the effect.—Oral caution.

2. Amalgamate the zinc.—Oral directions.

3. Put the galvanometer into circuit with each of the above metals (except copper) as one element of a galvanic cell and copper as the other. Observe the deflection in each case. Tabulate.

4. Repeat, using one of the other metals instead of copper, with all the others.

5. Repeat, using another metal, and so on through the series.

6. Tabulate and account for the effect.

XL.

Materials.—A Rumford photometer; a standard candle; a gas flame or other artificial light; a dark room.

Experiment.—1. Place the photometer at any convenient distance from the gas flame, say 8 ft., and move the candle back and forth on nearly the line between the screen aud the gas jet until the two shadows appear of the same density.—Oral cautions.—Measure the distances from the screen to the lights.

2. Bring the photometer a few inches nearer and repeat. See how accurately you can set the candle; *i. e.*, how far either way you can move the candle without changing the density of the shadow appreciably.—State this distance in your notes.

3. Repeat for two or three other distances of the screen from the gas jet, tabulating all cases under the headings, "Distance of candle from screen"; "Distance of gas jet from screen."

4. Continue the table by squaring these distances and recording under proper heads; and finally by finding and recording the ratios of these squares as "Candle power of gas jet." Average these candle powers.—Would it have given the same result to average before squaring? What physical law is involved? What do you think of the accuracy of the piece?

XLI.

Materials.—A Bunsen photometer; as above.

Experiment.—In full as above.

XLII.

Materials.—A plane mirror fastened to a block by rubber bands; black pins; a straight-edge; support to bring paper nearly to the level of the eye.

Experiment.—1. Place a sheet of paper on the support; draw a line across the middle of it from right to left; and place the mirror vertically over this line so that the silvered edge shall exactly coïncide with it. Set up a pin vertically in front of the mirror and three or four inches from it, and holding the eye steadily in any position sight along the straight-edge toward the reflection of the pin in the mirror. Draw a faint line along the straight-edge while in this position. See if the line points exactly toward the reflection of the pin; if not, change it. Finally make the line heavy and carry it quite from the mirror to the edge of the paper.

2. Repeat, using another position of the eye.

3. Repeat, using another position of the eye. Continue until four or five lines are drawn, criticised and made heavy (or inked.)

4. Remove block and mirror and prolong the lines made until they meet in pairs. Locate an average position for these intersections and letter it B.—Letter the position of the pin A; connect A and B and call the intersection with the line of the mirror P. Discuss in full the position of the object A and its image B as actually found in your construction. Retain this very paper in your note-book and not a copy.

XLIII.

Materials.—As above.

Experiment.—Proceed as above, except draw an arrow on the paper in front of the mirror, set up a pin at each end of the arrow, and proceed with *each* pin as above. Connect the points wdere the images of the pins are found and complete the image of the arrow. Discuss as above, naming eight facts about the image of an object as seen in a plane mirror which are justified or nearly justified by your construction.

XLIV.

Materials.—Straight-edge; a piece of thick plate glass; a triangular glass prism.

Experiment.—1. Draw a straight line about 5 inches long; place the glass plate upon it, and note and describe the effect produced when the line is viewed obliquely through the glass.

2. Draw this as seen.—Draw also a cross section showing the path of the rays through the plate to the eye.

3. Repeat 1, using the prism, with its lateral edges parallel to the line, instead of the plate. Describe also the effect as seen when you look directly down upon the line.

4. Repeat 2 with the prism:—both figures.

XLV.

Materials.—Support; straight-edge; prism with flat ends; pins; protractor.

Experiment.—1. Place a sheet of paper on the support and insert a pin vertically in the middle of the edge distant from you. Set up the prism in the middle of the sheet and trace its outline on the paper. Move the eye until the pin is seen through the prism, and, without changing the position of the eye, set up three more pins, one beyond the prism and two on the side next the eye, all three of which appear to cover the first pin as seen through the prism. To do this you will find it best to set up a pin near the front edge of the paper which hides the first pin and then the other two in succession. Remove the prism, mark and letter the position of the pins and connect by a line those beyond the prism and also those on the side next the eye. Produce the first line across the paper and produce the other until it intersects the former. Discuss the case.—Draw the angles of incidence and refraction.—Read and measure the angle of deviation.

2. What effect accompanies refraction? Look at the edge of a sheet of paper to observe it best. Describe this effect.

XLVI.

Materials.—A reflection apparatus; a porte-lumiere.

Experiment.—Throw sunlight upon the piece, adjust carefully, and verify the law of reflection.—Why is there not exact verification? When the index moves one degree, through what angle does the mirror move? The reflected beam? Why?

XLVII.

Materials.—A refraction apparatus; a porte-lumiere.

Experiment.—1. Fill half full of water, throw a horizontal beam of light upon the vertical slot, and read the angle of incidence and also the corresponding angle of refraction. Read to quarter degrees.

2. Repeat for another angle.

3. Repeat until at least six pairs of angles are read and recorded under columns headed "Angle of Incidence," "Angle of Refraction."

4. Complete the table by finding and tabulating the sines of the above angles, and, finally, the ratio of these sines.—Name of this ratio? What do you observe about it in the several cases? What is the average ratio?

XLVIII.

Materials.—Concave mirror and mount for same; two millimeter scales mounted back to back; a graduated slide one meter long.

Experiment.—1. Place the mounted mirror and scales upon the slide about 5 or 6 inches apart and adjust the mirror so that an inverted image of the scale may be seen upon looking just above it into the mirror.

2. Adjust the distance of the scales from mirror until no parallax can can be detected. Measure and record this distance.—Repeat if necessary for great assurance.

3. Place the mirror before a window and let the image of a cloud or tree be focused upon the scale used as a screen. Measure and record this distance.

4. Compare all results found in 2 with those of 3 and deduce a fact concerning mirrors. In general if the head be moved laterally the image will move along the scale. This appa_ent motion is called parallax. Parallax can only be corrected by placing the image and object at equal distances from the observer.

XLIX.

Materials.—A double convex lens and mount for same; two pairs of millimeter scales mounted, and a graduated slide.

Experiment.—1. Place the mounted lens upon the slide between the millimeter scales and about 5 or 6 inches from them. Adjust the scales until an inverted image of one may be seen upon looking through the lens.

2. Adjust the distance until all parallax is destroyed. Measure these distances and solve for for focal distance.

$$\frac{1}{f}=\frac{1}{p}+\frac{1}{q}.$$

3. Change the distances slightly and repeat 2. Tabulate all results.

4. Set the lens before the window and focus the image of a cloud upon one of the scales used as acreen. Measure and record this distance.. Compare the result with those of 2 and 3.

Exercises for Courses in Physics I and II.

In addition to the class work having to do with the demonstration of physical laws and principles, and the table work as indicated in the foregoing list of quantitative experiments, it is desirable that the members of the class get some good notion of the *graphical method*, and an *expert use* of the straight-edge, triangle, dividers and protractor. Exercises to this end, in addition to those prescribed in the text-book, are given below. For this work the English scale and protractor of Prang's school square will be sufficient; in addition to which each pupil should possess a metric scale at least 2 dm. long, divided in millimeters; a pair of dividers *in good condition*, with pencil point; and a stock of coördinate paper.

Some preliminary oral instruction should be given upon the care and use of the instruments and upon the method of coördinates. A few of the exercises below have this end in view. As far as this work has already been done in geometry it may be omitted here, but it will be of no use for physical purposes if the student has drawn only *illustrative figures*, and has not learned to work with *fine lines* and with accuracy at least equal to the breadth of a line. When the construction is once made in *fine lines, with extreme accuracy, and the result declared*, the important lines named or called for in the exercise may be strengthened or inked.

To many teachers much of this work will seem like "Trigonometry dodging," and so it is; but it should not be forgotten that at present no high school places trigonometry (if it has a course at all) before physics, and that without some work in exact construction students never get an idea of the simplest physical principles—like the doctrine of the lever—in their generality.

1.

Upon coördinate paper construct the equations,—

(a). $y = 3x + 4$; (b). $y = -3x + 4$; (c). $y = 3x - 4$;
(d). $y = 6x + 4$; (e). $y = 3x + 6$.

Use any convenient scale, but label the figures and declare the scale. What effect has changing the coëfficient of x? The independent term?

2.

Construct the equation $y^2 = 8x$.—Get at least 8 points in the line. Of what shape is it?

3.

Represent graphically the following school attendance:—

			A. M.	P. M.				A. M.	P. M.
Tu.,	Sept.	18	12	16	Mon.,	Oct.	1	34	36
Wed.,	"	19	17	21	Tu.,	"	2	36	38
Th.,	"	20	24	25	Wed.,	"	3	41	41
Fri.,	"	21	25	25	Th.,	"	4	41	40
Mon.,	"	24	33	34	Fri.,	"	5	38	36
Tu.,	"	25	34	37	Mon.,	"	8	38	39
Wed.,	"	26	33	36	Tu.,	"	9	27	22
Th.,	"	27	34	35	Wed.,	"	10	22	18
Fri.,	"	28	33	30	Th.,	"	11	12	4
					Fri.,	"	12	0	0
					Mon.,	"	15	33	37
					Tu.,	"	16	38	41

Is this a case of continuous or discontinuous number? Should you use a curved or a broken line? What do you do on Oct. 12, when there was no school? Compare with your barometer curve.

4.

Near the left hand edge of your coördinate paper, and with a center where two cm. lines intersect, describe a quadrant with a radius an exact decimeter. At the right hand end of the horizontal radius erect a perpendicular tangent to the arc. With your protractor lay off arcs of 12°, 15°, 22°, 30°, 35°, 45°, and 52° (any others would do as well); draw fine lines through these points and the exact center; and extend these lines until they cut the perpendicular. See if the angles formed at the center have exactly the value indicated above, and when just right let fall perpendiculars from the points on the arc to the horizontal radius. Letter the figure in full and *tabulate as sines* the lengths of these perpendiculars; *tabulate as cosines* the distances cut off from the center to the foot of each perpendicular; and *tabulate as tangents* the distances cut off on the first perpendicular above the horizontal radius. Imagine the figure rotated or displaced in any way while the lines preserve the relations to each other indicated above, and be sure that you get a good working notion of sine, cosine and tangent.—In your table make the dm. the unit, and estimate the mm. to tenths so as to record as thousandths of a dm.

5.

Divide one edge of a slip of cardboard, 6 in. long and ¾ in. wide, carefully into inches and tenths of inches and number the inch divisions 0, 1, 2, etc.; and also number the tenths of the first inch. Next cut another narrow slip of cardboard exactly 9/10 in. long, and divide it carefully into ten equal parts. Calling the long slip the *scale* and the short one the *vernier*, place the divided edges against each other and number the divisions of the vernier in the same direction as the scale, the lower edge of the vernier being of course zero. Place the divided (or *graduated*) edges together so that 1 of the vernier shall be exactly opposite 1 of the scale and *inquire how far the* 0 *of the vernier is above the* 0 *of the scale.* Place the mark 2 opposite 2 and make the same inquiry, and so on. Place the vernier down at random against the scale and *read* it, remembering that *reading the vernier is ascertaining how far above* 0 *of the scale the* 0 *of the vernier is.* The whole inches and tenths you observe directly and the hundredths by coïncidences as above. Formulate a rule for reading a vernier of this kind. Find the lengths of several objects (as pins), true to hundredths of an inch, by your vernier. If you chose you might extend the vernier and mount it so that it would slide smoothly along the scale, and also extend the scale and provide it with a foot so that when the vernier came against this foot the zeros would exactly coïncide. See the barometer vernier for an example of the simpler form.

5a.

Instead of the inch scale use a slip 3 or 4 cm. long of your coördinate paper, dividiug 9 mm. into ten equal parts and proceeding as above. Would such a vernier even if carefully made be of much practical use? Why?

6.

Draw a triangle the sides of which are 4.5 cm.; 6 cm.; and 7.5 cm.; and measure the three angles with your protractor. Extend the sides if necessary for this purpose, and so hereafter. Find the sum of these angles. Repeat. State the law of the case.

7.

The boundary of a triangular field has the following description:

Beginning at the point A the first side, AB, runs N. 18° W. 37 rods; the second side, BC, S. 61° W. 54 rods; and the third side from C to the point of beginning.

Calling all lines parallel to the left-hand edge of your paper meridian lines, and using a scale of ten rods to the inch, construct a triangle representing the field, and find and *declare* the magnitude and direction of the third side.

8.

A boat is acted on by a wind which would alone drive it S. 42° E. at the rate of 3.5 mi. per hour, and is at the same time in a current running

N. 14° E. at the rate of 4.25 mi. per hour. Construct, using a scale of 1 inch to the mile, and find and declare the direction and velocity of the boat under the action of both the forces.

9.

The actual course of a boat under the combined action of wind and current is S. 30° W. at the rate of 3 mi. per hour. If the wind is a north wind (blowing toward the south) and the current sets northwest (N. 45° W.), what is the velocity of both wind and current? State the order of your work and result.

10.

If the wind is a west wind and the current is known to move at the rate of 8 mi. an hour, what must be the velocity of the wind and the direction of the current under the combined action of which the boat moves N. 70° E. at the rate of 12 mi. per hour? Use a scale of 1 cm. to the mile. In this as in all the above cases state the *order* as well as the result of the work, and best in form of *steps*, or points of construction.

11.

What must be the direction of a current of 2 mi. per hour and a wind of 1¾ mi. per hour that under their combined influence the boat may be borne north at the rate of 2½ mi. per hour? Choose your own scale.

12.

A weight of 300 lbs. suspended from a cord is drawn aside by a horizontally acting force so that the supporting cord makes an angle of 34° with the vertical. Construct and find and decla.e the tension of the string and the intensity of the horizontally acting force.

13.

A pair of rafters having a horizontal slope of "one to two" has a tank of water weighing 240 lbs. resting on the ridge. What is the horizontal thrust on the walls?

14.

The base of a triangle is 7.27 in. long and the angles at the base are respectively 23° and 32°. Construct the triangle, measure the altitude, and calculate the area. Of what physical problem might this abstract exercise be the statement?

15.

Three concurring forces OA, OB, and OC in equilibrium have intensities represented by the numbers 4, 5, and 6. Construct and measure and declare the angles between the lines representing these forces. What name may be given to each in reference to the other two? Construct and measure the resultant of any two and compare in magnitude and direction with the third. How if the intensities had been represented by the numbers 4, 5, and 9? How if by the numbers 4, 5, and 10?

16.

A weight of 1000 lbs. is hung upon a crane which is held in place (the post vertical, the arm, rigidly connected with it, horizontal) by a guy-rope making an angle of 30° with the post. Construct and find and declare the tension of the guy-rope.

17.

Construct on a scale of 100 ft. to the inch the course of a projectile thrown horizontally with a velocity of 100 ft. per second. Carry the construction as far as you can on your paper.

18.

Repeat but with an angle of elevation of 60°.

19.

Construct simple harmonic motion for the period of 2 sec., locating a point for every sixteenth of a second. Make the radius of the circle of reference 2 inches. Letter and describe in full. When is the velocity greatest? When the acceleration? Give examples in nature of this kind of motion.

20.

Repeat, using a circle of radius 1 in., establishing only eight points, and compound with uniform motion at right angles to the simple harmonic motion in which the uniform velocity shall be the maximum velocity of the S. H. M. Name and describe the curve produced. Give examples in nature.

21.

Repeat with one-half the above uniform velocity.

22.

Construct the position of a seconds pendulum for every eighth second. Treat the amplitude as negligible in reference to the length.

23.

Construct a Blackburn's pendulum-figure in which the times are as 1 to 2. Leave all lines of construction, but strengthen the curve after carefully drawing it. Name all the physical principles which enter into the construction. All the mathematical principles.

24.

Repeat for ratio 2 to 3.

25.

Repeat for ratio 3 to 4.—Suppose it were possible with the apparatus to make the periods the same, what would the curve be?

26.

A bent lever of which the two arms are 27 and 37 inches long respectively and form an angle with each other of 130° rests upon a fulcrum at the vertex of the angle. What weight at the end of the long arm will keep the short arm horizontal if it is loaded with a weight of 240 lbs.? Neglect the weight of the lever. How nearly would the unloaded lever come to rest in this position if it were uniform and had weight?

27.

The arms of a horizontal straight lever without weight are 12 and 23 inches long. A force of 125 lbs. acting at an angle of 125° with the lever on the short arm is in equilibrium with an unknown force acting at the end of the long arm and making an angle of 100° with it. Compute this force. Can there be a lever without weight? When may the weight be neglected?

28.

How long must a straight uniform beam weighing 10 lbs. to the running foot be that, resting on a fulcrum 7 in. from one end, it may by its own weight support a weight of 1800 lbs. at the end of the short arm? Compute, draw to a scale, and justify your result.

29.

A filament of soft iron of negligible length is placed at a distance of 3 in. from the N pole of a bar magnet 6 in. long, and at a distance of 5 in from the S pole. The strength of each pole of the bar magnet is 100 dynes and of each pole of the filament at this place in the field is 2 dynes. Construct the bar magnet and position of the filament to a natural scale, and the forces acting between the two bodies to a scale of one-tenth, or one-twentieth. Neglecting friction, what direction will the filament assume? Might an analogous construction be made for any filament within the field?

30.

Draw the statical couples which act in the case represented in *Experiment XXXII* and show how they act to produce equilibrium.

Part II.

Experiments for Course Entitled "Physical Laboratory Practice."

I.

Materials.—A metal cylinder; a steel scale graduated on one side in inches and hundredths and on the other in fifths of a mm., two well-squared wooden blocks; rubber bands.

Experiment.—1. Find the length and diameter of the cylinder in inches and hundredths, and in cm. and hundredths, and calculate its volume in cu. in. and cu. cm. Use here and hereafter all precautions for measurement indicated in Part I. Form two tables with proper title and headings for the columns, one for the English and one for the metric measurements.

2. Clamp the cylinder between the blocks so that when the system rests on the table the cylinder and two faces of the blocks shall be in good contact with the table and one end of the cylinder nearly flush with the ends of the blocks. Measure the distance apart of the blocks at a point as near as possible to the middle of the end of the cylinder. Record in preceding table. Measure also the length.

3. Get two more sets of measurements and record.

4. Average results in each table and compute the relation of the cu. in. to the cu. cm.—If you are sure of your measurements only to the first decimal place, to what place are you sure of your result? Between what limits do the former lie? Between what must the latter lie?

II.

Materials.—A screw micrometer; two pieces each of straight iron and copper wire with well squared ends; a steel scale.

Experiment.—1. Describe the piece and show to what degree of accuracy it measures. State the graduation of the horizontal and the circular scale and give a rule for "reading."

2. Number the four wires and find by repeated trials the diameter of each. Measure at both ends and along several diameters.

3. With the steel scale find the length of the wires.

4. Calculate the volume of each.—Retain only so many places as you have a right to. If your lengths are wrong by one hundredth, how far will this invalidate your result? If the diameter is measured incorrectly by the same amount, how far? Where then must you put the stress of your work?

5. Consult the table of the "Properties of Uncovered Wire" and ascertain the gauge numbers of the wires and the electrical resistance of each per 1000 feet.

PRECAUTIONS.

Turn back the screw and inspect the longitudinal scale to see whether you have English or French units, and how divided. Inspect the circular scale to see into how many parts it is divided. Notice how far the sleeve advances on the longitudinal scale when you turn it quite around and thence infer how far it will advance when you turn it one division of the circular scale. *Turn it down lightly* against the stop, notice the zero error and allow for it in all readings. Usually there will be no error unless it is turned down too hard, *which you should avoid.* Light contact, just sufficient to hold the wire, is best.

III.

Materials.—Vernier calipers; bicycle ball.

Experiment.—1. Inspect and explain the calipers and give a rule for reading. (The vernier construction in Part I should precede this.)

2. Get three good readings of the diameter of the ball in three directions and compute the volume. Compare this piece with the preceding in convenience and accuracy.

IV.

Materials.—A spherometer; true plane; a microscopic cover-glass.

Experiment.—Inspect the piece, handling carefully, until you understand it, as you will easily do by comparing with the micrometer gauge. Be sure that you read correctly the longitudinal and circular scales.

Get the zero error by turning the screw down until it *just touches* the plane. Test this by reflection and also by racking the instrument.

Turn up the screw, place the cover-glass beneath it and lower the screw upon it. Get several readings at different points on the cover-glass so as to find the average thickness of the glass.

V.

Materials.—Balance A or B; set of corrected weights; cylinder of I; beaker; pure water; and usual accessories of a specific gravity balance. (To follow work in weighing of Part I.)

Experiment.—1. Weigh in air and water the cylinder of I and calculate the sp. gr. by this method.

2. Claculate the volume by the above. State method and reason for it. Compare with the volume found in I.

3. Taking the volume from I and the wt. in air from this experiment, calculate the density. Relation of density to sp. gr.? Of weight to gravity? Of weight to mass?

VI. VII.

Materials.—"Sartorius balance No. 3"; set of corrected weights; watch; piece of quartz or metal.

Experiment.—1. By the method of "double weighing" get the relative length of the balance arms. Express the length of the right arm in terms of the left arm as unit.

2. Determine the sensitiveness of the balance for loads 0, 1, 2, 5, 10, 20 grams in each scale-pan. By sensitiveness is meant the number of scale divisions through which the index is moved by a mg. (or cg.) weight in one pan, in addition to the load.—State also what is the least weight that will change visibly the position of equilibrium of the index.

3. Find the time of oscillation with loads 0 and 10 grams.—Keep your notes in such form as to constitute a "*Report on the Performance of Balance No. 3.*"

VIII. IX.

Materials.—Balance and set of weights from 1 cg. to 20 g.

Experiment.—Assuming the above named weights to be correct (or taking the corrections from the attached paper), make a table of corrections for the other weights of the series by the method of VIb, Part I. Letter the weights so as not to assume that their marked value is the true value, and report in the following form:—

x = "2" cg., too large by ____________, etc.

X. XI.

Materials.—Aluminum foil of two thicknesses; shears; balance; set of corrected weights (or balance the performance of which is known); set stencils or stamps.

Experiment.—1. Measure and weigh a small rectangle of the thinner foil, and calculate the edge of a square large enough to weigh 1 mg. Cut out a square slightly larger than this; stamp with the proper number; flatten; bend up one corner, and weigh. Correct by cutting off shreds from adjacent sides until you have the closest possible approximation to the marked weight.

2. Repeat for 2 mg.

3. Repeat for 1 cg. with the thicker foil.

4. Repeat for 2 cg. with the thicker foil. Present to teacher for justification.

XII. XIII.

Materials.—As above, but without the stencils and with two sizes of wire instead of foil.

Experiment.—Proceed substantially as above so as to secure well corrected weights of the values 1 mg., 2 mg., 5 mg., 1 cg., 2 cg., and 5 cg., in which the values of the weights shall be indicated by the size and number of bends in the wire. Leave one segement a little longer than the others and turn it up at right angles to the plane of the segements, so that, for example, the 5 cg. shall be a good regular pentagon with one of the ends turned up at right angles to its plane, as a holder for the forceps.

XIV. XV. XVI. XVII.

Density and specific gravity work from Part I repeated with better equipment and greater precautions.

XVIII.

Materials.—A one-arm (Westphal) balance and equipment in case; distilled water; sample of brine.

Experiment.—Set up carefully; inspect, and get the theory of its use; ascertain the sp. gr. of the brine; rinse the suspension system, and put in order and return to the case.—This is an exercise, very common in a teacher's experience, of setting up and using a new piece. Preferably do not *read* but *infer* function of parts from structure. Find the actual weight of the riders and show how they are used. Give an estimate of the usefulness of the piece compared, for example, with a Jolly balance.

XIX.

Materials.—A Hare's apparatus; oil; water.

Experiment.—1. Read H. & B. or some good authority concerning this piece. In performing the experiment be very careful about reading the vertical heights accurately and allowing for capillarity. Read four times at different heights, and tabulate and average the results. Find the sp. gr. of the oil.

Read the barometer and calculate the tension of the air in the tubes in one of the above cases. What forces act upon a film of either liquid stretching across the lower end of each tube? Neglect capillarity.

XX.

Materials.—A 30 lb. spring balance; spring-brass wire; means of holding wire, etc.—Balance.

Experiment.—If you desire to use the balance in a horizontal position, find the true zero for this position and work from it. Using about a meter of the wire each time, find the breaking strength of the wire in three cases and tabulate them. Be careful to watch the index of the balance and read just at the instant of breaking. Keep the wire on the spool tightly coiled and leave it so with the free end well fastened.

Weigh a measured piece of the wire and find what length of the wire will break under the strain of its own weight. Where will it break?

XXI.

Materials.—Reservoir of water; connecting hose; mercurial manometer; meter bar.

Experiment.—Place the manometer at different heights along the bar and take readings of both water and mercury from the zero line. Calling h the ht. of water in the reservoir above the zero line, and d the distance as read upon the bar of the surface of the mercury from the zero line, deduce a formula for H. the vertical height of the liquid. Call d negative when below the zero line. Tabulate your results, giving all distances in mm.

Inspect the table and deduce the law of liquid pressure and the sp. gr. of mercury. A form of tabulation accompanies the piece.

XXII.

Materials.—A well-cleaned capillary tube; clean mercury; balance and weights; rubber hose; steel scale; distilled water.

Experiment.—1. Put the hose upon the tube and by "suction" draw a little mercury slowly and carefully into the tube—a thread of mercury at least half as long as the tube. Hold the tube nearly horizontal and measure the length of the thread of mercury.

2. Weigh the tube and mercury.

3. By blowing or shaking or both expel the mercury into the bottle; see that there are no small globules adhering to the tube, and weigh again. Find the weight of the mercury, and, assuming the thread to have been cylindrical, calculate from the above data and the known density of mercury the radius of the tube.

4. Place one end of the tube in the water and measure the height to which the water rises. This can be done by clamping the tube to a scale (not the steel scale) by rubber bands, by using thread markers, etc. Before measuring draw the column of water repeatedly somewhat higher than it naturally rises and observe whether it subsides to the same level.

5. From the formula

$$T = \frac{rh}{2 \cos. 25\frac{1}{2}^\circ}$$

calculate the surface tension of water. Consult S. p. 32; Anthony and Brackett, p. 100, or some other manual, and be prepared to discuss the above formula and define all terms used.

XXIII.

Materials.—A torsion pendulum set as in Part I; the weight of the ring, the platform and spindle, and of the bar being known.

Experiment.—1. Get the inside and outside diameters of the ring and calculate the mean radius. Also calculate the moment of inertia of the ring by the formula $I = Mr^2$.

2. By experiment as in XIIIa, Part I, find the time of oscillation, t, of the platform and stem; also of the platform, stem and ring, *t*. By the formula

$$I = I \frac{t^2}{t^2 - t^2}$$

calculate the moment of inertia of the platform and stem, *I*.

3. Lower the bar upon the system and determine the time of oscillation. By a method similar to the above, calculate the moment of inertia of the bar. Calculate the moment of inertia of the bar also by the formula in Anthony and brackett, p. 59 and compare with the above.—Write the formulas for the time of vibration of a simple pendulum, a physical pendulum, a torsion pendulum, and a pendulum of extension. See Physical Review, Vol. 2, p. 56.

XXIV. XXV.

Credit will be given for a good discussion of the thermometer, the barometer, the psychrometer, and the rain gauge, accompanied by good records of observation of the above instruments for one week. Consult

Davis and the *Smithsonian Instructions for Observers.*—Only for those who do not have a course in Meteorology.

XXVI.

Materials.—A rectangular wooden bar; supports; a multiplying lever; weights.

Experiment.—Place the bar on the supports and load the middle of the bar with ten or fifteen different weights, from the lowest that will produce a perceptible deflection to one that will nearly produce a "set" in the bar. Tabulate and represent graphically, making the weights abscissas and the deflections ordinates. Deduce the law of deflection as depending on the weight.—Manipulate with great care and observe accurately. Let the supports be near the end and unchanged during the experiment. Place the load accurately midway between the supports.

XXVII.

Materials.—As above.

Experiment.—As above, except instead of changing the weight change the length, the weight remaining the same. To get fifteen good readings considerable skill is demanded. Get as many as you can and between the widest possible limits. Give table and graph, and, if possible, deduce the law.—Begin by taking the largest weight used in the preceding case, with the supports near the ends. Bring the supports gradually nearer until no deflection can be observed. The distances between the supports may be abscissas and the lengths ordinates.

XXVIII.

Materials.—A seconds pendulum vibrating in front of one of variable length.

Experiment.—1. Verify the two principal laws of the pendulum and give a full account of your work. First make the times of vibration alike by changing the length of the rear pendulum.—In no case change the front one. Then keeping the amplitude of one the same (say 3 or 4 in.), change that of the other from a half inch upward to three inches or so.—In all pendulum work keep the amplitude small.

2. Change the length of the rear pendulum by two or three inches, measure the length of both, start the two pendulums together, and count the number of vibrations of the seconds pendulum until coincidence occurs the first time. Write the proportion connecting the lengths and the times, substitute the observed numbers, and reduce.—Repeat, making the difference between the lengths less than before.

XXIX.

Repeat the above, using *successive* coïncidences according to Whiting's method. Calculate the value of t. Begin by making quite sure that the standard pendulum beats mean solar seconds. It will be sufficient for the purposes of this exercise if by your watch you see that the number of vibrations does not differ sensibly from 300 in five minutes. But whatever be the number of vibrations, do not change the length of this pendulum. Call the attention of the teacher in charge to the fact.

XXX.

Materials.—A compound pendulum formed of several balls; one formed by a uniform bar with adjustable knife edges; a simple pendulum.

Experiment.—1. Raise or lower the simple pendulum until it synchronizes with the compound. Which is longer? Why? What is the name of the point of the compound pendulum opposite the ball of the simple pendulum? In what time would the point swing if it were free? Effect of all points above this point on its time of vibration? Below? Why is not this point at the center of gravity?

2. Repeat with the bar, and find position of the center of oscillation when the point of suspension is at the end of the bar. Place the second knife-edge there. Get the time of vibration upon each knife-edge. State the principle illustrated. How far is the center of oscillation from the end?

XXXI.

Materials.—A smooth board; a block provided with a hook; a spring balance; weights.

Experiment.—1. Level the board and clamp it to the table. Place a weight upon the block and, attaching the spring-balance to the hook, find what force, pulling horizontally, is required to start the block. Repeat twice, using different parts of the board.

2. Proceed as above with each weight and combination of weights given you. Tabulate all results, adding in each case the weight of the block to the added weight. In each case calculate in grams the force per gram of weight. Name of the result?

3. Place the block upon the edge and proceed as above. Name and define the forces in the case.

XXXII.

Materials.—Same as in XXXI. Also an inclined plane, and means of measuring the angle of inclination.

Experiment.—Find the friction by the method of sliding and the principle of the inclined plane. Wor. 117, etc. Compare the coëfficient of friction with that of the preceding problem. Draw to scale.

XXXIII.

Materials.—A bar turning about a pivot at one end between two stops against a known force; spring balances.

Experiment.—1. Attach a spring balance successively to the hooks on the bar and read the spring balance when the bar is about to touch the forward stop. Tabulate the results and see if they verify the law of moments.

2. Attach spring balances to each of *two* hooks, and pulling "squarely," read as before. What is the general law for several forces acting at right angles to the bar? Formula?

3. Pull upon one hook at an angle of 45° with the bar and observe At an angle of 30°. Interpret result.

XXXIV.

Materials.—A model of a door of known weight, one of the hinges being replaced by a hook; a spring-balance.

Experiment.—1. Attach the spring-balance to the hook and read when the outer edge of the door just clears the sill, being careful to avoid friction of the door against the frame. Measure the door (the weight is given) and calculate, on the doctrine of moments, the strain on the upper hinge. Compare with the observed strain. What would be the effect of separating the hinges? Of making the door wider? Longer? Heavier?

2. Suspend a weight of 5 lbs. from the nail on the door and proceed as before. Explain.

XXXV.

Materials.—Set of levers and weights; counterpoise; standard.

Experiment.—Verify the laws of the lever in the three classes of lever. Sketch each case.

XXXVI.

Materials.—An unbalanced lever of known weight; spring-balance; weights; wooden bar with hooks.

Experiment.—1. Verify the laws of the lever, in this case using the three kinds of lever and taking into account its weight. Sketch all cases. State moments, using grams as one factor.

2. Find the weight of the free bar and then ascertain what force applied to each of the hooks will just raise one end. Sketch each case. Measure and justify by calculation. State the law in the form of the doctrine of moments. How do these two cases differ? See if you can bring them under the same formula.

XXXVII.

Materials.—A meter-stick supported at the ends by spring-balances; a sliding weight.

Experiment.—1. Place the weight on the hook and, sliding it to the center of the stick, determine the weight by the balances.

2. Slide the weight to four other positions and read the distances to the ends; also read the balances. Sketch and discuss the five cases, under the principle of parallel forces. Discuss the amount and position of the resultant also when the weight and one of the spring-balances are the two forces.

Remove the weight from the hook and so relieve the spring-balances.

XXXVIII.

Materials.—An inclined plane set.

Experiment.—1. Draw a known weight up the plane by a spring-balance, measure the heighth and length of the plane and discuss relation of these dimensions to force and weight. Compute the work done in moving the weight up the plane.

2. Change the inclination and repeat.

3. Change the weight and repeat.

4. Draw a diagram and justify your work on the principle of the parallelogram of forces.

XXXIX.

Materials.—A meter-stick or other bar supported from the middle; a block of lead suspended from a fixed point; a known sliding weight; a dish of water.

Experiment.—Slide the known weight along the bar until it just balances the lead and read the lever-arms. Push the dish of water under the lead and raise it until the lead is entirely submerged but does not touch the vessel. Read again, and on the basis of the doctrine of moments calculate the sp. gr. of the lead. Give work in full.

XL.

Materials.—A small ring with three attached cords each terminating in a ring; three spring-balances; a vertical board with pegs or hooks at different points near the edges.

Experiment.—1. Insert the hooks of the spring-balances in the rings at the ends of the cords and place the rings of the balances over any three of the pegs (or screw hooks) in such a way as to make the cords tense.

2. Place a large sheet of paper back of the cords (or use the permanent stock of paper attached to the board) and carefully trace the directions of the cords on the paper. Lay off, on the lines thus traced, from the center, distances proportional to the readings of the balances, using any convenient scale. Upon either two of these lines thus traced construct a parallelogram and study the figure produced.

3. Turn the paper over, and, changing the balances to other pegs, repeat.

In your notes state the readings of the balances and the scale used. Choose such a scale as to make the figure as large as the paper will admit. Meaning of the word "scale" in this use?

Put your name on the sheet and present with your notes.

XLI. XLII. XLIII.

The same as XXII, XXIV and XXV of Part I, but with a better equipment and to be solved with greater accuracy.

XLIV.

Materials.—Sheet-copper steam-bath or hypsometer; tumblers; ice; a filled thermometer tube; dividers; strips of paper; Bunsen burner.

Experiment.—1. Stir some melting ice in an amount of water sufficient to immerse the bulb and lower part of the tube, using the ungraduated thermometer as a stirring rod. Notice the effect upon the column of mercury, and when you are sure that it will go no lower tie a string tightly around the stem for a marker.

2. Suspend the thermometer in the steam-bath and light the burner under it, after seeing that there is water in proper amount in the bath. When the column of mercury will rise no higher, mark this point with a thread marker.

3. Now lay the thermometer on a paper strip so that the end of the bulb exactly coïncides with the end of the strip and sketch the thermometer on the strip. Transfer the freezing and boiling points, as marked, to the paper with great care, making sure that the markers have not been disturbed. Divide the space between these points into ten equal parts, and one of these itself into ten equal parts.

4. On the other side of the stem give the Fahrenheit division for a few points.

XLV.

Materials.—Apparatus for linear expansion in three forms, two using a multiplying lever and the third using a micrometer screw to measure expansion.

Experiment.—With each form of apparatus (or at least two) ascertain the coëfficient of expansion of the rods provided. Compare and criticise the pieces as to stability, ease of adjustment and accuracy. See H. & B., p. 360, n. e., or any practical manual. What technical use might be made of the coëfficient of expansion of iron? Brass?

XLVI. XLVII.

Like XXVIII and XXIX, Part I.

XLVIII.

Materials.—Apparatus for moving a piece of smoked glass beneath a flexible stylus attached to a clamped tuning-fork; pendulum also with flexible stylus near the former; watch; violin-bow.

Experiment.—1. Smoke the glass, adjust carefully so that the pendulum and the fork stylus shall each touch the glass lightly; set the pendulum swinging; bow the fork; and draw the glass slowly and uniformly along the base.—Repeat if necessary until you get good traces of both vibrations.

2. As in a preceding experiment ascertain the time of oscillation of the pendulum.

3. Count the number of vibrations recorded on the glass by the stylus attached to the fork between two of the marks made by the pendulum. Between another pair of the marks, and average.—These numbers should not greatly differ.—Calculate the number of vibrations per second of the fork.

XLIX.

Materials.—Four open organ pipes, one of which is marked (low C).

Experiment.—Find (a) by ear and (b) by calculation the note rendered by each of these unmarked pipes, working from the marked pipe accompanying them.

L.

Materials.—Resonance tube mounted horizontally; piston; tuning fork.

Experiment.—See S. 21.

LI.

Materials.—As above; brass rod and clamp.

Experiment.—Find the velocity of sound in brass. See Expt. XXII.

LII—LVI.

The same as XXXV to XXXIX, Part I, with a different equipment. The practical work to be done with greater accuracy and the formulas used to be proved and explained; *e. g.*, the bridge principle, and the formula for battery resistance.

LVII—LX.

The same as XXX to XXXIII inclusive.—In the last two work out the formulas,

$$\frac{M}{H} = \frac{(d^2 - l^2)^2}{2d} \tan a, \text{ and } MH = \frac{n^2 I}{t^2},$$

from S. & G., Junior Course, pp. 87 to 100, or from some other book, and solve for M and H.

LXI.

Materials.—Two Leclanche or Grenet cells; line; switch; button; plug key; two bells mounted on a base, one single-stroke, the other a vibrator; a button dissected; an uncharged cell.

Experiment.—1. Inspect the line and all the pieces and notice where the circuit is broken. Insert the plug, switch in the single-stroke bell, and press the button. Switch in the vibrator. Trace the circuit through the pieces minutely and explain the difference. Examine the dissected button, the uncharged cell and the other pieces, and explain.

2. This qualitative work is given for the benefit of those who have not had similar work in Elementary Physics. Special credit will also be given for inspection and report upon the telephone system of the town, the lighting of the building, or any analogous work. For this purpose, two styles of arc lamps, dissected incandescent lamps, branch blocks, fuse blocks, commercial voltmeters, ammeters, wattmeters, etc., will be supplied.

LXII.

Materials.—A complete equipment for two terminal telegraph stations.

Experiment.—Examine, put in order, transmit signals, and draw and explain all the pieces. As in all electrical experiments, trace the circuit minutely, and name and be intelligent about the use of all parts of each piece. See Prescott, if you need to, concerning the lightning arrester, the plug cut-out, the switch, etc.

This experiment, qualitative like the preceding, is assigned for the purpose of practice in adjusting armature screws so as to get the best effect, and in diagraming electrical contrivances.

LXIII.

Materials.—Two Daniel cells; a tangent galvanometer; a copper voltameter of known resistance; a watch; connecting wires, etc.

Experiment.—Pass a current for a few minutes to see that the connections are good. Remove the positive electrode without touching it, wash in a large amount of water, dry, and weigh. Restore to its place, noting the *exact time* when the current began to flow. Leave for some carefully noted time (say 45 to 60 minutes), remove, dry, and weigh again. Divide the gain in weight, stated in grams, by the time in seconds, and this by the decimal .000326. The result is the current strength of the battery in Amperes. Read the galvanometer regularly every few minutes to see that the current is constant. See that the connections are good and use the large connecting wires provided. If the electrolytic bath needs renewing, use 100 parts of water (by weight), 20 parts of copper sulphate, and 5 parts of sulphuric acid. Explain the action and define all terms used. In Ohm's formula what terms are still unknown for this particular case?

LXIV.- LXV.

Materials.—A d'Arsonval galvanometer; battery; bridge, wire form; telescope and scale; resistance box; double key; unknown coils.

Experiment.—S., exercises 56, 57, 58.—Credit will also be given for either portion of the work upon resistance by fall of potential.—The equipment differs somewhat from that in Sabine, but the nature of the work is the same.—Read all three experiments before beginning the work; identify the pieces or their equivalents; notice all cautions and have regard for them; and diagram and explain as you go forward. If you have difficulty with the telescope and scale, call for a high resistance galvanometer of another type.

LXVI.

Materials.—A shunt-wound dynamo, rheostat; switch-board provided with switch, fuse-block, lamps, ammeter, voltmeter, etc.; line with branch-blocks, lamps, etc.; a speed-counter; a Siemens' electro-dynamometer; equipment as above.

Experiment.—See that the bearings are clean and well-oiled. Set lever of rheostat at "In" and start the machine. Close the switch and slowly turn the lever of the rheostat toward "Out" until the lamps show full brilliancy. Examine carefully to see that the brushes make good contact, that the connections are good, etc. See that the oil-cups work properly, and that the belt has proper tension. Read the voltmeter and ammeter and take the speed, repeating several times. Switch out a lamp and repeat after adjusting the rheostat. Notice the effect of changing the lever of the rheostat. Measure the current accurately by means of the electro-dynamometer. Find also the resistance of the rheostat coils, the field magnets, and the armature coils. In accounting for all observed effects it will be best to plot the characteristic curves. See Thompson, or Slingo and Brooker.

Wo.k of this kind in the care and good performance of a machine has little value unless continued for some time until some expertness is attained. But while this exercise will rarely be assigned, all students taking this course will find it of advantage to observe the dynamo in action; to trace the circuit when current is used directly from the machine, and also when it is used for charging storage; and to gain a general intelligence of the piece.

LXVII.

Credit will be given for a good study of our bell-service system, including battery, clock, line, bells, switches, etc. A good diagram is required.

LXVIII—LXXVIII.

The same as XL to XLIX, Part I, inclusive, with a somewhat different equipment.

LXXIX.

Materials.—A compound microscope; a mounted object.*

Experiment.—Put on the deep eye-piece and the 1½ in. objective and get the best adjustment and illumination. Change to the higher objectives in succession, illuminating in various ways, and using various apertures of the diaphragm until the best effect is produced. Point to and name the parts of the instrument and state their use. Read Beale or any microscopic manual supplied. Get the *habit* of "focusing upward."

*Exercises LXXIX to LXXXII inclusive will not be taken by students who have had or are to have a full course in Microscopy, either as a separate course or in connection with Biology or Structural Botany.—All others should be sure to get this work

LXXX.

Materials.—A microscope, slides, covers; watch crystal; knife; potato; glass tube.

Experiment.—Cut a slice from the potato, wet the cut surface, and put also a few drops of water on the watch crystal. Holding the knife-blade so that the back slopes toward you, scrape (without cutting) the the freshly cut surface of the potato, transferring the starch granules from the knife to the crystal. Wash away by gentle irrigation fibres, frustules, etc., until the clean starch only is left, and with the glass tube or a pipette transfer a drop to the slide and cover carefully with a piece of thin glass. (Read Beale concerning manipulation.) Observe the granules and draw as well as you can by eye. Call the attention of a teacher. When you have truly seen *outlines*, *markings*, etc., put on the polariscope and observe. Run tincture of iodine under the cover.

LXXXI.

Materials.—Microscope; some mounted object; stage micrometer; eye-piece micrometer.

Experiment.—1.—Put on the one-half or two-thirds objective and the negative eye-piece. Place the mounted object upon the stage and focus upon it. Exchange the stage micrometer for the object, and if the lines are not in focus use the fine-motion screw until you get a good view of the lines, the distance apart of which is given on the label. If you cannot see them well use oblique light or the small aperture of the diaphragm. Put the eye-piece micrometer in its slot and bring one of its lines to coïncide with some line of the stage micrometer. See where the next line of the eye-piece micrometer falls and count the divisions, thus measuring the divisions of the former in terms of the latter. Repeat many times using different parts of each scale. Tabulate and average.

2. Draw out the draw-tube until the divisions of the eye-piece are exactly equal to an observed number of the stage micrometer divisions,—say five or ten,—and *measure the length of the tube*. Record in your notes.

3. Using the preceding results, measure the dimensions of the given object; also of a hair, a filament of silk, or any object that interests you.

LXXXII.

Materials.—As above; a camera lucida.

Experiment.—Draw some simple object carefully by means of the camera lucida supplied, If you cannot see the object well call for another