ELEMENTARY EXPERIMENTAL PHYSIOLOGY

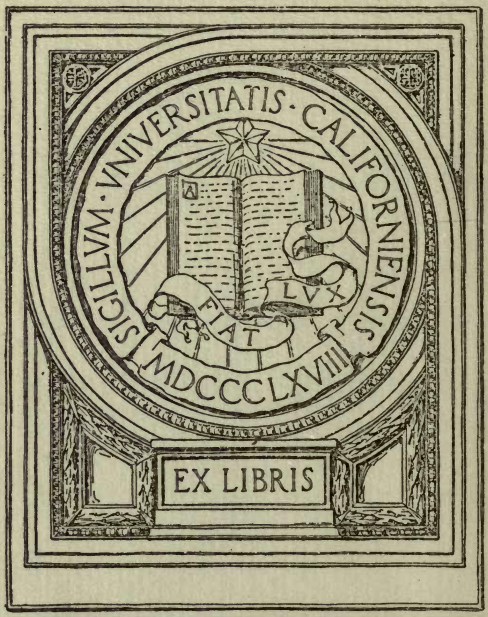
BY

J. N. LANGLEY, Sc.D., F.R.S.

PROFESSOR OF PHYSIOLOGY IN THE UNIVERSITY OF CAMBRIDGE

FOURTH EDITION

1920



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The practical work in this book is for the most part arranged in Lessons which, with the Demonstrations, occupy the Student for two hours. But in some cases this method has not been found convenient and a Lesson includes the whole of the work in a definite division of Physiology which may occupy the Student for either more or less than two hours. For the modification of the major arterial scheme, given in this edition, I am indebted to Dr H. Hartridge.

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LESSON I. APPARATUS FOR STIMULATION. SENSATION CAUSED BY ELECTRIC CURRENTS. MUSCLES OF FROG'S LEG.

The Practical work will be preceded by a Demonstration of the apparatus.

1. The electric current may be taken from a galvanic cell or from an accumulator.

a. **Daniell's cell.** Terminal screw on copper plate, the positive pole or anode. Saturated solution of copper sulphate, porous cell containing 10 p.c. sulphuric acid. Zinc plate amalgamated with mercury. Terminal screw on zinc plate, the negative pole or cathode.

b. **Leclanché cell.** Terminal screw on carbon rod, the anode. Porous pot containing manganese dioxide. Saturated solution of ammonium chloride. Terminal screw on zinc rod, the cathode.

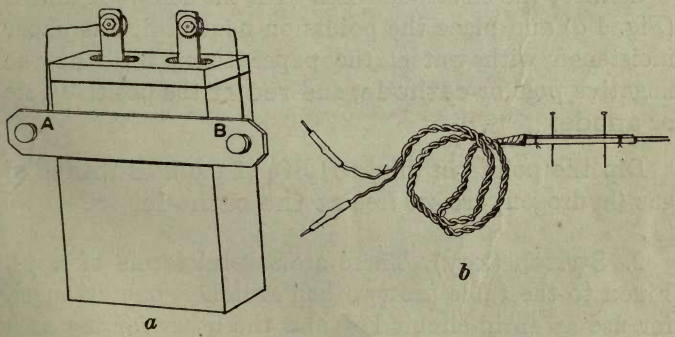

Fig. 1.

c. **Accumulator** (Fig. 1 *a*). The positive pole is coloured red, and the negative pole black. The screws on the top are for charging the cell and should not be touched. These are connected through a resistance with binding screws *A* and *B*, from which current should be taken.

Hold the ends of a voltmeter on the top screws. The voltage should be about 2; if it fall to 1·8 the accumulator requires recharging. Test the voltage of the current taken from screws *A* and *B* and that of a Daniell and a Leclanché cell.

Note the **electrodes** (Fig. 1 *b*), consisting of two insulated German silver or platinum points bound together and soldered on to insulated copper wires. The wires are differently coloured (or the beginning and end of one is marked), so that the wire connected with each electrode can be recognised. When it is required to fix the electrodes to cork, two pins are passed between them as in Fig. 1 *b*.

Connect the electrode wires with the screws *A* and *B* (Fig. 1 *a*) and place the points on neutral litmus paper moistened with water; the paper turns **blue at** the negative pole or **cathode**, and **red at** the positive pole or **anode.**

Dip the points in dilute H_2SO_4 (1 p.c.). **Bubbles** of gas (hydrogen) are set free **at the cathode.**

2. **Switch (key).** There are several forms of keys. Fixed to the table are two bell switches, one arranged for use as an in-circuit key and the other for use as a short-circuit key. Screw off the brass cover of each and

examine the connections; diagrams of these are given in Fig. 2.

3. The **galvanic current.** Connect one pole of the cell by an insulated copper wire with one binding screw of the in-circuit key (Fig. 2 *a*) and the electrode wires

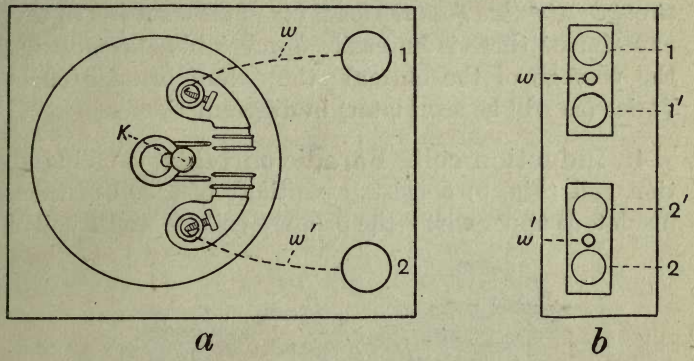

Fig. 2.

Fig. 2 *a*. Diagram of switch for use as an in-circuit key; 1 and 2 are the binding screws. For use as a short-circuit key, the two single binding screws are replaced by two pairs (1, 1′ and 2, 2′ of Fig. 2 *b*), each pair being connected by a brass plate. Note that when the knob *K* is pushed towards the binding screws the key is open (i.e. current cannot pass through it), and that when the knob is pushed away from the binding screws the key is closed.

with the other pole of the cell, and with the other binding screw respectively. Place the electrodes firmly on the lip or tongue, close the key and in a few seconds open it. Little or nothing will be felt, since the current is not of sufficient strength.

On a side table are three cells joined in series. Repeat

the experiment with these. A sharp prick will be felt on closing the key, there will be more or less pricking sensation during the whole period the current passes, and a slight additional prick when the key is opened. When a current is sent into a circuit the current is said to be 'made,' and when it is cut off from a circuit it is said to be 'broken.' Thus the *making of a current is a stronger stimulus than the breaking of the current.* In this experiment there is an easily appreciable effect during the passage of the current; the extent of such effect varies (as will be seen later) in different tissues.

4. **Induction coil. Faradic currents.** The induction coil (Fig. 3) consists essentially of a coil of thick insulated copper wire—the primary coil *P*—and a coil of

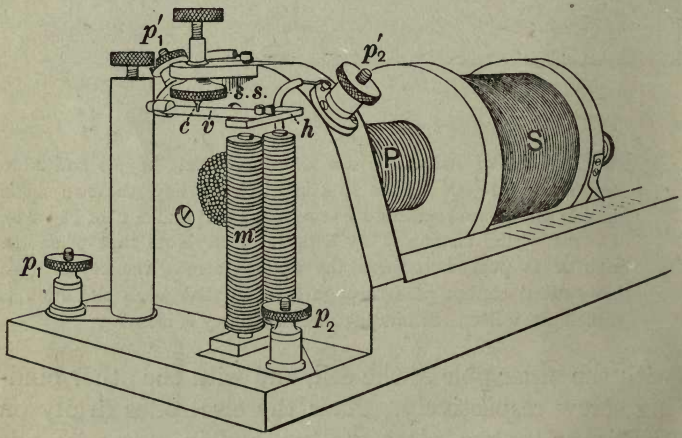

Fig. 3.

thin insulated copper wire of many turns—the secondary coil *S*. The ends of the primary coil are connected with the screws p_1', p_2'. The ends of the secondary coil

are connected with screws placed on the frame of the coil in front. The secondary coil is usually arranged to slide over and away from the primary, and there is a scale in centimetres on one side of the framework on which the distance of the secondary from the primary coil can be read off. In some forms there is also a scale on the opposite side graduated to show the relative strengths of the induced current at different positions of the secondary coil. A bundle of iron wires is placed in the central space of the primary coil, the wires are magnetised when a current passes into the coil and thus the induced current reaches its maximum more slowly and is of longer duration.

a. **Single induction currents.** Connect the poles *A*, *B* of the cell with the screws p_1', p_2' of the primary coil, interposing an in-circuit key. The key should be left open except when current is required. Connect the secondary coil with screws 1 and 2 (Fig. 2 *b*) of the short-circuit key, and the electrodes with the screws 1′, 2′. A diagram of the arrangement is given in Fig. 4.

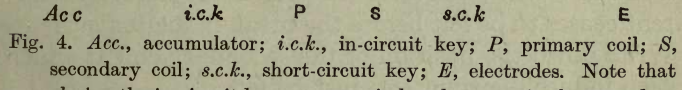

Fig. 4. *Acc.*, accumulator; *i.c.k.*, in-circuit key; *P*, primary coil; *S*, secondary coil; *s.c.k.*, short-circuit key; *E*, electrodes. Note that closing the in-circuit key causes an induced current in the secondary coil, and closing the short-circuit key prevents the current from passing into the electrodes.

An in-circuit key (open) must be used in the primary circuit, partly to avoid waste of current, but more especially because after a certain limited time an accumulator rapidly deteriorates if it is not re-charged. With a

Daniell, or other such cell, the former consideration only has to be borne in mind. The reason for using a short-circuit key in the secondary circuit will be obvious from § 5 *c*, Less. II.

Put the index of the secondary coil at 12 cm. of the scale, open the key of the secondary coil and place the electrodes on the lip or tongue.

Close the key in the primary circuit. This sets up an induction current in the secondary coil and a brief shock will be felt. After a short interval open the key in the primary circuit; this sets up another induction current in the secondary coil, and causes a rather stronger shock. Thus the *break induction current is a stronger stimulus than the make induction current.*

The stimulating effect depends, amongst other factors, upon the rate of electrical change. When the primary current is made, a brief induced current is set up in the primary coils in the opposite direction. This delays the rate of rise of the primary current at make. When the primary circuit is broken the current falls at once to zero. Thus the induced current in the secondary coil is stronger at break than at make, since it depends on the rate of change of current in the primary circuit.

Move the secondary coil away from the primary about 2 cm. at a time, and note that the make induction current ceases to be felt before the break induction current. Write down the position of the secondary coil at which each induced current can just be felt.

Since both the make and the break induction currents are currents which rise to a maximum and then fall again to zero each has the possibility of stimulating twice, during the rise and during the fall as in the case of the make and break of a constant current. In consequence, however, of the brief duration of the induced

current the fall occurs so soon after the rise that the tissue is not capable of responding to it in the conditions of the experiment.

b. **Rapidly repeated induction currents (tetanising currents).** In order to obtain a rapid series of induction currents the inductorium is supplied with a vibrator (*v*) and a small coil (*m*) with soft iron core (Fig. 3). One binding screw of the primary coil is connected with the coil of wire of *m*, and the other end of this to a binding screw (p_2) at the base of the machine (Fig. 3). Change the battery wires from the screws at the top of the machine to those at the base. Screw down *c* so that it just touches *v*. The screw *c* can be fixed by the set-screw *s.s.* Leave the connections of the secondary coil and electrodes as before. Close the primary circuit (if necessary flick the hammer *h*), the hammer will be set in rapid oscillations, each downward movement of the hammer breaking the primary circuit, each upward movement making it. Put the index of the secondary coil at 35 cm., place the electrodes on the tongue, and gradually push the secondary towards the primary coil; note the position at which the shocks are first felt. Note also the position at which the shocks cannot be borne comfortably. The method in which the primary current is made and broken will be easily understood from the figure. When the current is passing in the primary coil, *v* is in contact with *c*, but since the current also passes round the coil *m* the soft iron core of this coil becomes magnetised, and consequently attracts the plate *h*; as this goes down the contact of *v* and *c* is broken, hence the current ceases to pass in the primary coil, the core of *m* is no longer magnetised, the plate *h* flies up, *v*

comes again in contact with *c* and the cycle of events starts again.

In some induction coils there is a central pillar as

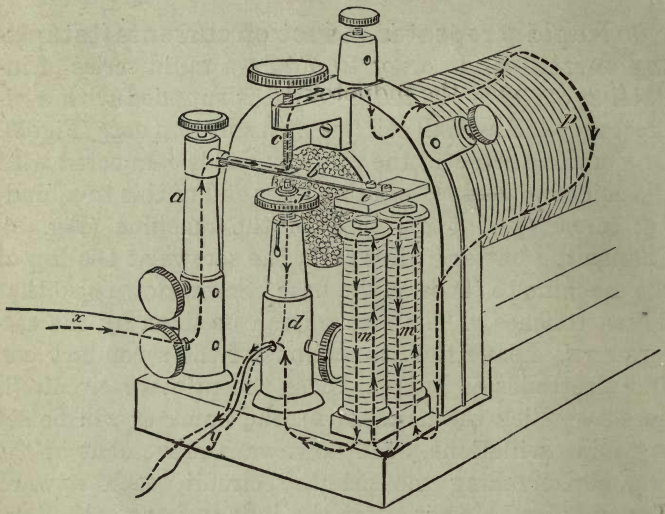

Fig. 5. The extra pillar is for the purpose of equalising approximately the make and break currents. Screw *c* is raised out of reach of the vibrator, screw *f* is raised till it nearly touches it. A thick wire is connected with the upper binding screw on pillar *a*, and with the top binding screw of the primary coil. Thus when the vibrator is draw down it comes in contact with *f* and the greater part of the current ceases to pass through the primary coil. Since, however, the circuit of the primary coil is still complete, the extra current decreases the rate of electrical change at the 'break' to approximately the same extent as it does at the 'make.'

in Fig. 5. For ordinary use this is not required, and the screw *f* should be lowered out of range of the vibrator.

5. A leg of a frog is given you. Tear off the skin. Sketch the anterior and posterior surfaces, marking the

ileo-fibularis, the gastrocnemius, and the sartorius muscles (Fig. 6).

With small pointed scissors, cut through the connective tissue on either side of the ileo-fibularis, pass one blade of the scissors close under it, cut it through, remove it, and note the sciatic nerve. Isolate the nerve throughout the thigh by cutting and tearing the tissue

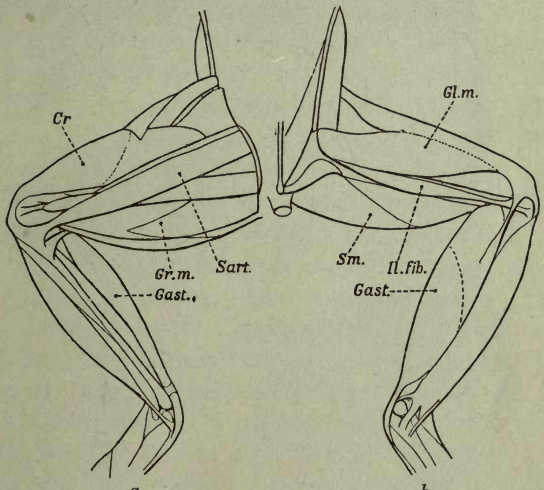

Fig. 6. Muscles (*a*) of ventral surface, (*b*) of dorsal surface of right leg of frog. *Sart.*, sartorius; *Cr.*, cruralis; *Gr.m.*, gracilis major; *Gast.*, gastrocnemius; *Gl.m.*, glutæus magnus; *Il.fib.*, ileo-fibularis; *Sm.*, Semi-membranosus.

around it. Pinch it several times proceeding from above downwards, at each pinch (**mechanical nerve stimulation**) contraction occurs in the lower leg. Pinch the upper part of the nerve again, there is no contraction of the muscles; the conductivity of the nerve has been destroyed; hence in dissecting a living nerve it must not be picked up with forceps.

LESSON II. NERVE STIMULATION. REACTION OF MUSCLE.

1. Cut off the head of a pithed frog, and squeeze the body upwards to remove most of the blood. Cut away the skin on the lower half of the back. Lift up the tip of the urostyle with forceps, and cut through the muscles attached to it, keeping the scissors close to it. Cut away the urostyle. Lift up the cut muscles on one side, and separate from them the nerves seen below. Cut away the wing of the iliac bone (which runs parallel with the urostyle) so that the nerves of the lumbo-sacral plexus (7th, 8th, 9th) are exposed. Pass a thread under the nerves close to the vertebral column, tie them and cut them above the knot. On tying there will be contraction of the leg (mechanical nerve stimulation). Lift up the nerves by the thread, and isolate them down to the pelvis where they form the sciatic and crural nerves.

With strong scissors cut through the pelvis, keeping to the mid line between the legs so as not to injure the sciatic on either side. Cut through the remaining tissue connecting the leg to the body. The nerves of the opposite side will be required for § 3.

2. **Chemical nerve stimulation.** Place the nerves over the rim of a watch glass filled with saturated sodium chloride solution, cutting off the ends close to the ligature. There will soon be twitching of the muscles of the leg, due to chemical stimulation of the nerve. Cover the leg with wet blotting paper and keep for § 7.

3. Dissect out similarly the nerves of the opposite side, but instead of tying them in order to hold them up, cut across the vertebral column a little above its end, and hold them up by the piece of bone cut off. Place the leg with its attached nerves on a board covered with cork, and fix with pins the tissue just above the leg. Keep the nerve wet with physiological salt solution (Ringer's fluid)[1].

Cut longitudinally through the skin of the body of the frog and expose the muscles over the sternum.

4. **Galvanic current.** Connect the electrodes with the cell interposing an open in-circuit key as in § 3, p. 7. Hold the electrodes steadily on the muscles on one side of the sternum. Make the current and in a couple of seconds break it. At the make the muscles will contract and draw the arm up. At the break the contraction will be much less. The *making of the current is a more effective stimulus than the break.* If the muscle is in good condition the arm will be more or less raised during the whole period of the passage of the current.

Place the electrodes under the nerve (§ 3), and make and break the current. There will be a contraction at make and at break but no effect will be seen during the passage of the current. The relative strength of the two contractions depends on the condition of the nerve, the strength of the current, and its direction in the nerve. Test the latter by reversing the position of the electrodes.

5. *a.* **Single induction currents.** Connect the electrodes with a short-circuit key, and this with the second-

[1] Ringer's fluid is a mixture of salts in approximately the same percentage as in serum. That used for the frog may consist of NaCl ·65 p.c., KCl ·02 p.c., $CaCl_2$ ·025 p.c., $NaHCO_3$ ·015 p.c.

ary coil of the inductorium; close the key; connect the primary coil by an open in-circuit key with the cell (cp. Fig. 4). With two pins (Fig. 1 *b*) fix the electrodes a little above the level of the tissue, and rest the nerves on them, covering the whole with a small piece of blotting paper moistened with Ringer's fluid to prevent the nerve from drying. Put the index of the secondary coil at 15. Open the short-circuit key.

Close the primary circuit; the muscles contract. Open and close the key in the secondary circuit; this of course has no effect, since there is no current in the secondary coil as long as the primary current remains constant. Open the key, and break the primary circuit; there is again contraction. Determine the position of the secondary coil at which contraction is first obtained (i) on making, (ii) on breaking the primary current.

Close the short-circuit key and push the secondary coil over the primary so that very strong induced currents will be obtained. Make and break the primary current, no contraction is caused. The resistance of the nerve is so great compared with that of the key that practically no current passes through the nerve (cp. Exp. *d*).

b. **Series of make or break induction currents only.** Put the secondary coil at 15. Close the short-circuit key in the secondary circuit, make the current in the primary circuit, open the key in the secondary circuit, break the current in the primary circuit, and repeat; thus contractions are obtained at the break only of a primary current.

In a similar manner obtain contractions at the make only of the primary current.

c. **Direction of induction currents.** Put the secondary coil over the primary, and place the electrodes on moistened neutral litmus paper. Send a series of break currents through the electrodes, after a time the paper will turn red at one pole and blue at the other (cp. p. 6). Send in a series of make currents, the colouring will be reversed.

d. **Unipolar stimulation.** Disconnect one of the electrodes from the short-circuit key and open the key. Make and break the primary current, there will probably be no contraction. Push the secondary coil nearer the primary; at some position of the coil the make and break of the primary current will cause contraction. Repeat, touching the leg with wet finger; the contraction will be greater. Thus a break in the secondary circuit does not prevent the nerve being stimulated. It is for this reason that an in-circuit key must not be used in the secondary circuit.

6. **Rapidly repeated induction shocks.** Arrange the induction machine for tetanising currents (cp. p. 11). Close the key of the secondary circuit. Make the primary circuit. When the hammer is steadily oscillating open the secondary key; the leg is immediately thrust out straight and kept rigid in **tetanus.** In a few seconds, break the primary current, the limb at once becomes flaccid.

7. **Reaction of living and dead muscles.** Have ready a piece of faintly blue and a piece of neutral litmus paper, and some hot water.

a. Strip the skin from the frog's leg used for chemical nerve stimulation (§ 2). Cut off on one side the thigh muscles, and press the cut surface on the litmus paper; the reaction will be **faintly alkaline.**

b. Place the rest of the leg in the hot water for two or three minutes. Observe that the muscles become contracted and opaque, i.e. **rigor mortis** sets in. Remove excess of water with a cloth, cut off the remaining thigh muscles, and press the cut surface on the litmus paper; the reaction will be **distinctly acid.**

c. Stimulate the nerve of the leg used in § 6 for five minutes continuously, and for five minutes more at short intervals. Remove excess of fluid from the surface of the thigh muscles, cut them across and test their reaction, it will be **faintly acid.**

LESSON III. THE REVOLVING DRUM. THE MUSCLE CHAMBER. NERVE MUSCLE PREPARATION. LATENT PERIOD OF MUSCULAR CONTRACTION.

1. **The revolving drum.** Tracings are taken on smoked paper covering a revolving drum. The rate of revolution can be varied in two ways: (1) by shifting

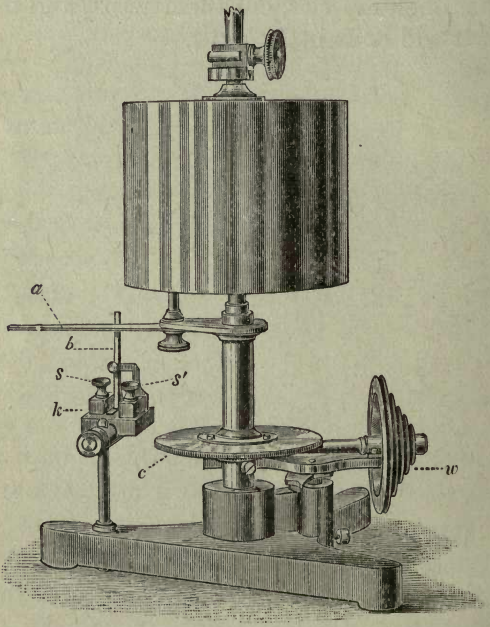

Fig. 7.

the belt on two sets of pulleys, one on the shaft connected with the motor, the other on the stand of the

drum (*w*, Fig. 7), and (2) by putting in a high or low gear. The direction of revolution of the drum is reversed by twisting the belt connecting the pulleys into a figure of 8.

Make yourself acquainted with the method of use of the three following drums:

a. Fig. 7. In this cogs at the end of the axle of the pulleys *w* can be geared into the cogs of a small or a large wheel on the spindle of the drum. In Fig. 7 the high gear is engaged. To engage the low gear, pull back the pulleys *w*, raise them so that the cogs on the axle engage with wheel *c*, and clamp. Turn the whole drum till the pulleys *w* are in line with the pulleys on the shaft driven by the motor.

When the gears are engaged the drum must not be turned by hand either backwards or forwards. If it is required to revolve the drum by hand, take off the belt and turn round the pulleys *w*, or take off the belt, disengage the gearing and turn the drum itself.

The key (*k*, Fig. 7) is called a knock-down key. It is used as an in-circuit key in the battery current, so that when the drum revolves, the arm (*a*) knocks down the vertical rod (*b*) and breaks the current.

b. **Lucas drum.** In this[1] the gearing is inside the case at the base of the drum. The slow gear is engaged when the steel spring (*Sp*, Fig. 8) is in the upper groove *G* and the high gear when the spring is in the lower groove *G'*. The spring can easily be moved from one to the other by the fingers. It must not be moved above groove *G* or below groove *G'*. The knock-down key is

[1] Made by the Cambridge Scientific Instrument Co.

fixed to the casing. The drum can be moved backward or forward by hand without any re-arrangement.

Observe the rate of revolution of the drum with high and low gearing and with different connections of the pulleys on the shaft and on the drum.

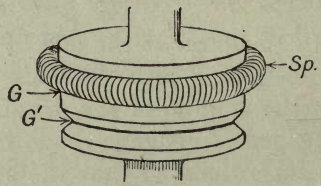

Fig. 8.

c. **Sherrington drum.** In this (Fig. 9), although the gears may be engaged, the drum only rotates when the cross-bar handle *H* is at right angles to its position in

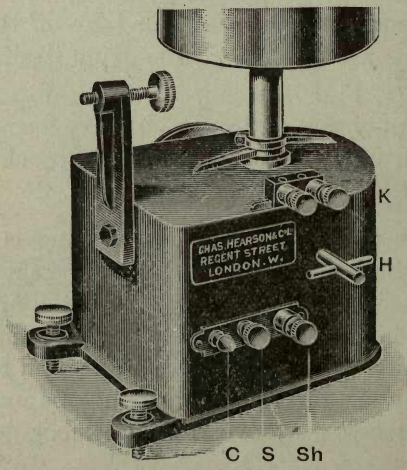

Fig. 9.

the figure. Take the pulleys in the right hand (if the machinery is in motion, the pulleys must be prevented from rotating), loosen the screw *S*, lift up the catch by the button *C*, and push in the pulleys. On the projecting pulley shaft *Sh* will be seen three grooves, when the catch is in the innermost groove the fast gear is engaged, when it is the outermost groove the slow gear is engaged; when it is in the middle groove the gearing is disengaged. Fix the catch in each groove in succession; after fixing, release the pulley, turn the handle *H* and note the effects. In place of a knock-down key, there is a projection on the inner side of *K*, which when pushed in by the arm on the drum shaft makes contact with the two binding screws on *K*. One end of *K* is moveable, so that the projection can be taken out of range of the arm.

2. **Tracing of a single muscular contraction.** *a*. Connect the cell with the primary coil of the inductorium, interposing the knock-down key as an in-circuit key (cp. Fig. 7). Connect the secondary coil with a short-circuit key, and this with the binding screws connected with the electrodes (*H*, *H*) of the **muscle chamber** (Fig. 10).

Adjust the heights of the drum and of the muscle chamber so that the lever *G* when horizontal is a few centimetres above the lower edge of the drum and can be brought nearly to the level of the upper edge by lowering the drum.

b. **The nerve muscle preparation.** Take a pithed frog and cut through the skin all round the animal at the middle of the trunk, turn the edge of the skin downward, and seizing it with a cloth, tear the skin from the lower half of the trunk as far as the knee. On a glass or

glazed plate, place a piece of blotting paper soaked in Ringer's fluid (cp. p. 16, footnote), on this place the frog on its belly. Prepare (as in Less. II, § 1) the nerves giving origin to the sciatic nerve, remove the ileo-fibularis muscle (Less. I, § 5).

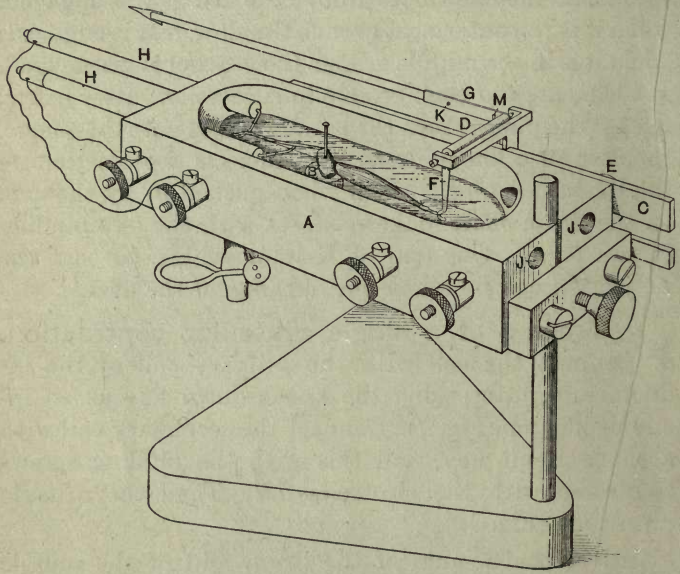

Fig. 10. Lucas muscle chamber.

Holding the nerve up by the thread, isolate it as far as the knee by cutting the tissue around it and the branches of the nerve. The nerve must not be pinched or stretched. Tear now the skin from the lower leg. Tie a thread round the tendo Achillis of the gastrocnemius muscle, and tie the two ends to make a loop about half an inch from the tendon. Cut the tendon below the ligature and pulling on this isolate the muscle up to the

knee. Cut away most of the muscles just above the knee without injuring the nerve, and with strong scissors cut through the leg just above and just below the knee.

Thrust a pin through the knee-joint between the bones, and put the pin in the hole in the muscle chamber (Fig. 10). Unclamp the screw at *E*, slide forward the brass carrying the lever, and pass the loop attached to the tendon of the muscle over the hook on *F*; pull back the brass piece till the muscle is lightly stretched and the lever is horizontal. Place the nerve over the ends of the electrodes *H*, *H*, and pour in Ringer's fluid to cover the muscle. Hook a 10 gram weight in the hole in the lever next the axle. In this position the load on the muscle is 2 grams.

Bring the lever to mark on the revolving cylinder, adjusting it so that it presses very lightly on the smoked paper. Place the index of the secondary coil at 10.

With the key in the secondary circuit shut, let the drum revolve once and obtain a base line. Arrange the belt on the pulleys so as to give a slow speed; turn the pulleys by hand till the bar *a* (Fig. 7) is a couple of inches past the knock-down key, close the knock-down key. Open the secondary circuit key, and let the drum revolve; stop the drum as soon as it has passed the knock-down key.

Without shifting the position of the lever, take four similar tracings with increasing speed of drum, the last being the maximum speed.

3. **Latent period.** Lower the drum so as to bring the writing point above the previous tracing. Take a tracing with the maximum speed of the drum; close the

key in the secondary circuit, close the knock-down key, open the key in the secondary circuit; turn the pulleys by hand, making the movement as slow as possible as the rod touches the knock-down key, so that the tracing of the contraction and of the relaxation of the muscle make a single line. This marks the moment in the myogram at which the nerve was stimulated, and there is a space between this and the beginning of contraction. The time taken by the drum in passing over this space is the latent period. (A similar curve may be taken higher on the drum with a load of 10 grams instead of 2 grams.)

4. **Time measurement of the parts of the curve.** *a*. This may be taken by means of a broad steel band

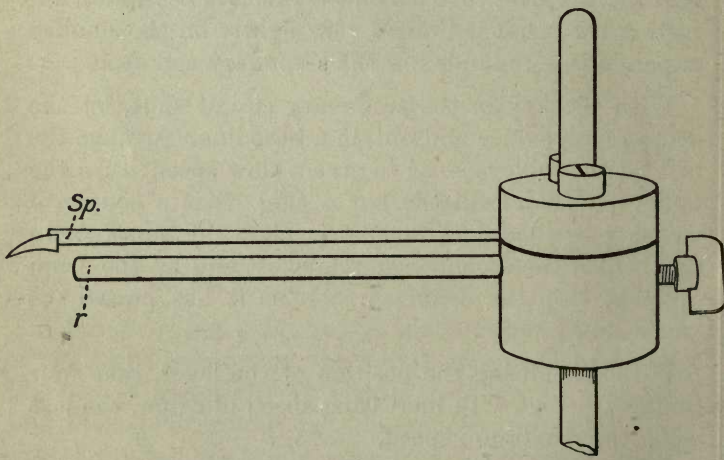

Fig. 11.

(Fig. 11), the rate of vibration of which has been determined. Place it so that the writing point is close under

the curve of muscle contraction. Set the drum revolving. Depress for a moment the steel band to the rod (*r*) beneath it, and bring the writing point to write on the drum for one revolution and then remove it. With the band given you a double vibration (crest to crest of the wave) takes $\frac{1}{60}$ sec. Measure the duration of the latent period of the contraction and of the relaxation.

b. Connect in one circuit two cells, a key (in-circuit), a tuning-fork vibrating 100 times a second, and the bobbin of a time-marker, as in Fig. 12.

The current flows from the battery by the wire *f*, through the tuning-fork, down the pin connected with the lower prong to the mercury cup *Hg* and so to the binding screw *e*. Here the current divides into two circuits, one passes through the coil *d* lying between the prongs, and the other passes by the wires *g* and *b* through the coils of a time-marker, and both circuits are brought to the binding screw *a*, from which the current passes to the battery.

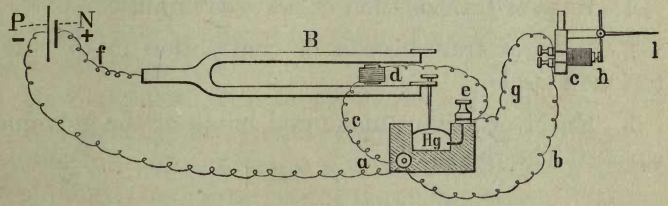

Fig. 12.

The two ends of the wire wound round the coil (*c*) are connected with the binding screws to which the current is conducted. When the circuit is made the current passes round the coil, the soft core of the coil becomes magnetised and the hammer (*h*) and lever (*l*) are drawn down; when the circuit is broken the hammer and lever are drawn back by a spring.

See that the surface of the mercury is quite clean, put on it a few drops of 95 % alcohol, adjust the pin so that it just touches the mercury, flick the tuning-fork, it will continue to vibrate,

making and breaking the current at the mercury contact. Each time the current is made the core of the coil *d* of the tuning-fork becomes magnetic, the prongs are drawn together and the current broken, the core then ceases to be magnetic and the tuning-fork makes the current again.

Bring the point of the lever to write on the drum immediately below the tracing. When the lever of the time-marker is oscillating steadily in unison with the tuning-fork (if it does not, adjust the strength of the spring of the time-marker), start the drum and stop after one revolution. An undulating line is traced, each undulation with the tuning-fork given you represents $\frac{1}{100}$ of a second.

Adjust the point of the muscle lever accurately to the commencement of the contraction, then press it down and so trace a line downwards to the time tracing. Shift the lever along the curve and draw lines in the same way from the summit of the contraction, the end of the relaxation, and from the line indicating the moment of stimulation.

DEMONSTRATIONS.

1. Rate of transmission of nervous impulse.

2. Rate of transmission of contraction in the sartorious muscle.

3. Effect of rate of make and break of the galvanic current. The rheonome.

LESSON IV. MAXIMAL CONTRACTION. TETANUS.

1. **Relation of height of contraction to strength of nerve stimulus.** Arrange the apparatus for single induction shocks. Make a sciatic-gastrocnemius preparation and place it in the muscle chamber. It is best to have the nerve and the points of the electrodes immersed in the Ringer's fluid. Put on a 10 gram weight. Place the secondary coil as far as possible from the primary; make and break the primary circuit, pushing the secondary coil slowly towards the primary until a contraction is obtained. Then push back the secondary coil 2 or 3 mm. at a time till the stimulus causes no contraction.

Arrange the lever to write on the drum, take off the belt driving the drum and pull back the pulleys so that the drum can be turned by hand. Turn the drum round to mark a base line.

Now stimulate with break shocks only (cp. Less. II, § 5 *b*), pushing the secondary coil nearer the primary a quarter of a centimetre at a time. When a contraction is obtained (the **minimal contraction**) move the drum about 5 millimetres between each stimulation. (The drum may be moved a definite distance by marking the pulley in equal sectors with chalk and turning it one sector between each stimulation, the high gear being in.) The contractions increase up to a certain point—the **maximal contraction**—and then remain constant. When the maximal contraction is obtained repeat the stimuli, pushing the secondary coil a quarter of a centimetre at a time away from the primary. The heights of

the contractions should decrease in the same ratio as they previously increased.

In this experiment there is no difficulty in obtaining the main result, viz. that *the difference in the strength of the current required to produce a minimal and a maximal contraction is small*, but it will probably be found that the minimal current (threshold) varies slightly, and that the same height of contraction is not constantly obtained with the same position of the secondary coil. This is due partly to an increase of irritability caused by the stimulus, and partly to the difficulty of opening and closing the key at the same rate, i.e. to the difficulty of keeping the induced current of constant intensity.

Repeat the stimuli, pushing up the secondary coil a centimetre at a time. A large increase in the strength of the stimulus will cause no increase in the height of the contraction. When the induction current is very strong, there will be an increase in contraction height, due to the break induction current stimulating at the break as well as at the make.

2. **Fusion of single contractions to form tetanus.** Arrange for single induction shocks, introducing into the primary circuit, in place of a key, an oscillating rod and mercury cup. This is a thin band of steel about 35 cm. long and 1 to 2 cm. wide; at one end, at right angles to the band (Fig. 13), is fixed a pointer, about 3 cm. long. The band can be fixed at any part of its length by a wide clamp and connected with the clamp is a binding screw. A cup containing mercury is placed underneath the pointer and the clamp is arranged on the stand at such a height that when the band descends in oscillation the pointer dips into the mercury.

Shift the oscillating rod in the clamp supporting it, so as to allow its full length to oscillate, and adjust its height so that the pointer just touches the mercury when at rest. Open the key in the secondary circuit and, by moving the oscillating rod in and out of the mercury by hand and shifting the distance of the secondary coil from the primary, determine the position of the coil at which contractions are only obtained at

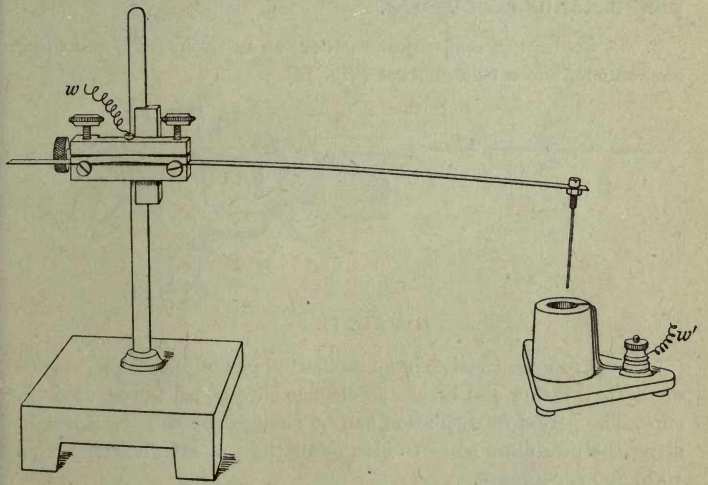

Fig. 13.

break. If such a position cannot be clearly obtained, reverse the connection of the wires of the secondary coil and try again. Set the drum running at a rather slow velocity (about 6 cm. per sec.), put the rod into oscillation, then open the key in the secondary circuit for about 5 seconds and close it again. Stop the drum, shorten the rod in its clamp by about 4 centimetres, adjust it to the mercury level, and take another tracing of

the same duration. In this way take a series of tracings, 6 to 8 in all, with the rod shorter and shorter, shortening it less and less each time. Observe the gradual fusion of a series of single contraction curves into the curve of tetanus.

Finally remove the oscillating rod and mercury cup and arrange the apparatus for currents of rapid rhythm (tetanising currents) (cp. p. 11) and stimulate. A complete tetanus is obtained.

3. *a.* Connect in one circuit the cell, an in-circuit key, a beating metronome, and a time-marker (Fig. 14).

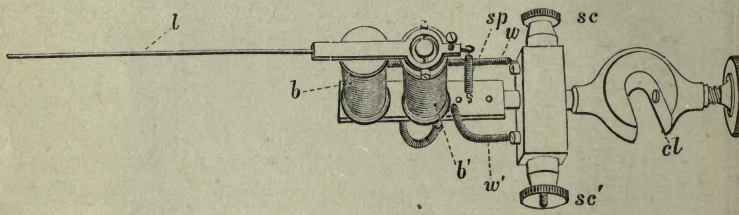

Fig. 14.

The metronome consists of an oscillating pendulum which (at each oscillation) makes and breaks an electric current led to two mercury cups. The period of oscillation can be changed by shifting a weight along the pendulum so as to give oscillations at rates varying from 40 to 200 per minute.

Arrange the metronome to beat once a second, and by means of the time-marker, record periods of one second duration on the running drum.

b. Instead of the beating metronome a clock may be used to make and break the circuit, or a chronograph, i.e. a small clock with a recording lever may be brought to bear directly on the running drum.

With compasses measure the length on the drum of a period of one second, and count in the tracing which just fails to be a complete tetanus the number of oscillations per second of the muscle.

LESSON V. POLAR STIMULATION. FATIGUE.

1. Make the following preparations from a pithed frog, and place them in saline solution:—

a. **Rectus abdominis preparation.** Remove the skin over the abdomen. The two rectus abdominis muscles will be seen one on either side of the mid-line arising from the sternum and ending in a point at the pelvis. Note that it is divided into segments by transverse tendinous insertions (cf. Fig. 16). Cut through the xiphisternum transversely, and, taking this in forceps, cut out the rectus muscle of one (or both) sides.

b. Two sciatic-gastrocnemius preparations.

2. **Polar stimulation in muscle.** Connect the accumulator with a battery giving a current of about

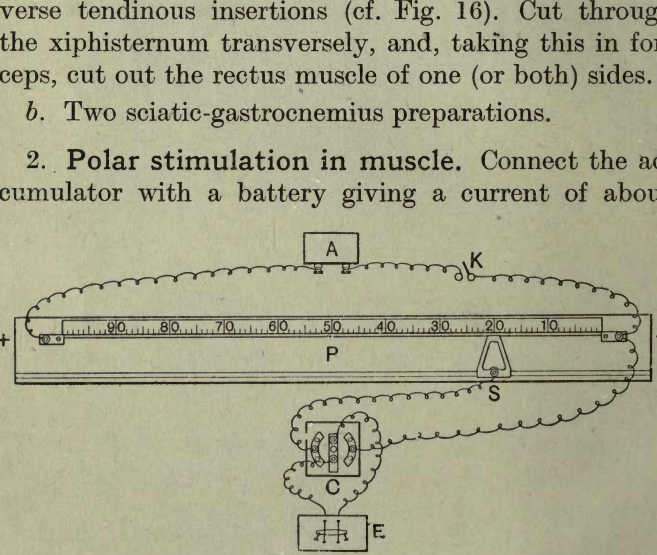

Fig. 15. *A*—accumulator. *K*—in-circuit key. *P*—potentiometer. *S*—slider. *C*—commutator. *E*—electrodes with muscle pinned across them.

4 volts with a potentiometer, a commutator (reversing key) and electrodes as in Fig. 15. (With a current of

2 volts the potentiometer is better omitted, since the branch current is not strong enough to give marked local contraction.) The electrodes consist of two wires passed, about 2·5 cm. apart, through a piece of cork.

Pin the rectus abdominis, at about its normal length, across the electrodes. Put the slider at 20 of the rheochord scale. Turn the moveable bar of the commutator so that the positive pole of the battery is connected with the right-hand electrode. Watch one of the middle

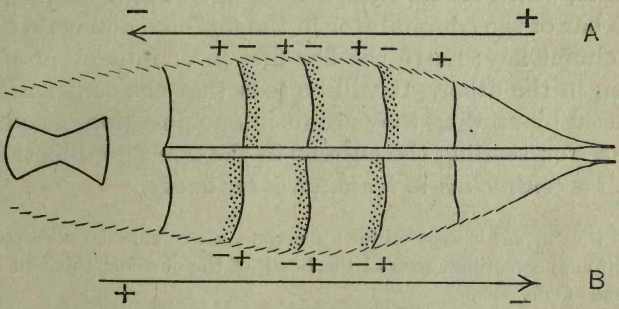

Fig. 16. Diagram of rectus abdominis muscle of the frog, showing in the middle portion the position in which prolonged contraction occurs according to the direction of the galvanic current.

tendinous insertions of the muscle, best with a lens and by oblique light, and sharply close the in-circuit key and in two seconds open it. Move the slider to the left 10 degrees at a time, and stimulate as before after each move. The first effect will be a twitch at make and break; at some stage of increase in the strength of the current, a wheal will be formed on the right-hand side of each tendinous insertion, i.e. *a protracted contraction is produced at the cathode* of each segment (cf. diagram, Fig. 16, A). This contraction differs from the twitch in being

local and relatively slow, and in lasting during the whole time of the passage of the current and for a short time afterwards.

When the protracted contraction is obvious, turn the bar of the commutator in the opposite direction, so that the direction of the current is reversed. On closing the in-circuit key, it will be seen that the protracted contraction is now on the left-hand side of the tendinous insertions, i.e. at the opposite ends of the muscle segments, which are now the cathodes (cf. Fig. 16, B). Put the bar of the commutator in the mid-line and close the in-circuit key; move the bar first in one direction and then in the other. It will be seen that the contraction caused by sending the current in one direction, at once ceases on sending the current in the opposite direction, i.e. *the contraction is inhibited at the anode.*

If the current is kept on for some time, a weak similar slow contraction is sometimes seen at the break of the current; this will be at the anode.

The quick contraction at the make and at the break starts from the cathode and the anode respectively, but it is conducted so rapidly through the rest of the muscle that no difference in the time of the contraction at the two ends can be seen by the eye.

3. **Polar stimulation of nerve.** The apparatus remaining as in the previous experiment place the sciatic nerve of the nerve muscle preparation across the electrodes, pin down the knee joint and keep the nerve and muscle moist with saline solution. Put the slider of the rheochord at 10 and stimulate with ascending and descending currents, i.e. with currents running from and to the muscle respectively, repeat with the slider at 20, and so on till a contraction is obtained at make with

each direction of the current. Note that there is no contraction at break. If the currents are further increased in strength a contraction will also be obtained at break.

Unpin the joint, hold the muscle by the tendon, and dip the upper third to a half of the nerve for 2—3 seconds in water at 70°—80° C. Replace the nerve in the electrodes so that one electrode is on the dead part and the other on the living part. Repeat the stimulation as before. It will be found that the first effect of the ascending current is to cause contraction at the break instead of at the make.

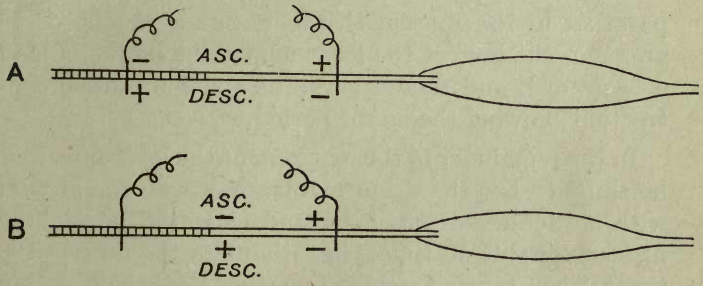

Fig. 17.

The explanation of the change in response is as follows. A stimulus is only set up where a current enters or leaves the axis cylinder; on sending a current lengthways through a nerve the greater part of the current enters and leaves the axis cylinders at the poles, part enters and leaves in other parts of the course of the nerve, but this is insufficient to stimulate. A stimulus cannot of course be set up in a dead nerve, thus when one electrode is on the dead part of the nerve and the other one on the living part, a stimulus is only set up at

the poles which are on the living muscle (cf. diagram, Fig. 17, A).

It is to be noticed that when the current is increased to a certain degree the portion which enters or leaves the living part of the axis cylinder near their junction with the dead part becomes sufficient to set up a stimulus (cf. Fig. 17, B) and contraction will be obtained both at make and break with each direction of the current.

A similar experiment may be made with the sartorius muscle.

4. **Fatigue.** Arrange the apparatus for recording the latent period (Less. III. § 3). Fix one nerve-muscle preparation in the muscle chamber, put a weight of 20 grams in the hole of the lever next the axle (i.e. a load of 4 grams), and take a curve of a single muscle contraction showing the latent period.

In the remainder of the experiment the lever must not be shifted. Let the drum revolve half way round, and with stationary drum, open and close the key in the primary circuit 50 times, i.e. stimulate the muscle 100 times. Then take a tracing of another single contraction using the knock-down key.

Repeat as in the preceding paragraph about half-a-dozen times.

In the curves obtained note the change of form. The most striking feature is the progressive and great prolongation of the period of relaxation; the physical condition of the muscle is altered so that it is less extensible. The rate of shortening is throughout slower; the extent of the shortening is at first greater and then becomes less and less. There is some prolongation of the latent period.

Instead of producing fatigue by a series of single induction shocks, it may be produced by tetanising the muscle for a given period as 10 secs.; or the drum may be allowed to revolve continuously, the key in the secondary circuit being closed, the knock-down key closed, and then the secondary circuit key opened at each revolution, so that each contraction of a series of break shocks is recorded.

LESSON VI. ACTION OF SOME CHEMICAL SUBSTANCES AND OF TEMPERATURE ON MUSCLE.

1. In a recently killed frog make the following preparations and place them in Ringer's fluid:—

a. Cut through the tissue on either side of the lower tendon of the sartorius muscle (Fig. 6). Pass a thread under the tendon, tie and cut the tendon near the knee joint. Hold up the end of the muscle by the thread, and with fine pointed scissors cut through the connective tissue on either side and below it, so that the muscle is freed up to the pelvis. Cut away the muscles covering the upper attachment, and cut the sartorius as close as possible to the bone.

b. Prepare similarly the sartorius of the opposite side, but tie it at the pelvis instead of cutting it. Tie loops in the threads at such distance as is suitable for fixing the muscle in the moist chamber (cp. p. 24).

Instead of tying the upper end, it is better to cut through the pelvis in the middle line, and to cut away all the muscles except the sartorius so that the muscle is obtained attached to the bone.

c. Make a sciatic gastrocnemius preparation.

2. **Action of salts.** When a muscle is placed in pure NaCl solution, Ca salts diffuse out of it, and if the former is approximately isotonic with blood plasma, spontaneous contractions (twitchings) occur. The time before they begin and their duration varies in different muscles; in the sartorius of the frog they usually begin in a few seconds and go on for several hours. The addition

of a small percentage of soluble lime salt stops them. K salts approximately isotonic with blood plasma (about ·75 p.c.) cause contraction and rapid death.

Take the sartorius muscle § 1, *a*, and place it in about 20 c.c. of pure NaCl ·6 made up in distilled water. In a short time (the time varies with the condition of the muscle) fibrillar twitchings and some more general contractions will be seen. Transfer it to a mixture of NaCl ·6 and $CaCl_2$ ·05 p.c., the spontaneous contractions cease. Put it back in the NaCl ·6 p.c., the contractions begin again. Transfer it to a mixture of NaCl ·6 and KCl ·2 p.c., the muscle contracts at first more vigorously, then becomes quiescent, and gradually loses its irritability.

The twitching of the muscle in pure sodium chloride decreases as the muscle is left in the body after the death of the frog. It is less in winter than in summer.

3. **Action of veratrin.** Take the sartorius muscle § 1, *b*, and fasten it in the moist chamber. Arrange the electrodes to touch the upper and lower surfaces, near the ends of the muscle. Fill the chamber with saline solution. With a drum rotating about 10 cm. a sec. take a tracing of a single muscular contraction (p. 23, § 2). Leave the lever in position, run off the salt solution, and replace it by ·001 p.c. veratrin sulphate made up in saline solution[1]. In about five minutes take a series of 5 tracings of the effect of single break induction shocks in the following way. Let the drum revolve continuously, and as soon as the break shock is sent into the muscle, close first the key in the secondary circuit and then the knock-down key in the primary, then open the

[1] Dilute solutions of poisons are made up in Ringer's fluid unless there is reason to the contrary.

key in the secondary circuit. Note the slow relaxation of the veratrinised muscle with the first stimulus, and the return to normal as the stimuli are repeated. The first contraction will probably be higher than the normal one. If the muscle is left unstimulated for about five mins. the prolonged contraction caused by veratrin will again be obtained.

Instead of this method, a sciatic-gastrocnemius preparation may be left in ·001 p.c. veratrin for half an hour, then washed in saline solution, fixed in the muscle chamber and the nerve stimulated.

Or, 3 or 4 drops of a 1 p.c. solution of veratrin may be injected into the dorsal lymph sac of a brainless frog; and the sartorius or the sciatic-gastrocnemius preparation made when the reflex contraction is prolonged on pinching the foot.

4. **Effect of cold and heat.** Fix the nerve-muscle preparation (§ 1, *c*) in the muscle chamber. Take a tracing of a single muscle contraction showing the latent period, and take the temperature of the fluid with a thermometer.

Move the drum half way round, run off the fluid, add saline solution at 2° C., leave it for about 3 minutes, take a tracing of a single muscle contraction, take the temperature of the fluid, note the form of the curve so that at the end of the experiment the temperature may be written against it.

Repeat with saline solution at 20° C. and at 30° C.

Write on the tracing the temperature at which each curve was taken. Note the differences in duration of contraction. Cold retards the changes in the muscle so that both contraction and relaxation are slowed. The height of the curve depends in part on the upthrow of the lever, and other methods are required to determine the effect of temperature on the degree of contraction.

Lower the drum, adjust the 4th speed. (Steel spring in upper groove, cord on large pulley on shaft and on small pulley on drum.) Set the drum in motion, pour Ringer's fluid at 40° C. into the muscle chamber, and renew it when it cools; the muscle will slowly shrink, and become opaque. (Heat rigor.) Open and close the key, there will be no contraction. In frog's muscle heat rigor sets in at 39°—40° C., in mammalian muscle at about 47° C.

DEMONSTRATIONS.

1. Action of curari on muscle and nerve.

a. Two sciatic-gastrocnemius preparations are made. Two watch-glasses are put close together, one containing saline solution and the other curari ·025 p.c. The muscle of one preparation is placed in the saline solution and the nerve in curari; the nerve of the other preparation is placed in saline solution and the muscle in curari, and left for an hour or longer. Then both nerves are stimulated with Faradic currents. The former causes contraction as usual, the latter does not cause contraction. Direct stimulation of each muscle causes contraction, but it is less widespread in the curarised one. Thus curari does not abolish the irritability and conductivity of the nerve, but prevents the impulse affecting the muscle—an action which is commonly spoken of as a paralysis of nerve-endings.

The slow action of curari in this case is due to its slow diffusion through the thick muscle: in the sartorius, the nerve is paralysed in a quarter of an hour by curari of one-tenth of the percentage used above. When curari is injected into an animal, the nerves are not all paralysed at the same time, thus in the frog the nerves to the hind limbs are paralysed before those to the fore limbs.

b. The brain of a frog is destroyed, the sciatic nerve isolated out in the thigh, and the thigh except the nerve ligatured in two places with a stout woollen thread. A couple of drops of 1 p.c. curari are injected into the dorsal lymph sac. In 20—30 mins. pinching the skin causes a reflex movement in the ligatured leg, but not in the rest of the body. The experiment shows that at this stage, though the curari has paralysed the nerve-endings to which it has had access, it has not paralysed the spinal cord.

2. **Action of veratrin.** The fore brain of a frog is destroyed and 3 or 4 drops of 1 p.c. veratrin are injected under the skin. In about a quarter of an hour, when the skin is pinched in the mid-line over the end of the urostyle, the frog jumps, but it leaves the legs extended for some time instead of drawing them up.

LESSON VII. ACTION OF SOME CHEMICAL SUBSTANCES ON NERVE AND MUSCLE. UNSTRIATED MUSCLE.

1. Muscles may contract in two ways under the influence of drugs. There may be a series of brief quick contractions (twitchings) like those caused by induction currents, or there may be a slow gradual contraction somewhat like the protracted contraction caused by the galvanic current, lasting a relatively long period, and in some muscles lasting for hours. In some cases the contraction is caused by an action on the nerve ending or on the small part of the muscle immediately under it; in other cases it is caused by an action which may occur at any part of the muscle fibre. Curari stops the former but does not stop the latter. The following experiments will illustrate these points.

2. **Protracted contraction caused by nicotine.** This is best seen in the rectus abdominis muscle of the frog. It occurs to a greater or less extent in the other muscles of the frog, but is not known to occur in the mammal.

Expose the rectus abdominis muscle in a frog immediately after death; gently press the surface of the muscle with blotting paper to remove excess of fluid, and draw a fine brush moistened with ·01 p.c. nicotine transversely across the middle of a muscle segment, the segment will slowly contract.

Expose the thoracic muscles, blot, place a drop about 1 mm. in diameter on the end of one of the muscles

close to the tendon, there will be no change; then place a similar drop on the middle of the muscle, there will be local contraction, slow enough to be followed by the eye. The part of the muscle fibres under the nerve endings (neural region) is much more responsive to nicotine (and to some other stimuli) than the part near the tendon.

3. **Spontaneous contractions of unstriated muscle.** Tie the lower end of the large intestine, and of the small intestine. Cut out the large intestine; tie loops in the threads, and fasten it by the loops in the moist chamber, with no weight on the lever, cover with saline solution. Set the drum for the slowest speed. Take the time at which the drum is started, let it run for half an hour and from this calculate the duration of the single contractions.

4. Remove the skin from the legs.

a. Cut out both sartorii, place one in curari ·005 p.c. for 15 mins. or more, and the other in saline solution.

b. Cut off both feet, place one in ·01 p.c. curari for 15 mins. or more, and the other in saline solution.

c. Make a sciatic-gastrocnemius preparation.

5. *Action of cocaine on nerve.* Cocaine annuls the conductivity of nerve fibres; the conductivity is recovered slowly on removing the cocaine in contact with the nerve; the recovery is naturally more rapid if the circulation is going on, but occurs in cut out nerve placed in saline solution.

Place the nerve-muscle preparation (§ 1, *c*) on blotting-paper moistened with saline solution, find (approximately)

the minimal tetanising current which will cause contraction when applied to the end of the nerve. Brush 1 p.c. cocaine over the end of the nerve for about $1\frac{1}{2}$ cm. and stimulate at intervals of about 3 mins. till moderately strong currents applied at the end of the nerve have no effect; the lower part of the nerve must not be raised from the moist paper, or there may be sufficient escape of current to it to cause contraction. Place the preparation in saline solution and in 15 to 30 mins. stimulate again; the time required for recovery is however often long.

Point of action of NaCl twitchings. Rinse in saline solution the sartorius which has been in curari; place it, and the other sartorius which has been in saline solution, in pure NaCl ·6. Both will twitch, but the curarised muscle probably less than the other. Thus the NaCl twitchings are due to an action on the general muscle substance. When the twitchings have developed, place the muscle in saline solution to stop the twitchings, and transfer to ·1 p.c. nicotine; the curarised muscle will not contract, so that in this case the action is not on the general muscle substance.

Twitchings caused by guanidine. Rinse in saline solution the foot which has been in curari and place both feet in about 20 c.c. of guanidine chloride ·05 p.c. The uncurarised muscle will twitch, the curarised muscle will not. Thus in this case the twitchings are due to an action in the region of the nerve endings.

Brief twitchings are caused in frog's muscle by dilute nicotine (·001—·1 p.c.) and long continued twitchings in mammalian muscle by physostigmine. Both are prevented by curari.

DEMONSTRATIONS.

1. **Prolonged contraction of muscles combined with catalepsy.** The brain and spinal bulb of a frog are destroyed, and 2 c.c. of 1 p.c. nicotine injected with a hypodermic syringe into the dorsal sac. The frog is placed on its back with the head supported so as to prevent fluid running out of the dorsal sac. In a minute or two, the toes are separated, and there is twitching in the muscles of the legs. A little later the fore limbs become stiff, and they are usually raised in slight jerks to meet across the sternum. When the fore legs have ceased to move, if they are pulled gently up at right angles to the body, they stay in this position. Similarly new positions given to the fore arms and feet are more or less retained (catalepsy). The body reflexes are gradually abolished owing to paralysis of the motor nerves. Destruction of the spinal cord does not stop the catalepsy.

In 20 to 30 minutes from injecting the nicotine, the tonic contraction becomes less, and the fore legs gradually become flaccid.

If the spinal bulb is not destroyed, the first effect of nicotine will be to cause crawling movements.

The catalepsy is due to an altered physical condition caused by nicotine in the neural region of the muscle fibres; the elasticity of the muscle being much diminished. The catalepsy of hysteria in man is similar in external appearance, but it is due to an action of the central nervous system, and the muscles (so far as is known) are in tetanic and not in tonic contraction.

2. Peristaltic action of intestine and ureters.

LESSON VIII. CILIA. AXON REFLEX. RHEOSCOPIC FROG.

1. **Cilia.** Place a pithed frog on its back, cut through the lower jaw in the middle line, and carry the incision down the œsophagus as far as the stomach. Pin back the parts divided, and moisten the mucous membrane, if it is at all dry, with normal saline solution. Place across it in a line, as high up as practicable, three small thin pieces of cork. The pieces of cork will be seen to be driven by ciliary action towards the stomach; probably the middle piece will travel the fastest. Warm saline solution will increase the ciliary activity.

2. **Axon reflex in nerves to muscle.** The nerve fibres supplying a muscle divide into several branches and the branches supply separate muscle fibres. If any one branch is stimulated, the nervous impulse spreads over all the branches, and causes contraction in several muscle fibres. In some muscles which are divided into two or more segments by tendinous insertions, some of the nerve fibres send branches to two adjoining segments and in consequence stimulation of certain parts of one segment will cause contraction in the adjoining segment. This can be shown in the gracilis major of the frog (cp. Fig. 6).

Expose the gracilis major on one side, place a crystal of NaCl a little below the tendinous insertion; in a short time there will be twitchings of the muscle fibres near the salt and some twitchings in the muscle on the opposite side of the tendon.

Expose the gracilis of the opposite side and stimulate different points on one side of the tendinous insertion with weak faradic currents; the ends of the electrodes being close together. At some points contraction will be obtained on the opposite side of the tendinous insertion, at others on the same side only.

Similar experiments may be made on the rectus abdominis and sub-maxillary muscles of the frog. In the former, salt placed on one segment causes great shrinking of the segment and some twitching in the segment above or below or in both. In the latter there are no segments, but the branching of the nerve fibres is greater than in the skeletal muscle, and salt placed on the anterior part will cause twitching in the posterior part.

3. **Stimulation by the injury (demarcation) current and by the current of action. (Rheoscopic frog.)** Arrange a coil for single induction shocks. Remove the skin from the legs of the frog and dissect out both sciatic nerves from the vertebral column to the knee. Suck up with blotting paper any blood or lymph from the legs and place the frog on a clean dry cork board. With a scalpel make a transverse incision into the extensor muscles of one thigh, e.g. the left, just above the tendons. Cut off the end of the left sciatic near its origin. With a glass rod lift up the nerve, and let it fall across the thigh muscles so as to come in contact with the surface and the cut end. As the nerve makes contact, a contraction of the muscles supplied by it will occur. The injury current of the thigh muscles stimulates the nerve. Divide the Achilles tendon of the right gastrocnemius, fix the tendon by a pin close to the left knee, and, taking care not to injure the right sciatic, fix the right knee with a pin. Raise the

left sciatic with a glass rod and place it across the belly of the right gastrocnemius with its cut end lying close to the tendon of the muscle. Stimulate the right sciatic with single induction shocks, each time the right gastrocnemius contracts the left contracts also. The current of action in the muscle stimulates the nerve. Stimulate the right sciatic with tetanising currents; tetanus will be produced in the left gastrocnemius as well as in the right.

DEMONSTRATIONS.

1. Injury current in muscle and its negative variation shown by the galvanometer.

2. Stimulation of motor points in the arm of man.

LESSON IX. WORK AND EXTENSIBILITY OF MUSCLE.

1. Make a sciatic-gastrocnemius preparation and a similar preparation without the sciatic. Place in saline solution.

2. **Work done by a contracting muscle.** Fix the nerve muscle preparation of § 1 in the muscle chamber and set up the apparatus for taking a single muscular contraction. Put on a weight of 10 grams attached to a long hook (Fig. 18). Adjust the point of attachment of the muscle and the length of the lever so that the magnification of the contraction is a whole number.

Determine the position of the secondary coil which gives a maximal contraction on break of the primary, without being unnecessarily strong. When once decided upon keep the strength of stimulus constant. Trace a base line by moving the drum on about one centimetre.

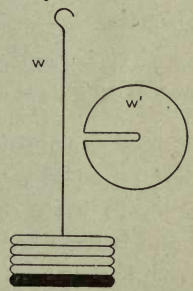

Fig. 18. Weights used for successive weighting of muscle (reduced).

Stimulate the nerve with a single break shock, recording the contraction on the stationary drum. Close the secondary key, move the drum on about half a centimetre by hand, add another 10 grams weight, the muscle stretches, set the lever horizontal, move the drum half a centimetre, and stimulate again with a single break shock. Proceed in this way till the load is 50 grams, then add 20 grams at

a time until the load is 200 to 300 grams, or until the muscle fails to raise the weight. Mark opposite each contraction the load the muscle is carrying at the time. Measure with a pair of compasses the height of each contraction in millimetres. (There is a millimetre scale on the induction machine.)

Determine the work done in gram-millimetres at each contraction by the formula $W = \frac{w.h}{m}$ where W = work, w = height in mms. of the contraction, m = the magnification of the contraction. The work done increases as the load increases up to a certain point and then decreases.

On squared paper plot out (*a*) the curve of the height of contraction with increasing load, the height in mms. being the ordinates and the weight in grams the abscissæ; (*b*) the curve of work, the gram-millimetres of work being the ordinates and the load in grams the abscissæ.

The experiment may be repeated using a tetanising current for one second instead of single induction shocks.

3. **Extensibility of muscle.** Fix the gastrocnemius of § 1 in the muscle chamber. Bring the point of the lever to write on the drum, and turning the drum by hand trace a base line with the muscle unloaded (except with the weight of the lever). With a pair of compasses mark off on this a number of points ·5 cm. from one another. Put on a load of 20 grams attached to a long hook (Fig. 18), the muscle stretches, and the lever falls, recording a nearly vertical line. Move on the drum ·5 cm. by hand, and put on another 20 grams, the lever again falls but less than before. In this way record the magnified extension of the muscle for each successive 20 grams

weight until ten or twelve have been added, moving on the drum ·5 cm. after each addition. The extension becomes less and less, and the lower extremities of the lines traced by the fall of the lever are obviously points on a curved line. Remove the weights in succession turning the drum as before. The muscle does not return to its original length, i.e. its extensibility is imperfect.

4. Substitute for the muscle a strip of sheet india-rubber, and test the extensibility of the rubber in exactly the same way. Observe that each weight added stretches the rubber an equal amount and a line joining the extremities of the tracings is a straight one.

5. Plot out on squared paper the curves of extensibility.

DEMONSTRATION.

The ergograph.

LESSON X. SOME ACTIONS OF THE SPINAL CORD.

A. Lymph-Hearts. Reflex Action.

1. A frog is given you in which the brain but not the spinal cord has been destroyed[1]. Placing the animal on its belly, watch the movements of the posterior **lymph-hearts.** They may be seen beating on either side of the extremity of the urostyle, in a depression between that bone and the hip-joint.

The beat of the posterior lymph-hearts is due to nerve impulses proceeding from the spinal cord by the 10th spinal nerve. After the destruction of the spinal cord in § 16, note that the lymph-hearts no longer beat.

2. Place the frog in a sitting posture. Observe that its hind-limbs are drawn up under the body; but that it differs from the normal frog in the following respects.

Its head is depressed, instead of being erect.

Its fore-limbs are spread out, or flexed, instead of being held nearly vertical; thus the angle which the body makes with the table is diminished.

There are no respiratory movements, either of the nostrils or of the throat.

3. Gently pull out one of the hind-limbs, until it becomes quite straight, and then let it go. It will be immediately drawn up into its old position under the body.

[1] The nervous structures in the skull and in the canal of the 1st vertebra are destroyed with a seeker. If the latter part is not destroyed, a part of the spinal bulb is left and the reflexes are more complex than with the spinal cord alone.

If this experiment be made soon after the operation of removing the brain, or if much blood has been lost, the leg may be drawn up slowly instead of sharply.

4. Gently tickle one flank with a feather or a blunt needle; a contraction of the flank muscles of that side will be observed.

5. Pinch the same spot rather sharply with a pair of forceps; the leg of the same side will be first extended, and then drawn up and swept over the flank, the movement tending to thrust away the points of the forceps.

6. Pinch with the forceps the skin round the anus; both legs will be drawn up and thrust out again; the movement tending as before to sweep away the points of the forceps.

Leave the animal alone for five minutes and watch it carefully: if no disturbing circumstances are brought to bear on it, it will remain perfectly motionless.

7. Place the animal on its back; it will make no effort to regain its normal position, i.e. all sense of equilibrium has been lost.

8. Pass a hook through the lower jaw, and fasten it to the cross bar of a stand so that the body can be raised up and down. The hind-limbs, after a few movements of flexion and extension, will remain pendant and motionless.

9. Gently pinch the tip of one of the toes of either leg; that leg will immediately be drawn up.

10. Fill a beaker with water; and place a little acetic acid ·5 to 1 p.c. acid in a watch-glass: let the tip of one of the toes of the frog touch the acid. In a short time

the foot will be withdrawn. Dip the foot into the water, in order to wash away the acid. Measure, with the aid of a rapidly beating metronome, the time between the moment when the toe comes into contact with the acid and the moment when it is withdrawn. Make, at intervals of two minutes, three such observations (being careful that the toe dips in the acid to exactly the same extent) and take the mean of the three.

11. Cut a small piece of blotting paper one or two mms. square, moisten it with 1 to 5 p.c. acetic acid, and place it on the flank of the animal. The legs of the same side will be speedily drawn up and swept over the flank as if to remove the piece of paper. Wash away the acid.

12. Place similar pieces of acid-paper on different parts of the body; different movements will be witnessed in consequence; all however tending to remove the irritating substance.

13. Wash off all the acid from the frog, and when it has become perfectly quiet, place it in a basin of water; it will sink to the bottom (unless the lungs be accidentally much distended with air), and no movements of any kind will be witnessed.

Observe that all the movements produced in the foregoing observations, although complicated, co-ordinated, and purposeful in character, are partial, and only by accident bring about locomotion. However stimulated, the animal never springs or leaps forward.

14. Make a small cut through the skin of the back and inject half-a-dozen drops of chloral hydrate, leave for five minutes, and repeat § 10; the reaction time will be much prolonged.

15. Inject one drop of a 1 p.c. solution of sulphate of strychnine under the skin of the back. In a few minutes the slightest stimulus applied to any part of the animal will produce violent tetanic spasms of the whole body. A preliminary stage of increased reflex action may also be observed.

16. With a straight seeker or a piece of stout wire destroy the whole of the spinal cord. The spasms immediately cease.

17. Repeat any of the above observations (§§ 3—12). No reflex actions will now be produced. The lymph-hearts have ceased to beat.

B. Innervation of the muscles of the leg by the roots of the lumbar plexus and by its branches.

The spinal nerves which form the roots of the limb plexuses intermix in the plexus, and the branches from the plexus contain fibres from two or more spinal nerves. The branches of the plexus run to separate muscles or groups of muscles; thus most muscles (and each part of the skin) receive nerve fibres from more than one spinal nerve. This can be observed in the frog's leg; the movements caused by stimulating the several nerves can at the same time be noticed.

a. Pithed frog. On one side, tie and cut the 7th, 8th and 9th spinal nerves close to their exit from the spinal cord, stimulate them separately with weak faradic currents for a few seconds at a time. The movements produced vary in different frogs, but it will be seen that the

7th and 8th, and the 8th and 9th cause some movements in common, and that in general the extensors overcome the flexors. Expose the gastrocnemius, cut the Achilles tendon, pin down the knee and ankle-joints; stimulate again and note that contraction of the muscle is obtained from two nerve roots.

b. On the opposite side, remove the ileo-fibularis muscle. Tie the sciatic in the upper part of the thigh and cut the nerve above the ligature. Hold up the nerve; it will be seen to divide into two branches, one the peroneal nerve (external popliteal) passing dorsally over the knee, the other the tibial nerve (internal popliteal) passing more ventrally. Tie the peroneal nerve close to its point of branching from the sciatic and cut it just above the ligature.

Move the leg away from the mid-line, and bend the foot at the ankle-joint. Stimulate the *tibial nerve* with weak faradic currents for a few seconds. The leg will be drawn to the mid-line, there will be extension at the ankle-joint, the toes will be bent towards the plantar surface, and drawn together. Make a sketch of the position of the limb.

Stimulate similarly the *peroneal nerve*. The limb will be straightened at the knee, the foot bent back, and the toes separated widely. Tear off the skin, cut the tendo Achillis and stimulate again; the lower leg will be bent back at the knee and the bending of the ankle will be much greater.

Note that the gastrocnemius contracts on stimulating the tibial nerve but not on stimulating the peroneal nerve.

DEMONSTRATIONS.

1. Beating of lymph-hearts after removal of the skin over them in frog with brain destroyed.

2. Reflex action of frog without cerebral hemispheres or mid-brain.

3. Reflex action of frog without cerebral hemispheres. (The hemispheres may be destroyed by crushing them through the skull with pliers made so that the jaws have a parallel movement.)

4. Knee jerk and plantar reflex.

LESSON XI. HEART-BEAT OF FROG. INHIBITION. LIGATURE OF SINO-AURICULAR JUNCTION.

For the experiments on the heart it is essential to have fine pointed forceps and scissors.

1. Cut through the skin of a pithed frog in the mid ventral line, make transverse cuts and turn the skin back. Cut transversely through the xiphisternum just above the abdominal vein. Cut through the sternum in the mid line, pull the parts gently asunder, and cut through the muscles attached to their inner surface. Pin out the arms. The heart will be seen beating in the thin membranous pericardium. Note the alternate beats of the auricles and the ventricle; and the synchronous beats of the two auricles. Lay open the pericardium and observe (best with the aid of a lens)

a. The synchronous contractions of the two auricles, followed almost immediately by

b. The contraction of the ventricle; note that the ventricle during its contraction or systole becomes paler and more conical, and that its apex is thrown forwards and upwards; the obviousness of these changes, especially of the latter, depends upon the force of the contraction and on the amount of blood.

c. The contraction of the bulbus arteriosus immediately succeeding the ventricular systole. Note the distension of the bulbus and the rush of blood through it, as the ventricle contracts.

d. The pause, or diastole, which follows before the auricles again beat; if the heart is beating rapidly this may not be obvious to the eye.

e. The increased redness and distension of the ventricle after the auricular, and immediately preceding its own systole.

2. Tilt forward the apex of the ventricle, a thin thread of connective tissue—the ligament of the ventricle—will be seen passing from its dorsal surface to the pericardium; cut this through. Pull the ventricle forward by the ligament. Observe

a. The junction of the two superior venæ cavæ with the inferior vena cava to form the sinus venosus (cp. Fig. 19).

b. The whitish line marking the junction of the sinus venosus with the right auricle.

c. The wave of contraction; it starts in the endings of the great veins (the progress of the wave may be seen in the superior venæ cavæ); then follow in quick succession, contraction of the auricles, the ventricle, and the bulbus arteriosus.

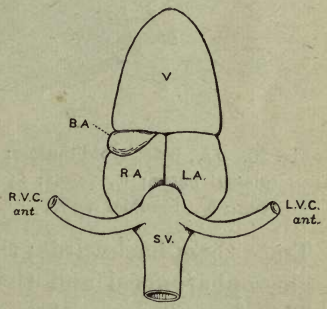

Fig. 19. Diagram of heart of frog with the ventricle turned forwards.

3. **Dissection of the vagus.** Make a transverse cut through the skin of the frog just below the lower jaw, and carry the cut as far as the vertebral column. Cut

away the skin over the lower jaw. Cut through the superficial muscles connecting the shoulder and sternum with the head.

Near the mid line of the lower jaw will be seen two nerves on each side, the hypoglossal and the glossopharyngeal. Near the symphysis of the jaw the hypoglossal—which is the more superficial of the two—lies on the outer side of the glossopharyngeal (cp. Fig. 20).

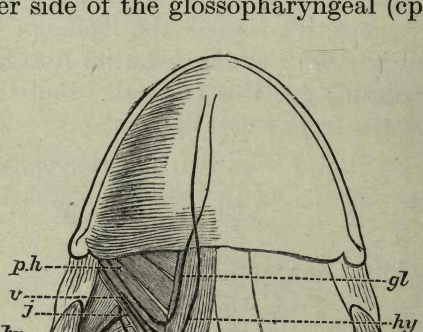

Fig. 20. *p.h.*, petrohyoid muscle; *gl.*, glossopharyngeal nerve; *hy.*, hypoglossal nerve; *v.*, vagus; *l.*, laryngeal branch; *j.*, internal jugular vein; *br.*, brachial nerve.

Trace them backwards; the hypoglossal crosses first the glossopharyngeal and then the branches of the aorta. The glossopharyngeal on coming to the aortic branches runs towards the angle of the jaw, along the upper border of a small band of muscle (part of the petrohyoid).

The course of the vagus is most easily followed by cutting away the sternum, putting a seeker through the anterior part of the skull from behind and tying the

arms to the seeker. Instead of this a short glass rod may be pushed down the œsophagus into the stomach and the frog turned on its side. The **vagus** will be seen on the lower edge of the slip of the petrohyoid muscle mentioned above, and close to the internal jugular vein. In the following dissection the vagus must not be pulled on or pinched. Pick up the hypoglossal, isolate it centrally for a short distance taking care not to injure the vagus, cut it and turn it forward. Treat similarly the glossopharyngeal. The vagus will now be more obvious, it will be seen to consist of two branches, the smaller, anterior one runs to the larynx; the larger one runs to the heart, lungs and stomach. Note the much larger nerve—the brachial—running to the arm. Trace the vagus to the skull, cutting away any tissue obscuring it. Pass a needle threaded with a wet silk thread under the vagus near the skull (the petrohyoid muscle may be taken with it), tie the thread, cut the nerve close to the skull and isolate it for about a centimetre. Do not isolate near the heart.

Cut off the arm, expose the heart if it is not already exposed and pin down the frog firmly. Place a piece of thin india-rubber membrane upon the tissue under the vagus and stimulate the nerve for about 5 seconds with weak tetanising currents, increasing the strength if necessary till an effect is obtained (strong currents cause local injury). There should be contraction in the larynx, but in no other muscle. Watch the heart, and note

The **inhibition of the heart-beat.** A second or two after the beginning of the stimulation the heart stops beating, all parts of it being flaccid (diastolic standstill); and it remains so during the stimulation and for a short time afterwards. The inhibitory effect varies

greatly with the condition of the frog; a slowing and weakening of the heart-beats may be caused instead of cessation. After the stimulation, the beat may become stronger than before. If no effect is obtained with a current distinctly felt on the tongue, place the electrodes on the undissected part of the vagus near the heart. Dissect out and stimulate the other vagus, the effect of one nerve is often more marked than that of the other.

4. Turn the ventricle forwards and stimulate the line of junction of the sinus and right auricle; the heart will stop beating; there may be a preliminary period of quickened beats caused by the direct stimulation of the cardiac muscle.

5. **Ligature of sino-auricular junction. Reversed beat.** Cut through the tissue on either side of the aortæ. Pass a thread underneath them, draw it backwards, tilting the ventricle forwards, tie it firmly round the junction of the sinus with the auricle. The auricles and ventricle will either cease to beat or beat with a slower rhythm than the sinus. If the heart has stopped touch the tip of the ventricle with a seeker; the ventricle will beat before the auricle (this is best seen somewhat later, when the conductivity of the heart has decreased). If the heart continues to beat, touch the ventricle several times at a rate rather faster than the beat; each touch will cause a reversed beat from ventricle to auricle.

Stimulate the ventricle with weak faradic (tetanising) currents; the stimulation does not cause tetanus, but either a beat at its beginning and end, or a series of beats.

DEMONSTRATIONS.

1. Upper part of sympathetic dissected in the frog.
2. Action of the sympathetic nerves on the heart.

LESSON XII. GRAPHIC RECORD OF BEAT OF FROG'S HEART. ACTION OF POISONS.

1. **Graphic record of cardiac inhibition.** Dissect out the vagus as in Less. XI. Stimulate it; if the stimulation does not stop the heart, the nerve has probably been injured and the vagus of the opposite side should be prepared.

Another way of dissecting the vagus is as follows.

Hold the head of a pithed frog between finger and thumb. Cut away the skin on the back of the head. Pass a scalpel carefully along the posterior edge of the skull, so as to cut through the muscles attached to it. The vagus nerve, the jugular vein, and the petro-hyoid muscle will come into view, and on a little further clearing of the muscles, the glossopharyngeal nerve also. Pass a threaded needle under the vagus; put the frog on its side, tie the nerve and cut it close to the skull. Now expose the heart.

A convenient lever to use for the experiment is shown in Fig. 21, but the straw *S* should be somewhat longer than in the figure. Arrange the lever as in Fig. 21 (2), and put it at such a height that by raising or lowering the drum a tracing can be taken at any level of the blackened paper without shifting the lever. Put a piece of plasticine on the short arm *A* so as nearly to counterpoise the long arm, and adjust the lever so that the writing point presses lightly only on the paper.

Pass a silk thread through the ring of a small wire clamp (Fig. 23 *Cl.*) and tie in the thread a loop 2 to 3 inches long. Fix the points of the clamp in the extreme tip of the ventricle, in doing this the ventricle must not

be taken up with forceps. Place the frog board under the lever, and pin down the frog firmly in such a position that the heart is vertically under the hook (*h*) attached to the lever. Raise the frog board, pass the loop of the silk thread over the hook and gently lower the board till the lever is nearly horizontal. Set the drum at slow

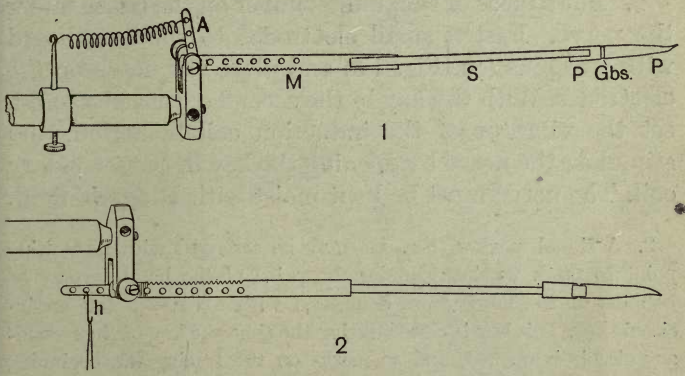

Fig. 21. Brodie's heart lever *S* is a straw or a flat strip of wood fixed by composition or sealing-wax to the thin metal strip *M* and to the writing point *P*. The writing point consists of two pieces of parchment paper or thick writing paper joined together by gold-beater's skin *Gbs*. The arm *A* can be fixed vertically or horizontally by a set screw. Two arrangements of the lever are shown in (1) and (2).

speed so that the diastole of the heart takes 2 to 3 mm. Keep the heart moist with Ringer's fluid.

Stimulate the vagus as in Less. XI, p. 65 for 5 secs., holding the electrodes in the hand. Mark on the drum the beginning and end of the stimulation.

Stimulate again, keeping the current on; after a variable time the heart will begin to beat notwithstanding the stimulus (escape of the heart).

When the heart begins to beat after vagus stimulation it will for a time probably beat more strongly than before the stimulation, and if the contractions of the ventricle have been of unequal strength, they will become equal. By repeated stimulation the beat will (usually) be considerably improved.

2. Put a piece of thin india-rubber on the tissue under the nerve. Fasten small electrodes to the frog board with two pins (cp. Fig. 1 *b*) and place the nerve on the electrodes. With the key in the secondary circuit closed, set the vibrator of the induction coil in action, and stimulate the nerve by opening the key in the secondary coil. The nerve must be kept moist with Ringer's fluid.

3. A signal marker (Fig. 14) may be arranged with its writing point to mark vertically under the point of the heart lever. The bobbins of the marker are connected with a battery and an in-circuit key. This key is closed during the time the key of the secondary circuit is opened, and so marks on the tracing the beginning and end of the stimulation.

4. *a.* **Effect of nicotine.** Let fall on the heart two drops of 1 p.c. nicotine. There will be temporary slowing of the beat. In a few minutes stimulate the vagus, no inhibition will be produced, but there may be increase in rate and strength of the heart-beats. Stimulate the junction of the sinus and auricle, the heart will stop.

Nicotine has a brief stimulating effect on the peripheral ganglia, it then paralyses the pre-ganglionic fibres, but does not (except in large amount) paralyse the post-ganglionic fibres.

b. **Effect of arecoline (and pilocarpine).** Let fall on the heart two drops of 1 p.c. arecoline nitrate. The

beat will become slower and weaker. Muscarine has a similar effect; the effect of pilocarpine is more variable.

c. **Effect of atropine.** Wash off the arecoline with saline solution. Add a couple of drops of 1 p.c. atropine

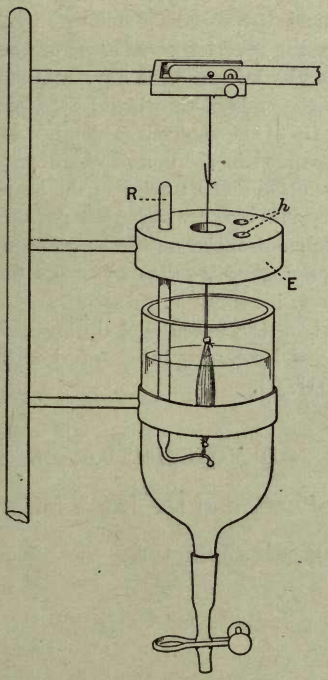

Fig. 22. *R*, rod to which to fix tissue. *h*, holes for electrodes.

sulphate. The beat will gradually become quicker and stronger. Stimulate the junction of the sinus and auricle, no slowing will be caused. (If the current is strong, slowing or temporary cessation may be caused by lowering the conductivity of the tissue between sinus and

auricle.) Arecoline, muscarine and atropine act on the endings of the post-ganglionic fibres and on the heart muscle.

5. The action of these poisons may be determined in the following way. After cutting away the pericardium, and severing the ligament of the ventricle, the aortæ are cut through, and holding the heart up by these, the superior venæ cavæ are cut through and a ligature tied round the inferior vena cava and surrounding tissues close to the liver; the ends of the thread are tied to make a short loop. The extreme tip of the ventricle is clamped as in § 1. The heart is cut out and suspended in the muscle chamber (Fig. 22) which is filled with saline solution and a tracing of the heart beat taken.

The vessel is then lowered, a watch-glass put on it, and a drop or two of ·5 p.c. arecoline dropped on the heart. When the heart beat has stopped the watch-glass is taken away and the vessel raised so that the heart is in saline solution.

In a minute or two, the vessel is again lowered, another watch-glass placed on it and 1 p.c. atropine dropped on the heart.

See also Less XIII, § 1.

DEMONSTRATIONS.

1. Current of action of the frog's heart.
2. The string galvanometer.

LESSON XIII. ACTION OF ADRENALINE AND OF SALTS ON THE HEART.

1. **Perfusion of heart and effect of adrenaline.** Expose the heart of a pithed frog. Cut through the pericardium and the tissue on either side of the aortæ. Pass a thread under the aortæ and pull it backwards. Cut out the larynx. Turn the ventricle forwards, cutting through its ligament. Cut away the thin membrane overlying the inferior vena cava, this requires care to avoid cutting the vessel. With fine pointed scissors pick up the wall of the vein close to the liver, cut a small hole in it with fine pointed scissors. Remove the blood with a sponge and insert the point of a cannula of the shape shown in Fig. 23 (*Ca.*) and tie it in. (If this fails, make a cut in one of the auricles as far as possible from the ventricle and tie the cannula in this.) Cut across the aortæ, and cut out the heart attached to the cannula.

Clamp the tip of the ventricle with the small wire clamp (Fig. 23 *Cl.*), pass a thread through the loop of the clamp and fix the cannula and the heart as in Fig. 23, taking care that the lever is at such a height that by moving the drum up or down the whole of the blackened paper can be used. Put a small glass dish on the table under the heart. Connect a Mariotte's bottle (cp. Fig. 24 *M*) containing Ringer's fluid, with the cross piece of the cannula, the connecting rubber tubing having a clamp on it. Set the drum so that the heart tracings are only a few mms. apart.

Raise the bottle so that the lower end of the tube in it is about 2 cm. above the level of the heart. Open the

clamp on the tubing, and take a tracing of the heart-beat for a minute or two. Then drop into the cannula ½ to 1 c.c. of ·001 p.c. adrenaline. The heart-beat will gradually increase in force and frequency. As the heart pumps out the fluid the effect of the adrenaline will gradually pass off.

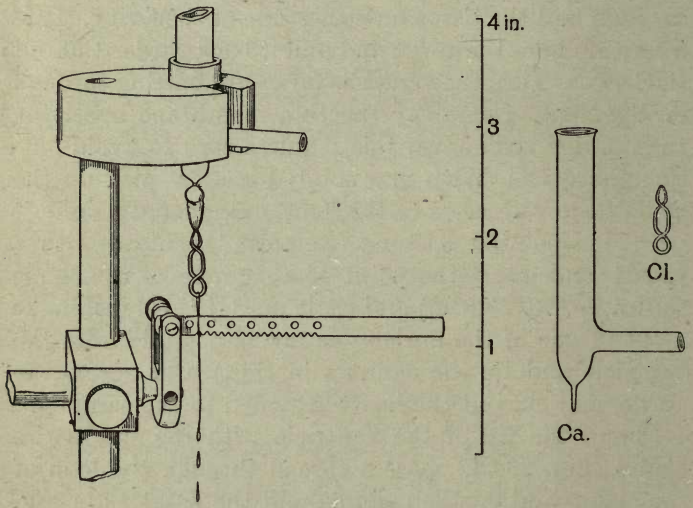

Fig. 23.

2. The effects of arecoline and atropine should be similarly determined if they were not observed in Less. XII. Observe the effects of the following variations in the percentage of salts in the fluid used for perfusion. In each case, a tracing of the heart-beat is taken using Ringer's fluid for perfusion. The india-rubber tube from Mariotte's bottle is then clamped (the new fluid may be injected into its peripheral end to wash out the Ringer's fluid), and the new fluid dropped into the cannula.

a. Pure sodium chloride ·65 *p.c.* The heart becomes weaker and gradually stops in diastole. Perfuse with Ringer's fluid, the heart recovers.

b. Sodium chloride ·65 *p.c.* + *potassium chloride* ·1 *p.c.* The heart-beats become weaker and rapidly stop in diastole. Perfuse with Ringer's fluid, the heart recovers.

c. Sodium chloride ·65 *p.c.* + *calcium chloride* ·2 *p.c.* The tone of the heart increases, and the heart beats at a higher level. Add a little 1 p.c. $CaCl_2$, the heart stops in systole. Perfuse with Ringer's fluid, the heart recovers.

LESSON XIV. ACTION OF ADRENALINE ON BLOOD VESSELS. STIMULATION OF VENTRICLE.

1. Expose the heart of a pithed frog, and tie the sino-auricular junction (Less. XI, § 5). Tie one aorta a short distance from the heart. Tie a small cannula, having a short piece of rubber tubing on one end and containing saline solution, in the other aorta facing the peripheral vessels, and cut the aorta near the heart; by pinching the tubing force saline solution into the neck of the cannula in order to prevent blood clotting in it. Cut out the heart and place it in saline solution for § 2.

Fill the cannula with Ringer's fluid by means of a pipette and connect it with a 3-way tube so that the mid-branch is uppermost. Brush off any clots that may have formed at the cut ends of the veins. Place the frog on a disc in a funnel and fix the 3-way tube with plasticine (*p*) to the edge of the funnel (cp. Fig. 24). Connect the distal end of the 3-way tube with a Mariotte's bottle at a slightly higher level. Put a glass dish under the funnel and open the clamp (*Cl.* Fig. 24). When the tubes have been emptied of air through the tube (*t*) close the latter with a small piece of glass rod. The fluid will then be forced through the blood vessels.

Count the drops which fall from the funnel in two or more successive minutes. Then inject with a hypodermic syringe $\frac{1}{2}$ c.c. ·001 p.c. adrenaline into the tube *T*, and count the drops in each successive minute; the flow will soon become very slow owing to the contraction of the blood vessels caused by adrenaline.

A signal may be arranged as in Less. XII, § 3, to write on the drum, and the key closed for a moment as each drop falls. Thus a record may be obtained of the rate of flow.

2. The heart which was placed in saline solution will probably not be beating, but it may be beating slowly. Arrange a lever to write on the drum, and connect the heart to the lever as in Less. XII, § 1. Pin the sinus to the frog board. Pin thin wire electrodes to the stand,

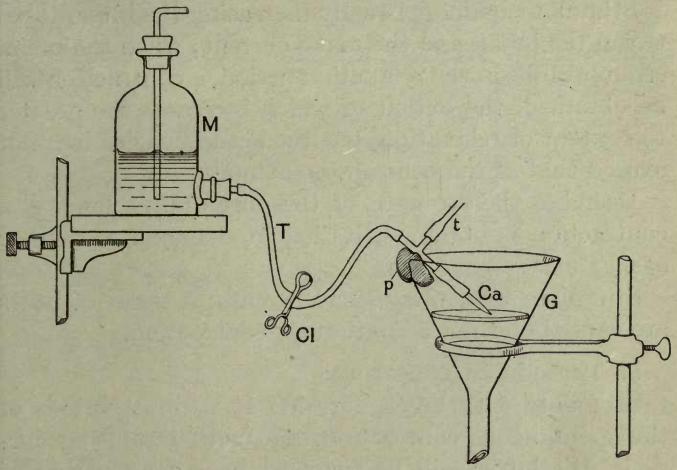

Fig. 24.

arrange the points to touch two sides of the ventricle near its tip, and connect for single induction shocks. Move up the secondary coil till a contraction is obtained at make and break. When stimulating, the key must be opened and shut quickly and steadily. Set the drum moving slowly.

a. If the heart is not beating:

Stimulate with a make and after a few seconds with a break current; a single contraction is obtained with each

stimulus. Repeat this several times; the contraction may increase gradually in height (*staircase effect*) but this depends upon the condition of the heart.

Stimulate with the break current immediately following the make; a single contraction only will be obtained of the same height as before, i.e. for a short time after beginning to contract the ventricle is not irritable, it has a rather long *refractory period.*

Stimulate again, gradually increasing the interval between the break and the make current; when the break stimulus falls in the relaxation period, a contraction will be obtained, the extent of which increases the greater the extent of relaxation, but the actual height does not exceed that of the contraction at make.

Decrease the strength of the currents, as long as a contraction is obtained, its height does not vary (*law of maximal response*).

Stimulate with tetanising currents; a series of beats are caused and not a continuous contraction.

b. If the heart is beating:

Stimulate with break currents at various periods of the spontaneous contraction, and with tetanising currents, the latter will be followed by a long period of quiescence.

LESSON XV. HEART OF MAMMAL.

Dissection of the Sheep's Heart[1].

1. Observe the attachment of the parietal pericardium to the roots of the great vessels.

Remember that the parts of the heart which are right and left in the body are called right and left after removal. The front of the heart may be recognised by a groove filled with fat, the interventricular sulcus, which runs from about the middle of the base of the ventricles to rather below the middle of the right margin of the heart. The front is also more convex than the back. Holding the heart with the front towards you, note that the right ventricle, which will be on your left hand, is much more yielding than the left ventricle, which will be on your right hand. Note also the pulmonary artery arising nearly in the middle line of the heart at the upper part of the ventricles, and immediately behind this the aorta.

2. Tie a short glass tube into the superior vena cava and connect with it a piece of india-rubber tubing. Ligature the inferior vena cava and the left vena azygos which opens close beside it. Tie a glass tube about two feet in length into the pulmonary artery. Fill the india-rubber tubing with water, and squeezing it press the

[1] The heart should be obtained from the butcher with the pericardium; to secure this it is advisable to purchase the 'bag,' i.e. the heart with the lungs still attached to it.

water onwards. The water will mount in the tube connected with the artery, and will only descend a little way on unclasping the india-rubber tubing. Pour water into the long glass tube by means of a funnel, and observe the column of water which the semilunar valves will sustain. Note the distension of the arterial walls and the bulging at the attachment of the valves. When the pressure of the column of fluid is removed the artery by its elasticity returns to its previous dimensions.

3. Repeat the above observation with the pulmonary veins and aorta.

4. Compare the united sectional areas of the superior and inferior venæ cavæ when distended, with the area of the aorta below the origin of the innominate artery.

5. Having removed the tubes, lay open the superior and inferior venæ cavæ, and bring the incisions to meet in the front of the auricle. Note

The size and form of the auricular cavity. The auricular appendage with its muscular fretwork.

The septum auricularum.

The fossa ovalis, or expression of the fœtal foramen ovale, which is early closed by the growth of the septum auricularum.

The Eustachian valve, a slightly projecting membranous fold, immediately beneath the entrance of the inferior vena cava, and again beneath this

The opening of the comparatively large left azygos vein.

The auriculo-ventricular orifice.

6. Cut open longitudinally the azygos vein, and

observe the **coronary vein**[1] opening into it a very short distance from the heart.

7. Cut away most of the auricle, and holding the ventricle in the left hand, pour water suddenly into the auriculo-ventricular orifice. The **right auriculo-ventricular** or **tricuspid valve** will float up and close the orifice. Note the star-shaped junction of the valve-flaps.

8. Introduce a pair of scissors between two of the valves, and cut through the wall towards the apex. Having arrived at the bottom of the ventricular cavity, turn the scissors sharply round and carry an incision at an acute angle with the previous one, alongside the septum, towards, but not into, the pulmonary artery. Lifting up the flap, note:—

The thickness of the ventricular wall, the projections of its inner surface or columnæ carneæ, the band of muscle (moderator band) running from wall to wall of the ventricle across its cavity. The ventricular cavity does not extend to the apex.

A pale strip will be seen extending from the top of the moderator band in the direction of the foramen ovale; this is the continuation in the right ventricle of the **auriculo-ventricular bundle.** Cut through the endocardium and isolate the bundle in its course on the septum.

The **tricuspid valve**, its form, and attachment to the auriculo-ventricular ring, the **chordæ tendinæ**, and their attachment to the summits of the papillary muscles.

[1] In man, the left azygos vein joins the right, and this runs into the superior vena cava; the coronary vein (coronary sinus) opens direct into the right auricle.

9. Holding the heart vertically, pour water into the pulmonary artery; observe from below the form of the **semilunar valves**, and their mode of closing.

10. To observe the valves from above, insert into the pulmonary artery a short wide tube, fill it with water, and cover it with a piece of glass, excluding air-bubbles.

11. Prolong the incision of § 8 so as to lay open the pulmonary artery. Note

The form and attachment of the **semilunar valves.**

The small nodule of tissue in the middle of the free edge of each valve, the **corpus Arantii.**

The slight depressions in the arterial walls opposite each valve, the sinuses of Valsalva.

12. Lay open the left auricle in a manner similar to that employed for the right. Note that the left auriculo-ventricular valve, the **bicuspid** or **mitral**, has but two flaps. Observe its manner of closing (cp. § 7).

13. Lay open the left ventricle in a manner similar to that employed on the right side, carrying the incision at first along the extreme left of the heart. Note the thick walls, the mitral valve, &c.

14. Lay open the aorta, and examine its semilunar valves, corpora Arantii, and the sinuses of Valsalva, which are here very distinct. Note that the **coronary arteries** open respectively into two of the sinuses.

DEMONSTRATIONS.

1. The beat of the isolated mammalian heart and the effect of adrenaline upon it.

2. The stethoscope and the sounds of the heart.

3. The cardiograph.

LESSON XVI. BLOOD VESSELS. CIRCULATION.

A. Minor Arterial Scheme.

This consists of an india-rubber bag, or enema syringe, connected by a tube to a vessel of water and furnished with two valves, one on each side of the bag and opening in the same direction, so that when it is alternately compressed and released by hand, water is drawn from the vessel and delivered into tubes beyond the bag. The tubes consist of a piece of glass tubing about 5 or 6 feet long and a piece of rubber tubing of similar length and bore and are connected to the syringe by means of a three-way tube.

There are clamps upon the long india-rubber tube close to its junction with the three-way tube and upon the small piece of india-rubber which connects the three-way tube with the glass tube, so that the flow of water may be through either the glass or the india-rubber tube.

A small piece of india-rubber tubing is also placed on the end of the glass tube, into which a tube finely drawn out can be inserted.

1. Clamp the india-rubber tube at its proximal end close to the pump, and leave the glass tube open so that all the water flows through the latter. Work the pump with a uniform force at about 30 to 40 strokes a minute. To ensure regularity, the strokes had better be timed with a metronome. The water will flow from the open mouth of the glass tube in jerks, corresponding to the strokes of the pump. At each stroke as much will issue from the distal end as enters at the proximal end.

2. Introduce into the open mouth of the glass tube a fine nozzle, so as to offer considerable resistance to the outflow of fluid. Work the pump with the same force and frequency as before. The outflow will still be intermittent though less fluid will issue from, and consequently less enter into, the tube at each stroke.

3. Clamp the proximal end of the glass tube and unclamp the elastic tube. Let the distal end of the latter be quite open. Work the pump as before. There being little resistance to the outflow, the elasticity of the tube is not called into play, and consequently the flow will be, as in the case of the glass tube, intermittent.

4. Working the pump as before, insert the fine nozzle into the open mouth of the tube. Considerable resistance will now be offered to the outflow of fluid, the elasticity of the walls of the tube will be called into play, and the water will issue from the end of the tube in a continuous instead of an intermittent stream. If the tube be sufficiently long and sufficiently elastic in proportion to the force and frequency of the strokes, the flow will be uniform as well as continuous.

B. Major Arterial Scheme.

The pump, *P*, driven by a motor represents the left ventricle of the heart. It is filled from the rubber bag, *B*, which represents the left auricle. The valve *A.V.* represents the left auriculo-ventricular valve, and the valve *S.V.* the semilunar valve. The rubber tube *A* represents the arteries, it passes in a coil of about 20 feet through the vessel *Pl.* and thence through alternative tubes *a*, *b*, *c*, *d* stuffed with sponge representing the capillaries, into a broad vessel *V* representing the vein.

From A and V, representing a main artery and vein respectively, tubes run to mercury manometers, M_a, M_v, by which the pressure in these can be recorded on a revolving drum. Levers are placed on the arterial tube, at L_1 and L_2, by which the passage of the pulse-wave can be recorded. A recording tambour, *R.T.*, is connected with the vessel *Pl.* by which variations in volume of the arterial tube in the vessel can be recorded; the vessel P thus represents a plethysmograph.

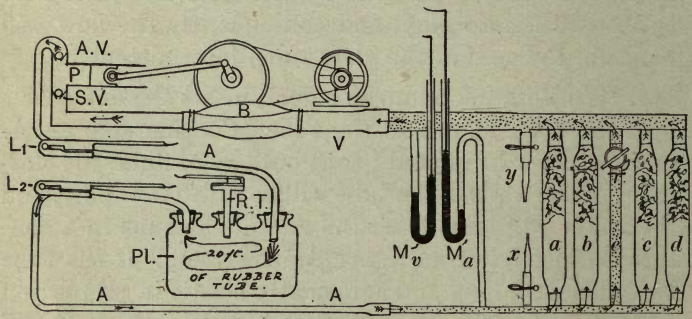

Fig. 25.

On the course from the arterial tube to the venous tube is a tube e supplied with a tap, T, the opening of which causes changes in arterial and venous pressure corresponding to those caused by dilatation of small arteries and capillaries. x and y are tubes by which the effect of opening the arteries and veins can be observed.

All the shaded parts are of metal, the capillary tubes are of glass, both are connected with the rest of the system by india-rubber tubing, that leading to the manometers being thick-walled (pressure tubing). In order

to fill the system, the pump is disconnected and the tubing connected with a water tap.

When the system has been filled with water, connect the pump, and set the motor in action.

1. With tap T closed, observe:

a. The large rise of pressure in the arterial manometer (arterial pressure) and the difference between the pressure during the stroke of the pump (**systolic pressure**) and after it (**diastolic pressure**). The mean of the systolic and diastolic pressure is the **mean arterial pressure.** The difference between the systolic and the diastolic pressure is the **pulse pressure.**

b. The small pressure in the venous manometer and the absence of pulse variation. (For complete absence of venous pulse in the scheme the elasticity of the arterial tube must be high.)

c. The rise of the lever connected with the plethysmograph and its correspondence with the pulse waves.

2. Note by the rise of the levers L_1 and L_2 the time taken by the pulse wave to travel through the arterial tubing; this may be recorded on a revolving drum, or taken with a stop-watch. Inject a little coloured fluid into the arterial tube near its origin and note the time of its first appearance in the capillary tubes. Compare the rate of travelling of the fluid with that of the pulse wave.

3. Increase the rate of thrust of the pump, and observe the rise of mean arterial pressure and the decrease of the pulse pressure.

4. Open gradually the tap T to increase the resistance, and observe the fall of arterial pressure, the rise

of venous pressure, and the appearance of pulse waves on the venous side.

5. Open *M* and *N* and observe the flow from the tubes, and that the suction of the pump draws air into the system through the venous tube. In the body the heart does not act in this way, but inspiration does.

6. Examine the circulation in the frog's web which is placed under the microscope. The frog has had its brain destroyed, and has been curarised. The sciatic nerve has been tied and cut. Stimulate the peripheral end of the sciatic for a few seconds with a tetanising current; note the contraction of the arteries causing slowing or complete cessation of the circulation.

DEMONSTRATIONS.

1. Action of valves in a large vein.

2. The effects in the rabbit on the temperature of the ear, and on the calibre of its blood vessels, following

a. Section of the sympathetic nerve in the neck.

b. Stimulation of the peripheral end of the sympathetic.

3. Normal kymographic tracings of the blood pressure of a mammal obtained by the use of a mercurial manometer.

4. The effects on the arterial blood pressure, as indicated by the tracing, produced by

a. Inhibition of the heart through stimulation of the peripheral end of the vagus.

b. Dilatation of the small blood vessels through stimulation of the central end of the depressor nerve.

5. Methods of measuring the velocity of the blood current in large vessels.

6. Comparison of venous and arterial pressure.

7. Methods of using the sphygmograph.

8. The flow of lymph from the thoracic duct.

LESSON XVII. SYSTOLIC BLOOD PRESSURE IN MAN. PULSE TRACING.

1. **Armlet sphygmomanometer.** The subject whose blood pressure is to be measured sits at the table on which is the apparatus (Fig. 26) and rests his forearm on the table at the level of the heart. The observer straps the sphygmomanometer bag (*B*), which should be about 6 inches long (as in Martin's armlet), over the biceps of the subject and connects the tube of the bag

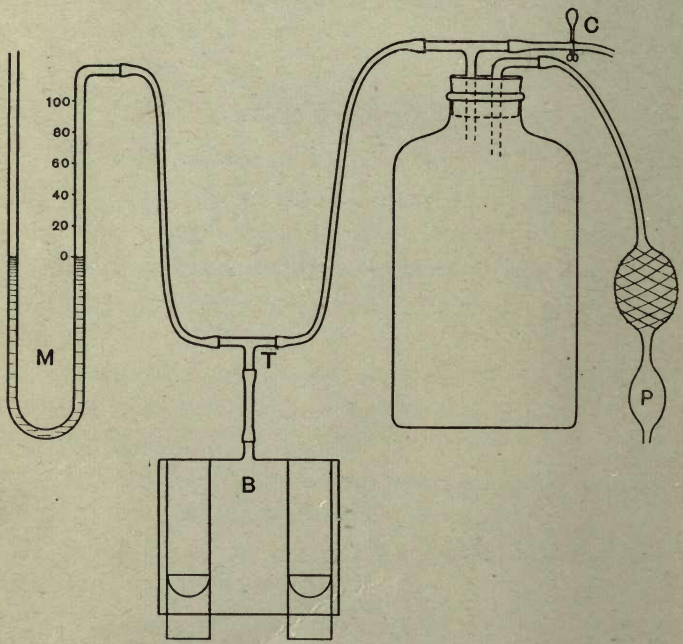

Fig. 26.

with the 3-way tube (T). The latter is connected on the one side with a large bottle, and on the other with a mercury manometer (M). The bottle is also connected with an india-rubber spraying apparatus (P) or a bicycle pump. The observer feels the pulse in the radial artery of the subject, fixes the clamp C and pumps air into the bottle. This causes a gradual rise of pressure in the bag on the arm and in the manometer. At a certain rise of pressure the heart can no longer force blood through the arteries enclosed by the bag, and the pulse at the wrist ceases to be felt.

The difference in millimetres in the height of the two columns of mercury in the manometer at the moment the pulse ceases to be felt is noted—a.

The clamp C is then slightly relaxed so that the pressure falls slowly; the difference in the height of the two columns of mercury at the moment the pulse at the wrist is again felt is noted—b.

The mean of a and b is taken as the **systolic blood pressure** in the arteries of the arm in millimetres of mercury.

The observations should be repeated several times since it takes practice to determine the exact moment at which the pulse disappears and reappears.

2. **Pulse tracing with two tambours.** In taking a pulse tracing the subject rests his arm on a table at about the level of the heart, supporting the wrist on a pad, and bending the hand slightly backwards. The observer feels the pulse at the wrist with the 1st and 2nd fingers, makes a mark on the skin along the line of the radial artery, and a cross mark where the pulse is best felt.

Connect a receiving tambour (e.g. the "wrist tambour" of Mackenzie's polygraph) with a recording tambour by means of india-rubber tubing having a 3-way glass tube on its course. The 3-way tube is for adjusting the pressure, if necessary, in the recording tambour; the latter should have a light lever about 6 inches long.

The receiving tambour is placed on the wrist so that the knob is on the cross mark on the skin, and before fastening it, it is held steadily with varying pressure and with slight variation of the position of the knob and of the hand until the pressure and position which give the maximum excursion of the lever of the recording tambour is determined. It is then fastened on the wrist. Arrange the lever to write on a revolving drum and arrange the rate of the drum so that a single pulse tracing takes about a centimetre. Whilst taking the tracing the hand must be held perfectly still.

Take a pulse tracing, note the quick primary rise—the systolic rise—the gradual fall broken by the predicrotic and the dicrotic wave. In general the less the peripheral resistance the quicker will be the primary rise and fall and the greater the dicrotic wave, but the curve is also affected by the force and frequency of the heart-beat and by other factors. Note that slight variations in the position of the receiving tambour and in the degree of flexion of the hand alter the pulse tracing.

3. For the mercury manometer in § 1 substitute one having a float with writing point, and fix the manometer near the drum so that its writing point is vertically under that of the recording tambour (§ 2). Revolve the drum to obtain a base line. Fasten the armlet on the arm, and the receiving tambour on the wrist.

Start the drum. Pump up the pressure in the armlet till the pulse ceases to show on the tracing. Then let out slowly the air from the armlet. As the pressure falls the pulse reappears on the tracing. On the tracing measure with compasses the height of the column of Hg at which the pulse tracing ceased and began again. Compare the result with that obtained in § 1.

4. Keeping the apparatus as in § 3 determine how long (about) you can hold your breath. Then set the drum in motion, and in 5 to 10 seconds pump up the armlet till the pulse tracing just ceases. Continue to hold the breath for some time longer, it will be found that the pulse tracing reappears, to disappear again soon after respiration begins. The reappearance of the pulse wave is due to increased blood pressure caused by the increase of CO_2 in the blood.

5. Use Hill's bulb sphygmomanometer, a diagram of which is given in Fig. 27.

Take the gauge G (cooling it if necessary to the temperature of the room by holding it by the closed end and waving it in the air) and dip the open end into the coloured fluid given you (eosin in 1 p.c. sodium carbonate). The fluid will rise to the level of the side hole,—the zero point.

With the bulb half-full of air, slip the open end of the gauge into the tube connected with the bulb. Place the bulb on the wrist of *A*, and cover it with the left hand as in the fig.; whilst *A* holds the end of the gauge.

With the first two fingers of the right hand, feel the radial pulse of *A*. Press on the bulb, and note the pressure on the gauge at which the pulse just disappears, and then on relaxing slightly the pressure just reappears.

Compare the pressure with that obtained by method *a*.

After use, press the end of the gauge on blotting paper, dip it into distilled water, and press it again on blotting paper.

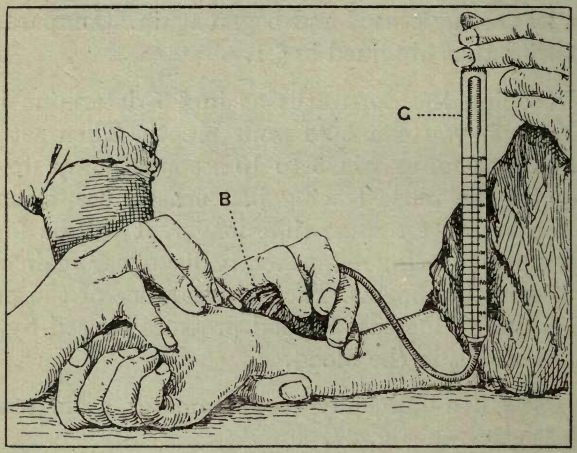

Fig. 27.

6. The details of construction of Marey's and of Dudgeon's sphygmograph will be demonstrated. Fasten one of these on the wrist as the receiving tambour was fastened in § 2, and take a pulse tracing.

7. Vascular dilatation and in consequence a fall of blood pressure and an increase in the dicrotic wave may be observed by inhaling a little amyl nitrite. A few drops are placed on a cloth or piece of cotton wool, and inhaled once. If no effect is felt, it is inhaled again, but cautiously, since excess causes dizziness and may cause fainting. Observations may be made with the sphygmomanometer and with the sphygmograph.

LESSON XVIII. RESPIRATION.

1. By means of the spirometer make three estimations of the number of c.c. you expire and inspire in normal and maximal respiration.

2. Determine the amount of CO_2 in expired air.

3. Observe with Haldane's apparatus the change in respiration with increase of CO_2 in the respired air.

The methods of experimenting will first be demonstrated.

DEMONSTRATIONS.

1. Graphic record of dyspnœa, apnœa, and of the action of the vagus on respiration.

2. Rhythmic contraction of the diaphragm and the effect of stimulating the phrenic nerves.

3. Collapse of the lungs on puncturing the thorax.

4. Estimation of the gases of arterial and of venous blood.

5. Estimation of the gases in alveolar air.

LESSON XIX. THE DIGESTIVE AND EXCRETORY SYSTEMS.

1. Cessation of the circulation leads to a rapid decrease in the effect of most autonomic nerves. In consequence when the central nervous system has been destroyed in a frog, it is necessary to dissect the nerves quickly. The first stimuli should be for 1–2 secs. only, and the stimulus should cease immediately the contraction begins.

The circulation will continue if the fore-brain only is destroyed. In this case it is best to inject into the dorsal sac the minimal amount of curari required to paralyse the motor nerves (about $\frac{1}{2}$ c.c. of ·02 p.c. solution). The blood vessels which it is necessary to cut in the dissection should first be tied.

Arrange the inductorium for tetanising currents of a strength just sufficient to be felt on the tongue. Thread a small ligature needle (instead of a ligature needle two fine pointed forceps may be used) for passing the thread under the nerves. Note the position of the bladder in the frog dissected for you.

In a just pithed frog cut through the abdominal wall in the mid line, and carry the cut up through the sternum. Make two transverse cuts in the abdominal wall midway, and pin back the lower flaps. Pin the legs firmly. Turn the viscera to one side and pin them back. The nerves of the lumbo-sacral plexus will be seen through a thin membrane, cut this through to expose the nerves. Pass a thread under the 9th nerve (the lowest large one). Cut through the ramus communicans of the 8th nerve (cp. Fig. 28), tie the 9th nerve near its

exit from the vertebral canal, and isolate it for a short distance.

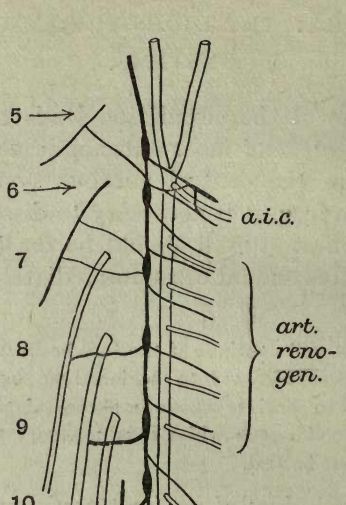

Fig. 28. Diagram of abdominal sympathetic of the frog. The numbers on the left refer to the spinal nerves and are placed opposite their exit from the vertebral column; the usual position of their junction with the rami communicantes are shown.

Watching the thin walled bladder, and the rectum, stimulate the nerve. The bladder will contract, and the rectum will probably be drawn downwards. (There is generally some spontaneous contraction of the rectum, each contraction lowers the irritability for a time.) In some frogs the 10th nerve is larger than the 9th instead of being barely visible; in these the 10th nerve causes

contraction of the bladder and rectum and the 9th may have little or no effect.

If the stimulation is stopped immediately contraction begins, the effect can be obtained a number of times. Note that the contraction of the bladder is entirely, or almost entirely, confined to the side on which the nerve is stimulated. Cut and stimulate the 9th nerve on the opposite side.

DEMONSTRATIONS.

1. The effect of stimulating the chorda tympani on the flow of saliva.

2. The chyle in the lacteals of a rabbit a few hours after a meal.

3. Passage of urine from the pelvis of the kidney to the bladder.

LESSON XX. TOUCH.

NOTE. In many experiments on touch, taste, and smell, two students should work together. One (*A*) should close his eyes, or be otherwise prevented from seeing what is going on, the other (*B*) should apply the tests to him, and record the results. At the end or midway in the experiment they change rôles.

1. **Threshold for two points** (tactile spatial discrimination). It will be sufficient for the student to determine the threshold roughly, within a centimetre in the case of the fore-arm. *A* sits with the fore-arm bare, and extended on the table, palm uppermost; eyes being shut.

B has a pair of compasses and a millimetre scale; he separates the points 3·5 cm. and touches *B*'s arm either with one point or with both points. The two points must be applied with equal pressure, and both at the same moment, and they should be applied length-ways to the arm. *A* says whether he feels one point, or two points, or is doubtful whether it is one or two; *B* writes down after each observation whether he applied one point or two points, if two their distance apart, and *A*'s statement.

If *A* is right three times out of four with the single point and the two points, *B* without telling *A* puts the points of the compasses at 3·0 cm., and makes similar observations; then with the points 2·5 cm. apart, and so on. Probably *A* will be unable to distinguish two points when they are 2·0 or 2·5 cm. apart. The minimal dis-

tance at which they can be distinguished, say four out of five times, is the threshold.

If the points are separated a little less than the threshold, they will probably be felt as two if they are more down the arm, or if they are put transversely to the arm.

When the approximately minimal distance is reached at which *A* does not distinguish the two points, he is told to open his eyes, and observe the application of the points.

A shuts his eyes once more, and the points are applied to the tip of the fore-finger; the points being at first 1 cm. apart, ·75, and so on; now and then a single point being applied. The threshold will probably be less than ·5 cm. *A* opens his eyes, the points are applied at a distance a little above the threshold.

Similar observations may be made on other parts of the body.

If the threshold is determined for the back of the neck, the two points being applied on either side of the mid-line, it will probably be found that they are not distinguished if they are applied longitudinally, or both on one side of the neck.

2. **Cold spots in the skin.** Take two metal rods 1 to 1·5 mm. in diameter and rounded at the ends and dip them into a freezing mixture or into ice and water, dry before using (the rod may also be cooled by dipping it into ether, and allowing the ether to evaporate). Mark out with dilute Bismarck brown an area about 2 cm. square on the fore-arm. Lightly press the end of a rod on one corner of the enclosure for 2 secs.; if it is felt as cold, mark it brown, if not place the rod on the immediately adjoining spot of skin, and so along the side of the square, marking all the points felt as cold. Map out

similarly line after line of the square. It will be found that in some places cold is felt keenly and at once, in other places dully, and in others not at all.

Test the cold spots again, and mark the points most sensitive to cold with methylene blue. In re-testing, an interval of a few seconds must be allowed between two applications to the same spot.

3. **Sensation of heat in different parts of the skin.** Dip a small metallic knob (or a bulb of a mercury thermometer) into water at 65° C. to 70° C., quickly dry it, and apply it to the fore-arm, and note the sensation. Warm it again, and apply it to the forehead, the sensation of heat will probably be much greater than in the preceding case. Compare similarly, the tip of the finger, the cheek, and the palm of the hand and the back of the neck.

4. **Warm spots in the skin.** Proceed as in § 2, but warm the rods in water to 55° C., or as hot as can be borne without pain, and mark out the spots where heat is felt. The results will probably be much less precise than in the case of the cold spots.

5. Touch lightly with a piece of cotton wool the tip of the forefinger, the skin below the nail, and the hairs on the wrist. Note the difference in the delicacy of sensation.

6. **Successive temperature contrast.** Put one hand into water of 40° C. and the other into ice-cold water. After a minute put both into water of 20° C. This water will feel warm to the hand which has been in the cold water and cold to the hand which has been in the hot water.

Or,

Put one hand into water of 20° C. It will feel cold. Now keep the hand in water of 10° C. for one minute and again put it into the water of 20° C. It now feels warm.

7. **Effect of temperature on estimation of weight.** Place two metal discs of equal size and weight, one cold, the other warm, on corresponding fingers of the hand; the cold one will feel the heavier. Place both on the forehead, and estimate the relative weights.

8. **Estimation of weight with and without the aid of the sense of movement (muscular sense).** *A* sits with hand outstretched at a table and with eyes shut. *B* has metal discs of equal size of 10, 11, 12, 13, 14, 15 grams. He takes 10 grams and 13 grams, and placing first one and then the other in the palm of *A*'s hand, writes down which, if either, *A* feels to be the heavier. If *A* is wrong 3 times out of 4, then 10 and 15 grams are compared; if *A* is right 3 times out of 4, the 10 and 12 grams are taken, and so on. Having determined approximately the difference which can be distinguished in light weights, heavier weights are taken, viz. 300, 330, 360, 390, 420, 450 grams, and the power of distinguishing these is tested in the same way. These weights should be tin cans with handles, of equal size, 6 to 8 cm. in diameter, the weight being made up with shot.

If with the lighter weights 10 and 12 grams could be distinguished, but not 10 and 11, then with the heavier weights, probably 300 and 360 will be distinguished, but not 300 and 330.

B now gives to *A* the 300 gram tin, and the tin just below the threshold for the pressure sense; *A* takes them one in each hand, and lifts them up and down, and changes them from one hand to the other. He will probably then be able to detect a difference he was previously unable to detect.

These experiments require some practice; it may be found that a sense of difference of weight is distinct at one moment, and disappears the next.

9. **Localisation.** (*a*) *A* places one hand, say the left, on the table with digits outstretched, the right arm being extended from the side and the eyes shut. At the call of *B*, *A* attempts to touch with the forefinger of the right hand the tip of the finger called. *B* marks on a sketch the result.

(*b*) *B* marks five spots at some distance from another on *A*'s left fore-arm, and makes a sketch of the arm and the spots. *B* touches one of the spots, and *A* immediately tries to put his right fore-finger on it. *B* marks in the sketch the results.

10. **Stimulation of nerve trunk and of nerve-endings.** Place the elbow first in warm water, and then in a mixture of ice and water. There will be a sensation of pain in the fingers and cold in the elbow. The application of cold to the trunk of a nerve does not cause a sensation of cold.

11. **Tactile illusions.** Cross the second finger over the first or the third over the second, and place between their tips a small marble (or any solid round body a little larger than a pea) so that it touches the radial side of the first, and the ulnar side of the second finger-tip. On gently rolling the body about, a sensation as if of two distinct bodies will be felt.

The same illusion is experienced if the tip of the nose be gently rubbed with the tips of the fingers so placed.

DEMONSTRATIONS.

1. Instrument for testing pain (Algometer). In this instrument a blunt point is pressed with variable and known pressure against the skin.

2. Frey's hairs for determining the threshold for touch.

LESSON XXI. TASTE AND SMELL.

See Note under Touch, p. 100.

1. **Rough determination of threshold for the tip of the tongue.** Take the following aqueous solutions, label each set 1, 2, 3, 4, 5; No. 1 being the strongest solution.

Cane sugar, 6, 3, 1·5, ·75, and ·375 p.c.

Sodium chloride as cane sugar.

Fuming sulphuric acid, 1, ·5, ·25, ·05, ·01 p.c.

Sulphate of quinine, ·2, ·1, ·02, ·004, ·0008 p.c.

Have ready small pipettes of equal size, one for each set of solutions (the pipette must be washed out with water if it is used for a weak solution after a strong one); a dish of water to clean out the pipettes; an additional pipette with pure water; a tumbler of water to rinse out the mouth.

B lets fall a drop of one of the weaker solutions (No. 4) or of water on the tip of *A*'s tongue; after 5 seconds *A* says what he thinks it is, and this is noted by *B*. *A* takes a mouthful of water and ejects it, preventing the test substance so far as possible from coming into contact with the back of the tongue and soft palate.

This procedure is repeated till all the No. 4 solutions and water have been tested.

Then No. 3 solutions and water are similarly tasted; and so on. When it is clear that a solution is distinctly tasted, no stronger solution of that substance should be applied. It will probably be found that a strong solution

of cane sugar must be applied before it is tasted; a rather less strong solution of salt; a still less strong solution of acid; whilst a relatively weak solution of quinine will be effective.

2. **Comparison of sensitiveness to bitter substances of the tip and of the back of the tongue.** Take the solution next below that which gives a bitter taste on the tongue. Put two drops on the tip of the tongue and rub the tip against the lip; as soon as it is clear that it is not tasted put two drops on the back of the tongue and press the back of the tongue against the soft palate. It will usually be tasted at once.

3. Determine roughly in the manner given in § 1 the threshold for the various substances when placed on the back of the tongue. In these experiments care should be taken, so far as possible, to rinse out the mouth without pressing the back of the tongue against the roof.

4. Take a few c.c. of the solution of sugar next below that which is tasted on the tip of the tongue, and roll it about in the mouth, it will taste sweet. This is largely due to a greater area being stimulated, and perhaps also to some part of the mucous membrane being more sensitive to sweet than the tip of the tongue.

5. Take any of the No. 1 solutions, and place a drop upon the middle of the upper surface of the tongue, it will not be tasted, provided it does not spread to other regions.

6. Arrange for a constant current with two Daniell's cells. Apply one electrode to the middle region of the upper part of the tongue, the other electrode to the back

of the tongue. When the anode is on the back of the tongue an acid taste with some bitter will be set up there; when the cathode is applied to the back of the tongue the taste will be alkaline with some bitter. On applying the electrodes elsewhere, probably the acid and alkaline sensation will alone be felt.

7. Lightly press the point of a needle on the tongue, and note approximately the degree of pressure at which touch passes into pain. Then apply to the tip with a camel-hair brush a 1 p.c. solution of cocaine, repeating if necessary. At a certain stage touch will still be felt, but not pain.

8. Apply an extract of gymnema with a camel-hair brush to the back of the tongue (10 grams of the leaves of *Gymnema silvestris* pounded, boiled for 5 minutes in water and filtered); leave for about 30 secs.; wash out the mouth; test the taste sensations with the stronger solutions; the acid and salt will still be tasted, but not quinine or sugar. The solutions must of course not overpass the regions to which gymnema has been applied.

9. **Threshold for smell.** Prepare standard solutions of camphor thus: dissolve ·1 gram of camphor in strong spirit, dilute with water to 200 c.c. Put a little of this solution into a test-tube and label (1). Take 1 c.c. of (1) and add 4 c.c. of water, label this (2). Take 1 c.c. of this, add 4 c.c. of water and label (3), and so on till 9 solutions are obtained. Label 10 a test-tube containing water only.

B takes water only and the weakest solution of camphor, and gives first one, then the other, to *A* to smell, and records the answer. Then similarly with the solution next stronger in the series, and so on but not using any solution stronger than that which is said to be

smelt. (When the minimal strength of solution is thus approximately determined A and B should change rôles, to allow an interval before the final determination.) Then B takes water and the apparently minimal solution, and offers them to A five times each in indeterminate order. If A is right four times out of five with each fluid, test similarly with the next weakest solution.

LESSON XXII. THE EYE.

1. Take a fresh eye of an ox or sheep, and note

The transparent **cornea.** Surrounding and continuous with this, the dirty-white **sclerotic** which forms the outer coat of the rest of the eye; the posterior two-thirds will probably be covered with fat.

The **conjunctiva**, a continuation of the mucous membrane of the eyelids. In taking the eye out of the orbit this membrane is cut through where it passes from the eyelids to the sclerotic. Dissect it forwards in any one place; it will be traceable to the junction of the sclerotic and the cornea. (Its epithelium is continuous with that of the cornea.)

2. Clear away the fat surrounding the four straight muscles, it will be seen that their tendons form a layer under the conjunctiva of the sclerotic.

3. Cut away the conjunctiva and muscles, and remove the fat around the **optic nerve**; this pierces the sclerotic on the nasal side, and not in the axis of the eye.

4. Cut through the cornea close to its junction with the sclerotic and remove it; the anterior chamber of the eye, containing clear, limpid **aqueous humour**, is thus laid bare. Observe the iris with its central aperture through which projects the anterior part of the lens.

5. At a little distance from the cornea cut through the sclerotic, being careful not to cut too deeply; it will separate easily from the pigmented subjacent **choroid**,

except at the junction of the sclerotic with the cornea, and at the entrance of the optic nerve. In other places there is only a loose connection, largely by means of blood vessels. Remove a strip of the sclerotic, a few mm. breadth, stretching from the optic nerve to the cornea. Note its dark inner surface, or **lamina fusca**; note also in the front part of the choroid, close to the cornea (region of the ciliary muscle), the pale fibres spreading from the junction of the sclerotic and cornea, backwards over the choroid.

6. Carefully pinch up the choroid about half-way between the optic nerve and the cornea with a fine pair of forceps, and snip it through. Underneath it will be seen a thin membrane, the **retina.** The pigment layer of the retina will probably be torn away with the choroid.

7. Tear away a piece of the retina to expose the clear **vitreous humour** which occupies the posterior cavity of the eye.

8. Extend the gap laterally and tilt the eye; through the vitreous humour will be seen the ciliary part of the retina with the choroid coat becoming folded longitudinally as it approaches the lens, and so forming the **ciliary processes.** If they are not distinctly seen, cut away more of the coats of the eye.

The nervous elements of the retina cease at the level of the commencement of the ciliary process. Their termination is marked by an uneven line, the **ora serrata.**

9. Holding up the choroid and retina, cut them through as far forward as the ora serrata; it will be seen that the vitreous humour separates readily from

the retina as far as that line, but in the region beyond its thin outer coat, the **hyaloid membrane**, becomes attached to the ciliary processes. If an attempt be made to separate them here with the handle of a scalpel, it will be found that the pars ciliaris retinæ (or the non-nervous continuation of the inner coat of the retina) together with some of the pigment layer of the retina (the outer coat) will come away with the vitreous humour.

10. Turn the eye with the cornea uppermost, and cut away the free edge of the iris; make two incisions at right angles to one another on the surface of the lens, it will be seen that the lens is covered by a membrane; this is the anterior part of the **lens capsule.** Carefully remove the lens, and trace out the limits of the lens capsule, noting that it forms a complete investment for the lens.

11. Gently separate with the handle of a scalpel the lens capsule from the front part of the ciliary processes, and observe that a membrane, the **suspensory ligament** or **zone of Zinn**, passes from the edge of the capsule to the ciliary processes, of which it forms the innermost layer, dipping down into their depressions.

12. Looking into the eye from the front, observe

The entrance of the optic nerve.

The blood vessels radiating out from the entrance of the optic nerve.

The iridescence, mainly below the entrance of the optic nerve; it is caused by the irregular reflection of light from the wavy connective-tissue fibres of the choroid. In this region (the tapetum) the hexagonal cells of the retina have no pigment.

13. Separate the rest of the retina from the choroid and observe that

The pigment-layer generally adheres rather to the choroid than to the retina.

Apart from the pigment-layer the retina appears like an expansion of the optic nerve.

The retina is firmly attached to the choroid at the ora serrata.

DEMONSTRATIONS.

1. Effect on the iris of stimulating the sympathetic nerve.

2. Effect of adrenaline on the iris of the frog.

3. Muscles of the eye dissected in the head of a sheep or dog.

4. Section through centre of the eye[1], showing the position of the lens and other parts.

[1] A fresh eye is placed in a glass receptacle, e.g. a glass stopper, the depth of which is half the diameter of the eye; the vessel is filled up with gum, the eye arranged so that the optic nerve is horizontal; it is then placed in a freezing mixture; when the eye is frozen a razor is passed along the top of the vessel cutting the eye in two.

LESSON XXIII. VISION.

1. **Retinal image.** Remove very carefully the sclerotic and choroid from a small portion of the posterior surface of the eye of an ox or a sheep[1]. Place the eye in the end of a blackened tube just large enough to hold it, with the cornea outwards.

Stand 6 to 10 yards from a window, and look towards it; an inverted image of the window will be seen on the retina; move towards the window, the image will become blurred.

2. **Accommodation.** Standing some feet before a window, close one eye and hold a needle up before the other, at a distance of about six inches, so that it is at right angles to one of the horizontal bars of the window.

Look at the window-bar, the needle will appear dim and diffuse.

Look at the needle, the window-bar will appear dim and diffuse.

The eye can accommodate itself for either the needle or the window-bar, but not for both at the same time. The accommodation for the near object is accompanied by a distinct feeling of effort.

3. **Diffusion circles and accommodation.** Facing a window, or a white surface, close one eye and hold a fine needle vertically before the other. At about six inches the needle will be seen distinctly. Bring it nearer

[1] Or better, take the eye of an albino rabbit, without cutting away the sclerotic.

the eye, the image will be dim and diffuse, and at the same time larger. The dimness and apparent increase of size are due to **diffusion**, resulting from imperfect accommodation.

Prick a small hole in a piece of card, hold it before the eye and again bring the needle close to the eye. It will be seen distinctly at a much smaller distance than before, and at the same time will appear magnified. It will be seen more distinctly because the diffusion circles are cut off.

4. **Limits of accommodation.** Prick two small holes in a card 1 to 1·5 mm. apart, place it touching the nose and forehead, and look through the holes, say, with the right eye.

a. Look at the needle held about a foot away; a single, distinct image will be seen. The rays passing through the two holes are united on the retina.

b. Bring the needle closer to the eye; at a certain distance it will become double; this marks the **near** limit of accommodation.

c. Fixing the needle on a sheet of paper, walk away while looking at it through the two holes; at a certain distance it will become double, this marks the **far** limit of accommodation. This experiment succeeds best with short-sighted people.

Compare the near and far limits of accommodation as fixed by looking at a vertical needle through horizontal holes with those fixed by looking at a horizontal needle through holes place vertically. The results will differ according to the amount of astigmatism in the eye.

5. **Accommodation and inversion of retinal image.** (Scheiner's experiment.)

Sit facing a window. Fix a needle vertically about 12 inches in front of you. Look through the holes as in § 4.

a. Look at some distant object, two blurred images of the needle will be seen; slide the nail of the middle finger along the card, and block out the right-hand hole, the blurred image of the left-hand side will disappear.

The rays passing through the two holes have not united when they fall on the retina. Thus the image on the right side of the retina is cut out, and this is referred to the left side.

b. Hold the point of a second needle a little in front of the card, and look at this; when it is distinct, the other needle will become blurred and appear as two. Block out the right-hand hole, the right-hand image will disappear. Here the rays passing through the two holes have united and crossed before they fall on the retina, so that blocking the right-hand hole cuts out the image on the left side of the retina, and this is referred to the opposite, i.e. to the right side.

6. **Inversion of retinal image.** Hold a card with a pin hole a short distance from the eye. Move the head of a pin from below upwards, between the eye and the pin hole; the head of the pin will be seen inverted. The pin casts a shadow on the retina; the shadow on the lower part of the retina is referred to the upper part of the field of vision.

7. **Helmholtz's Phakoscope.** This should be used in a dark room. *A* looks with one eye through the hole

opposite the needle. *B* looks through the hole at the side. A lamp or candle is placed at some little distance from the prisms and shifted about until *B* sees on the eye of *A*, when the latter looks at a distant object, two small bright patches of light on the cornea, two larger but dimmer patches on the anterior surface of the lens, and two small and very dim (not readily seen) patches on the posterior surface of the lens.

Let *A* now accommodate for the needle in front of him, making every effort not to move the eyeball. *B* will see the two patches on the anterior surface of the lens approach each other, while the other two pair remain motionless, thus showing that during accommodation for near objects the *anterior surface* of the lens becomes more convex.

Observe that in accommodating for near objects the pupil becomes smaller, and in accommodating for far objects the pupil becomes larger.

8. **Astigmatism.** *a.* Draw on a card a star composed say of eight lines passing through the centre, the angle between each two neighbouring lines being the same and the lines of equal tint and of equal thickness.

Place this at about the distance which has been determined (§ 4) as the far limit of accommodation (if this distance is more than eight or ten yards use convex spectacles.)

Probably one or more of the lines will be seen much more distinctly and with less blurring than the others. Approach gradually nearer the star, and note whether the other lines become all visible at once or in succession.

Repeat this first with one and then with the other eye closed; the astigmatism may be different in the two eyes.

Then holding the star at a distance a little greater than the near limit of accommodation, fix the centre of the star with one eye, keeping the other closed, and bring the star gradually nearer; the lines will probably not all become dim at the same moment; the line last seen with near accommodation will probably be at right angles to that first seen with far accommodation.

Instead of the star a number of parallel horizontal and parallel vertical lines may be drawn.

Or, *b*. Fix a needle vertically on a board. Looking at the needle with one eye, accommodate the eye exactly for it. Then hold another needle horizontally before the first, and move it backwards and forwards until both needles are seen distinctly at the same time. This will be found to be the case when the needles are at some distance apart.

More exact results are however obtained by Scheiner's method (§§ 4, 5).

9. **Irradiation.** Cut out two patches of exactly the same size, of white and of black paper.

Place the white on a sheet of black and the black on a sheet of white paper.

Place them some distance off and adjust the eye so as to throw them a little out of the range of accommodation.

The white patch will appear larger than the black one.

10. **Blind spot.** Make a bold mark on a sheet of white paper, place the sheet on the table, and, closing the left eye, fix the axis of vision of the other, by steadfastly looking at the mark at a distance of about 25 cm.[1] Dip a new quill-pen in black ink and place it a little to

[1] Fix a small square (about 5 by 5 mm.) of black paper on the point of a teasing needle.

the right of the mark. Keeping the axis of vision fixed, and the head at the same distance from the table, move the pen slowly to the right. At a certain distance it will become invisible; mark this spot on the paper. Carry the pen still farther outwards. It will again become visible; mark this spot also. The two spots will indicate the outer and inner limits of the blind spot. Similarly the upper and lower limit may be traced, and with a little practice an outline of the blind spot, showing even the commencement of the retinal blood vessels as they emerge from the edge of the optic disc, may be constructed.

The size of the blind spot may be calculated from the formula $\frac{f}{F} = \frac{d}{D}$, where f is the distance of the eye from the paper, F the distance of the retina from the nodal point of the eye (average = 15 mm.), d the diameter of the outline on the paper, and D the outline of the blind spot.

11. **Region of distinct vision.** Draw a circular dot about 2 mm. in diameter, and round this draw eight similar dots nearly but not quite touching it. Fix the gaze on a mark on a piece of white paper about 30 cm. distant. Close below this place the figure of nine dots, and move it downwards, keeping it about 30 cm. from the eye. At a very short distance the dots can no longer be counted; then they become a blurred patch, and probably a little farther they form a single mass.

12. **Purkinje's figures.** *a.* Go into a dark room with a lighted candle: looking steadfastly with one eye towards a wall[1]; hold the candle to the side of that eye so

[1] A light-coloured wall or white blind is the best. A wall, the paper of which has any very marked pattern, should be avoided.

that while the eye is illuminated the image of the candle is not seen, and gently move the candle up and down. In a few seconds the subdued reddish glare caused by the candle-light will be marked by branching dark lines, which will be seen to form an exact image of the retinal vessels as seen with the ophthalmoscope. The dark lines are shadows of the blood vessels; consequently the structures in which the physiological processes which give rise to the sensation of light begin must lie behind the retinal blood vessels.

A cup-shaped space, in which the blood vessels are absent, may with care be seen; this is the yellow spot.

Or, *b*. Turn the eye inwards towards the nose so as to expose as much as possible of the thin sclerotic behind the cornea. Let an assistant with a lens concentrate the rays of a candle or lamp on the sclerotic as far behind the cornea as possible, so that the rays may pass directly through it towards the opposite side of the eye, and gently move the focus to and fro. The same image is still more distinctly seen. The smaller the focus on the sclerotic, the more distinct the image.

If the movement of the light is stopped, the image soon fades away.

In the first method the image moves in the same direction as the light when the light is moved from side to side, but in an opposite direction when moved up and down.

In the second method the movement of the image is in the same direction as that of the light, whether up and down or from side to side.

13. **The yellow spot.** *a*. Maxwell's method. Place a moderately strong, but perfectly transparent solution of chrome alum in a flat-sided glass vessel. Resting the eye for a minute or two, suddenly look through the vessel at a white cloud. A rosy spot or cloud will appear

in the centre of vision and remain for some little time, but will gradually become less distinct.

The pigment of the yellow spot absorbs the blue-green rays between the lines *E* and *F* of the spectrum, these rays removed from those passing through the chrome alum, viz. red and greenish blue, leave a rose colour.

Or, *b*. Look through a sheet of blue glass at a white sheet of paper for 5 to 10 secs., the glass being 10 to 15 cm. from the eyes; then shut one eye, keeping the other open for two or three seconds, and so alternately. In the middle of the visual field a small dark patch—often rosy at first—will be seen owing to the greater absorption of the blue rays by the pigment of the yellow spot. Around the dark patch, a lighter, larger area will be seen.

14. **Colour vision in different parts of the retina.** *A* rests his chin on a block in the centre of the circle of a perimeter and looks steadily, say, with the left eye, straight before him at a mark on the centre of the crossing arms (or axis of the arm) of the perimeter[1].

B stands on *A*'s left; he has discs ·75 cm. in diameter of white, red, green, yellow and blue.

B taking a black screen in one hand covers the posterior part of the left-hand quarter circle, slips the red disc inside the circle at 65°, exposes it for about two

[1] A simple form, sufficient for the purposes of this section, is easily made. A hoop is taken made of thin wood, about 5 cm. broad and with a diameter of about 65 cm.; it is cut in half, and the pieces are fixed one in a horizontal, the other in a vertical plane near the top of a vertical stand about 12 cm. high, and the inner surfaces blackened. Or the experiment can be made still more simple. The observer (*A*) stands over a table on which is a strip of black cloth. He rests his forehead on a block about 30 cm. from the cloth and looks straight down on it. *B* places the coloured discs on the cloth at various distances, uncovering them for a moment.

seconds by removing the screen; *A* states what colour he has seen; it will probably be greyish.

The observation is repeated, putting the disc 5° nearer the centre each time till *A* sees a distinct red. The red is then taken back 10° to 15° and shown again for a moment to make certain that it only appears greyish; then a disc of blue is shown, it will probably be seen as a brilliant blue.

The other discs are then shown in succession; probably green will appear greyish, whilst white and yellow will be recognised at once as white and yellow.

B then takes the white, yellow and blue discs, and commencing at the periphery shows them in irregular order, till the angle at which the three colours are distinctly recognised is approximately determined.

Similar observations should be made showing the discs against the lower quarter circle.

Then a yellowish-green disc and a purple disc should be taken, and shown, beginning at the periphery, they may at first appear grey, but soon the former will appear yellow, and the latter blue.

15. **After-images.** On a table in the dark room is placed an electric hand lamp, and a small tracing paper screen behind which stands a lighted candle. The lamp is connected to the electric light circuit and the switch is controlled by *A*. *B* seats himself so that he can readily see either the lamp or the tracing paper screen by rotating his head. The lamp is switched on and *B* gazes at it for 10 seconds without moving his eyes. The lamp is then switched off and *B* at once looks steadily at the centre of the tracing paper screen. After a few moments a dark image of the lamp filaments will be

seen on a bright ground, *B* immediately announces, "negative after-image." *A* now cuts off the light of the candle from the screen by means of an opaque object, and *B* will see the negative image change to a bright image on a dark ground—the positive after-image.

A uncovers the candle and the image becomes negative again. This process may be repeated for some time, 6 minutes or longer, but it will be found that there are periods during which both images temporarily disappear. Important points in the successful working of the experiment are that *B* should sit quite still and should keep his eyes fixed on the centre of the tracing paper screen during the observation of the images.

As a variation of the above experiment the candle may be moved to and fro, so as to vary the intensity of illumination of the tracing paper screen.

16. **Positive after-image.** When waking in the morning, close and shade the eyes for a minute or two, then suddenly look at the bright window for a moment or two, and then close and shade the eyes again. The image of the window exactly corresponding to the natural one, i.e. with the sashes dark and the panes bright, &c., will last for some little time, i.e. the sensation is of longer duration than the application of the stimulus.

To succeed, the retina should be in rest beforehand, and the exposure to the stimulus momentary or nearly so.

Or, in the evening, having closed and shaded the eyes for some time, suddenly look at a lamp and immediately close the eyes. A similar positive after-image will be seen.

17. **Negative after-image.** Look fixedly for about twenty seconds

a. At a white patch (e.g. white wafer) on a black ground, and then look at a white surface (or preferably pass a white surface over the whole, keeping the visual axis fixed); there will be visible a corresponding dark patch on the white ground.

b. At a black patch on a white ground, and turn to a grey surface; there will be visible a white patch on a grey ground.

c. At a red patch on a black ground, and turn to a white surface, there will be visible a blue-green patch.

And so with the other colours, the colour of the negative image will be complementary to that of the actual object.

d. At a red patch on a black ground, and turn to a yellow surface; there will be visible a green patch.

e. Look fixedly at a brightly illuminated window and then close the eye. The *positive* after-image will probably not be seen; in its place there will come the *negative* after-image with the sashes as bright lines and the panes as dark spaces. This will in turn be succeeded by coloured images.

18. **Contrast.** *a.* Cut out two strips of the same grey paper. Place one on white paper and the other on black paper (or better still, velvet). The strip on the black surface will appear distinctly brighter than the other. Arrange that the two strips are close to one another, look fixedly at them for 20 seconds and then close the eyes. The after-image of the strip on the black

surface will appear much darker than that of the other strip. (The difference of brightness between the two is often more apparent in the after-image than in the original strips.)

b. Place three candles in front of a white, otherwise un-illuminated surface; pass between them and the surface an opaque body with a sharp clean-cut edge, so that part of the surface is illuminated by the three candles, part by two, part by one, and part un-illuminated; stand two or three yards back and look fixedly at the junction lines of the variously illuminated surfaces; it will be seen that each area is lighter close to a darker surface and darker close to a lighter one than it is elsewhere.

19. **Simultaneous contrast.** *a.* Cut out a thin cross of grey paper, and place it in the middle of a sheet of bright green paper. Cover the whole with a sheet of thin tissue-paper. The grey patch will appear pink. The exact tint of the patch will depend on the tint of the green, of which it will be the complementary colour.

Surround the grey cross with a broad, dark black rim. The effect of contrast will be lost; the grey patch will appear grey.

On a red ground the grey cross will appear green, and with the other colours similar complementary effects will be produced; but the results are most striking in the case of red and green.

The effect is greatest when the patch is grey, not white, and is always heightened by covering with tissue-paper.

b. Cut a thin strip of grey paper and place it across the junction of a red with a green paper, and cover with tissue-paper.

The grey will appear green on the red side and pink on the green side.

c. Place a sheet of white paper on a table before a window illuminated by reflection from a white cloud, not with direct sunlight. On the side of the paper opposite the window place a lighted candle,

and between it and the paper place a book edgeways, or any object which will throw a shadow on the paper. Between the paper and the window place a similar object, throwing a like shadow. The distance of the candle should be such that the two shadows are of nearly equal intensity.

The shadow from the candle, though illuminated by the white sunlight, will appear blue, the complement of the reddish-yellow colour of the rest of the paper illuminated by the candle.

Through a small black tube, e.g. a piece of black paper rolled up, look at a point on the edge of the blue shadow so that half the field of view is blue and the other white (or yellowish). While looking let someone blow out the candle; the half of the field previously blue will now become faintly yellow, and the white (or yellowish) half will become blue.

The daylight-shadow heightens the effect on the candle shadow, but may be dispensed with.

In place of sunlight and candle, two coloured lights may be used.

In the above experiments avoid looking at the colours too fixedly and for too long a time. Otherwise the results will be modified by after-images.

20. **Test for red-green blindness**, by Holmgren's wools. All the wools are spread out on the table. *B* (who has been found to have normal colour-vision) gives the light green wool labelled No. 1 to *A*. *A* selects[1] six wools of the same colour as No. 1, but of different shades (saturation). *A*, if he is red-green colour-blind, will probably select one or more of the red shades. This is tested further by *B* giving *A* the light red wool labelled No. 2 to match.

Yellow-blue colour-blindness: a similar experiment is made, matching light yellow and light blue.

[1] Note should be made of the wools taken up by *A* compared with the test wool and then rejected, since a slightly colour-blind person will compare wools which would not be compared by a person with normal vision.

21. **Lantern test.** The Edridge Green lantern test is more practical than the above, for with it the conditions can be closely imitated under which railway and lighthouse signals have to be correctly recognised. The lantern consists of a circular box which contains three rotatable discs. These discs are drilled with holes which are then fitted with glass windows. The colours in the first and second discs are, standard signal red 1 and 2, yellow, green, standard signal blue-green, blue and purple. The third disc contains ground glass to represent mist, ribbed glass to represent rain, four neutral glasses to represent fog of different density.

Behind the lantern is fixed an electric lamp, the light from which passes through an aperture in the box and so through the glass windows in the discs when they are rotated into position.

In front the lantern has an iris diaphragm by which the size of the coloured lamp image and therefore its apparent distance can be varied.

The lantern is placed on a table in the dark room and is connected to the electric light supply.

A sits opposite the lantern and as far from it as possible. *B* switches on the light and asks *A* to describe what he sees. By rotating the discs, *B* interposes successively the coloured glasses alone and with the other glasses between the light and *A*, and *A* in each case describes what colour he sees. The normal sighted will recognise the red, green, yellow or white lights, whether modified or not. A common mistake of the colour-blind is to call red or green, the yellow glass when combined with one of the neutral tint glasses.

22. **Colour wheel. Flicker.** On a colour wheel or top put two paper discs, a white and a black, interleaved so that the combined disc is half white and half black. When the wheel is rotated slowly, the individual sectors will at first be seen; increase gradually the ratio of rotation, at first more and more sectors will be seen, and later a marked flickering (coarse flicker). With still greater rapidity this passes into a fine flicker, and then into a continuous sensation. Note the speed at which flicker ceases. When a continuous sensation is produced it will be seen that the white and black discs pass into a grey.

23. Take the wheel into a brighter light; the rapidity of rotation has to be increased to abolish flicker. Take the wheel into a darker light; flicker ceases at a lower rate. Replace the white by a grey disc, fusion occurs more readily.

Repeat with yellow and blue discs, differing greatly in brightness, flicker is marked, and only disappears with rapid rotation, though much less rapid than with the black and white. Repeat with red and blue-green discs (of approximately equal brightness), flicker is less marked and ceases sooner.

These experiments show that a greater rapidity of rotation is required to get rid of flicker. the greater the difference in brightness of the two halves of the disc.

24. *Colour Equation.* The yellow and blue discs and also the red and blue-green will fuse so as to give approximately grey surfaces if the amounts of each colour are suitably adjusted by sliding one disc over the other. The greys obtained by mixing two colours in this way are always coloured to some extent owing to the pigment colours not being exactly complementary, and the coloration of the grey will become much more obvious if larger black and white discs are placed on the same wheel to form a grey background. The coloration of the grey may then be neutralised by adding a third disc to the two colours; green if the coloration is inclined to red; red if inclined to green. The relative amounts of the three coloured

discs on the one hand and of the black and white discs on the other may then be adjusted till the whole surface becomes a uniform grey. The quantities of each colour may then be read off by means of a scale graduated in degrees and expressed in the form of an equation, as in the following instance.

$$156Y + 156B + 48G = 106W + 254Bk.$$

Take overlapping discs of red and blue; by adjusting the relative amounts of the two, and rotate, all shades of reddish-blue, blue-purple, red-purple, bluish-red can be obtained.

25. **Colour wheel. Contrast.** Rotate a disc having alternate rings, one ring consisting of green and the other of black in one half of the circle and white in the remaining half. The white and black instead of fusing into grey will appear pink. In order to avoid after-sensations, the disc should only be uncovered and observed, when it has attained its full rate of rotation.

26. Take now a disc of alternate rings of green and white, and view when it is rotating rapidly, the pink colour will be much less distinct than in the previous experiment.

27. **Binocular antagonism.** Set up the stereoscope, and into the frame place two squares of cardboard on which have been drawn designs. The designs should be dissimilar and should be of different colours; e.g. on one draw in red a square divided into a series of small squares, on the other draw in green a circle divided into segments by a number of diameters. On first looking at the designs through the instrument, both will be seen at one and the same time lying superposed on one another.

Very shortly one of them disappears, the other remaining visible.

A few moments later the images reverse, there being an intermediate stage during which both are visible.

Many variations are possible, portions of the designs alone may disappear, portions may reappear together, but rarely if ever do both images disappear at the same time.

Cover one design up with a sheet of white paper, the other design is seen without interruption. Now suddenly remove the sheet of paper and it will be observed that the design now uncovered will immediately take the place of the other and will keep it unchallenged for several seconds.

28. **Visual illusions.** *a.* Draw a horizontal line 10 cm. long. Then, keeping the line horizontal in front of you, draw a vertical line through it of what seems to you of equal length. Measure it.

b. Draw a horizontal line about 2 cm. long; under this at a distance of about 1 cm. draw another line parallel to it and of equal length. At each end of one line draw a V, making the limbs of the two V's point towards one another (thus giving the line an arrow-head at each end); at each end of the other line draw a V, making the limbs of the two V's point away from one another. The former line will look shorter than the latter.

c. Measure on a card equal squares; without putting in the outline of the squares, fill in one with fine vertical lines one to two millimetres apart and the other with similar horizontal lines the same distance apart. Place them a short distance off, they will appear not square but oblong, the side at right angles to the direction of the lines looking longer than the side parallel to the direction of the lines.

DEMONSTRATIONS.

1. Kühne's artificial eye.

2. Colour-wheel (cp. §§ 22—26), and colour matches of the colour-blind.

3. Mirror contrast.

4. The ophthalmoscope, (*a*) indirect method, (*b*) direct method.

5. Test types.

LESSON XXIV. HEARING. REACTION TIME.

1. **Reaction time for hearing.** Arrange a drum to rotate about 10 cm. a second. Put in circuit a battery, a Morse key, to make the circuit when the button is pressed down (another key may be used but not quite so conveniently), a time-marker, and a second key, to break the circuit when it is opened. *B* screens off the Morse key, says 'Ready,' and one to four seconds later presses down sharply the button of the Morse key. *A* stands by the other key and as soon as he hears the click of the Morse key opens his own key.

Practise this a dozen times to get accustomed to it.

Then take a tuning-fork tracing once round the drum. Arrange the marker to write on it, set the drum going and repeat the experiment. The marker will mark the make and break of the current, i.e. the moment of the sound and the moment at which *A* opens the key. The time between the two, the reaction time, is read off from the tuning-fork tracing; it should be rather less than $\frac{1}{5}$th of a second.

2. *Reaction time for cutaneous sensation.* Arrange in circuit 2 Daniell's cells, a knock-down key (or other key breaking the circuit on opening), the primary coil of an induction machine, and a time-marker. Connect the secondary coil with electrodes. Connect with the time-marker a key, say a Morse, and a cell.

Place the electrodes on the moistened skin, or better on the tip of the tongue, and push the secondary over the primary coil, until the break shock is distinctly felt. Then proceed as in the preceding section. *B* silently opens the (screened off) primary key. *A*, as

soon as he feels the induction shock, closes the time-marker key. The reaction time will be found to be greater than in the case of hearing.

DEMONSTRATIONS.

1. Upper limit of range of hearing.
2. Dissection of the semicircular canals in the skate.
3. Model of human ear.
4. Dissection of internal ear of mammal.

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