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LABORATORY WORK
IN
PHYSIOLOGY

LOMBARD

THIS BOOK
WAS PRESENTED TO
UNIVERSITY COLLEGE,
LONDON,
BY

Professor C. Lovatt Evans.

December 1946

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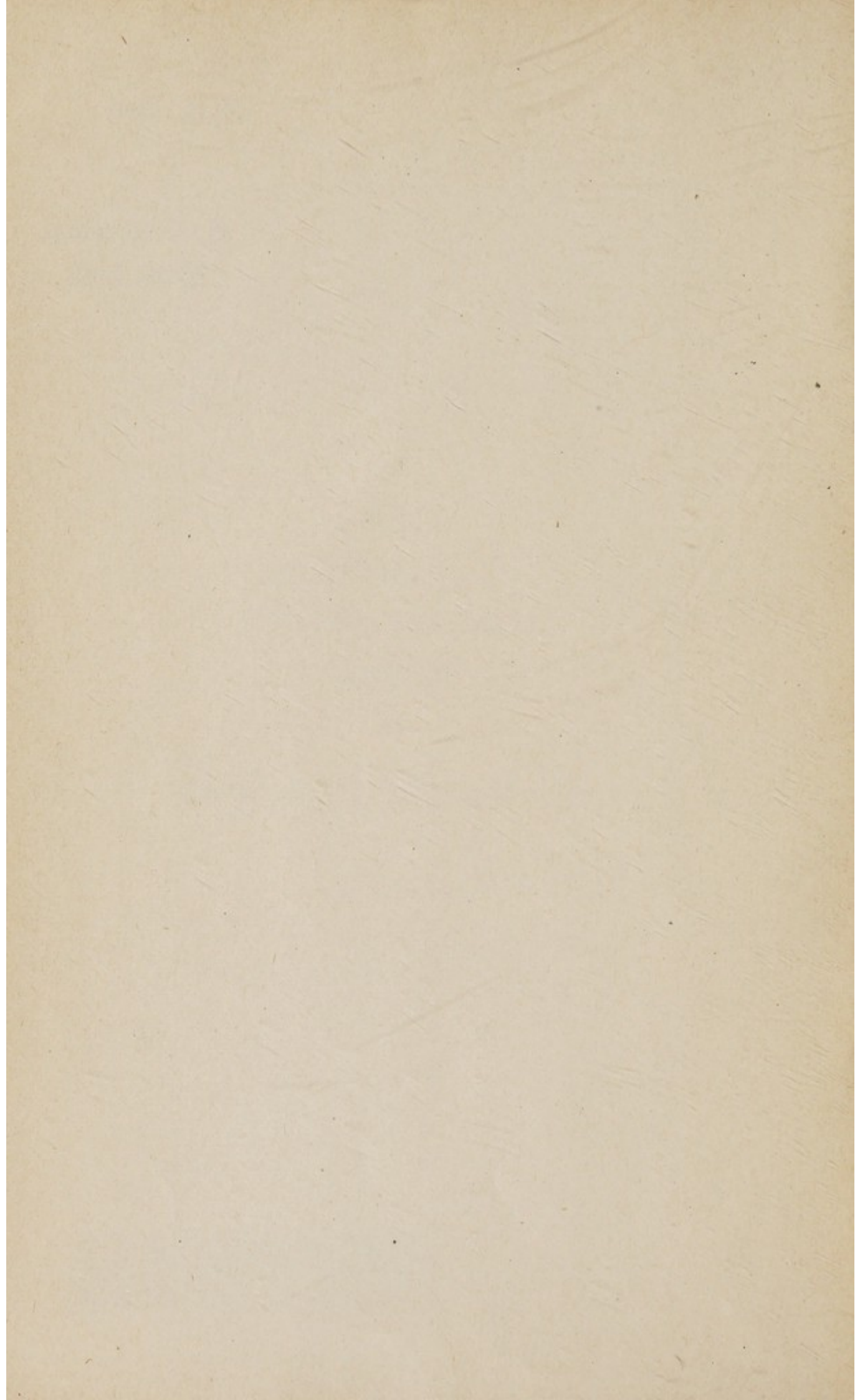



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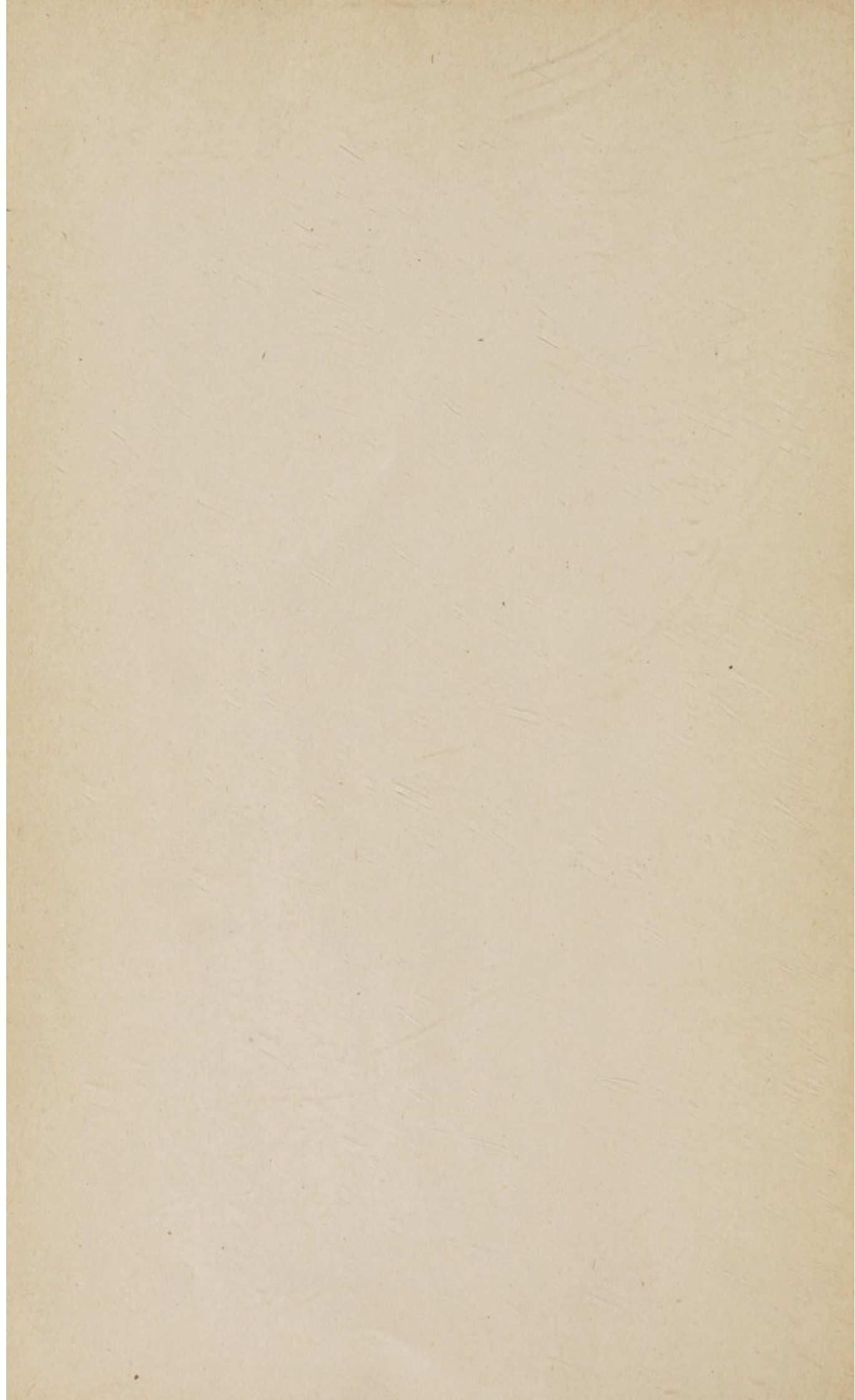
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DIRECTIONS

FOR

Laboratory Work in Physiology

FOR THE USE OF

MEDICAL STUDENTS

WARREN P. LOMBARD, A.B., M.D.

PROFESSOR OF PHYSIOLOGY, UNIVERSITY OF MICHIGAN

UNIVERSITY
COLLEGE
LONDON

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PREFACE.

The course which is here outlined, is the result of fourteen years of laboratory work with medical students. It contains only such experiments as can be actually performed by the student himself in the eight weeks allotted to the work of experimenting, and like every such course necessarily omits many experiments which would be interesting and instructive. It is supplemented by demonstrations by the instructors and by such students as show special aptitude for and have the time to devote to such work.

The experiments are arranged so as first to teach the student the use of the graphic method, time recording instruments, and the electrical apparatus employed for excitation. At the same time he becomes acquainted with the general physiology of striated, non-striated, and heart muscle and of the nerves of the frog. He then studies the reaction of his own muscles and nerves to various forms of electrical excitation. A little more than one half of the course is thus spent, and at the end of this time the student is prepared to take up the study of the subjects, so important to every medical man, central nervous processes, the circulation and respiration. Only two experiments are made on the mammal, but in these the circulation, respiration and peristalsis are studied. Five of the eleven experiments on the circulation are made on the human subject. It is believed that the medical student should as far as possible study the Physiology of man, and it is hoped that other experiments of this character will be developed in the near future and be substituted for those now made on animals. It is needless to say that the frogs are rapidly killed before being used, and that the mammals employed are thoroughly anesthetized by the student, under the direction of an instructor.

As most of the students taking the course have no knowledge of physiological methods, the directions for the work have been made as explicit as possible with the object

of saving time. Nevertheless, the harm which comes from machine-like work is fully recognized, and students are encouraged to cultivate independence, and permitted to perform the experiments in other ways than those called for in the notes. They are made to feel that the capacity to observe and correctly interpret the results of an experiment, is of even more importance than the ability to make an experiment successfully, and that one who has trained his powers of observation and has learned to accurately report the phenomena he has witnessed, can make a reliable diagnosis and keep a trustworthy case-book. As the students at this University take a special course in Physiological Chemistry, the work of this laboratory deals only with the physical problems met in the body. For similar reasons but little attention is given to the special senses.

It gives me great pleasure to acknowledge the valuable aid of my past and present Assistants, Prof. Sidney P. Budgett, Dr. Augustus E. Guenther, Dr. G. G. Crozier, Prof. Wilbur P. Bowen, Dr. Carl J. Wiggers, Mr. Fred M. Abbott, and Mr. Neal N. Wood, in developing the methods employed in this course.

WARREN PLIMPTON LOMBARD.

Physiological Laboratory,
University of Michigan,
August 1st, 1906.

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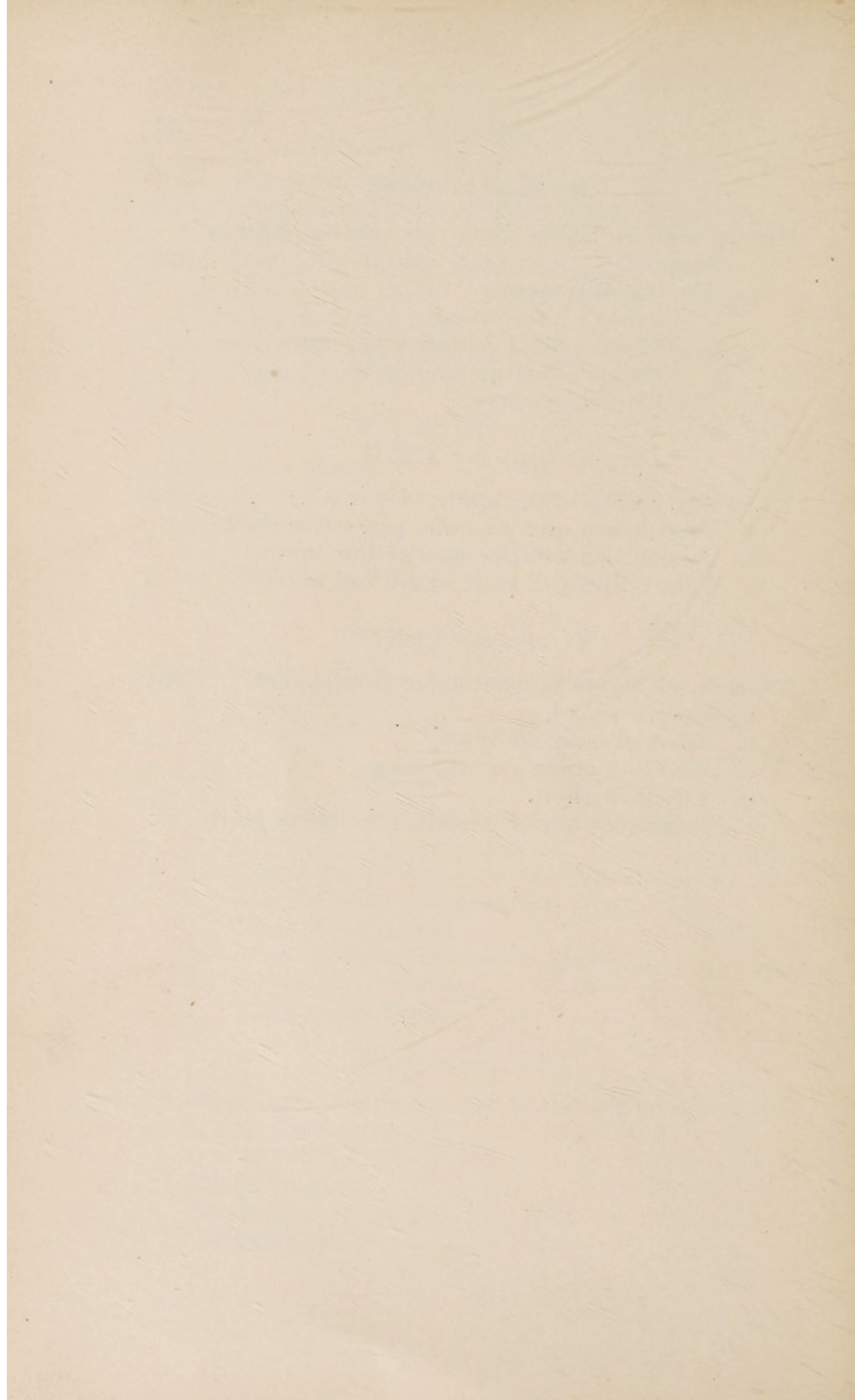
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GENERAL DIRECTIONS.

The laboratory hours are from one to five.

Each student must have receipt from the Treasurer, to show that the laboratory fee has been paid, and have the following articles, before beginning the work :

Towel.

Strong scissors with fine points.

Forceps with fine points.

Dividers.

Celuloid triangle (6 in.).

Reading glass.

Flesh pencil.

Tube of office paste.

2 sheets of millimeter, cross-section paper.

40 sheets of note paper of regulation size.

40 sheets of cardboard of regulation size.

In addition, each student must have a copy of these notes, and must make a deposit of 25 cts. for key of desk.

Each section will be divided into two divisions. Division A will make the experiments in the order in which they are given in the notes. Division B will make the experiments in the following order: I-VI inclusive; XXIV-XXXIII, inclusive, and VII-XXIII, inclusive.

Two students will work together. They will be supplied with most of the apparatus required in the course, when assigned to their desks.

Each student is expected to perform every experiment, and to give a full report of the results, accompanied by graphic records which he himself has obtained, when such are demanded by the experiment. For method of keeping the notes and mounting the records see Experiment I.

Do not begin an experiment until you have read the directions in the notes, and have clearly in mind the object of the experiment.

Be prepared for a quiz on each experiment at the time it is made, and to pass an examination both on methods and results at the end of the course.

Do not cut or mar desks or stools.

Learn to see dirt. Before leaving the laboratory see that your table is clean and neat; that all apparatus is dry; that the battery has been disconnected (it is not enough to leave the key open); that all apparatus is covered.

A list of the following apparatus will be found in the desk, and is to be checked up in the presence of the instructor and signed by both students. Larger special pieces of apparatus will be supplied from time to time when needed.

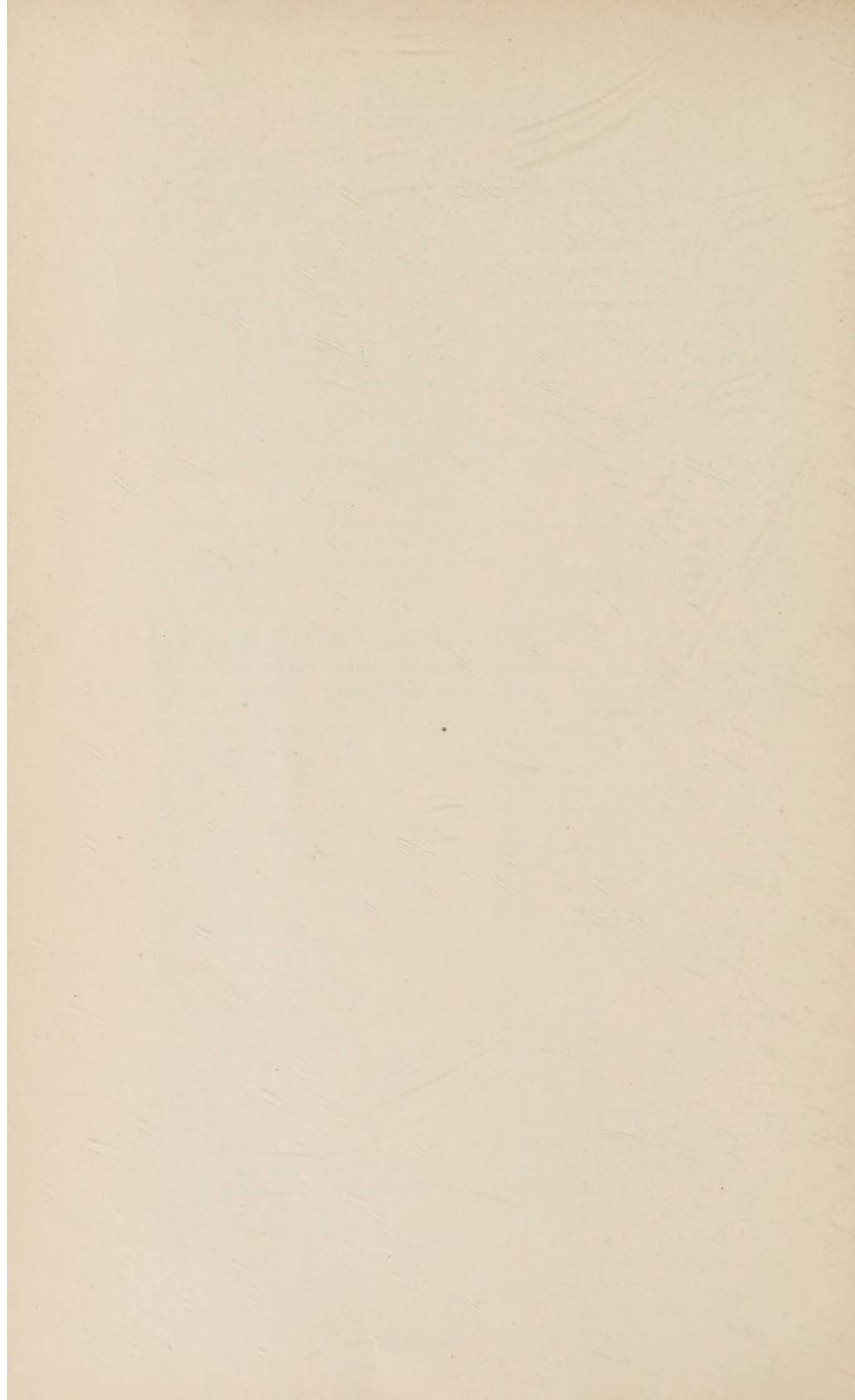
DIVISION A.

Acetic acid, 10 per cent.	Ligatures.
Battery jar.	Moist chamber, with wire.
Board for frog.	Two pads, gauze.
Brush for salt solution.	Piece of metal to clamp to drum.
Bunsen burner, with tubing.	Pins.
Two cells, dry.	Pinch cock.
Clamp, burette.	Plate.
Two clamps, cabinet maker's.	Potassic iodide and starch solution.
Clamp, large muscle.	Pulley.
Six clamps, for rods.	Ring stand.
Coil, aluminum.	Rod, glass with clips for boots.
Cloth to cover apparatus.	Rod to support heart lever.
Dropper, coarse point.	Rod, L, brass.
Electrodes, boot form in dish.	Rod, Iron.
Electrodes, copper.	Rod, L, nickled.
Electrode, indifferent (sheet of copper).	Rod, zinc.
Electrode, active (brass).	Rubber band, large.
Electrodes, pin.	Two rubber bands, thin.
Electrodes, platinum.	Two signals, electric.
Filter paper.	Spring, steel with pointer.
Finger piece, wooden.	Stand, long.
Fork and yoke.	Stand, short.
Glass Slide on support.	Sodium chloride, 0.6 per cent.
Two Glasses, drinking.	Sulphuric acid, 0.01 per cent.
Glass dish for Salt Solution.	20 Weights, 10 grms.
Hook for frog.	Silk thread.
Two hooks, pin.	2 Wires, insulated, extra long.
Induction Coil.	2 Wires, insulated, long.
Key, mercury.	4 Wires, insulated, medium.
Kymograph and drum.	2 Wires, insulated, short.
Lever, heart, with support.	Zinc Sulphate.
Lever, muscle, heavy.	Two Zincs for Electrodes.
Lever, muscle, light.	

DIVISION B.

Board for frog.	2 Pinch cocks.
Brush for salt solution.	Plate.
Cell, dry.	2 Pneumographs.
5 Clamps, for rod.	Rod, nickled.
1 Clamp, cabinet maker's.	2 Rubber tubes, with glass Ts.
Cloth to cover apparatus.	Signal, electric.
Coil, aluminum.	Sodium chloride, 0.6 per cent.
Electrodes, pin.	Spring, steel, with pointer.
Filter paper.	Stand, long.
Fork, with yoke.	Stand, short.
2 Glasses, drinking.	Tambour, carotid with spring.
Glass, for salt solution.	Tambour, radial.
2 Hooks, pin.	2 Tambours, recording.
Induction coil.	20 Weights, 10 grms.
Key, mercury.	Wire, fine copper.
Kymograph with drum, 4 fans.	2 Wires, insulated, extra long.
Lever, muscle, light.	3 Wires, insulated, long.
Lever, muscle, heavy.	2 Wires, insulated, medium.
Moist chamber with wire.	2 Wires, insulated, short.
Pins.	

Students are to use the apparatus supplied them, and no other. In no case is apparatus to be taken from the shelves or borrowed from other students.



EXPERIMENT I.

Extensibility and Elasticity of a Steel Spring.

APPARATUS.—The structure of the drum kymograph, the method of fastening the paper on the drum, of blackening the paper, and of fixing the record, will be explained by the instructor.

Examine your kymograph with care and be sure that you understand how the clockwork is wound up; how to change the gearing so as to obtain the faster and slower speeds of the drum; how to arrange drum to be driven by the clockwork or to be rotated by hand; and how to raise and lower the drum. The instrument will be in order when you receive it and must be in order when you return it.

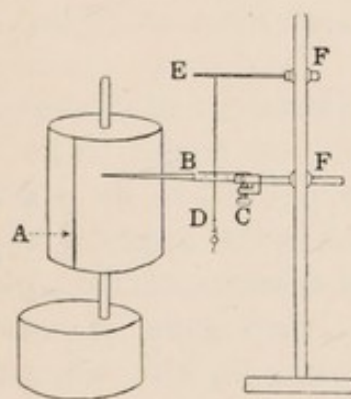


Fig. 1. Apparatus for recording extensibility and elasticity of a steel spring. A, joint of paper on drum; B, lever; C, supporting screw; D, pin hook for weight; E, steel spring; F, F, clamps.

Mount spring and heavier muscle lever on the longer iron stand, as shown in diagram. The stand holding the recording instruments should always be placed to the *right* of the kymograph, so that these instruments shall point in the direction that the drum revolves. The clockwork turns the drum clockwise, and when it is turned by hand it should be rotated always in this direction. If the drum be rotated backward, the recording points are liable to be injured. All

records should read from left to right. Decide at what part of the drum the record is to be made before finally clamping the recording apparatus on the stand. Fasten two pieces of thread to the writing lever at the hole second from the axis, and attach one of the threads to the spring

8 cm. from brass supporting rod, and the other to a pin hook as shown in diagram. Observe the following cautions:

- 1.—See that the axis of the writing lever is horizontal.
- 2.—See that the thread connecting the lever with the spring is vertical.
- 3.—See that the knots are securely fastened.
- 4.—See that every clamp is screwed firmly in place.

Now remove the drum from the kymograph, fasten a sheet of glazed "curve paper" smoothly around the drum, and blacken the surface evenly over the gas flame, rotating the drum constantly so as not to burn the paper. Replace the drum, place the kymograph so that the writing lever is tangent to drum surface, touching lightly. Notice that lever writes an arc on a curved surface. If barely touching when horizontal, it will leave the surface and fail to write as it moves up or down. The lever should press on the drum just enough to write for 2 or 3 cm. above and below the horizontal line falling through its axis. The position of the point with reference to drum and joint of paper is indicated in the diagram.

EXPERIMENT.—Turn the drum by hand in a clockwise direction to draw a base line 3 or 4 inches long. Turn it back (taking care not to injure writing points) to the starting point and mark the place by touching the lever lightly. Now turn drum clockwise $\frac{1}{2}$ cm. and then carefully place a 10 gram weight on the pin hook. Turn same distance again and add another weight. Continue in this manner until 9 weights have been added, then turn the drum $\frac{1}{2}$ cm. once more. The writing point has now recorded the curve of extensibility of the spring. To obtain curve of elasticity, turn drum $\frac{1}{2}$ cm. in same direction and remove one weight, and continue in this manner until all the weights are off, then turn $\frac{1}{2}$ cm. once more, and mark point by touching lever.

The vertical lines on the drum should be of equal length. If they are not, try to account for the error. Since steel is perfectly elastic, the writing point should return to the base line. If it does not, try to account for the difference.

MOUNTING OF CURVES.

With triangle and a needle, or other instrument with a sharp point, draw a rectangle about each record worth preservation. It is desirable to leave a generous margin about the curve. Cut out piece thus outlined, and mount on the cardboard by glueing the corners on with a little paste. If a knife be used to cut off the piece, cut upon a piece of cardboard. Do not cut on the table. To protect the curves, place over them the sheet of paper upon which the notes concerning the experiment have been written. Let the right hand end of the sheet overlap the cardboard slightly, and fasten it to the back of the cardboard with paste.

THE STUDENT'S NOTES.

Write as plainly as possible on the *upper left hand corner* of the paper which covers the curves, your name and the *number of each of the experiments* mounted on the card. Also head each mounted curve with the number of the experiment and the letter of the subheading to which it belongs, and label the corresponding notes on the cover paper in like manner.

The notes should contain an accurate statement, not of what the books say on the subject, but of the results actually obtained by you in performing the experiment. Do not describe the method of the experiment unless it is different from the directions in these notes, in which case let the explanation contain all the facts required to let another understand the exact conditions of the work. Mention all sources of error which are likely to arise from the method used. This is most important. An apparatus is a servant employed to make observations. You must know in what respects its report is to be trusted and where it is liable to deceive. It is worse than useless to employ apparatus in experiments or in physical examinations unless you know your apparatus thoroughly. If the results obtained differ from those which you know to be usually obtained in similar cases, try to explain why the difference occurs.

Look upon each experiment as a piece of original research, and do not be satisfied with simply carrying out directions. Learn to cultivate the power of independent observation and thought. You will be judged as much by the originality displayed in your reports as by the accuracy of your work. If you can learn to observe accurately and to record your observations concisely and at the same time in sufficient detail to make another understand the results of your experiments, you will be able to make a valuable physical examination and keep a reliable case book.

EXPERIMENT II.

Extensibility and Elasticity of Frog's Muscle.

APPARATUS.—Mount moist chamber on standard, and fasten threads to lever so that it will magnify the movement 6 times. Have all apparatus in readiness and the drum blackened before preparing the muscle.

MUSCLE PREPARATION.

Kill a frog under the direction of a demonstrator. Straighten hind legs by letting hand glide over body, and

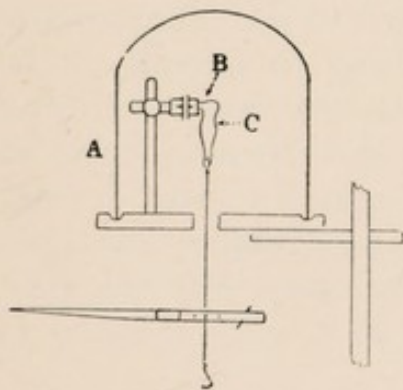


Fig. 2. Apparatus for recording extensibility and elasticity of frog's muscle. A, moist chamber; B, femur fastened in bone clamp; C, muscle.

wrap legs in dry cloth. Insert one blade of strong scissors into mouth as far back as angles of jaw, and with the other blade across the head as far back as possible, remove skull by a single cut of the scissors. In making the cut, hold frog, head down, over a plate. Cut off hind legs close to body. As there is a possibility that the brain may recover from the shock, complete its destruction by thrusting a blade of the scissors into the cranial

cavity and breaking up the brain. There is no evidence that the rest of the nervous system is capable of feeling; nevertheless, as a matter of precaution, destroy the spinal cord and all remnants of the brain with a pithing needle. Be sure that all of the central nervous system has been destroyed, for even comparatively small parts in cold-blooded animals can recover from severe shock.

Remove the skin from the leg, and see that it does not touch the muscles, as there is a secretion upon the skin which is injurious. Now put leg on piece of filter paper moistened with physiological salt solution. Clean off the

thigh muscles from femur without injuring tendon of the gastrocnemius muscle. Cut tendo-Achillis below ankle and separate gastrocnemius from tibia. Remember that you are not in the dissecting room, and that you are dealing with living tissues. Do not touch the muscle with the fingers, nor pinch it, nor injure it by pulling on it, etc. It can be handled by holding the tendon with forceps. Cut off tibia just below knee, insert and fasten femur in clamp in moist chamber, put pin hook through middle of tendo-Achillis, and in doing this avoid pulling on muscle. Place a piece of wet filter paper in the moist chamber.

a. EXPERIMENT.—Repeat the work of Experiment I, allowing an interval of *ten seconds* between the addition or removal of any two weights. The drum should be moved at the end of the 10 seconds, in order that any delayed effect of the change in load may be recorded in the proper place. After removing last weight and waiting 10 seconds, if the writing point has not returned to the base line, turn drum again and wait one minute; repeat this, turning drum at intervals of one minute, until lever ceases to rise or base line is reached. Plot the curves of extensibility and elasticity of muscle. If several curves are taken with the same muscle, keep them all and label 1, 2, 3, etc. Explain in your notes the differences observed.

b. PLOTTING OF CURVES.—The curves drawn by the writing point are inexact in two respects: the point does not move in a vertical line, and the drum may not be moved equal distances. To obtain exact curves of the extensibility and elasticity, proceed as follows. Take a piece of cross section paper and draw heavy lines for the two axes. Mark dots at equal distances along the horizontal axis (the abscissa) and number them 0-10-20, etc., to represent the weights used. Place along the vertical axis (the ordinate) at equal distances the numbers 0-5-10-20, etc., to represent the number of millimeters through which the writing point moved. As the separate movements are small, it may be wise to let each millimeter of movement be represented by 2 or 5 millimeters of the paper. Measure with the aid of a magnifying glass the exact height of each movement record-

ed. It is usually best to make the measurements all from the base line. The amount of the individual movements can be obtained by subtraction. Give these measurements in your notes, in order that they may be checked, and enter the results on the chart, by marking, for each observation, a dot at the point of intersection of the vertical line corresponding to the weight, and the horizontal line corresponding to the height of lift. Now connect the dots by straight lines. Mount the plotted curve at the side of the original. How does extensibility differ from elasticity? How do the curves obtained from muscle differ from those obtained from a steel spring? How do the different curves of elasticity obtained from the same muscle differ? Explain.

EXPERIMENT III.

Response of Muscle to Making and Breaking Induction Shocks of Various Strengths, and Use of Short Circuit Key.

APPARATUS.—Before preparing the muscle, arrange apparatus as indicated in the diagram, mounting the moist chamber and lever on the tall stand. Employ the light muscle lever in this experiment. When the weight is supported so as not to bring a strain on the muscle until it

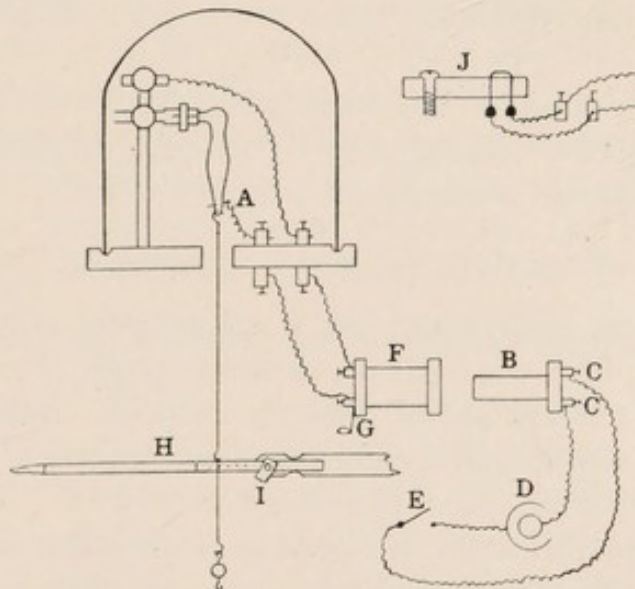


Fig. 3. Apparatus for recording contractions of frog's muscle, excited by induction shocks. A, pin electrode; B, primary coil; C, C, posts 1 and 2; D, dry cell; E, mercury key; F, secondary coil; G, short-circuiting key; H, light muscle lever; I, yoke of lever arranged to support it; J, scheme of mercury key in primary circuit.

contracts, we have what is known as an "after-loaded contraction." In this case the muscle is to be after-loaded. Connect the muscle with the sixth hole of the lever; see that the thread is vertical; rotate the yoke carrying the axis of the lever, until it supports the lever when the thread is tense, and tighten the screw that fastens the yoke to the rod. Now suspend ten grams from the lever. To obtain good results it is necessary to observe the following directions:

- 1.—Clamp mercury key to edge of table.
- 2.—Clean and brighten all wires at points of metallic contact.
- 3.—Connect wires of battery circuit (the primary circuit) to posts 1 and 2 of induction apparatus.
- 4.—Turn binding screws firmly down.
- 5.—Leave key in battery circuit open when not in use, to prevent waste of battery.
- 6.—See that surface of mercury in key is bright, and that platinum loop touches mercury in both cups when key is closed.
- 7.—Avoid closing key so forcibly as to jar mercury globules.
- 8.—See that thread is tense when lever is properly supported.
- 9.—When it is not the intention to stimulate the muscle, see that short-circuiting key is closed, to guard muscle against accidental closures of primary circuit.

Some Facts Regarding Induction Apparatus.

Recall the following facts concerning the induction apparatus. The wire of the primary coil, through which the battery current flows, has no metallic connection with the wire of the secondary coil, and consequently the battery current does not enter the secondary coil. The current which is used to excite the muscle is an induced current of very brief duration, which develops in the secondary coil at the instant that the battery current is thrown into, or is withdrawn from the primary coil. It is the disturbance of the magnetic field about the primary coil, that causes the induced currents in the secondary, and the induced currents are of very brief duration, lasting only until equilibrium has been established. The nearer the secondary approaches the primary coil, the more it comes under the influence of the magnetic field about it, and the stronger the induced currents become. Like movements of the secondary coil, result in a more and more rapid growth in the intensity of the induced currents as the primary coil is approached; a movement of a millimeter when the secondary is close to the pri-

mary increases the induced current as much as a movement of a centimeter or more when the coils are far apart. Rotation of the secondary coil on the pivot, because changing the angle at which the lines of magnetic force will cut the windings, also influences the development of the induced currents, and they become less the more the angle between the two coils approaches a right angle.

Why is the making, weaker than the breaking induction shock? When the battery current is made, an electro-motive force is set up in the primary coil, and this force induces a counter electro-motive force in that coil of opposite direction to that of the battery current. As a result, the disturbance in the magnetic field about the primary coil is slow to develop and comparatively slight, and the making induced current in the secondary coil gains its full intensity slowly and is feeble. When the battery current is broken, the electro-motive force induced in the primary coil has the same direction as that of the battery current, and consequently the breaking induced current in the secondary coil gains its full intensity very rapidly and is very strong.

a. Response to Making and Breaking Shocks of Increasing Strength.

EXPERIMENT.—Place muscle preparation in the moist chamber, insert pin electrode into the tendo-Achillis (not the muscle substance). Connect the short wire fastened to a bit of nickled rod, with binding post on support which carries the muscle clamp. The exciting current will pass through muscle from end to end. Place kymograph so that lever bears lightly on drum near the joint of the paper. Move secondary coil as far from primary as the construction of instrument permits, then turn it on the pivot until it is at right angles to the primary coil. Now open short circuit key and make and break the primary circuit by means of the mercury key: no contraction. The stimulus is sub-minimal. Gradually turn the coil to strengthen the induced current, making and breaking the circuit at each new position of coil. A position will be found, either while turning the coil or afterwards by sliding

it towards the primary, at which a small contraction will result. Notice that the contraction occurs on breaking the circuit and that no corresponding making contraction is seen. Now give muscle a rest of $\frac{1}{2}$ a minute and then try to put the secondary coil in such a position that the contraction will be so small as to be scarcely visible. Such a contraction is said to be minimal. These later trials should be made at intervals of not less than 10 seconds. Now move the drum a few centimeters, and record first a minimal contraction, and then, 1 cm. apart, a series of breaking contractions obtained by stimulating with gradually increasing stimuli. In stimulating, make the circuit, wait 5 seconds, then break, and wait 10 seconds. Soon a contraction will appear when the circuit is made, but smaller than the breaking contraction that goes with it. If the secondary coil has not been moved too rapidly this first making contraction will be nearly minimal. After a minimal making contraction has been obtained, continue stimulating and recording as before, excepting that now drum is to be turned $\frac{1}{2}$ cm. after each contraction. After a time the breaking and making contractions will be maximal, i. e., will cease to grow with increasing strength of current, and if the work is continued, a second growth in height of contractions may be seen, and supra-maximal contractions be recorded. Mark on the record to indicate which contraction is a minimal break, a minimal make, a maximal break and a maximal make.

b. Use of Short Circuit Key.

Move drum away, then slide secondary coil to a position which excites making contractions about half as high as the corresponding breaks. Return drum and record four making and four breaking contractions, stimulating with same time intervals as in part *a*, but with the strength of current unchanged. Close the short circuit key and stimulate: no contraction. Two paths are now open to the current, and the current is divided between them in inverse proportion to the resistances. The muscle, having much greater resistance than the metal of the short circuit

key, gets so little current that the stimulus is sub-minimal. This method of dividing the current is technically known as "shunting."

Leaving coil in same position, record a series of four making contractions, cutting out breaks with short circuit key, then record a series of four breaks, cutting out the makes in the same manner. Indicate which are makes and which are breaks in the last group of records.

EXPERIMENT IV.

Relation of Amount of Load to Height of Lift and Quantity of Work Done.

APPARATUS.—The same apparatus is to be employed as in Experiment 3, except that the heavy muscle lever is to be used. Because of the heavy load to be carried, care must be taken to fasten securely all clamps, threads, and hooks. The muscle is to be after-loaded, and the supporting screw must be carefully adjusted so that the whole height of each contraction shall be recorded. Have 20 ten-gram weights ready for use.

a. EXPERIMENT.—Place muscle in moist chamber, and make electrical connections as in Experiment 3. Find strength of current required to produce maximal breaking

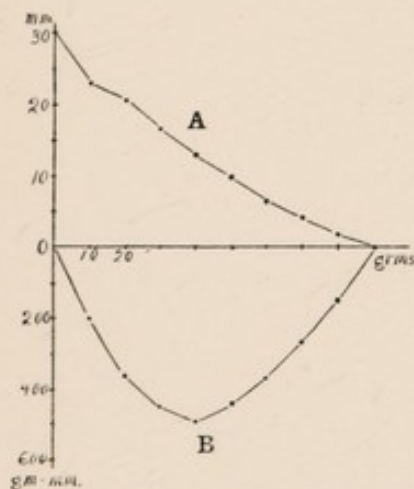


Fig. 4. Curve of lift and of work. A, curve of lift; B, curve of work.

contractions of unloaded muscle. In doing this avoid fatiguing muscle by too frequent excitations. For stimuli use maximal breaks at intervals of 15 seconds, and cut out the makes with short-circuiting key. Record on the drum at distances of $\frac{1}{2}$ cm., the contractions obtained with 0, 10, 20, 30, etc. grams, and continue the addition of weights until the muscle can no longer lift the load. If more than one

experiment is made with the same muscle, state the fact, since fatigue will modify the results.

b. PLOTTING OF CURVES.—State in tabular form on the cardboard, by the side of the original curve, the recorded height of lift, and the actual work done by each of the contractions, (the work being the product of the height times the weight lifted).

To plot the curves of lift and work, take a piece of cross-section paper, about 10 cm. square, and lay off axes as shown in diagram. Plot above the abscissa line a curve showing the heights of the contractions,—the ordinates representing the distances through which the weight was moved and the abscissas the weights. Plot below the abscissa line the curve of work, the ordinates representing the work and the abscissas the weights. In plotting the curves, 1 mm. of cross section paper can be used to represent any desired value of the curve to be plotted. The curve can magnify or reduce the values actually obtained. For example, 1, 2, or 3 mm. on the cross-section paper can stand for 1 mm. of lift, and 5, 10 or 20 mm. on the paper can represent 100 grammillimeters. Be sure to state on the plotted curve the values of ordinates and abscissas.

With what weight was the greatest amount of work done? What was the *actual* amount of work done with this weight? Have the results any practical bearing?

EXPERIMENT V.

Time Relations of Myogram.

The record of a single muscle contraction is called a myogram. Hitherto we have been concerned only with the height of the myogram, which can be best observed when recorded on a stationary drum. In order to study the time relations of the myogram, the record will have to be taken on a moving drum, and the rate of movement of the drum be determined with a tuning fork.

a. Influence of Rate of Drum on Form of Myogram.

There are today a great variety of methods for obtaining graphic records of physiological processes and the changes which they undergo under normal and pathological conditions. In many cases these records are taken on moving surfaces, and it is important that one should be able to estimate the influence of the rate of motion of the surface on the shape of the curve.

APPARATUS.—The apparatus for supporting the muscle and recording its contraction, and the electrical connections with the induction coil are to be the same in this, as in Experiment 3, the lighter muscle lever being used. In this experiment, however, the key in the primary circuit, instead of being opened by hand, is to be opened automatically by the drum when it is revolved. That this may be done, fasten a frog board by its iron rod to clamp on short stand. Place key in primary circuit on the board, so that it projects for two-thirds of its length beyond it, and clamp key to board by a cabinetmaker's clamp. Adjust board so that top of key is just above the level of the top of the drum. Clamp to the top of the drum, so that it projects a couple of cm. beyond it, the piece of metal supplied for this purpose. See that the piece of metal does not change its place, as it must hold a constant position with respect to the surface of the drum. Now move the key just near enough to enable the projecting piece of metal to open it.

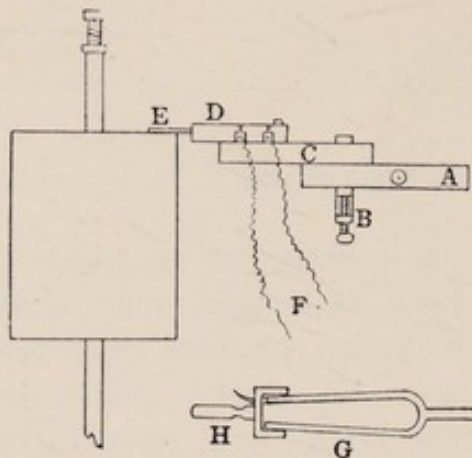


Fig. 5. Apparatus for automatically exciting muscle by letting the drum open the key. A, frog board; B, cabinet maker's clamp; C, mercury key; D, handle of key; E, piece of metal; F, wires to primary circuit; G, tuning fork; H, yoke.

EXPERIMENT. — Blacken a drum; bring key into position to be opened when drum is turned; leave key open when the current is not wanted.

Prepare a gastrocnemius muscle; suspend it in moist chamber and connect it with lever; thrust pin of pin electrode through tendon; adjust support so that muscle shall be after-loaded *when thread is tense and the lever is horizontal*. Let short-circuiting key be closed when it is not desired to excite muscle;

place secondary coil so that muscle shall give a maximal breaking contraction; short circuit all making shocks; rotate drum so that the part which opens key will point away from it. Now place stand so that the lever will write well upon the drum. Close key in primary circuit and then open short-circuiting key. Now open key in primary circuit by rotating drum by hand very slowly. A breaking contraction will be recorded. *Do not move the kymograph, or the stands holding key and lever*. Repeat the experiment four times, each time rotating the drum somewhat faster. Fix the record. State in notes in what respects the myograms obtained differ. Save the muscle to test the apparatus in part b.

b. Time Relations of Myogram.

APPARATUS.—Use the same apparatus as in a, with the following additions: Mount on long stand beneath the muscle lever a tuning fork, to mark rate of movement of drum. Put on the wire spring, used in Experiment I, a celluloid pointer, and clamp the spring beneath the fork, to give a base line to be used in measuring the curves. See that the three writing points are in the same vertical line.

EXPERIMENT.—The latent period, the duration of the period of rise and of the period of fall, are all longer for

a fatigued than for a fresh muscle; it is therefore best to test apparatus with muscle used in part *a*. When you have learned to perform the experiment promptly prepare a fresh muscle. Ascertain the current just strong enough to give a maximal breaking contraction, and in doing this avoid exciting the muscle more often than once in ten seconds, and call out as few contractions as possible. If you have to repeat the experiment frequently, state the number of the contraction the curve of which is measured. After the drum has been blackened, and the mercury key has been placed so that it will be opened when the drum revolves, see that the lever is horizontal when resting on its support with thread tense. Then move long stand so that fork and muscle lever will write on drum. If now the drum is revolved, the mercury key will be opened when the muscle lever is at a certain point on the drum surface. To find what this point is, with short circuit key closed, close mercury key; then open short circuit key, and open mercury key by revolving the drum *very slowly*. The recorded myogram should be almost a single line. The contraction of the muscle will mark the point of drum which was opposite the end of the lever when the muscle was stimulated. Now, without changing position of key, drum, or lever, close short circuit key, revolve drum two-thirds the way round, put yoke on fork, close mercury key; then pull yoke off of fork and immediately open mercury key by revolving drum rapidly. Stop drum at the close of one revolution. If the muscle had contracted immediately the second curve would have begun to rise at the same point as the first. It does not, because the muscle has a latent period. The distance between the beginning of the two curves shows the length of this period, because the tuning fork curve enables us to know how long the drum took to traverse this distance.

c. Measurement of Records and Computation of Time Intervals.

To determine the latent period, it is first necessary to fix the exact points at which the two contractions began. Draw through the point of origin of the first

recorded contraction the line MN , perpendicular to the base line. To fix the point at which the second contraction began, draw on the curve two fine parallel lines, one just above and one just below the line traced by the lever, as at AB , to aid the eye in fixing the point. Draw through it the line OP and estimate MO , the latent period, in thousandths of a second. One double vibration of the fork is ten thousandths of a second. A good way of ascertaining the length of the latent period, is to estimate the value of one millimeter of drum surface in thousandths of a second, by dividing the time of one double vibration of the fork

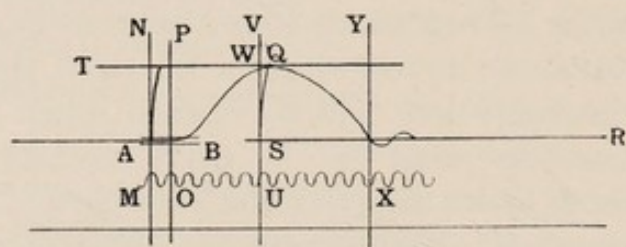


Fig. 6. Method of preparing myogram for determination of latent period.

by the number of millimeters in the wave which is recorded most nearly between MO , and multiplying this value by the number of millimeters in the recorded latent period.

To determine the period of contraction, draw TQ perpendicular to MN and tangent to the muscle curve at Q . With a radius equal to the length of the writing lever and a center on the base line traced by the muscle lever, as at R , revolve Q to this base line at S , draw the perpendicular UV through S , and estimate the number of thousandths of a second between OU . To do this count the complete waves, and estimate in tenths the fractions of waves. The line UV must not be drawn through Q , because the distance WQ is due to the fact that the muscle lever draws an arc instead of a straight line. To determine the period of relaxation, draw XY through the point where the muscle curve strikes the base line at X .

State in notes length of latent period, contraction period, and relaxation period, in tabular form. Also mention the most likely sources of error.

EXPERIMENT VI.

Genesis of Tetanus.

APPARATUS.—The apparatus is to be arranged as in Experiment 3, except that the mercury key is to be omitted, and the current of the battery circuit is to be made and broken as follows.

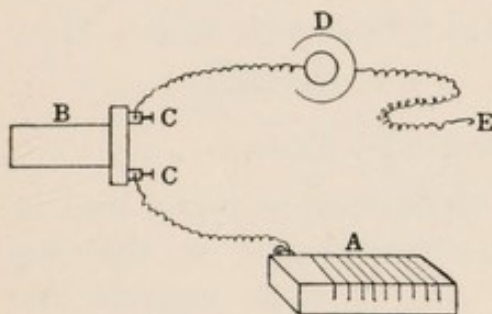


Fig. 7. Apparatus for studying summation of contractions. A, block of wood wound with aluminum wire; B, primary coil; C, C, posts 1 and 2; D, dry cell; E, bare end of insulated wire turned back on itself.

Fasten the block of wood on which the aluminum wire is wound, to the edge of the table by a cabinet maker's clamp. Connect the binding post on block with post 1 of coil; connect post 2 of coil with one pole of dry cell; and fasten an insulated wire to the other pole. Now bend the free end of this wire back on itself, so that the end shall

be smooth and rounded. See that the wire is bright. If this wire be touched to any part of the aluminum coil the primary circuit will be made, and if the wire is drawn across the coils, a series of making and breaking shocks will be given.

a. *Summation of Two Contractions.*

If two stimuli reach a muscle at a sufficiently short interval the second contraction process may begin before the first one is completed. What will be the result? In this, as in the preceding experiments, each student is to do the work independently.

EXPERIMENT.—Blacken drum and arrange for quick speed; make a muscle preparation and mount it in moist chamber, as in Experiment 3; place drum so that lever will record well. Open short circuit key; with the drum

still, excite the muscle by drawing free end of wire connected with battery across the last turn of aluminum wire on block (Fig. 7, *A*); choose a strength of induced current which will give a good breaking and no making contraction. Let muscle rest. Now start drum, and draw wire across windings *a* and *b*, at such a rate as to cause two separate contractions; repeat several times, and more quickly each time, until the two contractions look like one. Do not stop the drum between the tests; either perform them in rapid succession, or let the drum revolve several times, making a test with each revolution and at such a time that the records of the succeeding tests will follow each other. How do the records differ?

b. Incomplete Tetanus and Complete Tetanus.

APPARATUS.—Use the same apparatus as in *a*, and in addition mount a time signal (chronograph) so that the writing point will write below and in same vertical line with the muscle lever. Connect the signal with the binding posts on the side of the desk. In the time circuit, there is a battery, and a clock which interrupts the circuit once a second. The signal should record seconds on the drum. The drum should run 4 cm. per second.

EXPERIMENT.—Make experiment as in *a*, only this time draw wire across all the windings of the aluminum coil. In doing this see that the hand is moved at an even rate across the coil. The experiment is a test not only of the behavior of the frog's muscle under varying rates of stimuli, but your capacity to move the hand constantly at different speeds, i. e., muscle coördination. State in notes approximately the number of excitations per second required to tetanize. A complete tetanus is an apparently continuous contraction produced by a series of excitations. All our movements are tetani.

c. Complete Tetanus Obtained with Automatic Interrupter.

APPARATUS.—The apparatus is the same as in Experiment 3, excepting that the battery and key are connected with different posts of the primary coil.

Electrical Connections in Primary Circuit of Induction Apparatus.

Two kinds of coils are used by the students. Model A in which the secondary coil slides on metal rods, and Model B in which the secondary coil slides on the wooden base. The way in which the binding posts belonging to the primary circuit are connected with the primary coil and the automatic interrupter is different in these two forms of apparatus.

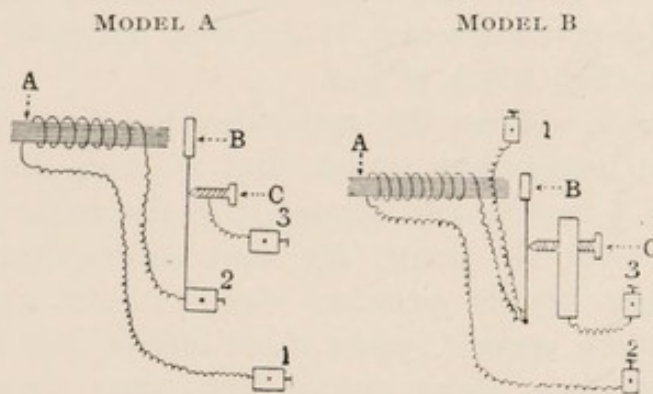


Fig. 8. Scheme of electrical connections of primary coil in two forms of induction apparatus. A, soft iron wires in primary coil; B, hammer; C, contact screw; 1, 2, 3, binding posts.

Model A—To obtain single making and breaking shocks use posts 1 and 2. To obtain tetanizing current use posts 1 and 3.

Model B—To obtain single making and breaking shocks use posts 1 and 2. To obtain tetanizing current use posts 2 and 3. In each apparatus if single shocks are needed, the battery and key are connected with the posts to which the two ends of the wire of the primary coil are directly attached. If a long series of rapidly following shocks are needed, as for tetanus, the battery and key have to be so connected as to bring the automatic interrupter into the circuit. This is done in Model A by connecting the battery with posts 1 and 3. The current can then enter by post 3, pass to the contact screw, down the spring, then through the wire of the primary coil, and away by post 1. In Model B, posts 2 and 3 are used. The current enters by post 3, passes to contact screw, down the spring, through the coil, and away by post 2.

In each case, as the current flows through the coil it magnetizes iron wires inside it, and the hammer is attracted. The movement of the hammer breaks the contact between the spring and the contact screw, and the current ceases to flow; the soft iron wires lose their magnetism, the hammer is released, and the spring again makes contact with the contact-screw. Thus the primary current is being continually made and broken, and a series of rapidly following induction shocks develop in the secondary coil.

NOTICE.—In order that the automatic interrupter may work well, the contact-screw is screwed up until it barely touches the spring when at rest.

EXPERIMENT.—After the apparatus has been arranged, the automatic interrupter tested, and a fresh drum blackened, prepare a muscle and mount it in the moist chamber. Now adjust lever to drum; see that short-circuiting key is closed; close key in primary circuit; start kymograph clockwork (quick speed); open short circuit key for a few seconds; then close short circuit key; stop drum a few seconds later and open key in primary circuit. If the curve does not return to the base line promptly when the excitation ceases, it is because the after contraction, known as "Contracture," is present.

d. Fatigue Caused by Tetanus.

EXPERIMENT.—This experiment is to be made in the same manner as *c*, excepting that the drum should revolve slowly and the tetanic excitation be permitted to act on the muscle until it is completely fatigued.

EXPERIMENT VII.

Independent Irritability of Muscle.

Arrange the induction apparatus for tetanizing current, and connect a pair of copper electrodes to the secondary circuit.

a. EXPERIMENT.—Kill a frog by pithing the brain. (Method will be demonstrated.) Have a pointed match at hand, and as soon as pithing needle is withdrawn plug the skull cavity through the foramen magnum, to prevent loss

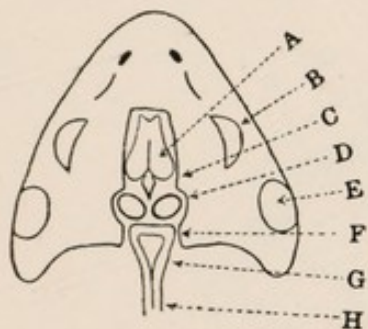


Fig. 9. Relation of brain to skull of frog. A, cerebral hemispheres; B, eyes; C, thalamencephalon; D, optic lobes; E, tympanic membrane; F, cerebellum; G, medulla oblongata; H, spinal cord.

of blood and to insure destruction of brain. Slit the skin on the back of left thigh longitudinally, separate the semimembranosus from the ileofibularis muscle, and expose the sciatic nerve, (see Fig. 10, Dorsal View). Carefully separate a portion of the nerve from the surrounding tissues without injury to the nerve or the blood vessels. Pass a ligature under the nerve, carrying the ends

around to the front of the thigh, and tie tightly, thus including all the structures of the limb except the nerve. Cover exposed nerve with filter paper moistened with salt solution.

Inject into the dorsal lymph sac about 1 cc. of a stock solution of curara. Use for this purpose a pipette with fine point and rubber bulb. To insert pipette, raise loose skin of back over forward part of dorsal lymph sack with forceps, and make *small* opening in skin with scissors. Lay the frog on a plate and cover it with moist filter paper. Observe that pinching the toes of either hind leg slightly, causes a contraction of the muscles of the leg thus irritated. As the drug takes effect, the ability of the right leg to re-

spond to such irritation gradually becomes less, and after 20 or 30 minutes it ceases altogether, although the left leg will respond as before.

When all the body but the left leg has become completely paralyzed, open the abdominal cavity and remove the viscera, care being taken not to injure the nerves behind them, (see Fig. 10, Ventral View). Cut the body in two, leaving the last two vertebrae connected with the legs. Split

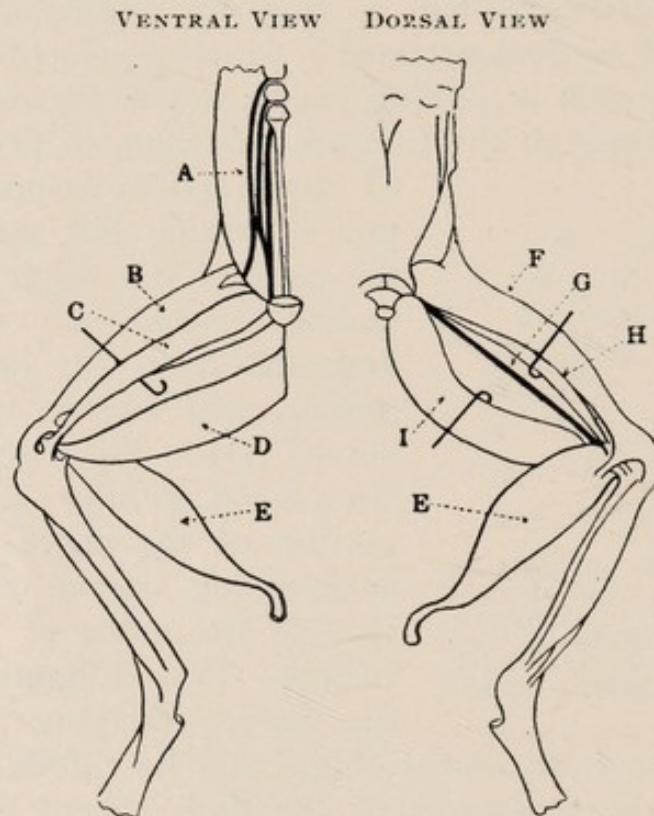


Fig. 10. Dissection of right leg of frog. A, sciatic plexus; B, cruralis; C, sartorius; D, gracilis magnus; E, gastrocnemius; F, glutaeus magnus; G, sciatic nerve; H, ilio-fibularis; I, semimembranosus.

these vertebrae lengthwise, and holding the fragments with forceps, dissect out the sciatic plexuses supplying the hind legs. Do not take hold of nerves with forceps, and avoid stretching them. Fasten pair of electrodes to the posts of secondary coil. Stimulate these plexuses in turn with the tetanizing current. What is the result? Now apply the stimulus directly to the muscles of the legs. What is the result?

Keep the preparation, to use in Experiment 8, which should immediately follow this one.

Answer the following questions in your notes, and state proofs:

Can curara paralyze before it produces anaesthesia?

Does curara poison nerve fibres?

Does it poison muscles?

What does it poison?

How did the drug reach the leg?

When an electric current is sent through a non-curarized muscle, as in the preceding experiments, what two kinds of stimuli may act on the muscle?

EXPERIMENT VIII.

Isolated Conduction in Muscle.

Although the separate fibers of a striated muscle are in close contact, they are like the nerve fibers in a nerve trunk, independent mechanisms. If a fiber is excited, the condition of activity which is aroused runs the length of the fiber but does not spread to neighboring fibers. This fact can be demonstrated most readily on a curarized muscle, and by employing unipolar excitations.

APPARATUS FOR UNIPOLAR EXCITATION.—Arrange induction coil to give tetanic excitations. Connect one pole of the secondary coil by an insulated wire with the binding post on the sheet of copper. The other pole of the secondary coil may be left free, or, if a strong current is needed, be connected with a gas pipe and so with the earth.

EXPERIMENT.—Remove the sartorius muscle (see Ventral View, Fig. 10), from the curarized leg of the frog used in the Experiment VII. Lay the muscle on the copper plate. Start the automatic interrupter and touch one edge of the muscle for a moment with the point of a needle or other metallic instrument with sharp point. The muscle will be seen to contract along the edge that is touched and to curl towards that side. If the other edge be touched, the muscle will draw together on the other side. With a reading glass one can see that the only fibers to contract are those near the point touched. The current enters the muscle wherever it is in contact with the copper plate (the indifferent pole), but being diffuse fails to excite; it leaves the muscle, to charge up the body of the experimenter, at the point that is touched by the needle (the active pole) and the dense stream causes excit-

ation at that point. The strict limitation of the contraction process to the fibers excited, shows that the excitation does not spread from fiber to fiber.

Why is it necessary to supply a curarized muscle in this experiment?

EXPERIMENT IX.

Contractions of Non-Striated Muscle.

APPARATUS.—Set up apparatus like that used in *b* of Experiment V, with the exception of the fork, which is replaced by a signal connected with the clock circuit, so as to give the time in seconds. No weight should be used on the lever.

EXPERIMENTS.—Kill a frog, remove the stomach, cut off from stomach a ring from 3 to 5 mm. wide, and hang this ring of non-striated muscle on a pin hook which has been fastened vertically in the clamp intended for femur. Connect the lower border of the ring with the pin hook attached to writing lever, and the pin of pin electrode. Keep moist chamber closed and moisten muscle frequently, as it is so small that it is especially liable to be injured by drying.

a. Time Relations of Myogram.—Proceed at once to determine the time relations of non-striated muscle. The method given in *b* of Experiment V is to be used, with the exception that the drum is to be revolved by the clockwork, and to have a rate of 2 mm. per second. See that writing points are in the same vertical line, and put part of curve showing this in your notes. Find the latent period, and the time of the rise of the curve.

b. Rate Required to Tetanize.—Set the drum turning slowly and find by experiment slowest rate of stimulation which will tetanize non-striated muscle (see Experiment VI, *b*). In order to tetanize, a second contraction should be called out a short time before the preceding contraction has reached its full height. If one knows the latent period and the contraction period, one can make a fair estimate of the required rate of excitation. It may be of advantage to introduce a signal magnet in the primary circuit to mark the time of excitation.

c. Spontaneous Contractions.—Set the drum to run at the rate of 1 mm. per second or slower, and record a

series of spontaneous contractions. Let the time be recorded in seconds. Spontaneous contractions may occur from the first, and interfere with the determination of time relations. If such is the case, the only way to secure the results is to give the stimuli at such a time that one can be sure whether the following contraction is a response to the stimulus or a spontaneous contraction.

How does the latent period and the contraction period of this non-striated muscle compare with that of the gastrocnemius? What rates were needed to tetanize these muscles? What was the rate of the spontaneous contractions?

EXPERIMENT X.

Frog's Heart—Its Structure, and the Relative Time of Action of the Different Parts.

APPARATUS.—Set up as shown in Figure 11. Clamp horizontally on short stand, the nickled rod with hole for wire and binding screw in end (*A*), letting the free end of the rod project about 7 cm. beyond the stand. Place a clamp on the end of the rod, and fasten vertically in this clamp the rod (*B*) carrying the lighter muscle lever. Thus arranged the lever can be either raised or lowered, or can be rotated so as to bring the point against the drum. Loosen the screw fastening the yoke (*C*) of the lever to the rod, and turn the yoke until it supports the lever with the tip 2 cm. below the horizontal plane passing through its axis; then turn the screw home. Now bring the drum up to the lever, and see that when it is horizontal it has such a height that it can be made to write on any part of the drum by raising or lowering the drum. Clamp the frog board (*G*) to the stand below the lever. Introduce into the fourth hole of the lever the short piece of copper wire (*E*) with cork button at the end, and fasten the piece of flexible insulated wire (*F*) to the binding post on the frog board. Observe that the two wires which project through the button may, when brought in contact with the heart, be used as electrodes. Put time signal on long stand, at such a height that it will write just below the lever when it is horizontal. In this experiment the signal will be used only to give a base line. Blacken the drum.

OPERATION.—Choose an active frog; pith brain as described in Experiment VII; cut off the projecting end of match; and put frog, back down, on the plate. Operate at once, before the effects of the shock have passed off. Make median skin incision from one half centimeter above pubis to

one half centimeter below jaw. Raise ensiform cartilage with forceps, and with sharp scissors cut in median line through sternum, pectoral girdle, and muscles of throat, always keeping point of scissors well away from the pericardium and aortae. Prolong incision through abdominal wall, avoiding the large vein. Slight haemorrhage can be checked with dry absorbent cotton. Now slide the heart lever up out of the way, and place the frog on the frog board so

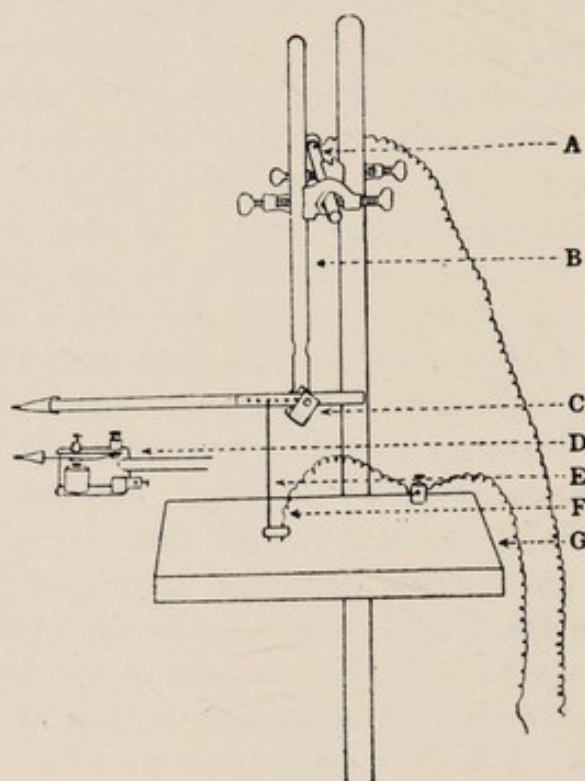


Fig. 11. Apparatus for recording the beat of a frog's heart. A, horizontal rod carrying binding screw for wire; B, vertical rod carrying lever; C, yoke supporting axis of lever; D, time signal; E, copper wire, connecting lever with cork button to rest on the heart; F, piece of flexible insulated wire, connecting short piece of copper wire, passing through cork button with binding post on frog board; G, frog board.

that its ventricle lies directly beneath the cork button on the prop of the lever. With the frog in this position, draw the fore legs widely apart so as to expose the heart beating within the pericardium, and pin these legs firmly to the frog board. Now pick up the pericardium over the bulbus arteriosus, and slit the pericardium throughout its length with sharp pointed scissors.

a. Gross Anatomy of the Heart.

Moisten the heart from time to time with normal salt solution; it must not be allowed to dry. Observe the position of the bulbus arteriosus (*H*) and the two aortic arches (*A*); the relation of the two auricles (*B*, *C*) to each other and to the ventricle (*E*), (the line of separation of the auricles lies behind the bulbus arteriosus); and the well marked auriculo-ventricular groove. Lift the ventricle with a camel's hair brush moistened with saline solution, and notice the place where the vena cava inferior opens into the sinus venosus (*F*); the white crescentic line where the

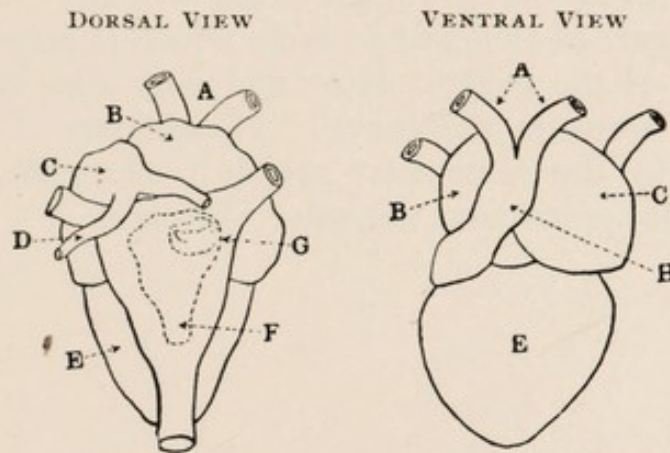


Fig. 12. The gross anatomy of frog's heart. (Ventral view after Cyon, dorsal view after Howes.) A, aortae; B, right auricle; C, left auricle; D, pulmonary vein; E, ventricle; F, sinus venosus; G, sinu-auricular valves; H, bulbus arteriosus.

sinus joins the auricle; also the frenum, a slender ligament which attaches the dorsal wall of the ventricle to the pericardium.

b. Origin and Course of the Wave of Contraction.

1.—INSPECTION.—Try to observe the place where the wave of contraction begins, and the order in which it spreads over the different chambers of the heart. See that when a part contracts and drives the blood out, it grows paler, while the part receiving the blood swells and flushes. Answer in your notes the following questions: What is the action of the auricles during the ventricular diastole, and during the ventricular systole? What changes are observed in the ventricle during auricular diastole, and during auricular systole?

2.—THE MYOCARDIOGRAM.—Adjust the cork on the prop of the lever, to the ventricle, with the prop vertical and the lever horizontal. Be careful that both of the wire points on the under surface of the cork are in contact with the ventricle, and that the cork does not touch the auricle so as to be moved directly by it. Once rightly adjusted, it should not be necessary to alter the position of the lever during the afternoon. The prop should be connected with the hole in the lever which will give a writing of one and a half to two centimeters in height. Record the beats with slow, medium and rapid speeds of the drum, studying the heart itself while the curves are being written. Mark on the record the part of the cardiac cycle which is responsible for each wave of the curve. How and why does the beat of the auricle show in the curve? Which part of the curve was made by the ventricular systole? Does the lever fall or rise in the ventricular diastole? Explain.

EXPERIMENT XI.

Refractory Period and Compensatory Pause.

APPARATUS.—The same frog and the same apparatus for recording the contractions of the heart may be used as in the preceding experiment. In addition arrange an induction coil to give single shocks, placing a time signal in the primary circuit, and arranging it to write just below and in the same vertical line with the heart lever. One cell in the primary circuit, with the secondary coil pushed half way up, usually gives sufficient strength of current. One of the wires from the secondary coil is to be fastened to the binding post on the frog board, and be brought in communication with the ventricle by means of the fine insulated wire passing to one of the pins in the piece of cork resting on the ventricle (see Fig. 11); the other wire is to be fastened to the horizontal rod supporting the heart lever, through which it communicates with the heart.

EXPERIMENT.—When all is ready, mark the relative position of the writing points on the drum. Don't forget that unless this is done, and the length of the lever is given in the notes, the experiment will not be accepted. Also, either before or after the experiment, place the lever horizontal, and let it record a base line to be used in measuring the curve. Let the drum run at the rate of 20 mm. per second. While the heart records its contractions, stimulate the ventricle with single breaking shocks every fifth or sixth beat, the makes being short circuited, to test the effect of exciting it at the following times,—during the systole of the ventricle, and early and late in the diastole of the ventricle.

State in notes in which case the stimulus produces no effect (the "Refractory period"); when it produces a contraction of increased height; when an extra contraction of less height than usual; and when one of usual height. Notice that an extra contraction is followed by a pause. Is

the pause long enough to compensate for the extra contraction, so that the rhythm of the beat is not changed afterward? Such a pause is called a "Compensatory pause," and is explained on the theory that the irritability of the ventricle is lessened by its extra contraction, so that it cannot respond to the stimulus which comes to it from the auricle at the usual time for the next beat. Can you detect a beat of the auricle at the time it usually comes, during the compensatory pause?

The curve of contraction is distorted by the fact that the lever records an arc. To determine the part of a contraction at which a stimulus was applied, it is necessary to draw a vertical line through the point of excitation as given by the time signal, to a base line which corresponds to the position of the heart lever when horizontal, and then having allowed for the relative position of the writing points, to draw through the heart curve an arc, the axis of which is on this base line and the radius of which is equal to the length of the lever.

EXPERIMENT XII.

Response of the Resting Heart to Stimulation by Induction Shocks.

APPARATUS.—Use apparatus the same as in Experiment XI, and in addition, mount a tuning fork on large stand above the electric signal. Be sure that the writing points are in the same vertical line. Prepare a frog, and expose heart, losing as little blood as possible.

EXPERIMENT.—Bring heart to rest by tying a ligature, the first Stannius ligature, about the juncture of the sinus with the auricles. To do this pass ligature under the aortic arches close to the auricles, then pass the ends around the heart posteriorly so that the ligature lies at the base of the auricles, and tie a single knot loosely over the crescentic line where the sinus and the auricles join. *Make sure that the ligature is in the proper place*, then tighten and tie securely. The heart should stop beating. If it does not do so within a few seconds, tie a second ligature closer to the auricles.

a. Myogram of Heart Muscle.

As soon as the beat stops, place frog on board and connect heart with lever. Move coil far away, and find smallest stimulus that will cause a contraction; then mark on drum relative position of writing points; finally record the curve of contraction and beneath it the tuning fork curve, and the moment of make and break of the primary circuit, as shown by the signal. Turn the drum by hand at rate of about 10 cms. per second. Assume that the signal records the exact moment of excitation, and calculate from the record the time relations of the myogram, as in Experiment V. *Save a part of the record which shows that the writing points are in the same vertical line, and state in notes length of lever in millimeters.* In what respect does the myogram obtained from the heart differ from that of striated muscle?

b. Bowditch's Staircase.

As soon as a sufficient number of myograms have been recorded, remove the fork, and stimulate about 15 times with same strength of current at intervals of 5 seconds, recording on drum moving 2 mm. per second. A gradually increasing height of contraction is usually given, which is called a staircase, and explained as a result of increased irritability due to frequent repetition of the stimulus.

c. All Contractions Maximal.

Now stimulate about ten times with gradually increasing current at intervals of 30 seconds, recording contractions on drum about 1 cm. apart. There is no increase in height of contraction due to increased stimulus. Any stimulus sufficient to cause heart muscle to contract causes a maximal contraction. This is often spoken of as the law of "All or none."

d. Effect of Frequent Stimuli.

Connect wires of primary circuit with automatic interrupter and record the response of the heart to frequent stimuli, using first a weak and then a medium current. Drum should turn 5 mm. per second. Weak stimuli should cause separate beats and stronger stimuli, increase of tonus, indicated by a higher base line.

EXPERIMENT XIII.

Location of a Few Motor Points on the Human Arm.

The few motor points surrounded by a circle in the diagram (Fig. 15), are to be located on each arm. In doing this, the unipolar method of excitation is to be employed. To use this effectively, the more efficient pole of the induction coil will have to be used.

THE MORE EFFICIENT POLE OF AN INDUCTION COIL.—When the manner of winding and connecting wires with posts can be plainly seen, the direction of induced currents can be found easily, for the direction of the primary currents can be observed by inspection of the battery and its connections, and the induced current flows in the opposite direction to the battery current at the time of the make, and in the same direction at the time of the break. But in most coils the windings and connections are hidden, making it necessary to determine the point in question in some other way.

Connect a dry cell with a key and a pair of platinum electrodes as shown in Figure 13. Lay a small piece of

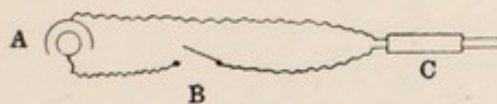


Fig. 13. Apparatus to detect direction of flow of current in a simple circuit. A, dry cell; B, mercury key; C, electrode.

filter paper on a clean plate, and slightly moisten it with only a few drops of a solution of starch and potassium iodide. Draw the ends of the electrodes slowly

and lightly across the moistened paper, first with the circuit open and then with it closed. Observe the dark line given at the anode while the current is passing, and the absence of color at the kathode. The current decomposes the potassium iodide, and the iodine, being the acid ion, goes to the anode and there gives the color reaction with the starch.

Now connect the cell to the primary coil of induction apparatus, the anode with post 1 and kathode with post 2.

Connect the platinum electrodes to the posts of the secondary coil. Place the ends of the electrodes on the moistened paper and make the primary circuit, then slide the electrodes

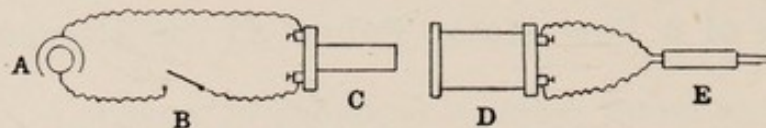


Fig. 14. Apparatus to detect direction of flow of current in secondary coil of an induction apparatus. A, dry cell; B, mercury key; C, primary coil; D, secondary coil; E, electrode.

to a fresh place and break. A dark dot will be given at one pole on making and at the other on breaking, but no effect will be seen during the time the primary current is flowing. Remembering that the color reaction indicates the anode, we can determine the direction of the current in the secondary circuit when the primary is made and when it is broken.

Since the excitation developed at the kathode where the current leaves the tissue, is stronger than that developed at the anode where the current enters it, and since the break induction shock is stronger than the make, it follows that the

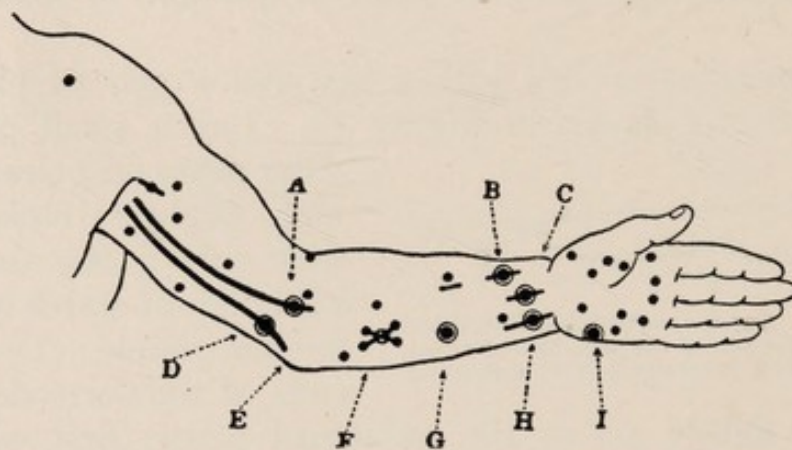


Fig. 15. Diagram of location of motor points on flexor side of arm. (After Erb.) A, median nerve in upper arm; B, flexor longus policis; C, median nerve at wrist; D, ulnar nerve in upper arm; E, ulnar nerve in groove between the internal condyle of the humerus and the olecranon process; F, flexor profundus digitorum; G, flexor sublimis digitorum; H, ulnar nerve at wrist; I, abductor minimi digiti.

more efficient pole of the secondary circuit is the one that is the kathode when the primary circuit is broken. Make a note of this point, stating whether the more efficient pole is the one to which the short circuit key is attached or the

opposite one. Of course it must be remembered that these are correct only when the primary circuit is connected as directed here.

PREPARATION OF SKIN.—Since the epidermis when dry offers great resistance to the current, it is necessary to moisten it thoroughly. For this purpose use a warm solution of common salt and borax. The solution can be warmed in a granite dish, standing on a tripod over a gas flame. Apply the solution with a sponge or cloth to the parts to be stimulated at intervals of a few minutes; or a pad soaked in the solution may be bound on and left 10 or 15 minutes. Unless the skin is thoroughly moistened, the stimuli are apt to be painful and inefficient. Do not spill the solution on tables or apparatus.

APPARATUS.—Connect two dry cells and a key to the primary coil of an induction apparatus, and connect a large copper plate (the indifferent electrode), to the least efficient pole of the secondary coil, and a small electrode (the active electrode), to the more efficient pole.

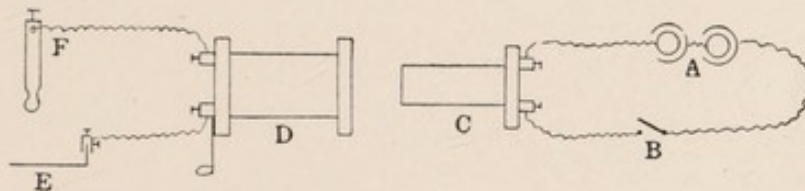


Fig. 16. Apparatus for unipolar excitation of human nerves. A, battery; B, mercury key; C, primary coil; D, secondary coil; E, copper plate used as indifferent electrode; F, exciting electrode.

EXPERIMENT.—Locate the motor points on the left arm first. Fasten with elastic band the copper plate on the back of the left hand, putting a wet gauze pad between to prevent the metal from touching the skin. Hold the stimulating electrode in the right hand and press it firmly upon the skin at the point to be stimulated. Let your companion make and break the circuit, first with the secondary coil moved far away and then with it closer to the primary, until a position of the coil is found that gives a moderate stimulus. As soon as a suitable stimulus is found, try to establish on your own arm the motor points corresponding to those marked with a circle in the diagram. Find for

each point the position of the electrode at which the best motor response is given. The stimulating electrode must be kept well moistened. If a good contraction cannot be obtained without the sensation being painful, it indicates either that the epidermis is not sufficiently moistened or that the right position for stimulation has not been found.

Locate carefully the motor points on both arms of each student. Mark the points on the skin. Demonstrate to instructor. No notes are required.

EXPERIMENT XIV.

Response of Human Muscle to Separate Induction Shocks and to a Tetanizing Current.

Wet the left arm over the motor point for the flexor longus pollicis, bind on a wet pad, and then arrange the apparatus. See that the hands are dry in handling the apparatus.

APPARATUS.—This consists of an arm rest, recording instruments, and the stimulating outfit used in Experiment XIII. The arm rest is to be placed on the table before which the subject is to stand, with the recording apparatus to the left, and the stimulating outfit to the right, with key and coil within easy reach of his hand. The arm is to

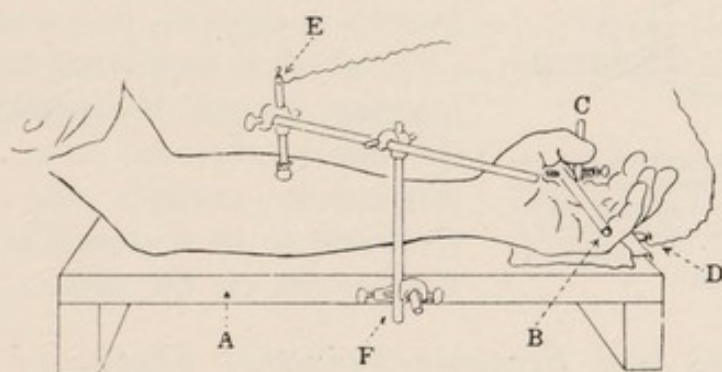


Fig. 17. Arm rest for support of hand and electrodes. A, arm rest; B, horizontal rod fixing hand; C, vertical rod on arm rest; D, copper plate, the indifferent pole, on which is the gauze pad; E, exciting electrode; F, vertical rod, clamped to horizontal rod on the arm rest.

lie in supination on the arm rest, and the hand is to be fixed by a horizontal rod (B) which presses lightly on the palm, and is clamped to the vertical rod on the arm rest.

The movement of the thumb is to be transmitted by a thread, which is fastened by a loop to the thumb and passes round a pulley to a lever, which is connected by another thread to a rubber band supported on an L rod, clamped to the same stand as the lever and above it. The thread from the thumb is fastened to the second, and that from the

finger to the third hole in the lever. When the flexor longus pollicis contracts, the lever will be drawn down, and when it relaxes the rubber band will pull the lever upwards. A time signal is to be placed in the primary circuit of the induction apparatus, and an indifferent and a stimulating electrode connected with the posts of the secondary coil.

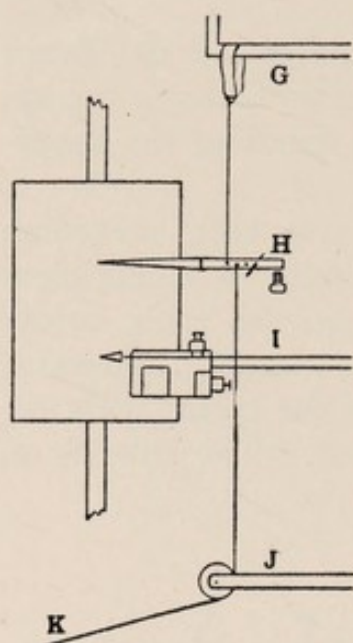


Fig. 18. Apparatus for recording movement of thumb. G, rubber band supported by I, rod; H, recording lever; I, time signal; J, pulley; K, thread to thumb.

The copper plate (Fig. 17, D), which is to act as the indifferent pole, is to lie on the arm rest in such a position that the back of the hand will press on a wet pad placed over the plate. Care must be taken that the pad does not come in contact with the vertical rod on the arm rest. The active pole* (E) instead of being held in the hand, is to be fastened above the arm in a clamp on a horizontal rod, which in turn is clamped to a vertical rod (F), which is supported by a clamp fastened to the horizontal rod at the side of the arm rest. This arrangement permits the exciting electrode to be fastened at any desired point on the arm.

a. *Making and Breaking Induction Shocks of Various Strengths.*

EXPERIMENT.—Put the wet pad on the indifferent electrode; then place the arm on the arm rest, so that the back of the hand rests on the pad; and fix the hand by fastening the horizontal rod across the palm. Adjust the active electrode over the motor point of the flexor longus pollicis muscle. Connect the thread to the thumb, and move the arm rest so that the thread shall have the proper position with respect to the pulley, and the elastic band be slightly stretched. Place drum in position. The lever should now be about horizontal, and flexion of the finger cause it to write well on the drum. The subject handles the key and

coil while his associate has charge of the kymograph, and turns the drum by hand. To stimulate, close the key, wait 2 or 3 seconds, then open, and wait 10 seconds. The student attending to the kymograph should keep the time with his watch and tell the subject when to stimulate. Begin with the coil placed so as to give no effect, and move it up a short distance after each time the circuit is broken. The signal marks the time of stimulation, and thus shows what stimuli fail to give contractions. In case insufficient current is obtained, cut out the time signal. Unless the current causes too much discomfort, continue until both making and breaking contractions of fair size are recorded. During the experiment the arm should be completely relaxed. Voluntary movements should be avoided as far as possible, and should be noted when they occur.

b. Tetanizing Current.

APPARATUS.—Connect battery, key, and signal with the automatic interrupter of the induction coil.

EXPERIMENT.—Moisten electrodes. Choose strength of current sufficient to cause a tetanic contraction. Start drum at fast speed and obtain a record.

EXPERIMENT XV.

Galvani's Experiment.

Arrange apparatus as shown in the diagram, making sure that the zinc rod and brass hook are bright and clean.

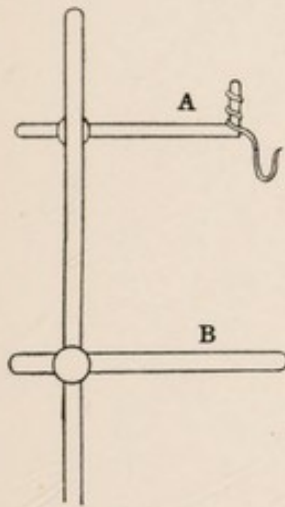


Fig. 19. Apparatus for Galvani's experiment. A, brass hook, supported on L. rod; B, zinc rod.

Kill a frog, open the abdomen, and remove the viscera from the posterior part, taking care not to injure the nerves. Cut the body in two transversely $\frac{1}{2}$ cm. above the point of exit of the nerves from the spinal column. Remove the skin from the lower part of the body, cut a small slit through the back between the nerves and the spine, and hang the preparation by this slit upon the brass hook. Adjust the zinc rod so that upon giving the preparation a slight swing the outside of the thigh near the knee will strike it. Set the preparation swinging. Upon each touch of the leg against the zinc

rod a contraction should occur, throwing the preparation away, and this should be repeated every time the swing brings the leg against the zinc.

We have here two unlike metals moistened by a liquid which is practically continuous through the tissues of the preparation; in other words, we have the essentials of what is called a Galvanic battery. This experiment is of considerable historical interest, for it was the observation of the contraction of frogs' muscles in a similar case that led Galvani to make his famous studies of what he supposed to be animal electricity, and which was followed later by the invention of the first battery by Volta.

We see here that a battery current, like an induced current, is able to excite muscle. In the next few experiments

the effects of the direct battery current upon nerve and muscle will be observed. Save the preparation for the next experiment, if made the same day.

No notes required.

EXPERIMENT XVI.

Polarization of Electrodes.

a. Polarizable Electrodes.

APPARATUS.—Arrange apparatus as shown in Fig. 20. Use an electric light switch as a short-circuiting key, fasten-

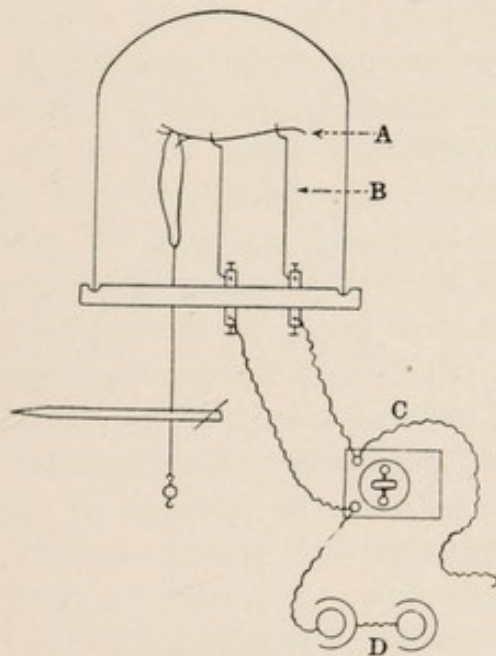


Fig. 20. Apparatus for observing polarization of electrodes. A, nerve; B, bare copper wires; C, electric light switch used as short circuiting key; D, battery.

ing two wires to each binding post. One wire from each post of the key is to be connected with a post on the outside of the moist chamber, and one wire from each post of the key is to be connected with the battery. Until everything is ready, however, leave one end of one of the battery wires disconnected. Fasten two short wires to the posts inside the moist chamber and place the free, bare ends so that a nerve can be laid across them, i. e., arrange these wires to be used as polarizable electrodes. It is

best to have the connections with the battery so that, when the short-circuiting key is open and the battery circuit is closed, the anode will be nearest the muscle, and an ascending current, i. e., away from the muscle, will flow through the nerve.

EXPERIMENT.—Make a nerve-muscle preparation from the frog used in the preceding experiment, (method of making preparation will be demonstrated); place the preparation in the moist chamber, and let the nerve rest across the

two copper wires. Bring the writing point of the lever against a drum, and arrange the kymograph to turn the drum 2 mm. per second. Start the kymograph, and let it run continuously until the end of the experiment. With key closed, connect wire with battery, and then open the key and let the current flow through the nerve for thirty seconds; (*mark the contraction which should occur when the key is opened, c*, because the current has been closed through the nerve); now disconnect the wire from the battery; (*mark the contraction, if any occurs, o*); then begin closing and opening the key regularly, once a second. If contractions result, continue until they cease. Notice whether the contractions are given on closing or on opening the key, or both, and *mark them accordingly, C and O*, since it is now the polarization current which is closed and opened.

Notice carefully, throughout the experiment any change in the contraction following closing and opening the circuit. The contractions observed after the battery has been disconnected are caused by a current going in the opposite direction from the battery current, i. e., a descending current. This current results from electrolysis which has taken place at the points of contact of the nerve with the wires. The condition set up at these points by the passage of the battery current is the same as that seen in a storage battery, and the wires are said to be polarized. In order to avoid such disturbing currents it is necessary, whenever the direct current is used as a stimulus, to employ non-polarizable electrodes.

b. Non-Polarizable Electrodes.

APPARATUS.—The non-polarizable electrodes used in this course, consist of two boot-like pieces of porous baked clay, hollowed at the top to hold a solution of zinc sulphate, in which two small pieces of zinc are immersed. The boots of the non-polarizable electrodes should have stood for some time in physiological salt solution, so that they are thoroughly saturated with it at the time they are employed. When they are to be used, dry the glazed tops thoroughly; put the metal clips on the tops of the boots; fasten the clips on a

glass rod; and fix the rod in a clamp on the support which holds the muscle clamp, in the moist chamber. Dry the wires just used as electrodes, and connect them to the

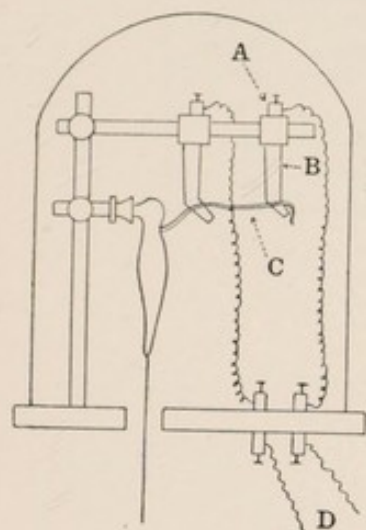


Fig. 21. Method of arranging non-polarizable boot electrodes in moist chamber. A, zinc; B, porcelain boot; C, nerve; D, wires to short-circuiting key.

zincs; with a dropper put about half a cubic centimeter of zinc sulphate into the boots, being careful not to spill any of it on the outside of the electrodes. Then insert the zincs into the tops of the boots.

EXPERIMENT.—Lay the nerve across the tips of the boots and repeat the experiment made before. If the electrodes are not polarizable, closing and opening the battery circuit should give the same effect as before, but there should be no response to the movements of the key which follows.

On completing the day's work, the non-polarizable electrodes must be thoroughly washed and soaked

over night in normal salt solution.

Pflüger's Law.

The polarization current which is set up, is strongest at first and gradually fades away; consequently in the course of an experiment, the student often sees the effects of the opening and closing of strong, medium, and weak currents. These effects, which differ with the direction in which the current flows through the nerve, have been classed under what is known as Pflüger's law. To recall this law one has only to remember the following facts, viz.: 1, that the closing excitation develops in the region of the kathode, and the opening excitation near the anode; 2, that the closing excitation is the stronger; 3, that by strong currents the conductivity of the nerve is lessened at the anode during the flow of the current, and at the kathode at the instant that the current ceases; 4, with an ascending current the

anode is nearer the muscle, and with a descending current the kathode is nearer the muscle. The law was tabulated as follows:

	ASCENDING		DESCENDING	
	Close	Open	Close	Open
Weak.....	+	—	+	—
Medium....	+	+	+	+
Strong	—	+	+	—

EXPERIMENT XVII.

Response of Nerve upon Closing and Opening the Direct Battery Circuit with Currents of Various Strengths.

APPARATUS.—Use the ordinary apparatus for recording muscle contractions. Introduce a rheocord into the circuit

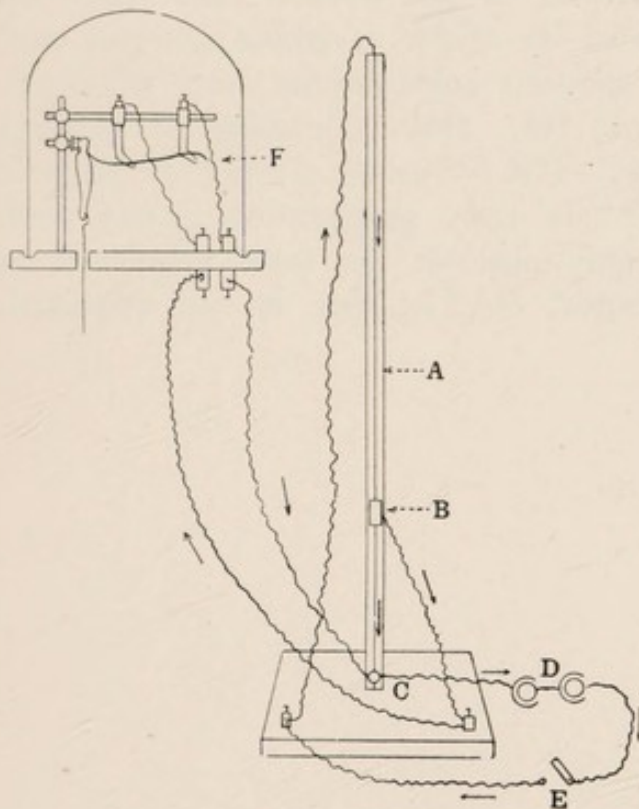


Fig. 22. Method of using rheocord. A, german silver wire; B, slider; C, double binding post at lower end of german silver wire; D, battery; E, key; F, nerve bridging the boot electrodes, the current being ascending.

used in the last experiment, making connections as indicated in Fig. 22. Mount a pair of non-polarizable electrodes, in the moist chamber, connecting the wires so that the current will ascend the nerve. Observe that the current passes down the fine German silver wire of the rheocord to the slider and there divides, part going to the nerve and part going through the lower part of wire. At the double post at bottom of wire

the two streams of the current unite again and pass together to the battery. Observe that the current traversing the nerve must increase as the slider is moved upward, because the resistance in the wire beyond the point where the circuit divides is increased.

EXPERIMENT.—Since the direct current rapidly changes the irritability of a nerve, the following *Cautions* must be observed:

1.—Do not apply the current at all except when you wish a record.

2.—Do not let the current flow longer than is absolutely necessary.

3.—Obtain the record by comparatively few stimulations.

4.—Do not excite oftener than once in 15 seconds.

Move the slider to the bottom, then close and open the key. There should be no response. Move slider up 2 or 3 cm. and repeat. Continue in this manner, and mark on the curve the positions of the slider at which minimal and maximal, closing and opening contractions were obtained. Record as in Experiment III. Did the closing or opening contraction appear first? Did Wundt's closing or Ritter's opening tetanus show? If your preparation reacts well, and if you like, you may observe the facts tabulated as Pflüger's law (see Exper. XVI); this is not required, however.

EXPERIMENT XVIII.

Stimulation of Human Nerves by Direct Current.

APPARATUS.—The electric current of the University is used. (Study diagram). It flows through 4 lamps, (which let 1.2 amps. pass) and then is shunted round 4 more lamps, and has at the terminals *A* and *F*, a voltage of $220/2 = 110$ volts. It then passes through 2 lamps *A* and *B*, (which let 0.35 amps. pass) and is shunted round 3 lamps, *C*, *D*, and *E*, and has a voltage at the terminals *N* and *P*, of $3 \times 110/5 = 66$ volts.

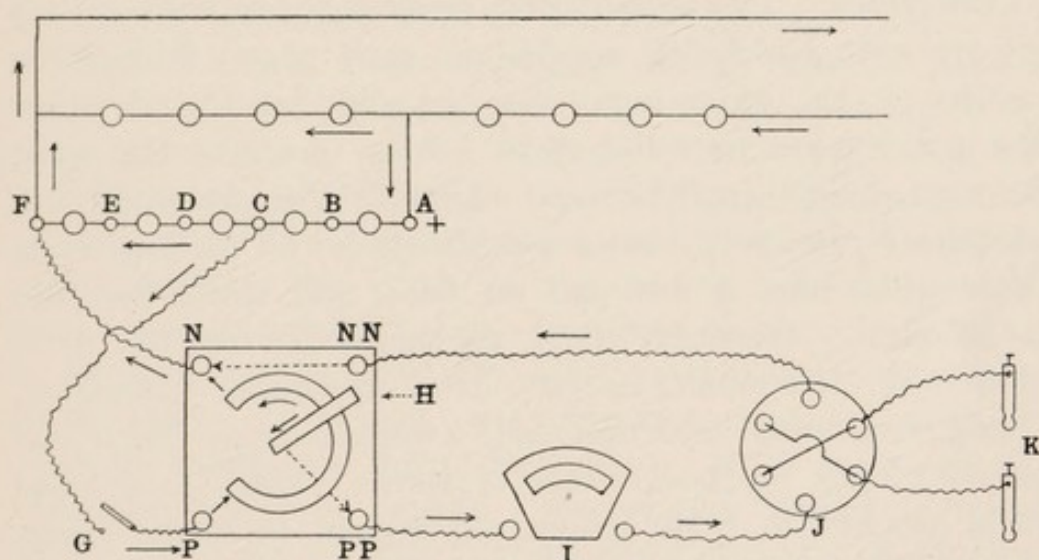


Fig. 23. Apparatus for stimulation of human nerves by a direct current. *A*, *B*, *C*, *D*, *E*, *F*, binding posts in second bank of electric lamps used to cut down the voltage; *G*, key; *P*, post where current enters, and *N*, where it leaves rheostat; *PP*, post connected with slider, from which current goes to milliammeter; *H*, slider; *I*, milliammeter; *J*, commutator for reversing current; *K*, electrodes; *NN*, pole on rheostat connected with *N* and receiving current returning from commutator.

In the rheostat it is again shunted, the current passing through the resistance from *P* to *N*, and a portion of it being led off through the metal slider (*H*) to the arm circuit. The resistance is equivalent to the German silver wire of the rheocord used in Experiment XVII. The slider is connected with the post *PP*, which gives the branch of current to the arm circuit, and the current returns from this circuit

to post *NN*, which is connected with post *N*. The amount which goes to the electrodes varies with the position of the metal slider. Note that *as the slider is moved clockwise the resistance between the slider and post N increases and hence more current will go to the arm*. A key (*G*) controls the flow of the current to the rheostadt. From terminal *PP* of the rheostadt the current flows through a milammeter (*I*), commutator (*J*) with cross wires, which permits the current to be reversed, to the positive electrode, the Anode; it then flows through the arm to the negative electrode, the Kathode, and back by way of commutator to the pole *NN* of the rheostadt, and thence to pole *N* and away.

EXPERIMENT.—When ready for this experiment report to instructor. Two stimulating electrodes are used in this experiment, one being applied to each arm. Either the median or the ulnar nerve may be stimulated, and either the motor point near the elbow or the one near the wrist be used. Choosing the one which in the preceding experiments gave best results, wet the places on the two arms thoroughly, bind a wet pad on each, and while the skin is becoming saturated, study the apparatus on the main table. *See that hands are dry when apparatus is handled*. Using your own induction coil, ascertain again the exact points giving the best motor response. Mark these, and then proceed to table where experiment is to be made. Bring slider against *flat side of checking-post*, and see that key is open. Then place the arms in the arm supports (see Fig. 17) and pressing the electrodes firmly over the motor points, make the electrodes fast.

In making the experiment the subject sits quietly, watches for first appearance of sensation or contraction resulting from the stimuli, and reports at which pole it occurs. The other student, who is the experimenter, handles the key and rheostadt, reads the milammeter, and records the results in a table of the following form, stating the number of milliamperes required to produce the effect sought.

TABLE OF STRENGTHS OF CURRENT REQUIRED TO PRODUCE EFFECT.

Kathode on.....hand.	
SENSATION.	CONTRACTION.
Kathode closing
Anode closing
Anode opening
Kathode opening

When all is ready the experimenter closes and opens key. There should be no movement of milammeter needle and no effect at electrodes. He then advances the slider a short distance, closes the key, saying "close," then as soon as the milammeter reading can be made, opens the key and says "open." Experimenter must watch milammeter, leaving subject to report effects. If the current is allowed to flow too long there are changes in irritability which destroy the value of the results. Advance slider again and stimulate again. Continue in this way, trying to find the least current that will give the effects mentioned in the table. Of course the experiment must stop when the stimulus causes too much discomfort. *KOC* is usually not obtained for this reason. No graphic record is taken. When table is completed, return slider to place of starting, rock the commutator, to reverse the current, then stimulate with various strengths of current as before. Observe that the order of appearance of *KCC*, *ACC*, *AOC*, *KOC*, are the same as before, but that they appear at the opposite hand. Do not take time to read milammeter in the second test. Table is to be made out for each student, and each reports results obtained by the experiment on himself.

Students are apt to become confused in this experiment because two electric currents are used, getting the impression that the two currents in some way neutralize each other in traversing the same path. This is not the case. The changes observed in the response of the nerves and muscles to the induction shocks when the direct current is passing are due to changes in irritability of the nerves caused by the direct current, the anode of the direct current lessening and the kathode increasing the irritability of the nerve. The tetanizing induced current is used simply as a means of exciting the nerve a definite amount. Like results are obtained if the nerve be excited by a mechanical stimulus, as a blow from a light hammer.

EXPERIMENT.—Wet arms and electrodes; place the latter over nerves, using the same motor points as in the last experiment, and fasten; see that slider touches flat side of checking post; then close key *G* and see that no current passes the millammeter. Now proceed as in Experiment XVIII until a position of the slider is found giving a direct current sufficient to cause a kathodic closing sensation but no contraction. With slider in this position and key *G* open, find position of secondary coil such that a tetanizing current will provoke a small contraction. Observe which is the more active pole, and rock the commutator so that anode of the direct current will be brought to that pole. With the apparatus as now placed, the influence of the direct current can be observed in two places, where *anode is applied at more active pole, and where kathode is applied at less active pole.*

Close key *O* and start the vibrator. When the contraction produced has continued about 5 seconds, close key *G* and thus introduce a weak direct current. Observe the effect at each pole, as regards the sensation and the contraction due to the induction shocks. The effect of the anode of the direct current to lessen irritability should be more marked than the effect of the kathode to increase it. Leave the direct current flowing for 5 seconds, then open key *G* and notice the after effects, especially at the pole at which the anode has been acting. As soon as the after

effects have been observed, open key *O* to stop the excitation, and wait 5 minutes for the effects to pass off.

Rock the commutator, reversing the direct current, and study in the same manner the other case: *kathode applied at more active pole and anode at less active pole.*

The experiment is to be performed upon each student, each writing in his notes the effects observed on himself.

EXPERIMENT XX.

Currents of Rest and Currents of Action.

a. Current of Rest detected by Rheoscopic Frog Preparation.

APPARATUS.—Mount on short stand a brass L rod, and fasten a muscle clamp, with the jaws horizontal, to the short arm of the rod. Connect a dry cell and a key with an induction apparatus so as to give tetanizing excitations, and connect a pair of copper electrodes with the secondary coil.

EXPERIMENT.—Prepare (*A*) a nerve-muscle preparation, (*B*) a nerve-leg preparation (a rheoscopic frog preparation), and (*C*) a piece of thigh muscle having one uninjured surface and one surface cut squarely across the fibers. To prevent drying, put between layers of filter paper moistened with physiological salt solution. Place knee joint of *B* in clamp with leg pointing upward and nerve hanging below. Avoid clamping the nerve. Place *C* on a glass slide; make a fresh cross section on *C*; then holding glass slide in hand, bring *C* up beneath *B* in such a way that the nerve of *B* shall fall suddenly across cut surface and normal surface of *C*. *B* should contract, because the injured part of the muscle *C* is undergoing katabolic change and is consequently negative as compared with the normal surface. The nerve closes the circuit and is stimulated by the so-called "Current of rest," the "Demarcation current."

b. Current of Action detected by Rheoscopic Frog Preparation.

Mount the glass side in holder on L rod, and the rod on a stand. Place *A* upon the slide, and clamp the L rod so that the nerve of *B* lies lengthwise upon the muscle of *A*. Stimulate nerve of *A* with tetanizing current of medium strength. Both muscles should be tetanized.

To find if currents spreading from electrodes have caused *B* to contract, ligature nerve of *A* tightly at its middle, with a moist ligature, and then stimulate above ligature. No contraction of *A* or *B* occurs. The ligature would not block an electric current, but by breaking the continuity of the nerve fibers, it effectually blocks a nerve impulse. It follows that *B* must have been stimulated by the "Current of action" the "Negative variation Current," of the muscle *A*. When *A* contracts, a wave of contraction passes over it, and at a given instant, some parts are undergoing greater katabolic change than others, and hence are electrically negative as compared with the less active parts. The nerve completes the circuit and is stimulated. Put preparation *A* and *B* in moist filter-paper, to be used in demonstration to follow, in which the currents of rest and action of muscle, nerve and heart are detected with the aid of a galvanometer and a capillary electrometer.

EXPERIMENT XXI.

The Reflex Frog.

The value of this experiment is great if it be properly interpreted. Through it we have the best physiological evidence of the method of spread of reflex processes in the spinal cord. When studying the movements which result from excitation, one should try to recall the finer anatomy of the spinal cord, the longitudinal paths of conduction, the method of communication between the posterior and anterior roots, and the way impulses pass from side to side of the cord.

a. Time of Recovery from Shock.

Pith a frog's brain and plug cavity of skull with as little loss of blood as possible. Note the time at which this is done. Place the frog on a plate, back upwards, and with the legs stretched out at full length, note the time required for recovery from the shock, as shown by the drawing up of the legs. Now cover with moist paper and leave for half an hour. At the end of this time observe the frog's position. If cerebrum and cerebellum have been completely destroyed, it will lie with nose against plate; if turned on back it will not turn over; if thrown in water it will not try to swim; if stimulated it will move legs but not jump; the power to perform highly coördinated movements is absent.

b. Spread of Reflexes.

Clamp nickled L rod on stand, and put frog-hook on short arm of L. Suspend the frog from hook passed through nose. Gently irritate flank with a needle and observe local twitching of muscles; excite more strongly and notice spread of reflexes to limbs. Pinch a toe gently and then more strongly (do not crush) and observe and note the

order in which the different parts of the leg and of the body respond to the excitation.

c. Are Reflexes Purposeful?

Place beneath frog a battery jar two-thirds full of water, so that by lifting the jar the body can be washed. *Caution.*—In this and the following tests requiring the use of acid, be sure to wash it off after each test. Put a bit of paper 1 mm. square, wet in 10% acetic acid on right flank, left flank, median line of lower back, and on various parts of leg, and state in your notes the results. Hold right foot lightly and put paper on the right flank. Reflex should appear in right leg, and later in the left leg. The word purposeful in the question heading this section is not used in the sense of well adapted to the needs of the animal, but directed by volition to accomplish a definite object. In short, do the movements of the frog justify the view that the spinal cord is the seat of intelligence?

d. Reflex Time.

Immerse tip of longest toe in 0.1% H_2SO_4 up to a definite mark, noting number of seconds between immersion and withdrawal. Repeat five times with each foot and report average for each. Immerse to the same mark each time, as the distance affected influences the result. Wash off acid after each test. Where is the time probably lost? Does the experiment favor the "neurone theory," or the theory of a continuous nervous network?

e. Spasm of Muscles versus Coördinated Movements.

APPARATUS.—Arrange induction coil to give tetanizing excitations. Connect a pair of copper electrodes with the secondary coil.

EXPERIMENT.—Remove frog from hook. Open abdomen by cutting away whole of anterior wall; remove viscera without injuring the sciatic plexuses behind them. When the flow of blood has ceased, cut through the middle of the sciatic plexus on one side, and free the nerves so that they can be laid across a pair of electrodes. Put frog on

hook. Apply electrodes first to the peripheral, and after, to the central cut ends of the nerves of the plexus, taking care to use the weakest effective tetanizing current and to avoid touching the electrodes to anything except the nerves. Explain how the resulting movements differ?

EXPERIMENT XXII.

Reaction Time to Sound.

APPARATUS.—Blacken drum and fasten it at highest point on kymograph. Arrange to turn it by hand. Fasten the heavier muscle lever, with supporting screw down, on long stand at such height that it will write 2 cm. from bottom of drum. Put L rod on stand above lever; put elastic band on rod; and connect band with lever by a thread put through second hole, so that band will be slightly stretched. Fasten one end of a thread to the strip of wood provided, by passing thread through hole nearest the end and back through other hole, and tying it so that thread will not slip. Fasten other end of thread to third hole in lever, leaving thread of such length that the end of the piece of wood to which thread is fastened will be so near the table that when it is pressed on by finger the lever will move about 4 mm. Bring writing point of lever to drum. Mount fork on short stand, and place this stand so that fork will write the time one centimeter below lever and in same vertical line.

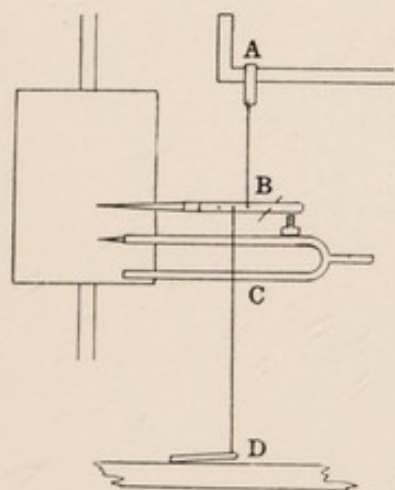


Fig. 25. Apparatus for recording reaction time for sound. A, rubber band; B, lever; C, tuning fork; D, strip of wood, which is to be pressed by finger against table.

EXPERIMENT.—The subject is to put finger on strip of wood and depress it so that the lever is pulled down and the wood rests on table; (see that the thread is vertical). He is to remove finger as soon as he can after hearing sound of fork. He must not react to sound of the moving drum, and to give quick response must have in mind the sound of fork. The experimenter must put yoke on fork; tell subject to close eyes; say "ready," and about a second

later whirl the drum; then pull yoke off fork and stop drum as soon as subject is seen to respond.

Rehearse the experiment two or three times without the pointers touching the drum. Then move drum up to pointers and see that they write well. *Mark the relative position of the pointers* on the drum by moving them. If the kymograph or either stand is moved at any time, the relative position of the writing points must be again marked. Do not fail to mount part of curve showing the position of writing points along with the rest. Take 10 reaction times with each student as subject, moving drum down after each experiment.

Reading of Curves.—Draw perpendicular with triangle from point where lever began to move, through the corresponding tuning-fork curve. Count the number of waves, starting with the crest of the first and estimating in tenths the value of any fraction of a wave at the end. State time in hundredths of a second. Give in notes result of the separate observations and the average of 10 observations. Throw out only such observations as were known to be faulty at the time they were made. Account for variations.

Ordinary reaction time to sound is 0.15—0.20 second; to a touch on the skin, 0.145 second; and to an electric flash 0.195 second.

EXPERIMENT XXIII.

The Knee-Jerk as Modified by Reenforcing and Inhibiting Influences.

If a blow be struck on the ligamentum patellae when the lower leg is in a position that puts the ligament under slight

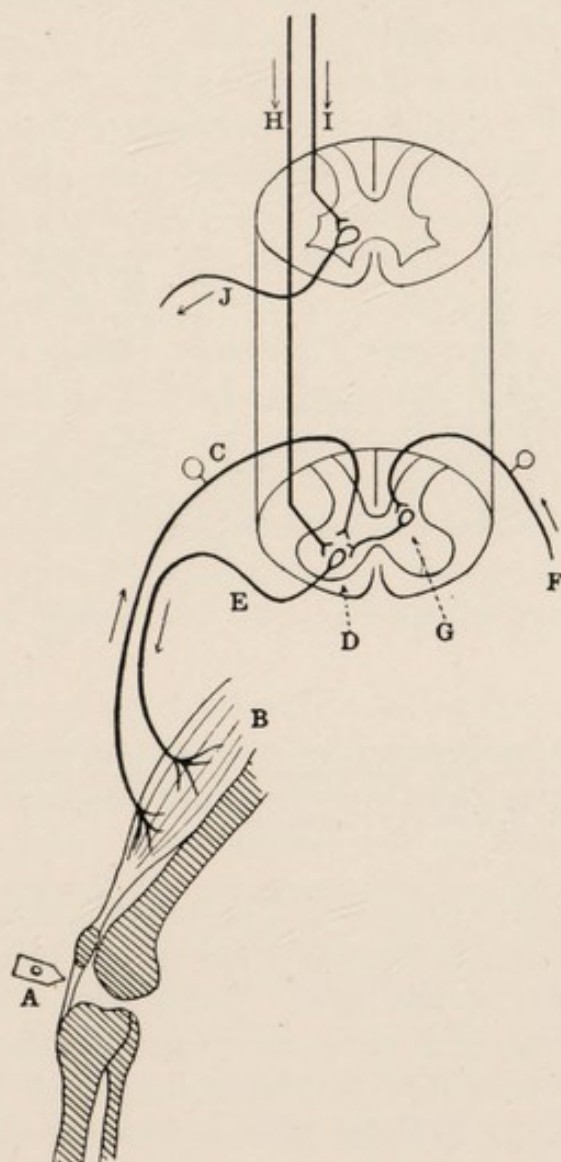


Fig. 26. Diagram of nervous paths followed by the nerve impulses causing the knee-jerk and its reenforcements. A, hammer placed to strike ligamentum patellae; B, quadriceps muscle; C, posterior spinal nerve root; D, motor cell in anterior horn of gray matter of lumbar cord; E, anterior spinal nerve root; F, sensory nerve from other leg; G, commissural cell; H, descending path from leg area in cerebral cortex; I, descending path from arm area in cerebral cortex; J, motor nerve to arm.

tension, a sudden twitch is transmitted to the vastus internus and crureus divisions of the quadriceps extensor muscle. The result is a sudden contraction of these muscles and a sudden forward swing of the leg.

Two explanations of the sudden contraction of the muscle are offered; viz: (1) The knee-jerk is a reflex act. The twitch acts as a mechanical stimulus to the sensory nerve ends in the muscle and its tendon, and causes a reflex contraction of the muscle, which causes the foot

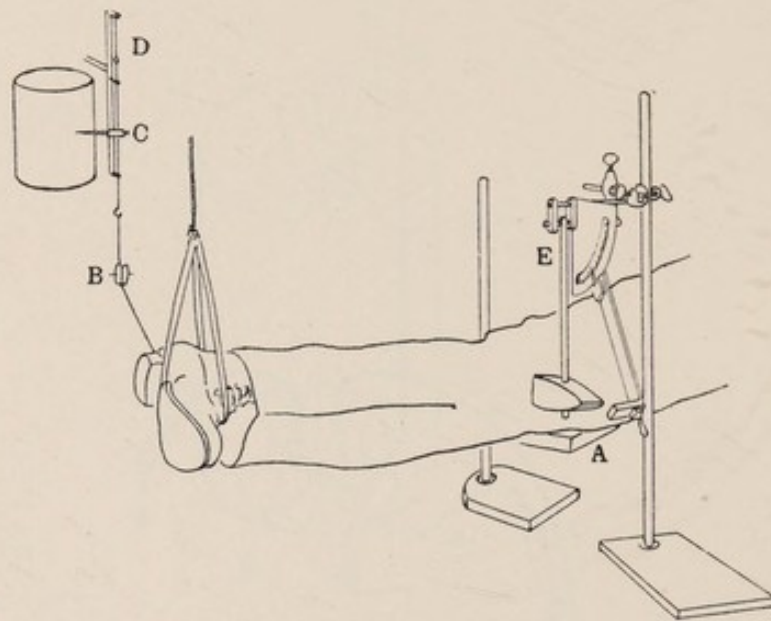


Fig. 27. Method of supporting thigh and foot and of recording the swing of the lower leg in the knee-jerk experiment. A, support under thigh; B, pulley; C, cross shaped writing needle; D, rubber band, twisted so as to keep point of needle against drum; E, knee-jerk hammer.

to swing if it is free to move. The anterior horn cells taking part in this act are in the leg areas of the third and fourth lumbar segments of the cord. The response of these cells to the sensory stimulus from the extensor muscles, is either reënforced or inhibited by other impulses reaching the anterior horn cells a short time before the impulses from the leg. (2) The knee-jerk is the result of the direct mechanical stimulation of the muscle. The greater the tension the better the muscle responds to the blow on the tendon. The anterior horn cells are always during waking

hours sending tonus impulses to the muscles which keep them under more or less tension, and these impulses are increased by reënforcing and decreased by inhibiting influences. It will be here assumed that the former explanation is correct.

APPARATUS AND POSITION OF SUBJECT.—The subject is to lie on his left side with his head on a pillow, his thigh on a support, and his foot in a swing. The position must be perfectly comfortable, so that he could go to sleep. Adjust the support (*A*) under the thigh so that the lower leg will swing freely. The subject must be in such a position that the cord suspending the swing is vertical when the leg is at rest; and throughout the work he must lie quietly and relaxed with eyes closed except when told to do otherwise. Connect the back of the swing by thread passing round pulley (*B*) to a cross shaped writing needle (*C*), so that the rubber band (*D*) supporting the latter is under a slight tension and the needle free to move. Adjust the hammer (*E*) so that when it hangs vertically, the middle of the striking face will just touch the skin over the middle of the ligamentum patellae, and so that the blow will be struck at *right angles* to the ligament. *Make this adjustment with great care*, then clamp the rod supporting the hammer.

EXPERIMENT.—Four students work together, each taking his turn as subject, experimenter, assistant, and clerk. The experimenter uses the hammer; the assistant sits near the head of the subject and applies the sensory or psychic stimuli when signaled by the experimenter; the clerk looks after the drum, and keeps record of any reënforcing or inhibiting stimuli, marking on the drum, 1, 2, 3, etc., to correspond to his notes. During the entire experiment the subject must be completely relaxed and the room perfectly quiet. Success depends entirely on the contrast between repose and action of the central nervous system. If those who make the experiment are not quiet and annoy or excite the subject, except when a special effect is desired, the whole experiment fails.

a. Minimal Blow Necessary to Excite.

Adjust arm supporting catch for hammer so that index points at 10° ; put hammer on catch, release hammer and let it strike the tendon, catching it as it rebounds, so that a second blow shall not be struck. Turn drum 5 mm. and continue, raising and lowering arm supporting hammer until the least blow is found which will cause a knee-jerk. Make note of the position of hammer for this minimal blow.

b. Record of Normal Knee-jerk.

Find position of hammer that will give a knee-jerk whose record on drum is about 2 cm. high. Make note of position of hammer. Start drum at 2 or 3 mm. per second and record a series of 20 normal knee-jerks, giving the blows rhythmically at such a rate that the foot has time to come to rest after each jerk. Observe that even when subject is relaxed and the room quiet, the knee-jerks vary in height, in other words, that the irritability of the reflex mechanisms is changing.

c. Motor Reënforcement.

Let the subject clench his hand at the instant a command is given him, the hammer being released at varying intervals. If the blow on the knee occurs at the exact instant the command to clench is given, or within 0.4 second after the command, the knee-jerk is greater than normal, i. e., reënforced, if the blow is struck between 0.4 and 1.7 seconds after the command, the response is lessened, i. e., inhibited. If the blow comes still later, the clench has no effect. Record 10 or more normal responses, and when they are of about the same height, try the effect of clenching, the clerk making a mark on drum to indicate the jerks with which a clench was given, then record another series of normal jerks. The explanation of the effect of the clench is that when the motor cells of the arm area of the cerebral cortex act, the motor cells of the leg area of the cerebral cortex are excited through association fibers, and impulses from the cells of the leg area of the cortex spread to the anterior horn cells of the leg area of the cord. If the

impulses coming from the brain reach the lumbar region of the cord before the sensory impulses from the leg, they so alter the condition of the anterior horn cells that the reflex response to the blow is altered. Sudden discharge of voluntary impulses to any other muscles, e. g., clenching the jaw, or even winking, will also cause a reënforcement or inhibition.

d.—Reënforcement by Sensory Stimuli.

Pulling a hair, tickling face with a camel's hair brush, an unexpected sound or odor, will cause a reënforcement. To show this, record 10 or more normal jerks by a series of rhythmical strokes, and when the jerks are of about equal height, test several sensory effects, marking on drum the time such stimuli are given.

e. Psychic Reënforcement.

With subject as quiet as possible, eyes closed, room perfectly still, record a series of 10 or more normal jerks, and while the record is being taken, test the effect (1) of speaking to subject, (2) of asking him to multiply two numbers given him, (3) let him think of some stirring poem, etc. The clerk should note all these occurrences with care, and also the effect of sounds produced in neighboring rooms or out of doors, the entrance of any one into the room, and all external influences that are able to excite the subject in the least degree. The susceptibility to such influences varies greatly with the subject. The student who was the subject of the experiment, is to have the record.

EXPERIMENT XXIV.

Conditions Determining the Blood Pressure, and the Output of the Ventricle.

PORTER'S ARTIFICIAL CIRCULATION APPARATUS.

The basin supplying and receiving the water represents the left auricle. The bulb which pumps the water represents the left ventricle. The valves at the inlet and outlet of the bulb represent the mitral and aortic valves. The piece of ratan and the side tube controlled by clamp represent the capillaries and the variable resistance of the small arteries. The tubes between the aortic valve and the resistance represent the arteries. The tubes between the resistance and the basin represent the veins. Two manometers connected with arteries and veins permit a study of pressures under varying conditions. A tube connects the ventricle with a tambour, by means of which changes in pressure in the ventricle can be observed. A tambour can be placed over the artery and enables the pulse to be recorded.

Make a diagram showing these various parts of the apparatus. After making the diagram, see that the clamp on the side tube is open and then fill the tubes with water, by pumping while holding the right hand end of the apparatus up at an angle of 45° . Always pump by compressing the bulb quickly and instantly removing the pressure, repeating rhythmically every *two seconds*. Compress the bulb only by means of the lever placed above it, and see that the rod limiting the movement of the lever is in its clamp, with the longer end upward. Using the apparatus in this way, prepare to demonstrate to the instructor the points enumerated below before proceeding to the second part of the experiment.

PART I.

1.—The fluid takes path of least resistance, nearly all of it going through the open side tube and but little through the ratan.

2.—Only a part of the fluid pumped escapes into the basin during systole.

3.—The part held back dilates the arteries and escapes during diastole.

4.—The part of the artery nearest the heart expands first.

5.—Finger placed on ventricle tambour feels a sudden rise of pressure followed by a sudden fall of pressure.

6.—Arterial manometer shows rise of pressure later than ventricle tambour.

7.—The mercury oscillates after each beat, because of its own inertia.

a. Effect of Changing Peripheral Resistance.

Without changing the rate or manner of pumping, gradually increase the peripheral resistance by slowly screwing up the pressure clamp on side tube; observe, 1.—Increase of arterial pressure, indicated by arterial manometer, and visible changes in size of arteries; also decrease of venous pressure indicated by venous manometer. 2.—Decrease of outflow, indicated by the size and character of the stream flowing into the basin from veins. 3.—Increased work for heart as felt by the hand and ventricle tambour.

CAUTION.—Keep watch of the manometer as the clamp is closed, and avoid forcing the mercury out of the tube.

b. Effect of Changing Rate of Heart Beat.

With clamp on side tube open wide, (small peripheral resistance) observe the following: 1.—Slow rate, (once in 3 sec.). The fluid escapes into the basin completely during the diastole. (The flow is intermittent.) 2.—Medium rate, (once in 1 sec.). The fluid pumped does not all escape into the basin during diastole. (The flow is remittant.) 3.—Fast rate, (three times per sec.). Marked

accumulation of fluid in the arteries causing distension of walls, and continuous outflow approaching constancy. The energy stored in the walls of the elastic arteries during systole drives the fluid on during diastole. The pressure, as shown by manometers, is never high when side tube is open, no matter how rapid the beat.

c. Effect of Changing the Volume Pumped per Beat.

Remove the rod limiting the pressure of lever on bulb, and replace it with its shorter end upward, and observe the effect on the pressure and the outflow, pumping at rate of once in two seconds. Demonstrate above points to instructor, before proceeding further.

PART II.

d. Record of Pulse from the Artificial Circulation Apparatus.

The method of air transmission devised by Marey, is employed to record a great variety of physiological movements. By this method, two little drums covered with rubber membrane are connected together by tubing. A plate of metal resting on the membrane of one of the drums (the recording tambour, Fig. 28), is connected with a light lever, and when air is driven out of or enters the other drum (the receiving tambour), by movements imparted to the membrane covering it, the lever rises or falls. There is a T tube at one part of the tubing connecting the drums, and this supplies a side opening by which air can enter or escape when the tambours are not in use. This opening is controlled by a pinch-cock. The level of the lever can be adjusted by placing the support of its axis at a suitable angle.

CAUTION.—Do not apply pinch-cock, excepting when the tambours are to be used. See that the lever of the recording tambour is horizontal just before a record is to be taken, and never let the membrane of the recording tambour be greatly stretched.

Adjust a receiving tambour to wall of artery, and con-

nect it to a recording tambour. Clamp the tube leading to arterial manometer. Replace rod limiting pressure of lever



Fig. 28. Recording tambour. A, tambour; B, aluminum plate, with bell-and-socket joint for pin acting on lever; C, lever with celluloid writing point; D, support of lever.

on bulb, with its longer end upward; then pump in the manner directed at the rate of once in two seconds. No pulse is given with side tube, representing small arteries, wide open. Gradually increase the peripheral resistance, and observe the resulting distension of large artery and pulsation of tambour. Several beats will be required to fill the artery before the tambour will respond. Record on drum. By careful adjustment of peripheral resistance and regular and uniform pumping, a pulse can be recorded that is a fair imitation of a normal pulse curve from man. Record curves as follows:

1.—Imitate a normal pulse, and dicrotic pulse, i. e., the pulse which comes with a low arterial pressure.

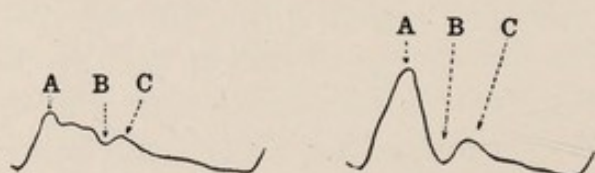


Fig. 29. Sphygmogram of a normal pulse and a dicrotic pulse. A, crest of primary wave; B, dicrotic notch; C, dicrotic wave.

2.—Effect of slight changes in peripheral resistance. Record ten or more normal beats; then make a slight increase in the resistance and mark on drum the time of the change; after ten or more beats with this resistance, return to the normal, again marking on drum.

In a similar manner make a curve showing effect of decrease of pressure.

3.—Effect of changing rate of beat. Record curves with the following rates of beat: 1 in 2 seconds, 1 in 3 seconds, 1 in 1 second, 2 in 1 second, 3 in 1 second. In each instance the curve should show the effect of changing the rate.

4.—Effect of changing the volume pumped per beat. Show effect of increasing and of decreasing the volume per

beat, always marking on drum the time the change is made.

NOTES.—Describe the form of the normal pulse wave which you obtained, and state in what respects the form of the wave is changed by vaso-constriction, vaso-dilation, increased heart rate, and increased pulse volume.

e. Comparison of Arterial and Ventricular Pulse Curves.

Mount a special tambour on rod so that the button will rest against ventricle tambour. Record ventricular and arterial pulses together. Note difference of form and delay of the arterial pulse.

PART III.

f. Effect of Lesions of Heart Valves.

Failure of a valve to close its orifice perfectly is called *insufficiency*. Abnormal narrowing of its aperture is called *stenosis*. These defects in the heart valves are usually accompanied by dilation of the cavities and hypertrophy of the heart muscle, which is known as *compensation*. These three conditions can be imitated in a way in the artificial circulation apparatus; insufficiency and stenosis by the use of suitable valves, which will be provided, and compensation by reversing the rod which limits compression of the bulb, thus permitting greater outflow at a stroke.

Arrange to record ventricular and arterial pulse curves, and then, with the same peripheral resistance as used for imitation of a normal pulse, and pumping at the rate of once in two seconds, record curves to show effects of the following lesions, alone and with compensations:

1.—*Aortic insufficiency*. The ventricular pulse is about normal, but the arterial pulse shows a sudden upstroke and a sudden fall.

2.—*Aortic stenosis*. The ventricular pressure is abnormally high and the arterial pressure is low, even with compensation.

3.—*Mitral insufficiency*. Pressure low in both curves.

4.—*Mitral stenosis*. Pressure very low in both curves.

Explain the results in each case, and state in which

cases the compensation made the curve more nearly normal, and why.

It must be borne in mind that these lesions in the living subject are accompanied by other changes, so that the results are of value only as indicating fundamental relations, which here are separated from complications usually present.

Leave apparatus in order for normal action.

EXPERIMENT XXV.

Circulation and Respiration of the Mammal.

Experiments on these subjects will fill two afternoons, the apparatus and general methods being the same for both days. The students will work in groups of four, and the parts of the work to be done by each student is shown in the following schedule. The number of the student as given in the schedule will be assigned by lot.

Schedule of Work.

FIRST DAY Experiment 25	STUDENT 1	STUDENT 2	STUDENT 3	STUDENT 4
Right carotid and vagus	Operate	Assist	Etherize	Apparatus
Left carotid and vagus	Apparatus	Operate	Assist	Etherize
Sciatic	Etherize	Apparatus	Operate	Assist
Tracheotomy and open chest	Assist	Etherize	Apparatus	Operate
	Account for apparatus		Account for apparatus	
SECOND DAY Experiment 26				
Right carotid and depressor	Assist	Etherize	Apparatus	Operate
Left carotid and depressor	Etherize	Apparatus	Operate	Assist
Tracheotomy and open chest	Apparatus	Operate	Assist	Etherize
Phrenic and peristalsis	Operate	Assist	Make nerve leg prepar't'n	Apparatus
		Account for apparatus		Account for apparatus

Success in the experiments, requires that the apparatus shall be thoroughly understood before the work is begun.

Students assigned to this work will be given an opportunity to study the apparatus, and be quizzed on these notes, the latter part of the preceding afternoon.

APPARATUS.—The arrangement of the apparatus is to be seen in Fig. 30. The following list of apparatus and instruments will be required, and everything must be at hand before the work is begun.

Apparatus to be Furnished by Laboratory.

Animal-board with head-holder.
Manometer outfit.
Artificial respiration outfit.
Bottle of ether.
Bulb and cannulae for artery.
Cannula for trachea.
Two burette clamps.
Three clamps for stand.
Screw clamp for trachea.
Four screw clamps for rubber tubing.
Four cords for animal board.
Two cords with hooks.
Etherizing cone.
Two cloth covers.
Dish for sodium chloride solution.
Dropper.
Small bulldog forceps.
Large bulldog forceps.
Jar for sodium sulphate.
Battery jar.
Ligatures, fine.
Ligatures, coarse.
Water manometer.
Aneurism needle.
Pinch cock.
Rod, nickled.
Rubber tube with glass T.
Scalpel.
Sponge.
Two small stands.

Receiving tambour.
 Recording tambour.
 Two towels.
 Silk thread and weight.
 Stimulating electrodes.
 Time signal.

Apparatus to be Furnished by the Four Students assigned to the work.

One dry cell.
 Induction coil.
 Kymograph and two drums.
 Mercury key.
 Two plates.
 Brush for salt solution.
 Fine and strong scissors.
 Fine and strong forceps.
 Five wires.
 Cabinet maker's clamp.

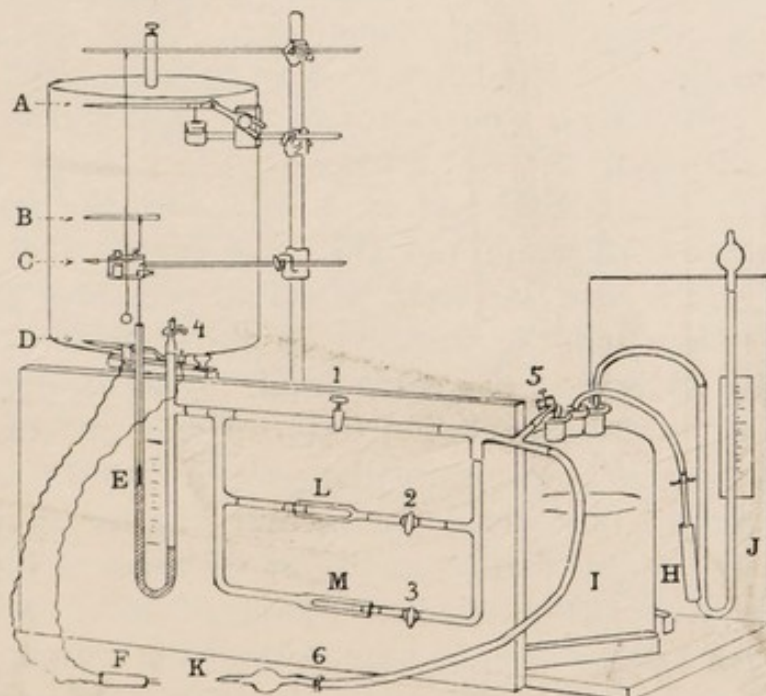


Fig. 30. Scheme of apparatus for studying the blood pressure of a mammal. A, tambour lever; B, pointer of a manometer float; C, time signal; D, short circuit key; E, mercury float; F, electrodes; H, bicycle pump; I, anticoagulation fluid pressure bottle; J, manometer communicating with pressure bottle, K, bulb and cannula; L, minimum valve; M, maximum valve; 1, 2, 3, cocks; 4, 5, 6, clamps.

DIRECTIONS TO STUDENT CARING FOR APPARATUS.

Connect time signal (*C*) and an electric light switch in the clock circuit. Place the induction apparatus behind the manometer outfit, and put a dry cell and a key in the primary circuit, connecting them so as to give a tetanizing current. Connect secondary coil with short-circuit key (*D*) on top of manometer board. Fasten a pair of electrodes (*F*) to key (*D*), with wires leading off in front of manometer. Start vibrator, open short circuit key, and test current with tongue. A current of medium strength will suffice. See that writing points of manometer (*B*) and key (*D*) write in same vertical line.

Now with cock 1 and clamp 5 closed, raise pressure to 90 mm. in bottle (*I*) containing anticoagulation fluid, by using bicycle pump. Pump very carefully, or the mercury will be forced out of manometer. Next raise bulb *K*, until it and its tube are vertical; open clamp 6; then gradually open clamp 5, and let fluid rise in tube and fill bulb; finally close clamp 5. Now lower bulb until on a level with the mercury of the recording manometer. Open cock 1, and as soon as the float has taken its new position, close cock 1, and put bulb in such a position that any drip will be caught in dish provided for the purpose. Place point of time signal (*C*) just behind and on a level with the pointer of the manometer float (*B*). The time record will in this position give a base line from which all pressures are to be read. Notice that the mercury in the two arms of the manometer is not at the same level. This is due to the weight of the anticoagulation fluid on one side of the U.

By means of pump, raise the pressure in the bottle of anticoagulation fluid until the mercury in the manometer connected with the bottle stands at 90 mm. Pump with care. Pinch off rubber tube at opening of bulb; open clamp 5; and then *gradually* open cock 1, until the mercury in the recording manometer rises to 50 mm. Close 1 and 5. The true pressure is twice the amount recorded, for the mercury falls on one side of the tube as it rises on the other. The object of raising the pressure, is to limit the amount of

blood which will leave the artery when it is connected with the manometer.

The apparatus must be ready to use the instant that the operation is completed. Have two drums blackened, and mark the position of the writing points on the drum which is to be used first.

During the taking of the records the man in charge of the apparatus must start and stop the drum; must mark the position of the writing points on the drum before each curve; must give the stimulations by depressing the short circuit key, and see that the drum runs for at least 10 seconds before and 15 seconds after each test; and must label each record with his name and the number of the curve before giving it to the assistant to fix.

Directions to Assistant.

It is the business of the assistant to see that the instruments, ligatures, and cannulae are in order, and are at the hand of the operator throughout the operation and the experiment. While the animal is being etherized, fill the animal board with water at 45° C.; heat some salt solution in a dish provided for the purpose, put a sponge in it, and place it on the operating table; also put two cannulae of different sizes in a dish of anticoagulation fluid. During the operation be ready to sponge the wound, to pass needed instruments to the operator, and to tie the ligatures when required. During the experiment, when the records are being taken, blacken the drums. There should always be a drum ready for use.

Anaesthesia.

Anaesthesia comes on in three stages: (1) imperfect consciousness, (2) excitement, (3) complete anaesthesia or narcosis. These stages show the following peculiarities, which must be kept in mind in administering ether. (See Cushny's Pharmacology.)

STAGE I.—Loss of consciousness begins toward close. Struggling because of dislike of drug; respiration irregular

from irritation of mucous membrane, salivation for same reason; pupil dilated.

STAGE II.—Lessening of reflexes toward end; struggling due to nervous excitement caused by drug; respiration heavy with pauses and gasps; pupil dilated.

STAGE III.—The danger period. Unconsciousness; respiration slow and shallow, often snoring; pulse slow and feeble; pupil small until danger point is reached, when it dilates; corneal and other reflexes are lost.

Rabbits differ from men, dogs, and cats, in that convulsive respirations immediately precede death in the third stage.

Directions to Anaesthetizer.

See that there is no gas flame in the same part of the room. Ether vapor travels far and is exceedingly inflammable.

Let the student who is to operate, hold the four legs of the rabbit between the fingers of the left hand, and hold the ears between the second and third fingers, and the nose between the thumb and index finger of the right hand. He should take care not to use unnecessary force, there is no need of hurting the animal.

The anaesthetizer puts some ether on the gauze of the cone, and places the cone over the animal's mouth and nose. The ether bottle is to be kept corked when not in use. It is well to place a towel beneath the head, and bring it up to the sides of the cone. Ether vapor is heavy and falls, hence the towel prevents waste and facilitates use. Do not "force the ether," i. e., let the animal have plenty of air to breathe. Remember that etherization is not asphyxiation. The man giving the ether *must think of nothing else*. If the animal dies through his fault, he must pay for another, (50 cents). Watch especially the respiration, and when in doubt, pinch foot, to see if leg reflex is present; also note the corneal reflex, which consists in a closing of the lid when the cornea is lightly touched. When well under, the animal should breathe regularly and quietly. If the respiration becomes irregular, with pauses, and the reflexes are

present, the animal is "coming out" and needs more ether. If the respiration stops, or becomes convulsive, immediately test the reflexes, and if the reflexes are absent and the pupil is dilated, stop the ether, start artificial respiration, and call instructor. The amount of ether should be lessened when the third stage is reached, and only a little given at intervals, to keep the animal asleep. In case coarse rales caused by

Operation for Isolation of Carotid and Vagus.

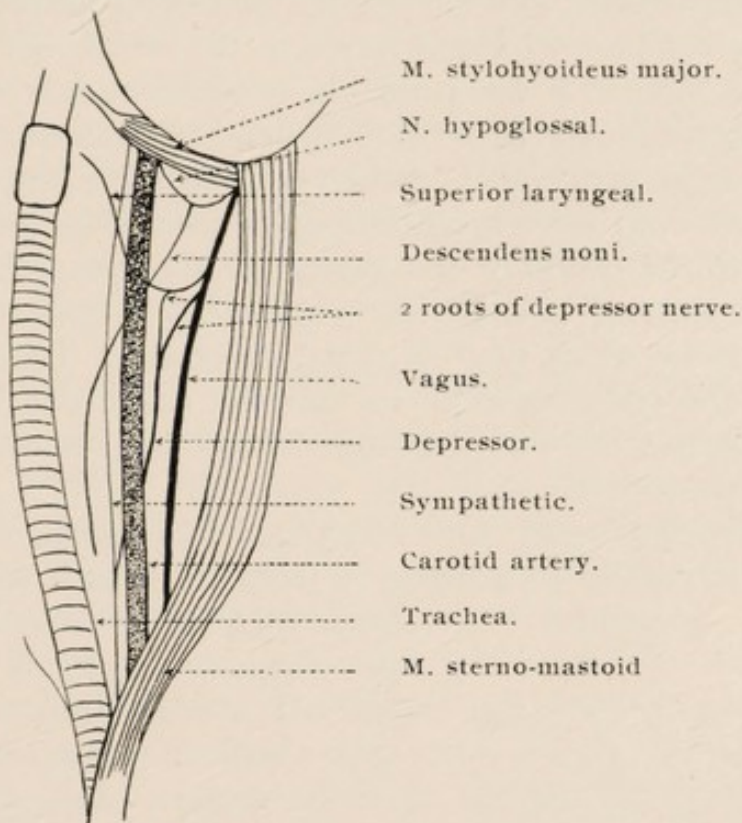


Fig. 31. Dissection of nerves of left side of neck of rabbit. The trachea has been pulled to the right and the nerves to the left.

collection of mucus are heard, swab out the throat with absorbent cotton on large forceps.

When the animal is sufficiently under to have stopped struggling, fasten it on animal-board, by placing a noose about each leg above the hock, and tying the cords to the cleats on the sides of the animal-board. Put head in head-holder. The instructor will show the method of application.

As soon as the animal's head has been placed in the head-holder, remove the hair from front of throat for a

space 1.5 in. wide, and from top of thyroid cartilage to sternum. Put the hair in a battery jar.

Sponge off the loose hairs, and as soon as the reflexes have ceased make a median incision with scalpel through skin, from top of thyroid cartilage to near top of sternum. Avoid veins at lower part of incision. Cut through the platysma muscle in the median line. Tie off any large vessels that have been cut, and have assistant sponge off blood with warm salt solution. Separate sterno-mastoid from sterno-hyoid; this brings the sheath of carotid artery into view. Close to the artery are the veins and nerves. From this time on it will probably be better to tear away the fascia longitudinally with the blunt end of an aneurism needle or similar instrument, rather than to use a knife. The descendens noni lies superficially; the vagus lies behind the carotid; to the inside of the vagus are the sympathetic and depressor nerves. Isolate the vagus, the largest of these, for a distance of an inch or more and pass a thread under it, tying the ends together so that the nerve can be lifted by the loop. Avoid pinching, stretching, or otherwise injuring the nerve.

Prepare the *upper part* of carotid for insertion of cannula, by carefully separating it from its sheath for a distance of at least an inch. Pass

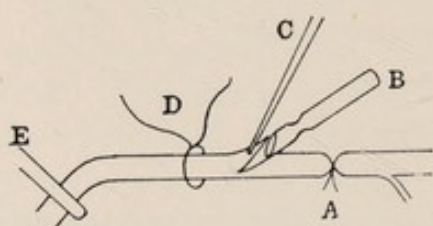


Fig. 32. Method of inserting cannula into carotid artery. A, ligature tied to the distal side of the place where the cannula is to be inserted; B, cannula; C, forceps; D, loop of ligature placed around artery, to the proximal side of point where cannula is to be inserted; E, bull-dog forceps.

two ligatures under it, and tie one of them tightly at the upper end of the exposed part of the artery; place the other so that it can be used at short notice to tie the cannula in place. Apply a pair of bull-dog forceps to lower part of artery to shut off blood. There are two methods of inserting a cannula, viz: 1. Grasp with

fine pointed forceps as small a part of the arterial wall as you can hold securely, and with fine pointed scissors make a diagonal slit in the direction of the heart and through about half the width of the artery. Still holding the flap,

insert the cannula which the assistant has just taken from the dish of Na_2SO_4 , and let him tie it firmly with the ligature which has been placed there for the purpose. 2. Place the index finger of the left hand beneath the artery; with sharp, fine pointed scissors make a cut in the wall of the artery; and without withdrawing the finger insert the cannula. It is of advantage to put the cannula into the upper part of the artery, so that the lower part can be used in case the cannula has to be put in a second time. Fill cannula with anticoagulation fluid, by means of a fine pipette, *the instant* the cannula is tied in. Now without losing time, place the animal-board so that the cannula can be readily connected with the bulb on the manometer outfit. Make sure that the cannula, bulb and connecting tube, are full of anticoagulation fluid, and then connect them. Fasten the tube of the bulb in a burette clamp, in the position which will bring the least possible strain on the artery.

a. Measure of the Blood Pressure in the Carotid.

As soon as the cannula has been fastened to bulb, remove bull-dog forceps, and make sure that there is no leak between the cannula and the artery. The blood should be seen to enter the cannula and diffuse into the fluid in the bulb. If all is right, gradually open stop-cock 1. Then start drum at rate of 5 mm. per second. The manometer float should rise, and the height of arterial pressure be recorded. Let the drum run until 25-30 cm. have been recorded. This record is to be divided later among the students, the operator taking the first part of the curve. Notice that curve shows larger waves of pressure due to respiration, and upon these, smaller waves caused by heart beats. The small waves do not show the amount of blood expelled by heart, but the effect of corresponding pressure changes in the artery, on the mercury in the manometer.

b. Maximal and Minimal Blood Pressures.

Observe that the valve *L*, controlled by cock 2, permits fluid to pass only *from* the manometer, and that the valve *M*, controlled by cock 3, permits it to pass only

toward the manometer. These valves permit us to measure the minimal and maximal pressures. *The mercury manometer records only the mean pressure*, for the inertia of mercury is too great to permit it to follow accurately the changes in blood pressure. *To find the maximal pressure*, first start the drum and take a short normal record, then stop drum and close stop-cock 1 and open cock 3. The float should rise and record the maximal pressure. Let drum turn a short distance, then stop drum, close cock 3 and open cock 1. *To find the minimal pressure* repeat the procedure, this time opening cock 2. The float should fall until it indicates the minimal pressure.

c. Excitation of the Peripheral End of the Right Vagus.

The operator now ties two ligatures around the vagus near each other and close to the center of the isolated portion of the nerve, and then cuts the nerve between them. Place peripheral end of vagus on the electrodes, taking care that they touch nothing else. Close key of primary circuit; see that vibrator works well. Record a curve of normal pressure for about 10 seconds and then let the apparatus man open short-circuit key. If weak, the current should slow the heart, and if strong, should stop it. Strengthen current if necessary. Excite for only about 10 seconds, then close short circuit and watch recovery about 15 seconds. Repeat the experiment 4 times, to provide a record for each student, and give an interval of half a minute between the succeeding tests.

d. Record of Respiration with Pneumograph.

Place a receiving tambour on a stand, so that cork attached to the membrane rests against the base of the thorax of the animal in the position to give the greatest movement. Connect with recording tambour, shown at *A* in Fig. 30. Take record of respiration with each of the experiments of part *d*.

e. Excitation of Central End of the Vagus.

Now while taking record of blood pressure and respira-

tion, excite central end of vagus with weak current. Afferent (sensory) fibers are excited, resulting in the following:

1.—Excitation of respiratory center, causing change in amount and frequency of respiration.

2.—Excitation of vaso-motor center, causing usually a rise, but occasionally a fall of blood pressure.

3.—Excitation of vagus center, causing slowing of heart and usually a fall of pressure, in spite of vaso-constriction which may occur.

4.—If current is too strong, and the anæsthesia incomplete, there may be reflex excitation of motor centers, causing convulsive movements which may mask the other effects and cause a rise of blood pressure.

Now let the student tie off the right carotid below cannula; remove cannula from artery; hold a dish under the cannula and then disconnect bulb from manometer tube; wash bulb and cannula out thoroughly; connect bulb again with manometer; put cannula in dish of Na_2SO_4 . Handle bulb and cannula with care, as they are fragile and hard to replace. Sponge up all fluid spilled and put apparatus in order for next experiment. Disconnect and remove pneumograph.

f. Excitation of Peripheral End of Left Vagus.

The student who is to operate, takes the animal-board to the operating table and proceeds to prepare the artery and nerve of the left side, the other students doing the work assigned in the schedule. When the operation is finished, test and record normal blood pressure as before. Any experiments not successful on right side may be repeated. In any case the operation is to be done and a normal record taken.

g. Excitation of Sciatic Nerve.

The sciatic nerve lies beneath the vastus externus on the middle of the external surface of the thigh. Remove hair over region; cut skin longitudinally for 2 inches; cut through vastus externus and expose the nerve. Animal must be well under the ether before nerve is handled, and

especially on stimulating. Pass a ligature under nerve and tie ends together. When ready to excite, ligate peripheral end of part exposed and cut peripherally to ligature; place nerve across electrodes, which must not touch anything else, then apply current. See rise of blood pressure due to reflex vaso-constriction, or, as not infrequently occurs a fall due to reflex vaso-dilation (see Howell, p. 541). If current is too strong or animal not well under, convulsive movements will be produced which will mask the effect desired.

h. Blood Pressure during Asphyxia.

Expose the trachea and place *low down* upon it a clamp used for rubber tubing, so that the trachea can be closed off quickly. Start drum at rate of one or two mm. per second, then clamp off trachea, marking the instant this is done by means of short circuit key. Observe the following stages:

1.—DYSPNOEA. Blood pressure rises gradually. Deep and prolonged respirations, with short expirations, soon affect the blood pressure in a marked manner.

2.—CONVULSIONS. Each convulsion is accompanied by a rise of blood pressure.

3.—Weakening and slowing of heart beats; respirations feebler and fewer; finally both heart beats and respirations stop.

i. Elasticity of Lung Tissue.

Make incision in trachea; insert cannula; and connect with a water manometer, noting the level of the fluid. Open the chest and observe the rise of water in tube when air enters chest and lungs collapse. To open chest, first make an incision with knife over the entire length of the sternum; grasp ensiform cartilage with strong forceps; push point of shears or bone forceps through chest wall at end of ensiform cartilage and cut sternum lengthwise, in the median line, to within an inch of its upper end. Keep point of shears close to sternum, to avoid cutting lungs or other organs. Pull the cut edges of the sternum apart and see the collapsed lungs. Note the amount of elastic contraction

of the lungs, as measured by height of rise of water in manometer.

NOTES.

In mounting the curves, be careful to preserve the part of each record which shows the relation of writing points, and the portion showing 10 seconds before, and 15 seconds after the period of stimulation. Draw long vertical lines across the curve, to the top of the paper, at points 4 seconds before stimulation, at the end of stimulation, and 10 seconds after stimulation; also draw shorter verticals at a distance of 3 seconds on each side of the long verticals and cutting the respiration and blood pressure curves.

To find the blood pressure, measure from the base line given by the time signal to the middle of the highest pulse beat near a long vertical, and multiply by two. For heart rate, count the pulse beats in the 6 seconds between the short verticals and multiply by 10. In a similar manner determine the number of respirations per minute. Write the figures obtained, on the cardboard above the mounted curve, at points corresponding to the observations.

In the notes accompanying the curves, state the cause of the changes in arterial pressure, pulse, and respiration caused by the excitations. Give brief statements of the results obtained under each of the subheadings of the experiment.

EXPERIMENT XXVI.

Circulation and Respiration of the Mammal, Continued.

a. Excitation of Right Depressor Nerve.

The depressor is an afferent nerve from the root of the aorta, and hence excitation of the peripheral end has no effect. Excitation of central end has little effect on the cardiac centers, but causes dilation of peripheral vessels.

Expose the carotid as in Experiment XXV. To find the depressor, remember that vagus lies behind artery and the depressor and the sympathetic to the inner side. High up the vagus gives off a transverse branch, the superior laryngeal, (see diagram, Experiment XXV) to the larynx. The depressor arises as a very slender nerve by two branches from this, or one from this and one from the vagus. Find the place of division, then trace the nerve down for an inch or more, tie a thread about it and cut peripherally to thread. Handle nerve with utmost care and see that it does not dry.

Now isolate carotid and insert cannula, connect with manometer; apply pneumograph; record normal curves of blood pressure and respiration. Excite central end of depressor while drum is running. The latent period is long. Excite only long enough to produce an evident effect, and let drum run till recovery is well under way. Take four records, waiting in each case until recovery is complete. Notice that rate of heart is practically unchanged.

b. Excitation of Left Depressor Nerve.

Prepare depressor and carotid of other side and repeat above experiment.

c. Tracheotomy and Artificial Respiration.

Remove cork of bottle in outfit for artificial respiration, put about an inch of ether in the bottom, replace the cork. Make an incision in the trachea, insert the cannula, and tie it firmly in place with a strong ligature. Now give the

ether by holding the cone above the tracheal cannula. To open the chest, first make an incision with knife over entire length of sternum, grasp ensiform cartilage with strong forceps; push point of shears or bone forceps through chest wall at end of cartilage and cut sternum lengthwise, in the median line to within one inch of its upper end. Keep point of shears close to sternum to avoid cutting lungs or other organs. Special care is necessary at the upper part, or blood vessels will be cut. While this is being done, the apparatus man should prepare artificial respiration apparatus and test the amount of ether it gives. Regulate supply of ether by means of clamps on tubes connecting with ether bottle.

As soon as the chest is opened, with clamp on side tube open, connect tracheal cannula with ether bottle, and start bellows, pumping at rate of once a second. Screw up clamp on side tube until the lungs are seen to expand and relax well.

Observe the effect of artificial respiration on the curve of blood pressure. The respiratory waves of the curve are now reversed, the curve falling soon after the air begins to enter the lungs, and rising soon after beginning of expiration, due to elastic recoil of lung.

d. The Current of Action of the Heart.

Draw chest walls apart with the hooks provided. Open the pericardium widely, taking care not to cut the heart in doing so. Now hold the bone of a nerve-leg preparation in forceps, with nerve hanging down; let the nerve lie upon the beating ventricle lengthwise; the muscle should contract with each beat. If it does not, lift it and try again. The warm blood quickly injures the nerve, and hence the latter should not be left long in contact, until the desired effect is seen.

e. Observation of Exposed Heart during Vagus Excitation.

Observe the effect of excitation of the peripheral end of a vagus nerve on the rate and strength of beat of the exposed heart. Test with weak, medium, and strong currents

f. Tension of Ventricle during Systole and Diastole.

Take the ventricle gently between the thumb and fingers, and feel it harden with each systole.

g. Observation of the Changes in Heart during Death from Asphyxia.

Open chest widely so as to obtain a good view. Stop artificial respiration and observe the effects of asphyxia on the rhythm of auricles and ventricles as the heart dies. Make notes of the order in which the strength of beat of auricles and ventricles changes. Notice any irregularities, and which auricle or ventricle gives out first. What part of heart is most distended at death?

h. Innervation of Diaphragm by the Phrenic Nerves.

These nerves are easily found, running down lateral and posterior sides of pericardium. Excite one, then the other, observing contraction of diaphragm from upper side. Open the abdominal cavity by one incision in median line; observe relations of organs; push viscera down and excite phrenic while looking at under side of diaphragm. Notice that contraction of diaphragm depresses the floor of the chest; thus increasing chest cavity and lessening abdominal cavity.

i. Peristalsis of Intestines.

Observe any peristaltic movements that may occur because of exposure to air and loss of blood. See direction of waves. Watch for anti-peristalsis. Try effect of mechanical and electrical stimulation of stomach and intestines. Excite bladder electrically.

NOTES.

Write up the notes as directed in the preceding experiment.

EXPERIMENT XXVII.

The Carotid Pulse in Man.

a. *The Form of the Pulse.*

Mount a recording tambour on a stand and connect it with an open tambour designed for carotid artery, leaving side tube open. *See that the lever of the tambour is horizontal.* Apply the open tambour to the skin of the neck over the artery, and fasten it in place with the U-shaped spring, placing the ball of the spring in the socket on the back of the tambour and placing the block against the

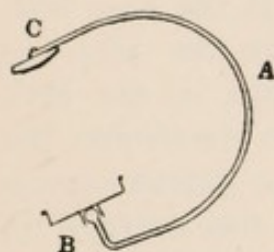


Fig. 33. Tambour and neck spring used to study the human carotid pulse. A, spring; B, ball-and-socket joint, on back of open tambour; C, block.

opposite side of the neck. Then test the working of the outfit by pinching the side tube. With each heart beat there should be an excursion of the lever of at least 5 mm. Adjust position of tambour on neck, and pressure of spring to give the largest pulsation, then bring writing point very lightly against drum. Start drum at 5 mm. per second, close side branch with spring clip and record the curve of the pulse.

Unless the friction of writing point upon drum is made as slight as possible, small waves of the pulse curve will be obscured. Mark on the curves to indicate the primary wave and the dicrotic notch. The former results from the systole of the ventricle, and the latter from relaxation of the ventricle and closure of the semilunar valve. The dicrotic notch therefore divides the pulse into its systolic and diastolic portions, and is to be looked for at about the end of the first third of the curve. Do pre-dicrotic or post-dicrotic waves occur in the record? Take records with four widely different speeds of drum, and observe the effect on the form of the curve.

b. *The Pulse Rate.*

Mount a time signal to write below the pulse curve, connect it with the *clock* circuit, start drum at 5 mm. per sec-

ond, and record the curves of time and pulse. Draw perpendiculars at intervals of ten seconds cutting the pulse curve, and determine the rate of the pulse for three consecutive periods of ten seconds.

c. Duration of Systole and Diastole.

Mount a fork in place of the time signal and record curves of pulse and fork with the fastest speed of drum given by clockwork. Then, without moving drum, remove clip from side tube, and record a base line for the pulse curve. When the curves have been fixed, draw arcs with dividers from beginning of primary wave and from bottom of dicrotic notch to the base line, using a radius equal to the length of the writing lever and centers on the base line. Draw perpendiculars from the points where the arcs cut the base line, through the fork curve. Count up the fork waves between the perpendiculars, and thus determine the duration of systole and diastole. Make this determination for five consecutive pulse beats and state the average in your notes. Results should be changed to 100ths of a second by using number found in calibrating fork.

d. Effect of Exercise.

Go through the form of taking a normal record, as in *c*, to make sure that the neck tambour is properly adjusted, and that the recording tambour is writing well. Then, without moving the drum or either tambour, detach the rubber tube where it joins the glass T. Take a quick run down stairs and back, connect up the tambour as soon as possible, and record the accelerated pulse. Determine duration of systole and diastole as before.

Which changes most in the quickening of the pulse due to work, the systolic or the diastolic portion? Are any other changes in the pulse curve to be observed? If so, describe them.

EXPERIMENT XXVIII.

The Radial Pulse Studied by the Tambour Method.

a. Form of Radial Pulse.

Connect a recording tambour with a tambour designed for radial artery, leaving side branch of tube open. Arrange

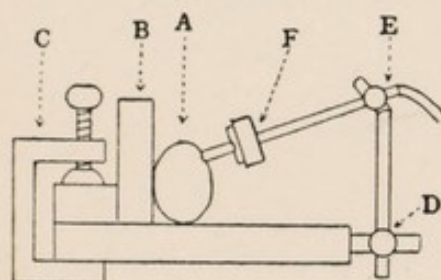


Fig. 34. Method of applying tambour to wrist, to obtain sphygmogram from the radial artery. A, cross section of wrist; B, back board of arm support; C, cabinet maker's clamp; D, clamp fastening L rod to the horizontal rod of arm rest; E, clamp fastening tube of tambour to short arm of L rod; F, tambour with disk, and prop to rest on artery.

arm rest and tambour as shown in the diagram. Mark the point on left wrist where strongest pulse is felt. Subject seats himself comfortably in chair, holding one end of arm rest in lap, while other end is placed on table or stool so as to tilt it at a suitable angle for the arm to rest easily. Place arm on rest with marked point toward tambour; fasten thumb with loop of cloth, using holes in back

board; apply button of tambour to marked spot, and adjust tambour so that rod bearing button is in line with tube of tambour and perpendicular to surface of wrist. Vary the pressure on artery by sliding tube of tambour in clamp until largest pulsation is given. An excursion of 3-5 mm. with each heart beat should be secured, but a smaller movement will suffice where this cannot be obtained. The arm must be relaxed and perfectly quiet. Record the radial pulse on a drum and observe whether the same waves appear as in the carotid pulse.

b. Postponement of the Radial Pulse.

Arrange to write carotid and radial pulse and fork curve in same vertical line. Make sure that the levers of the tambours are horizontal. Mark *relative position of points*, then record the three curves with fastest speed given

by kymograph. Without disturbing apparatus, remove clips from side tubes and, with the levers horizontal, record base lines for the two pulse curves.

Fix the tracing, and then, with centers on the base lines and the lengths of the levers as radii, draw arcs from beginnings of corresponding primary waves to their respective base lines; then correcting for positions of points, draw perpendiculars through fork curve and find duration of postponement of radial pulse as compared with carotid pulse. Take average for three consecutive beats.

EXPERIMENT XXIX.

The Radial Pulse as Recorded by the Jacquet Sphygmograph.

This is probably the most useful instrument for examination of the pulse that we have. It is fragile, and must be handled with care and returned in good condition. The strap *A* is buckled about the left wrist, with the end *B*

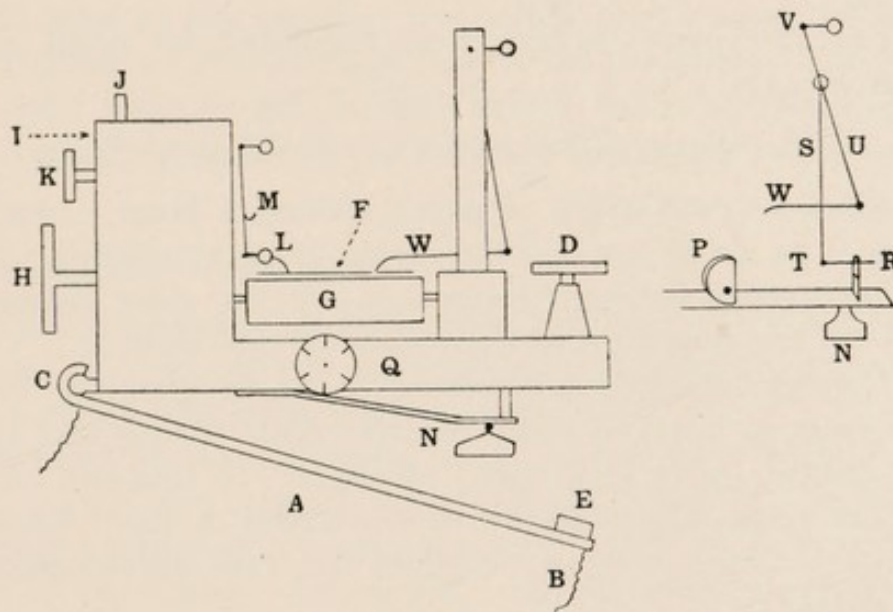


Fig. 35. Scheme of Jacquet's sphygmograph.

toward the hand. The instrument slips into groove *C* of base, and thumb-screw *D* is turned into socket *E*. The paper, shown in cross section at *F*, runs between the roller *G* and two small wheels above it. Clock for moving paper is wound by means of large thumb-nut *H*, started and stopped by lever at *I*, and lever *J* gives a change of speed. Clockwork for time marker *L*, is wound by means of thumb-nut *K*, and gives fifths of a second. *M* is a clasp for holding *L* up out of harm when not in use. Button *N* is pressed on artery by cam wheel *P*, turned by thumb-nut *Q*, to vary the pressure. Movements of *N*, are transmitted through rod *R*, to lever *S*, turning on axis *T*, thence to lever *U*.

turning on axis *V*, and finally to marker *W*. Position of writing point on paper is regulated by thumb-screw *D*.

CAUTIONS.

(1) Be careful not to injure the time marker. Raise and lower it with the fine point of a knife or pencil. It must *always* be lifted into clasp before removing the paper.

(2) Avoid bending the writing pointer when inserting the paper.

(3) Do not wind the clockwork too tight.

(4) Instrument must be held level to record time accurately.

(5) Pressure on artery is regulated by *small* movement of cam.

a. *Normal Curves and Effect of Position of Body.*

Place several strips of paper around a large drum, and blacken as usual, cutting the strips loose as needed. Place end of a strip between roller and wheels, start clockwork, and run the paper in, to the extent of one inch.

Having adjusted instrument so as to give the largest pulsation, proceed to make records while sitting and standing quietly, using slow speed of paper. In this and all subsequent tests, take care not to move arm or hand when the record is being written. Report the rate as recorded for six seconds.

b. *Effect of Compressing Brachial Artery.*

While the tracing is being taken, compress the brachial artery with hand or a tourniquet.

c. *Effect of Deglutition.*

Start the paper at the *fast rate*, record a few beats, then, while record continues, take several swallows of water in quick succession, marking on the record the *exact time* when the swallowing begins and ends. Determine the rate before, during, and after swallowing. The increase in rate is explained as a lessening of vagus influence. The swallowing center is in the medulla oblongata not far from the

vagus inhibitory center, and nervous impulses overflowing from the former inhibit the latter.

d. Effect of Inhalation of Amyl Nitrite.

Slow speed of paper. Record normal pulse for 10 beats, then begin to inhale a drop of amyl nitrite that will be placed upon a handkerchief by the instructor. Associate should mark on record the *exact time* of inhalation. Continue record to end of paper. This drug acts chiefly, when taken in small amounts, on the muscles in the walls of the small vessels, causing a dilation. Fall of blood pressure and increased diastole of the pulse results. The change in the level of the writing, frequently seen, cannot be taken as evidence of the diminished arterial pressure. The writing point must be placed high before the inhalation occurs, or it will run off the lower edge of the paper. *Do not repeat.*

e. Valsalva's Experiment.

This experiment and the following one are not without danger, and should not be practiced to excess, nor by anyone with an abnormal heart or arteries.

Record 10 normal beats, then take a deep breath, and, with mouth and nostrils closed, make a strong expiratory effort for eight or ten seconds, then breathe freely. *Mark time of each stage on record.* Report effect on rate and shape of pulse curve. The latter is especially interesting. The expiratory effort drives the blood out of the chest into the arteries, and prevents entrance of venous blood into the chest by compressing veins and right heart.

f. Müller's Experiment.

Record ten beats, then exhale as completely as possible, and with mouth and nostrils closed make a strong inspiratory effort for ten seconds, then breathe freely. Mark on record and report as before. The forced inspiration tends to keep the heart and large vessels dilated, tends to prevent blood from leaving chest, and causes a rush of blood into the chest by way of the veins.

The sphygmograph cannot give a measure of blood pressure. The changes to be observed in the level of the curve are in part due to alteration of the amount of distension of the venae comites about the artery.

EXPERIMENT XXX.

Capillary Circulation in the Web of the Foot of a Frog.

Destroy the brain of a frog by a pithing needle, and plug the skull cavity with a pointed match. Be sure to have the match ready to insert at the instant the pithing needle is withdrawn, so that the least possible blood shall be lost. Wrap frog in moist cloth and place on special frog-board, face down, and spread the web over the opening, keeping in place by pins through outer toes. Avoid stretching web too tightly, and keep it moist, not wet. Place board on microscope stage.

Examine first with low power. If the blood is not seen to circulate through the smaller vessels, the web has probably been stretched too tightly, or the frog has not recovered from the shock caused by pithing. Decide which of the vessels are arteries, capillaries and veins, observing where the blood flows from large to small and from small to large vessels, where the blood stream is most rapid and where it pulsates.

I. Now choosing a small artery, observe with higher power the following points:

- a. Pulsating stream.
- b. Rapid axial stream; lighter, peripheral layer,—the "inert layer."
- c. Eddies of the stream at a bifurcation.

II. Examine a small vein and observe:

- a. Constant stream (sometimes pulsating if the shock from the pithing has not been recovered from, and there is vaso-dilation).
- b. Slower current, and less marked "inert layer" than in artery.

III. Examine capillaries, and observe:

- a. Frequent anastomoses.
- b. Condition and behavior of corpuscles.
 - A. Red corpuscles (erythrocytes).
 1. Shape, transparency, color.

2. The number that can pass abreast in a capillary.
3. Position of long axis with respect to current.
4. Elasticity, and change in shape when compressed, or when turning a corner.
5. Passage through a capillary apparently smaller than cell.

B. White corpuscles (leucocytes).

1. Shape and color.
2. Peripheral arrangement.
3. Slow progression, and rolling motion.

IV. *Vaso-motor Action.*

Expose sciatic nerve, using the utmost care not to injure the blood vessels. Cut high up, and dividing branches, raise from wound and lay on a piece of moist filter paper placed over the skin. (There is an acid secretion on the skin which will injure the nerve.) Of course the nerve must be handled as little as possible and never be compressed. Now excite nerve with induction current at the same time that a suitable part of the web is being examined with a low power. The vessels should be seen to grow smaller and the circulation should be consequently slowed, or stopped.

V. *Diapedesis, i. e., Migration through Wall of Capillary.*

(This is optional.) This is not often seen to occur under normal conditions, but the phenomenon is of frequent occurrence when an irritant causes local inflammation. This can be best studied in the mesentery, a slight burn from a hot glass rod being a suitable irritant.

Examine with low power the effect upon the circulation of the part. Then choosing a capillary whose walls can be seen distinctly, watch carefully a leucocyte resting against the wall, and observe its change of shape as it passes through the wall. Make drawing illustrating the method of progression. Red corpuscles do not pass through, unless the walls have been greatly injured, since they do not possess amoeboid power.

EXPERIMENT XXXI.

Measurement of Human Blood Pressure in Different Positions.

The blood pressure is a measure of the potential energy available for overcoming the resistance offered by the walls of the vessels to the flow of the blood. Arterial blood pressure is a measure of the status of the following factors upon which it is dependent, viz: the amount of energy imparted by the heart to the blood, (varying with rate and strength of beat, and volume of output), and the amount of resistance encountered by the blood, (varying with the friction in the large vessels, determined largely by the elasticity of the walls, and with the friction in the small vessels, determined chiefly by the action of the vaso-motor nerves). Since a high blood pressure means excessive work for the heart, and since a very low blood pressure means that too little blood is being pumped, (because of lack of blood, imperfect heart action, or valvular lesions), or that the vessels are abnormally dilated, it is evident that a measure of the arterial pressure is of diagnostic importance.

If one presses with the tip of a finger upon the skin over an artery, at first very lightly, and then with more and more strength, he feels first a slight thrill, then a stronger pulse, and finally a lessening of the pulse, until it is altogether lost, except at the side of the finger nearer the heart. If the finger is gradually removed, these sensations are felt in the reverse order. With practise a fairly accurate estimate of the arterial pressure can be obtained in this way.

APPARATUS.—A sphygmomanometer is an instrument devised to measure more accurately than the finger, the systolic, i. e. maximal arterial pressure, and in the case of the Erlanger instrument, to also record the pulsations as a means of estimating the diastolic pressure.

THE RIVA-ROCCI SPHYGMOMANOMETER.—The instrument (see Fig. 36) consists of a reservoir of mercury, to

the bottom of which a capillary manometer tube passes, and which connects with a rubber cuff, which is strapped over the internal surface of the upper arm at the seat of the brachial artery, by a broad unyielding band of leather. Air is pumped into this system by a bulb, and is let out again, either rapidly through an outlet tube, or slowly through a fine pin hole in the cap of a vertical tube, controlled by the finger. A three-way cock permits communication to be made between the inflating bulb and the cuff, and between latter and the outlet tube.

GAERTNER'S TONOMETER.—This instrument permits one to know what pressure applied to the second joint of the

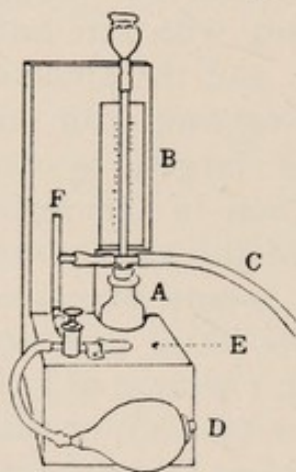


Fig. 36. Laboratory form of Riva-Rocci instrument. A, reservoir of mercury; B, capillary manometer tube; C, tube connecting with rubber cuff on arm (or in the case of the Gaertner experiment, with the pneumatic ring); D, rubber bulb; E, outlet tube; F, vertical tube, with pin hole in the cap.

finger, will prevent the blood from entering the finger, as shown by the sensation and change of color which follow the return of the blood. Gaertner considers this to be the mean arterial pressure. The instrument consists of a mercury manometer, connected with a pneumatic ring, to be placed over the second joint of the finger, and an inflating bulb. The same apparatus may be used as by the Riva-Rocci method, with the substitution of the ring for the finger, in the place of the bag for the arm.

ERLANGER'S SPHYGMOMANOMETER.

—(See Howell's Physiology, p. 456. Fig. 191 and 192.) This instrument records systolic and diastolic pressures. The mercury manometer, arm

piece and inflating bulb, are the same as for the Riva-Rocci. In addition to this the arm piece is in communication with a rubber bulb, which is enclosed in a glass bulb, which is connected with a recording tambour. The tambour records the fluctuations in pressure. Two forms of the apparatus exist in the laboratory, differing essentially in the stop-cocks used to govern the flow of the air. These are described on cards accompanying the instruments.

EXPERIMENT.—Each student is to determine the systolic pressure of his associate with the Riva-Rocci, Gaertner, and Erlanger instruments, and the diastolic pressure with the Erlanger apparatus, under the following conditions:

1. From the right arm in the sitting position.
2. From the left arm in the sitting position (the usual method).
3. From the left arm, standing, with arm supported on table.
4. From left arm, lying down.

In the sitting position, the subject's arm is to be placed, extended, on the table, on a level with his heart. In order to take the required number of observations, the student must thoroughly understand the instruments and the method of work, and have practiced taking the pulse in a number of preliminary tests. The results should be systematically tabulated, and a suitable table for entering them should be prepared before making the observations.

a. The Systolic Pressure.

1. GAERTNER'S TONOMETER.—Apply an Esmarch bandage to the finger. Connect the tube from finger ring or bag with the Riva-Rocci manometer. Using the bulb, carefully raise the pressure to 130 mm. Now turn the stop-cock so as to shut the inflating bulb off from the manometer. Remove the bandage. The falling pressure as indicated by the manometer can be controlled by placing the finger over the leak in the top of the vertical tube (*F*). Read the pressure when the formerly bloodless extremity of the finger first begins to flush and become cyanotic with the returning blood.

2. THE RIVA-ROCCI SPHYGMOMANOMETER.—Connect the arm bag with this instrument. While feeling the subject's pulse with the fingers of the right hand, with the left raise the pressure in the manometer to about 150 mm. Controlling the leak as before, read the pressure at the instant the return of the pulse is felt. CAUTION.—Do not mistake the pulse in your own fingers for that of the subject

3. THE ERLANGER SPHYGMOMANOMETER. — Having connected this instrument with the cuff on the arm, proceed as before and read the pressure at the instant of the return of the pulse. The danger of error from feeling the pulse in one's own finger tips, is slight if one notes that the pulse which is felt coincides with the pulsations of the tambour attached to the glass bulb.

b. The Diastolic Pressure.

THE ERLANGER SPHYGMOMANOMETER.—See that tambour lever writes lightly upon the drum. Raise pressure to about 100 mm., then allow it to fall to 90 mm. Shut off the leak and record on the drum a series of at least 15 pulse beats at this pressure. Now start the drum, open leak and allow pressure to fall 10 mm., close off leak and record another series of 15 pulse waves. Continue after this manner until the height of the pulsations decreases markedly. Be careful to mark on record the pressure at which each series of pulsations was obtained.

"After a certain level (in normal pulses 25 to 40 mm. below the systolic pressure) the extent of the oscillations diminishes rapidly. The lowest point at which it remains maximal is the diastolic lateral pressure." (Sahli.)

EXPERIMENT XXXII.

The Normal Sounds of the Heart.

The normal heart sounds may be heard with the unaided ear, but the stethoscope is commonly used. It consists

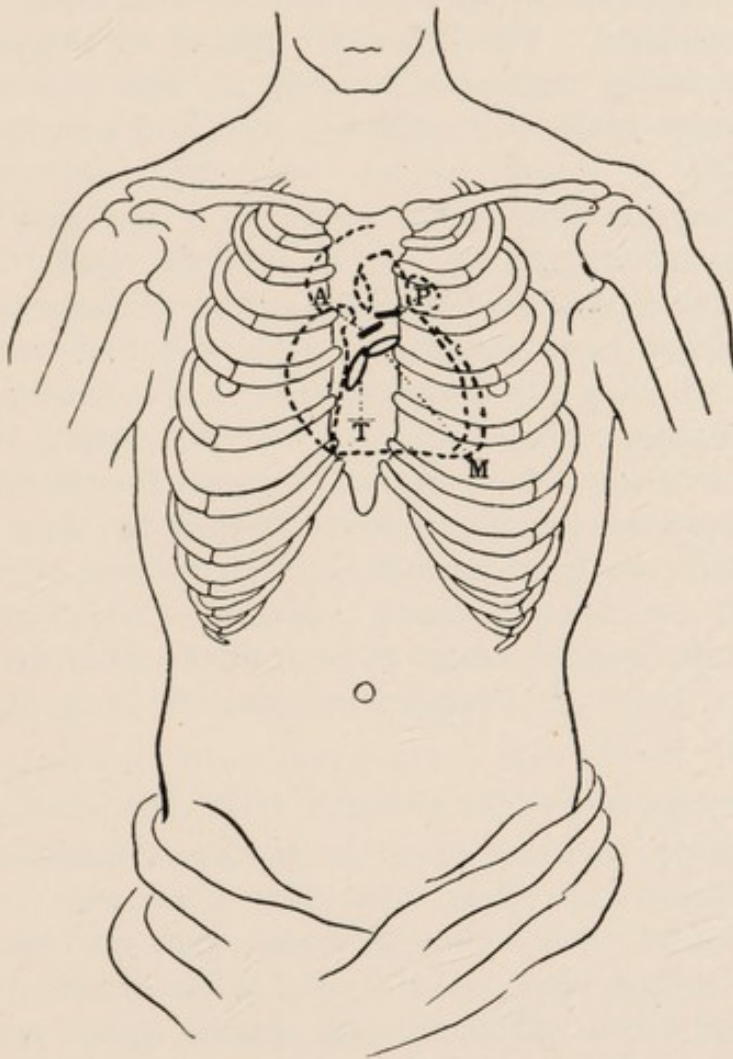


Fig. 37. Diagram showing position of heart in chest, position of valves as projected on the wall of the chest, and the parts of the chest where the sounds of the heart are heard best. M. position of apex beat, and sound from mitral valve; T, sound from tricuspid valve; A, sound from aortic valve; P, sound from pulmonary valve.

essentially of a receiving disk and a pair of ear-tubes, connected with tubing. It aids by multiplication of the sound and by excluding outside sounds. Distracting noises, to

be avoided, are apt to arise from (1) rubbing of tubes against each other or against clothing, (2) breathing by the listener upon the metal spring holding the ear-tubes, (3) movement of the receiving disk upon the skin, (4) movements or breath sounds of the subject, and (5) talking *by either subject or listeners*. The multiple instrument enables several persons to hear the same sound at once, and therefore is useful in teaching. The ear tubes should be cleansed before inserting them for the first time, to avoid possible infection. The tubes are placed in the ears with the tips pointing inward and upward. The receiving disk is held firmly against the skin. Avoid kinks in the rubber tubes.

The diagram shows the position of the heart in the chest, and the letters, *A*, *P*, *T*, and *M* mark the areas where the disk is placed in listening to the separate valve sounds. Each letter is connected by a dotted line with a dark spot showing the position of the corresponding valves. These four areas, known as the aortic, pulmonary, tricuspid, and mitral areas, are so named because the sounds made by the closure of the valves named are heard best in those places, but it must be remembered that no one of the valve sounds can be isolated at any point, but that all enter into the composite sounds heard at each area. It is the relative loudness of particular sounds that give the areas the names which they bear.

a. Auscultation over the Lower Part of the Chest.

One student of the group is chosen as subject, and he seats himself in a chair, the others seating themselves closely around him. The receiving disk is first applied over the mitral area, viz. at the point where the apex beat is felt, in the 5th intercostal space, slightly within the nipple line. With the disk in this position, listen to the heart sounds for several minutes. Observe (1) the two distinct sounds with a very short interval between them, (2) the greater loudness of the first sound, (3) the booming character of the first sound contrasted with the sharp click of the second. The *first sound*, which marks the beginning of the systole of the ventricle, is a compound

sound, composed of the click caused by the closure of the two auriculo-ventricular valves, the sound made by the contraction of the muscular substance of the two ventricles, and by the vibrations of the suddenly tensed chordae tendineae. The muscular element which prolongs the sound into the period of systole, helps to give it the booming character. Normally the two ventricles contract together, and the mitral and tricuspid valves close at the same instant, so that the action of the two sides of the heart is represented by a single sound. Compare it with the sound heard by placing the disk of the stethoscope on the muscle of the forearm and causing it to contract rhythmically. The *second sound* is produced by the closure of the aortic and pulmonary semi-lunar valves, which normally close at the same time. Now apply the disk over the tricuspid area and observe (1) the greater prominence of the valve sound and lessened muscle sound, (2) the clear and high pitched quality of the sound, (3) the comparative loudness of the first sound as before, and (4) the rhythm, which is also the same as in the mitral area. Change the disk quickly from one of these two areas to the other, so as to bring out distinctly the differences in the sounds. Apply it at intermediate points and observe how the characteristic sounds of one area gradually shade off into those of the other.

b. Auscultation over the Base of the Heart.

Apply the disk over the aortic area and observe (1) the greater loudness of the second sound as compared with the first, (2) almost complete absence of booming muscle sound, (3) the same rhythm as before. The sounds heard here are mostly valvular, and the aortic sounds predominate. Listen in same manner at pulmonary area, and compare the sounds heard in aortic and pulmonary areas. Listen at points intervening between mitral and aortic areas. Change the disk quickly between the four areas, and let the listeners try to recognize the area by the sounds heard. Use each student as subject in turn.

In diagnosis it is often necessary to locate an abnormal sound in relation to the pulse beat and thence to the

heart cycle. The first sound, produced by contraction of heart muscle and closure of auriculo-ventricular valves, is evidently *systolic*. The second sound, made by closure of semilunar valves, is evidently *diastolic*. Therefore, any sound occurring between the beginning of the first and the beginning of the second normal sounds must be *systolic*, and any sound occurring between the beginning of the second sound and the beginning of the first sound of the next cycle must be *diastolic*.

c. Time Relations of Heart Sounds and Pulse.

EXPERIMENT.—Record the radial and carotid pulse on a drum along with a signal connected with a cell and Morse key. Listen to heart sounds and let one listener so work the key that the click of the signal shall exactly coincide with the heart sounds. When he is able to do this well, as tested by all the listeners, run drum at fast speed and record the time of the sounds in relation with the two pulse curves. The reaction time to sound varies from 0.15-0.20 sec., according to the observer, hence to have the sound of the heart and the signal coincide, the experimenter will have to anticipate the beat, i. e., determine the rhythm by listening a short time and then tap at the instant that the beats are to be expected. Exact results cannot be obtained because there will be slight errors of judgment on the part of the experimenter, and because the rate of the heart varies somewhat with the respiration. Nevertheless, if care be used, a good picture of the relative time of the coming of the sounds of the heart and of the carotid and radial pulse can be obtained.

Notice that the first sound slightly precedes the primary upstroke of the carotid pulse (about .01 sec.), and that the second sound slightly precedes the dicrotic wave. Also observe that the primary wave of the radial pulse begins about half way between the two heart sounds. It is evident, therefore, that the place of any sound of doubtful nature can be located rather definitely in the cycle by its relation to the carotid pulse, but not so well by reference to the radial.

EXPERIMENT XXXIII.

Thoracic and Abdominal Movements in Respiration.

APPARATUS.—Mount two recording tambours and a time signal to write in a vertical line; connect the signal to clock circuit; connect the two tambours with special rubber tubes to two pneumographs, leaving side tubes open.

EXPERIMENT.—The subject seats himself comfortably, then the cord of one pneumograph is passed around his chest and the cord of the other around his waist. Tie them with a tension that will extend the pneumographs about 2 cm. Subject should sit so as not to see the curves and should pay as little attention to breathing as possible.

a. Normal Record.

After subject has remained quietly seated for at least two minutes, place clips on side tubes, start drum at 2 mm. per second and record curves for one minute. Natural, unconscious breathing is what we wish to study, and hence the subject should try to think of something else.

b. Effect of Using the Voice.

Record normal curves for 10 seconds, then read aloud for 30 seconds. In same manner try the effect of counting aloud in unison with the ticking of the clock. Always mark on curve the time when each test begins and ends, and what was done. Note the effects on rate and character of the movements.

c. Inhibitory Effects of Swallowing.

Take normal record for 15 seconds, then let subject drink a glass of water without stopping, taking record during the drinking and for 15 seconds after.

d. Effects of Effort.

In the same manner observe the effect of trying to hold two pin points as close together as possible without touching,

for 20 seconds; of clenching the fists as tightly as possible for 20 seconds; of clenching the fists as rapidly as possible for 20 seconds; of pressing the hands upon the knees strongly for 20 seconds.

Note the effect in the different cases, and explain the difference.

e. Relation of Rate of Respiration to Rate of Heart.

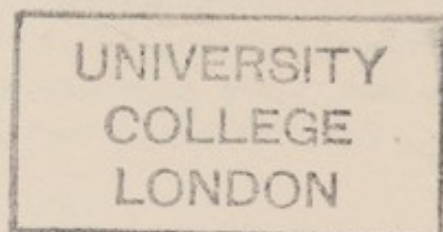
Replace the abdominal pneumograph by a carotid tambour; then study the following cases:

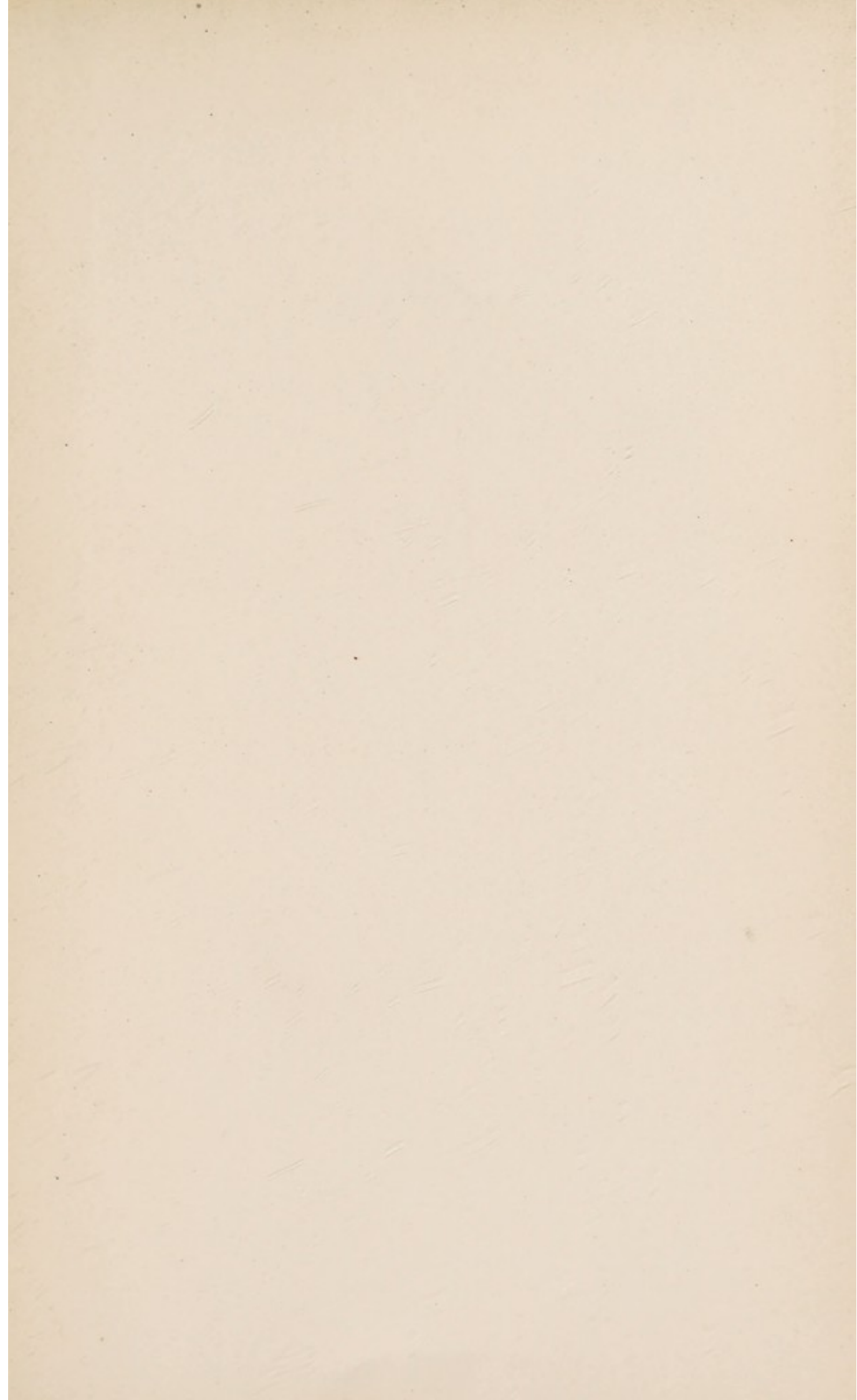
(1) Relative rates under normal conditions, sitting quietly.

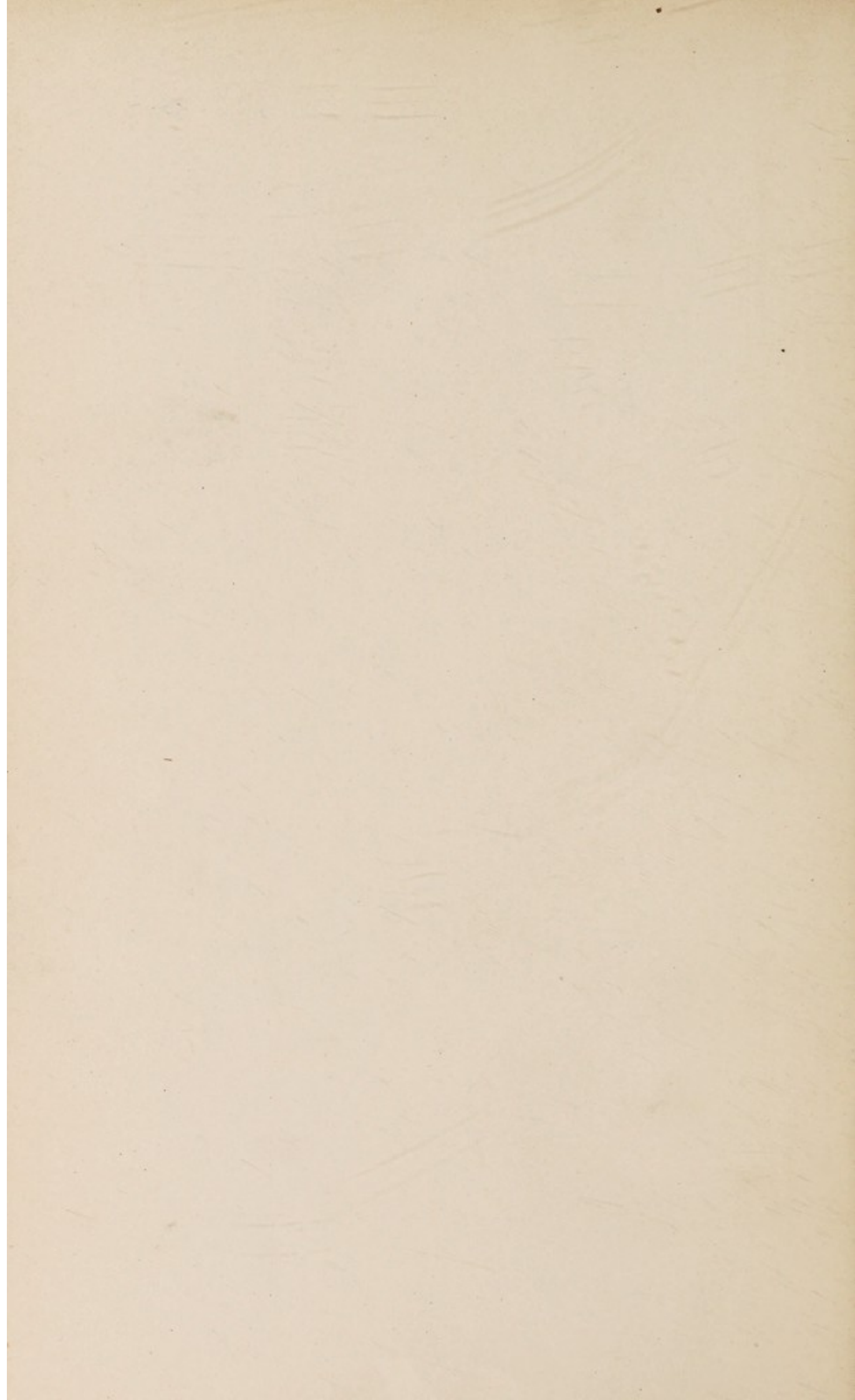
(2) Effect of adding a column of 20 or more figures rapidly.

(3) Effect of recalling exciting experiences.

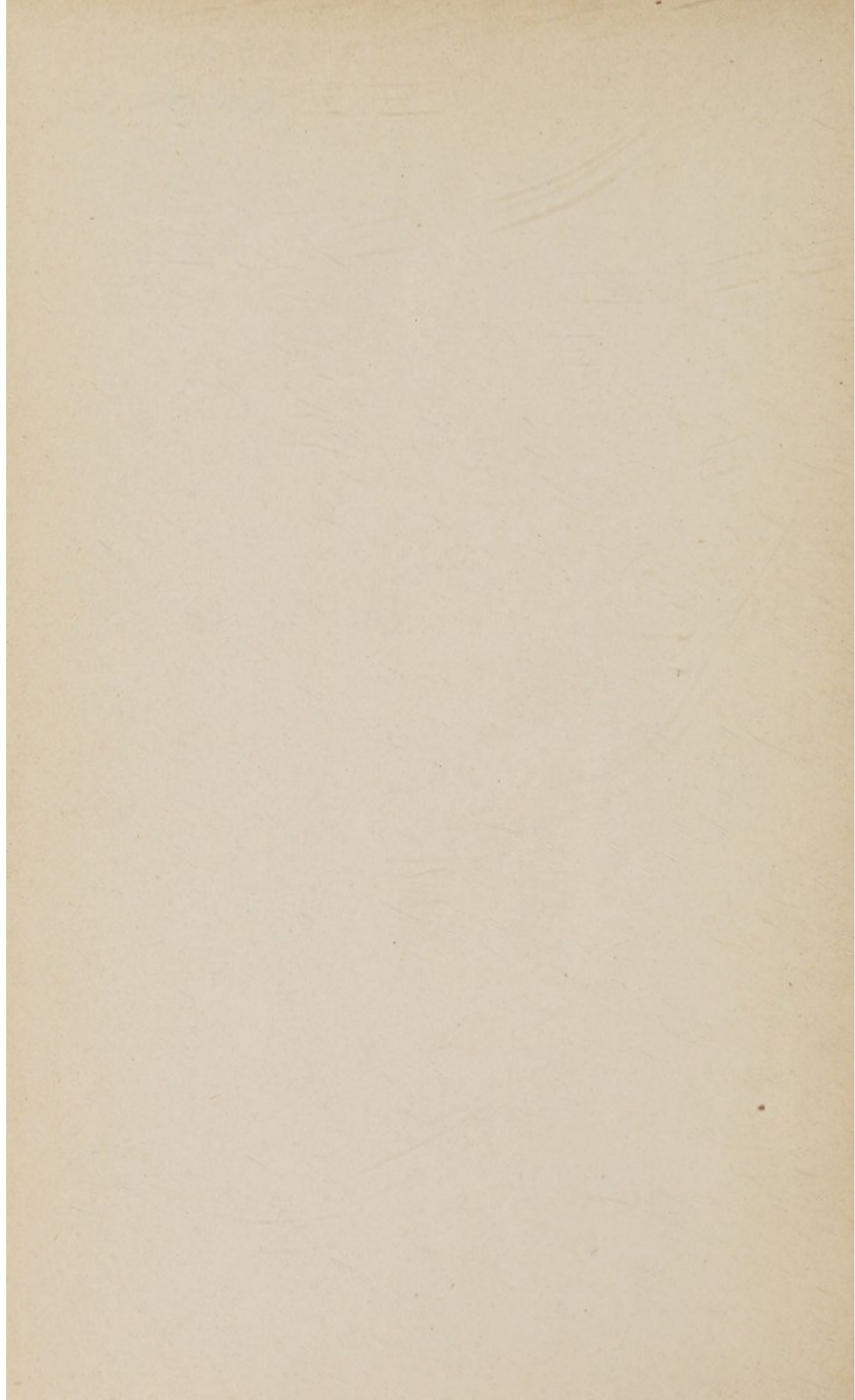
It is of course evident that voluntary control of the rate of breathing in all of the foregoing tests lessens their value. Usually it is only in the later tests, after the subject has become accustomed to wearing the apparatus, and the work has ceased to be interesting, that the subject will breathe naturally. It is best, for this reason for all the tests to be made first on one student and later on his associate.

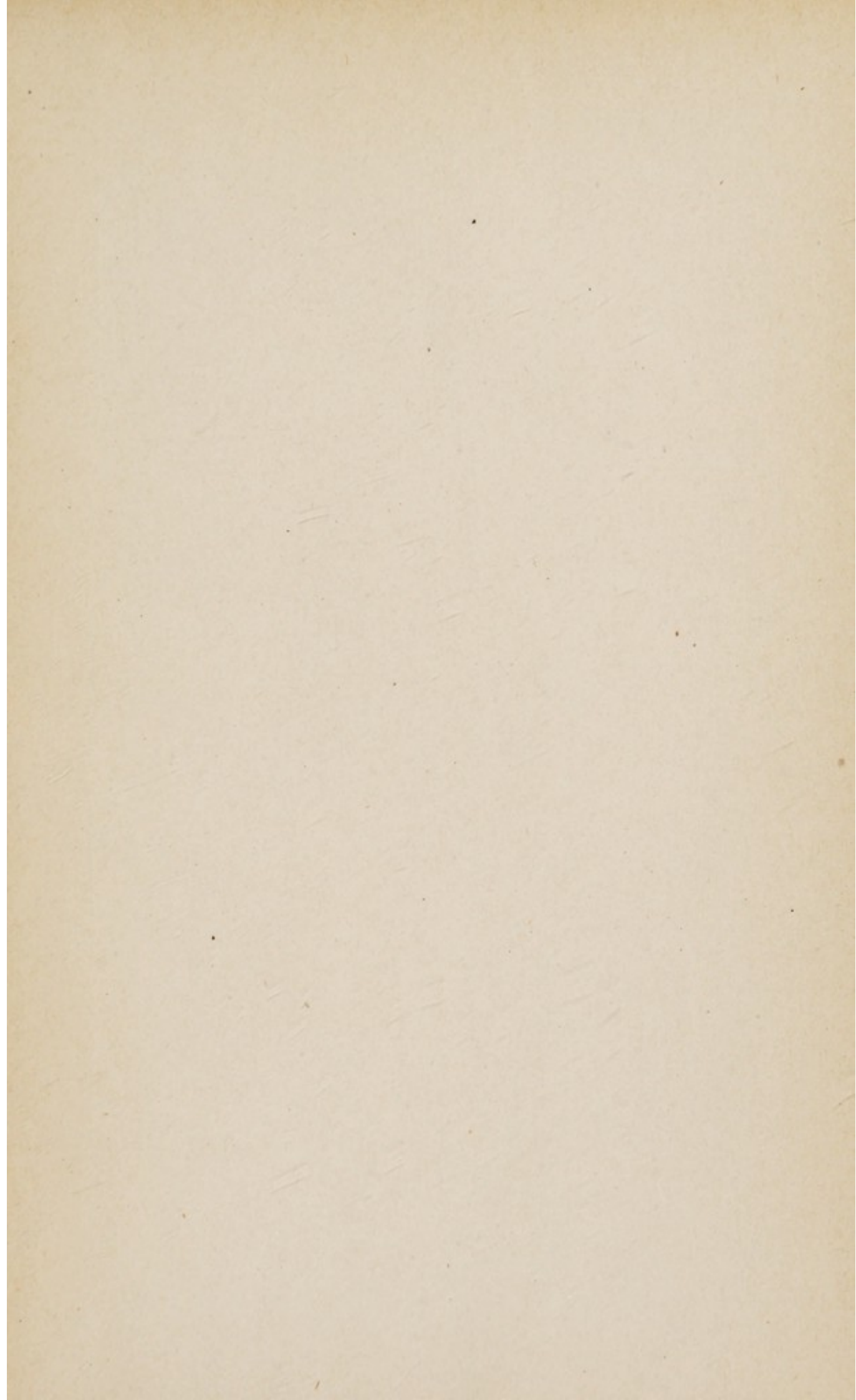


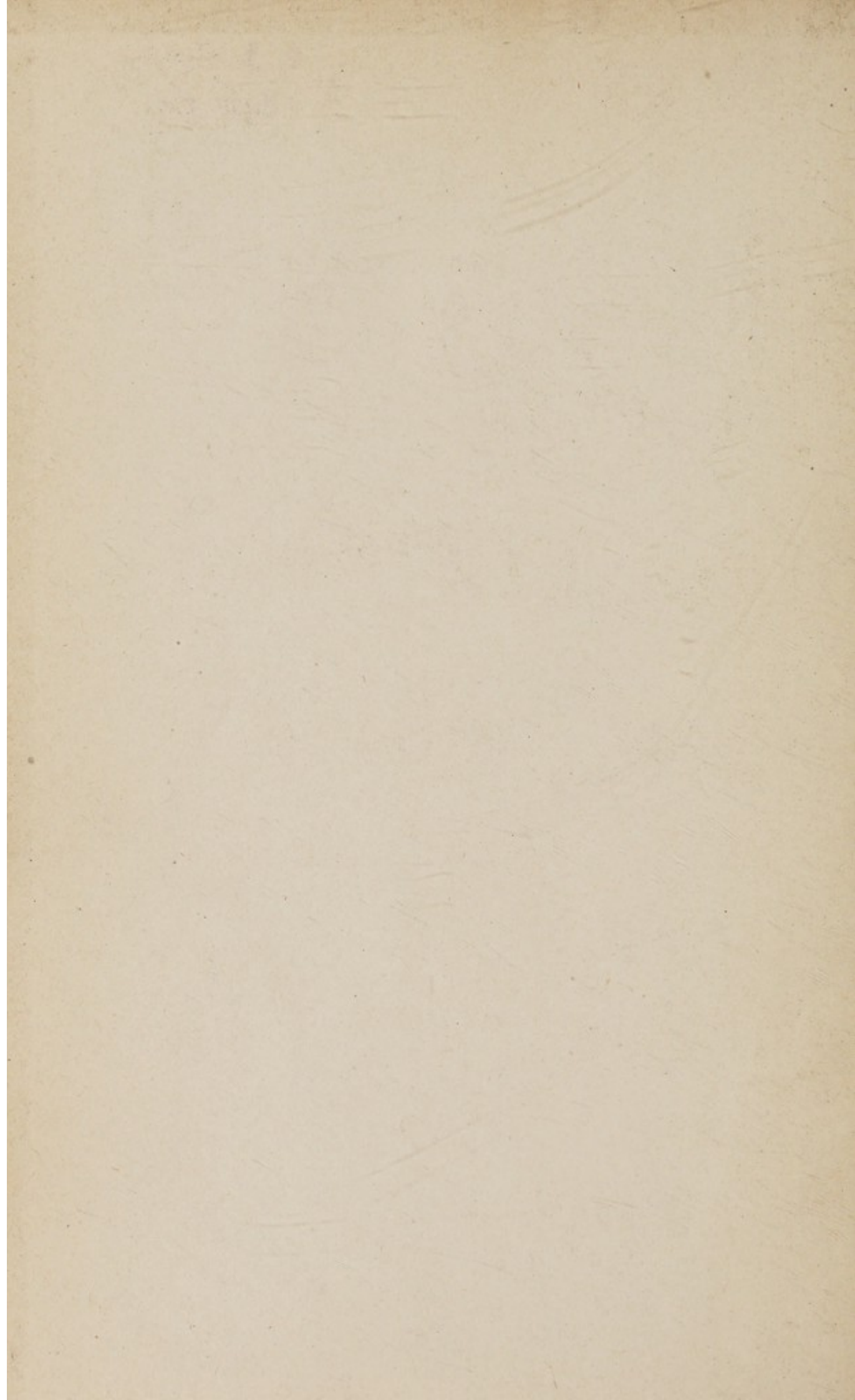




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