LABORATORY EQUIPMENT FOR PSYCHOLOGICAL EXPERIMENTS

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VOLUME THREE

OF A SERIES OF TEXT-BOOKS DESIGNED TO INTRODUCE THE STUDENT TO THE METHODS AND PRINCIPLES OF SCIENTIFIC PSYCHOLOGY

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PREFACE

The description of exercises given in Volume II of this series was of set purpose dissociated from the description of apparatus, in view of the fact that the same laboratory exercise may be tried with a very great variety of different kinds of material aids. These material aids can be mastered by the student very much better in the presence of the apparatus than through any written description. After he has mastered a given piece of apparatus he should be called upon to give a description of the construction and working of the apparatus in his report. The present volume is, accordingly, not designed primarily for the student. If the student is called upon to prepare his own apparatus as well as work out the exercises, this book will be of advantage to him; it may very properly be used therefore, by graduate students who are preparing to teach the subject. Its chief function, however, will be in offering suggestions to those who wish to give demonstrations or to teach laboratory courses.

No large expenditure of funds is necessary in order to secure a sufficient equipment with which to conduct a course in experimental psychology. The apparatus necessary for this course can with a few exceptions be constructed with the aid of carpenter's tools. Full lists of apparatus are given on pages 243 to 249 The Yale Psychological Laboratory is prepared to supply all of the necessary pieces of apparatus for this course to any one who may wish to purchase them. Correspondence is invited from any who wish to make purchases, and a detailed price list will be mailed on application. If modifications of designs furnished are desired, these modifications will be introduced wherever it is possible, at the direction of the purchaser. In general it is so highly desirable that the equipment of small laboratories for demonstration and practical laboratory courses be promoted, that one of the important functions of the Yale Laboratory in connection with its graduate work is the provision of material for the work of its students and others of like interest who become teachers of the subject.

No effort has been made in the following pages to describe all of the different pieces of apparatus available for the various lines of experimentation; only those are described which are judged in the author's experience to be serviceable for the purposes here considered. Furthermore, unless apparatus is distinctly the work of a single individual no effort has been made to give an historical account of the way in which it has been designed and modified by successive workers. A practical manual of laboratory equipment is all that is aimed at. Many of the figures are copied directly from the catalogues of makers and are acknowledged in the text where they appear. The other obligations of the author to investigators are numerous; many are acknowledged in the text, many require no special acknowledgment because the apparatus and method have been adopted in common use.

It is a pleasure to make special acknowledgment of the contributions of two gentlemen who make it their special business to design and construct psychological apparatus. The workshop of the Yale Psychological Laboratory had for a number of years the very competent

services of Mr. Charles Herbert Smith. Mr. Smith constructed many of the pieces described in this book and drew in many cases the figures. His successor, Mr. Teeuwen, prepared others of the drawings.

With the appearance of this volume the series of three text-books originally planned is completed. Subsequent volumes on the application of psychology to education and cognate subjects are in preparation and will be announced more fully later.

C. H. J.

New Haven, September, 1907.

CONTENTS

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GENERAL INTRODUCTION

A PSYCHOLOGICAL laboratory has two closely related functions. It should be supplied, in the first place, with apparatus that will make possible the demonstration of certain typical forms of experimental investigation before the elementary class which is pursuing an introductory course. For example, if one is discussing binocular vision as a form of perception it is very advantageous that the members of the class should have the opportunity of experiencing by direct observation some of the binocular combinations which can be made with an ordinary hand stereoscope. If the class is large, the apparatus should be duplicated so that each member of the class may have a reasonable opportunity to make the observation for himself. On pages 250-252 is given a list of the various demonstrations which can be used with the author's *Psychology, General Introduction*. Such demonstrations as these pave the way for more elaborate experiments on the part of the student.

In so far as the demonstrations cover the same ground as the laboratory exercises, which constitute the second function of a psychological laboratory, the equipment for demonstration will be the same as the equipment for the various individual exercises. There is, however, a certain equipment which is especially needed for purposes of demonstration and is not required for the laboratory exercises to be discussed in detail later. First among these are either charts or facilities for lantern projections. Charts have the advantage of keeping before the student for a long time the outlines which it is intended to impress upon him. The best form of cheap chart is a solar print, such as is made by Sprague and Hathaway, 36 Bromfield Street, Boston, Mass. These photographers copy directly any figure or negative on charts, which they supply for fifty cents each. The advantage of a lantern, on the other hand, is that it is possible for any one, with a little practice, to copy from any book the figures which may be desired for demonstration purposes. After meeting the initial expense of the lantern, the further acquisition of material is relatively cheap as compared with the purchase or preparation of charts. If possible an electric arc lantern should be secured. A laboratory of modest equipment can dispense with any of the more elaborate lanterns and will find a small hand lantern serviceable for many practical purposes other than those of demonstration. Somewhat better than charts or lantern slides for the demonstration of parts of the central nervous system and the organs of sense, are models. These give the student in plastic form a very much better idea of the shape and relation of the parts than do flat drawings. The most desirable models are suggested in the list on pages 250–252.

Special demonstration equipment may also include certain large pieces which are designed for use with large classes. These special pieces need not be discussed here. For most laboratories the same piece will serve for both demonstration and individual experimentation.

Turning from the first function of the psychological laboratory as a source of demonstrations for the elementary course, the second and more highly specialized function is to provide the material for individual laboratory exercises to be carried out by the students themselves. On pages 243–249 there is given a list of the apparatus with which the experimental course described in the *Laboratory Manual* can be conducted. On the left side of the pages are mentioned those pieces which are required, on the right those which are desirable. This list can be indefinitely enlarged as the resources of the laboratory permit. On the other hand, it can also be reduced. In case the left-hand list is reduced, it will be found that the completeness of the experiment suffers. Any one who can not try the complete experiment should not hesitate to do whatever he can. The results may be very suggestive, even if they lack something of the fulness and accuracy called for in the text.

There are certain general types of equipment which are not discussed in connection with the special exercises. First, some equipment for drawing and, secondly, some equipment for shop work are very desirable. A great deal can be done by the instructor or by the student in the way of preparing simple apparatus for the laboratory exercises. Thus, it will be shown in the description of the equipment necessary for the first exercise that all that is absolutely essential is a small number of cards, a measuring rod, a ruling pen, and a simple board tray. The ability to draw simple line figures is easily acquired, and should be cultivated in order to prepare such figures as those under discussion, and also in order to produce the graphic representations of results which are to be discussed later.

It is highly desirable that there be in the psychological laboratory provision for various electrical connections. The greater the variety of connections available, the more useful will this equipment be. If possible, connections should be secured with a direct current, such as is used for incandescent electric lights. In case such a current is not available, substitutes may be sought in various forms of battery currents. If batteries must be used, the Edison-Lalande batteries are to be recommended as the most permanent and productive in current. If the incandescent lighting current is used, it will be found that this current is supplied at a potential which is

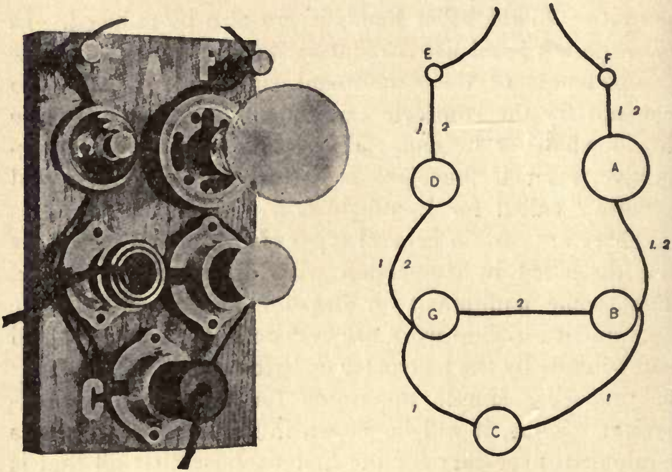


Fig. 1
From Studies. From the "Yale Psychological Laboratory," Vol. IV

too high for use in ordinary apparatus. A convenient method of reducing the current is a lamp battery described by Professor Scripture and represented in Fig. 1. In this battery the current is drawn through the wires *E* and *F*. Following the circuit shown in the diagram at the right, we find that from *F* the current passes first through the lamp at *A*. The lamp at *A* may be of any desired candle-power. It acts as a resistance and reduces the current supplied through *E* and *F* to any desired quantity. Thus, if a lamp of 32 candle-power is employed for *A*, the current will be reduced to about 1 ampere; a 64 candle-power lamp gives about 2 amperes, and a 100 candle-power lamp gives about 4 amperes. After passing through the lamp *A* the current may be carried along the path 1, 2, and may either be turned through *B* or be carried on to *C*. If carried to *C* and there drawn off through wires connected with the apparatus, the current supplied to the apparatus will be, after it is well established, 1 ampere. The current will then pass out through the series of connections marked 1, 1, 1, *E*. This simple connection has certain marked disadvantages, especially at the moment the current is turned off, when there is likely to be a spark which may burn out any delicate connections. In order to take up the spark, also in order to reduce the potential of the current throughout the experiment, it is better to leave open to the current the second path *B*, 2, *G*.

At *B* a small lamp is inserted. This lamp should have an amperage equal to that of the large lamp. For example, if the large lamp *A* is 32 candle-power, the small lamp should have an amperage of 1 ampere. The potential of the small lamp may be relatively small, ranging from 6 to 12 volts. If now with the connection *B*, 2, *G* made, the current is drawn as before to the apparatus from the plug at *C*, the circuit *B*, 2, *G*, constitutes a shunt, and any spark which is generated at the moment the apparatus is disconnected is taken up by the shunt circuit. The shunt circuit will also act so as to reduce the potential of the current used throughout the apparatus. Furthermore, the relation between the two circuits passing through the plugs *C* and *G* is such that when a connection is made through an apparatus of low resistance at *C*, the current at G is virtually broken, and, conversely, when C is broken G is made. This relation may be used by connecting apparatus at both C and G; or a simple connecting plug may be inserted at G, in which case the one source of supply will be through C. The following table, prepared by Dr. Scripture, is in use at the Yale Laboratory:

Lamps used in the batteries

LARGE LAMPS

Mark on Lamp	Trade Name		
A	110 volts	100 c. p.	4 amperes
B	110 volts	100 c. p.	3½ amperes
C	110 volts	64 c. p.	
D	110 volts	32 c. p.	
E	110 volts	16 c. p.	
F	110 volts	8 c. p.	

SMALL LAMPS

Mark on Lamp	Trade Name	
m	8 volts	4 amperes
n	8 volts	4 amperes
o	8 volts	4 amperes
p	12 volts	3 amperes
q	12 volts	2 amperes
r	12 volts	1 ampere
s	12 volts	0.7 ampere
t	10 volts	1 ampere
u	6 volts	1 ampere
v	20 volts	16 c. p.

Results of various combinations of lamps.

Lamps used......	Am	An	Ao	Bm	Bn	Bo	Bv	Cm	Cn
Potential in volts .	9	5	7	7	5	6	37	4	3
Max. cur. in amp...	4.0	4.0	4.0	3.5	3.5	3.5	3.5	1.9	1.9
Lamps used	Co	Cp	Cq	Cv	Dp	Dq	Dr	Dt	Du
Potential in volts .	4	7	10	25	4	5	11	10	5
Max. cur. in amp.	1.9	1.9	1.9	1.9	1.0	1.0	1.0	1.0	1.0
Lamps used	Dv	Eq	Er	Es	Et	Eu	Ev	Fs	Fv
Potential in volts..	15	3	5	7	4	2	8	4	6
Max. cur. in amp..	1.0	0.5	0.5	0.5	0.5	0.5	0.5	0.3	0.3

The lamp battery is relatively uneconomical in its use of the current as compared with a transformer through which the current from the main line may be reduced before it is used in laboratory apparatus. But a transformer is an elaborate piece of apparatus, and it permits only a relatively small range of modifications of the current at different points in the laboratory. The lamp battery is portable and very much cheaper in initial cost than the transformer. It is capable of readjustments by changing the lamps and yet is sufficiently fixed in its output so that the student will not derive from it a current large enough

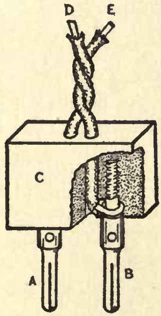


FIG. 2

at any time to endanger apparatus by any mistakes in connections which he may make. For all these reasons it will be found to be a very convenient adjunct to laboratory equipment.

The connections with this battery and with the current can be made by means of the ordinary screw sockets or by means of contacts of the following type. The plug for this contact is represented in Fig. 2, and consists of a hard rubber block bored with two holes. Through these two holes pass the wires D and E, which are to carry the current. At one end of the hard rubber block these holes are enlarged so as to make place for two screws A and B, which are set down into the hard rubber. These screws clamp down the ends of the wires. If the free ends of the screws are split and the two parts of each of the ends are spread slightly apart, they will spring firmly into the socket, which is represented in section in Fig. 3. The socket is just the converse of the plug. It is made of hard rubber and is bored with holes for two wires. These holes are enlarged so as to receive two metallic cups which are supplied with screws at their base and with shallow slots at their upper end, these slots being for a screw-driver. The cups are used to clamp down the supply wires, and screw

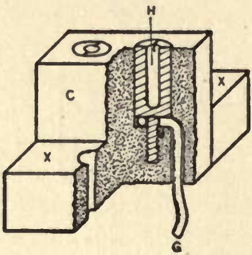


FIG. 3

far enough into the base so as to be below the surface of the block. They are thus protected, so that it is impossible for anything to come in contact with them except a pair of metallic points which can be fitted into the two cups. The hard rubber plug carrying these cups is supplied at its edges with two extensions by means of which it can be screwed into the wall. The advantage of such a plug and socket as this is that the current can be instantly made and broken without any screwing or unscrewing such as is common in the ordinary lamp plugs.

A fourth general type of equipment which will be found very convenient in the laboratory consists of table clamps, S-clamps, rods, and holders. A form of universal table clamp which is very convenient is represented in Fig. 4. It consists of a screw clamp to be fastened to the table and a split ball which is designed to carry the rod. This ball can, when unclamped, be so adjusted as to allow the rod to stand at any desired angle. When clamped firmly in position by means of the screw lever shown in the figure, it holds the rod at any position in which it has been set. A second very convenient table clamp is represented in Fig. 5. The two jaws of this clamp can be set at any desired distance from each other along the rod so that they can be fitted without difficulty to any table or block. Such a clamp holds a rod only in a position perpendicular to the table to which it is clamped. The S-clamp or right-angle clamp is represented in Fig. 6. By means of this, rods of various sizes can be fastened at right angles to each other. Rods can be secured either from the manufacturers or they can be bought in stock from any hardware dealer and can be cut into desired lengths by means of a hack-saw, which should be one of the tools in the workshop of the laboratory. An equipment of clamps and rods can be utilized for a great variety of purposes. For example, the Wheatstone stereoscope described on page 82 can easily be set up with rods and clamps, no special construction such as that described on page 82 being required.

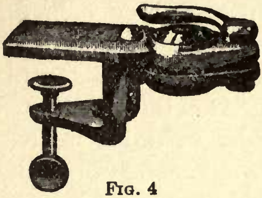


Fig. 4

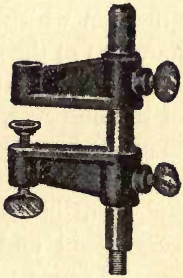


Fig. 5

Fig. 6

A general question of procedure which may be discussed at this point, rather than in connection with any of the particular experiments, is the question of the observer's general attitude toward the experiment. It will be found with all beginners that there is much distraction in the conditions under which the experiment is made. Furthermore, there is a natural feeling on the part of most students that a psychological experiment is a test of their individual ability and that they must, in order to do themselves credit, carry out the test with the greatest degree of rapidity possible and with the highest grade of attainment in number of striking judgments. To a certain extent this attitude must be fostered, for the success of all psychological experiments depends upon the highest possible degree of attention which the observer can give to the problem in hand. On the other hand, precautions may very properly be taken in order to avoid excessive anxiety on the part of the observer, lest he should fail to comply with the demands of competition in the experiment. It is better for an observer to recognize that regularity of reaction or of judgment indicates a higher type of efficiency than a few very rapid and accurate judgments in the midst of a general series which is uneven in its average. Above all things the observer should free himself from the disposition to adhere to any preformed theory of what the results of the experiment should be. Some experimenters have believed that the best way to avoid preconceptions on the part of their observers is to keep them wholly ignorant of the subject of the experiment and also of their own results. There can be no question that under certain circumstances it is highly desirable that the observer should not be confused by a knowledge of the results. For example, in most practice series it is better that the observer should give himself wholly to the task of practice rather than that he should have his attention divided between practice and thought about how rapidly or how slowly he is progressing. In other cases, however, it is better to give the observer definite information, at least as to the general direction in which the experiment is tending.

For example, in the experiments on sensation intensities, especially in the determination of initial thresholds (see page 128), it is very commonly advantageous to tell the observer the direction in which variations are being undertaken. If this is not done, the condition should, so far as possible, be arranged, as indicated under the description of the method of right and wrong cases, so as to take advantage of the chances which result when the observer makes a blind guess. The observer's attitude, it will be seen from this discussion, is always a factor in a psychological experiment.

No rigid rule can be laid down for the treatment of the observer. He will improve during his contact with psychological problems whatever procedure is followed; and he will ultimately find that a wholly unbiased opinion is the most productive for the investigation. But these matters of attitude can be cultivated only with experience, they can not be forced upon the observer at the outset. The more experience an observer can have with regard to a problem and its methods before he begins the investigation, the more rapidly he will become a mature observer. Procedure with knowledge, as it is technically called, is in general more advantageous than procedure without, except as indicated above, where the problem under consideration is one of practice and does not involve any knowledge on the part of the observer of the degree or direction of his change through practice.

In this connection it may be well to point out that the results obtained by beginners are very frequently so incoherent and different from the general results reported in the papers of trained experimenters that the instructor must constantly supplement the student's results by additional information or references for reading, in order to make the work productive. If the student obtains results which will justify only a very broad general conclusion, there should be no effort to force upon these vague results any greater refinement than they readily justify. It should be explained to the student that the results which he finds reported in the more elaborate investigations are the outcome not only of the method which he is pursuing but of a higher degree of training in observation and reaction. He should be encouraged to recognize individual differences as important matters in all psychological investigations. He should be encouraged in connection with each experiment to give as full an account as possible of his own subjective condition. This will in many cases throw light upon the character of the results which he obtains. Further discussion of the matter of exactness of psychological results, especially in so far as quantitative methods are in question, has been undertaken in the general introduction of the *Laboratory Manual.*

When the student has obtained his results, the next matter is the presentation of these results. In general it will be found advantageous to bring together all the results of an investigation whenever possible in a graphic representation. A graphic representation has the advantage over a table that it presents at a single glance the whole series of results in their relations. The student should be made familiar with the use of coördinate paper and with the principles of reduction to various scales. For example, the following table was secured by an investigator who carried out a practice series of measurements with the Müller-Lyer illusion until the illusion was much weakened. This table was brought together in the curve represented in Fig. 7.

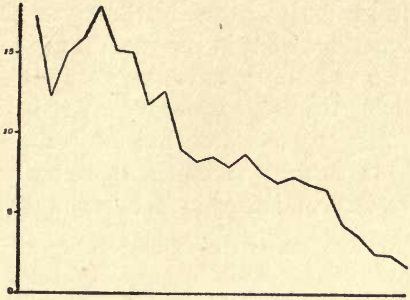


FIG. 7

Figure 10 *cm. in length, oblique* 3 *cm., at angle of* 45°.

Date	Avg. Ill. in m.m.	M. V.	Date	Avg. Ill. in m.m.	M. V.
April 26	17.3	2.3	May 27	7.9	1.2
29	12.3	2.0	June 1	8.7	1.4
May 2	15.0	1.6	6	7.5	1.8
3	15.9	1.6	6	6.9	1.4
5	17.9	1.6	7	7.3	0.8
10	15.1	1.0	8	6.8	1.3
12	15.0	1.9	10	6.5	1.0
17	11.8	1.0	13	4.4	1.1
18	12.6	1.6	14	3.6	1.2
20	9.0	1.2	15	2.5	0.9
24	8.2	1.3	16	2.4	1.2
25	8.5	1.2	17	1.7	1.1

The table contains the material which is expressed in the curve, but it is obvious that the comprehension of the whole matter is made very much simpler by the graphic representation. Students should be encouraged to prepare compact tables and then devise various methods of presenting these tables in curves. Attention should be called to the fact that the size of the figure is a matter of total indifference, provided the units of measurements in the horizontal are all of exactly the same kind and that the units of measurement in the vertical are in turn homogeneous. It is sometimes advantageous to emphasize one characteristic or the other of a given curve. In that case small units may be used for the horizontals and larger units for the verticals. Thus, the same table as that presented in Fig. 7 is condensed in its horizontal dimensions in

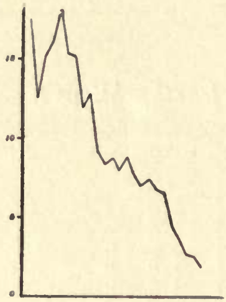


FIG. 8

Fig. 8. In the author's *Psychology, General Introduction,* graphic representations of this type will be found on pages 340, 372, and 373.

The most convenient unit of space measurement for all laboratory exercises is the centimeter and its multiples and subdivisions. The student should be made acquainted as soon as possible with these units, and meter rods should be provided in the general equipment of the laboratory. It is sometimes desirable to provide the student with measures of the metric system for his use outside of the laboratory. Millimeter coördinate paper may be purchased and may be cut into small strips, if it is desired to attain this end at very small expense. This paper is ruled with a sufficient degree of accuracy to be used for most of the measurements necessary in a psychological laboratory. All circular measurements can be very much simplified if apparatus is constructed with such a diameter that a degree of arc is exactly equal in length to some one of the metric units. If the diameter of the circle is taken as 114.5 cm. a degree of arc will be very nearly equal to one centimeter. If this rule of construction in all circles is adhered to, the graduation and regraduation of the circumference of these circles will be a very simple matter, for degrees can be marked off on the circle with the aid of a flexible metric tape.

EXERCISE I

A—APPARATUS AND PROCEDURE

The form of figure to be used in this exercise is represented in the text of the *Laboratory Manual* on page 18. Some description is there given of the methods to be employed in the preparation of the cards on which the figures are drawn. These cards should be large enough so that the boundaries of the cards shall not interfere with the inspection of the figure. A convenient size will be found to be 30 cm. by 15 cm. Any thin grade of cardboard can be used, or a heavy grade of drawing paper will serve very well. The most convenient dimensions for the figures themselves are 10 cm. in length for Fig. *A* (*Laboratory Manual*, p. 18); 3 cm. more or less, as suggested in the table of variations below, for the oblique lines; and angles from 15 to 75 degrees between the obliques and the long lines. The line *B* (*Laboratory Manual*, p. 18) should be drawn about 16 cm. in length, and its obliques should correspond to the obliques for Fig. *A*. A convenient method of describing these figures for purposes of record is by means of some such formula as the following: 10 cm., 3 cm., 45°.

The following variations may be suggested:

10 cm.	1 cm.	45°
	2 cm.	
	3 cm.	
	4 cm.	
	5 cm.	

10 cm., 3 cm.	15°
	30°
	45°
	60°
	75°

Each member of the class should be required in some part of the exercise to work with figure 10 cm., 3 cm., 45°. There will then be a basis for comparison of all observers.

Modifications of a different kind from those suggested in the tables may be introduced by omitting certain of the oblique lines, in order to ascertain, for example, whether an upper oblique is more important for the illusion than the corresponding lower oblique. The length of the main line of the illusion may also be modified. In that case the comparison between different figures should be made, not by direct comparison of the absolute amount of the illusion, but rather in percentages. Thus, if the illusion for 10 cm., amounts to 2 cm., the illusion will be stated as 20%. If the illusion when *A* is 5 cm. in length amounts to 10 mm. it should again be stated at 20%. Further variations may be introduced into the figure by moving the whole figure to a greater or less distance from the observer; this reduces the size of the retinal image while maintaining a proportional relation between all of the different parts. Again, the figure may be turned so that its long lines are vertical or oblique.

A convenient method of preparing these cards in such a way that the long lines can easily be matched with each other, is to set the cards against a straight edge and draw the long lines on both with one continuous ruling. In the same way, the easiest method of manipulating the cards is to place them in some form of tray or holder which has at one edge a straight strip. For this purpose a simple apparatus can be used consisting of a board that has tacked along one side a strip of wood which rises above the level of the board and gives an edge against which to rest the cards. This wooden tray can then be held before the observer, either in the hand or resting upon a table.

The procedure of the experiment is now very simple as stated in the *Manual*. The observer should move the card on which is drawn figure *A* until the length of the line *B* seems to him to be equal to the line *A*. After he has adjusted the cards so that they are satisfactory, one of two methods may be adopted for the measurement of the results. First, two persons may work together on the exercise, one acting as observer and the other acting as experimenter, and measuring the results immediately after each setting. Secondly, the observer may mark off

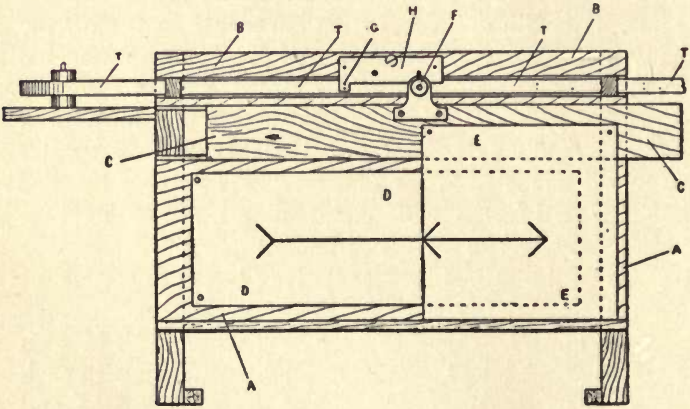


Fig. 9

on strips of paper the length of *B* after each setting, and may then measure the marked strip after the whole series is finished. If the observer is allowed to measure the line *B* after each setting, he is likely to be more or less distracted by his knowledge of the inequality between *A* and *B*.

The apparatus for holding the cards and recording measurements may be made much more elaborate, as indicated in Fig. 9. A wooden frame 50 cm. long and

30 cm. wide is made up of a wide board *AA* and a narrow board *BB*, held together by two side pieces shown in the figure. Between *AA* and *BB* slides the movable piece of board *CC*. This is matched to the two parts of the frame *AA* and *BB*, and is made loose enough to slide freely. It is held in position by a long, slightly bent strip of brass which acts as a spring and is placed between the upper edge of *CC* and the lower edge of *BB*. This spring will be found convenient in all types of wooden slides. It obviates the necessity of fitting the wood closely and frees the apparatus from all the effects of swelling through changes in humidity. Cards with the figure to be measured can now be fastened with thumb tacks upon *AA* and *CC*. The card *EE* will in this case need to be somewhat wider than described above. The advantage of the apparatus as thus far described is that the cards when once adjusted are held in position and can be rapidly adjusted without direct handling. Measurements which give no direct knowledge of the error can be made by the observer after each setting by measuring the amount by which *C* projects to the right beyond the frame.

The remaining parts of the apparatus represented in Fig. 9 provide a means for recording the settings without direct measurement. At the extreme left of the figure is an arm on which is placed a spool of ticker tape. This is unwound, as shown in *T*, *T*, *T*, *T*, and drawn across the upper part of the frame *BB*. Two strips of metal seen near the ends of *BB* hold the tape in place. At the middle of *BB*, and *CC*, are placed the recording points. The recording apparatus is constructed as follows: *F* is a short metal rod fastened to the sliding board *CC* and seen in the figure only at its end. The end of this rod *F* which is nearest to the ticker tape carries a small pin-point. The pin-point is held away from the paper by a coil spring placed around the rod. (For the details of such a spring see Fig. 18, page 29.) The observer, when he desires, can push against the upper end of the rod *F*, and thus drive the pin through the ticker tape, otherwise the pin is drawn back by the spring and the whole moves freely across the tape whenever the sliding board *CC* is moved. A second pin-point at G is fastened to a plate *H*, which is fastened in turn to *BB*. The pin-point at *G* is made double, so that its impression may easily be distinguished from the impressions of the point *F*. The plate *H* and the points at *G* are held away from the ticker tape by a spring. Pressure on the plate may, however, as in the case of the point of *F*, drive the pins at *G* into the tape. By means of a catch placed on *F*, a single pressure on *F* moves both *F* and the plate *H* downward to the tape against their respective springs, and there will thus be punctured in the tape two pin-records, one at *G* and one at *F*. Since *G* is fixed and *F* moves as the board *CC* moves, the distance between the pinholes in the tape will vary with every change in the positions of the two cards *DD* and *EE*. If the distance between the pins in *G* and *F* is determined when *A* and *B* are in reality equal, the amount of departure from this distance in the various settings will constitute a measure of the illusion. The advantage of this apparatus is that the observer can make a series of settings of the figure in rapid succession, and can readily record the results without the inconvenience of marking on strips of paper.

A further refinement of the apparatus consists in attaching to the sliding board *CC* a handle which will permit rapid coarse adjustments and slower fine adjustments. Such a handle is represented in Fig. 10. Let *B* represent the end of the board *CC*. The block *K* attached to *B* carries a screw rod *D*. The method of setting this rod into the block *K* is such that it shall have a screw movement and at the same time a hinge movement from *D* to *D′*. The upper end of the rod is turned so as to have a ball-shaped head carried on a shaft which is turned down to a diameter smaller than that of the ball or rod. This head is fitted into a cup which closes around it on all sides except one, where it is split so as to allow the narrow part of the shaft to swing forward into the position *D′* without drawing the shaft out of the cup. The bent brass strip at *S* acts as a spring to throw the rod into the position *D* against *N*. *N* is a half nut and is fastened to the frame of the apparatus. When the screw rod *D* is forced into this nut, the board *B* can be moved only by turning the rod and thus operating the screw in the nut. If the rod is drawn forward into the position *D′*, the threads of the screw no longer engage the threads of the nut and the board *B* may be pushed freely back and forth. This makes possible a rapid, coarse adjustment.

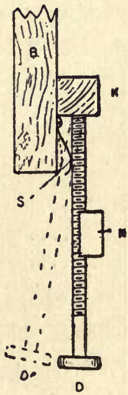


Fig. 10

The whole apparatus can be clamped to a table at any convenient angle. It is better to use it in a position nearly vertical and at about the level of the eyes of a seated observer.

An additional precaution which it is well to take in working with visual percepts is to cover all parts of the field not directly involved in the percept. A screen of gray cardboard with a circular or elliptical opening in the center, cut large enough to allow the lines to be seen, but not to expose any of the apparatus near the lines, is the most convenient means of avoiding distractions from the outlying visual objects. Such a screen can be tacked over the apparatus described above.

B—RESULTS

A table showing the results of a series of measurements which emphasizes to an unusual degree the difference between the two types of setting, but is otherwise typical, may be given as follows:

Table I

Observer J. C. B. Figure, Müller-Lyer; 10 cm., 3 cm., 45°. Mch. 10. All measurements reported in millimeters.

Illusion when B is too long at beginning.	Variation from avg. of five.	Illusion when B is too short at beginning.	Variation from avg. of five.	Variation from gen. average.
24.0	0.6	....	....	3.8
24.0	0.6	....	....	3.8
26.5	1.9	....	....	6.3
24.5	0.1	....	....	4.3
24.0	0.6	....	....	3.8
....	....	16.5	0.7	3.7
....	....	14.5	1.3	5.7
....	....	15.0	0.8	5.2
....	....	16.0	0.2	4.2
....	....	17.0	1.2	3.2
Avg. 24.6	M.V. 0.76	15.8	M.V. 0.84	....
General average for 10 determinations 20.2				General. M.V. 4.4

A general table showing the results for various figures examined by the same observer is as follows:

Table II

Observer J. C. B. Date, March 10.

Figure	Avg. 10 determinations	M. V.
10 cm., 1 cm., 45°	12.6	1.1
10 " 2 " 45°	18.0	3.1
10 " 3 " 45°	20.2	4.4
10 " 4 " 45°	22.7	3.5
10 " 5 " 45°	23.0	3.7

A table presenting the results for a group of observers using various figures is as follows:

Table III

Figure	10, 1, 45°		10, 3, 45°		10, 5, 45°		10, 3, 30°		10, 3,60°	
Subject	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.
A.B.C.	15.1	3.4	23.3	4.75	31.8	2.6	....	...	....	....
D.E.F.	11.0	2.1	15.7	2.1	21.1	2.7	....	...	....	....
G.H.I.	12.6	3.0	21.2	4.2	27.0	3.9	....	...	....	....
J.K.L.	....	...	19.0	3.5	....	...	7.0	3.3	0.0	3.4
M.N.O.	....	...	26.7	3.0	....	...	19.1	1.3	15.1	1.8

The results reported in Table II are represented in the curve shown in Fig. 11. Similarly the results reported

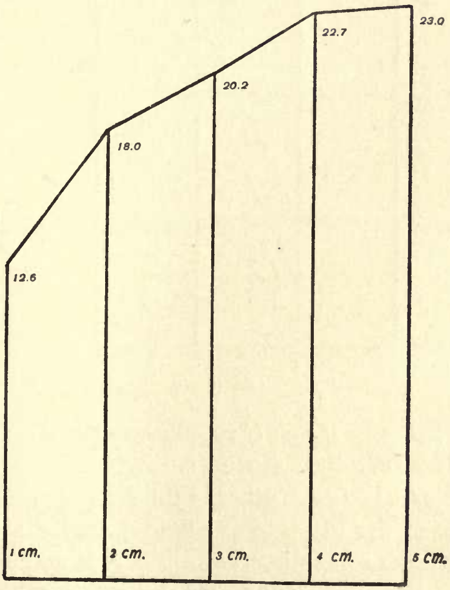


Fig. 11

in Table III for the first three observers are given in the curves in Fig. 12.

C—SUPPLEMENTARY EXPERIMENTS

The first supplementary experiment deals with the Poggendorff illusion (Fig. 13). The lines *A* and *B* and

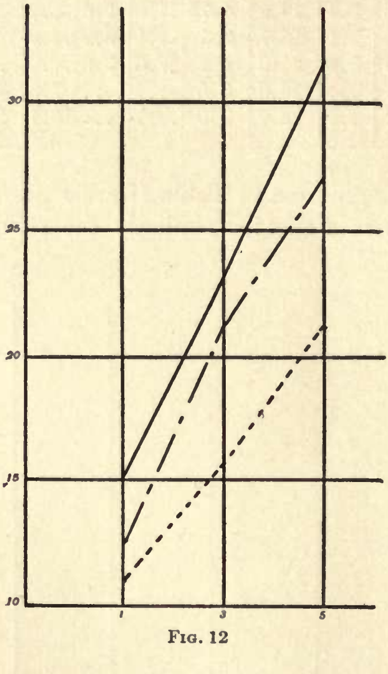


FIG. 12

the space between *B* and *C* should be drawn on one card; the lines *C* and *D* on a second card. The two cards can now be adjusted on each other in the same way as the cards in the case of the Müller-Lyer figure, until *A* and *D* seem to extend in the same direction. There is another method of treating this illusion; namely, by rotating one or both of the lines *A* and *D* until they seem, because of their rotation, to extend in the same direction. The method of measuring rotations is more complex than the method of sliding the cards back and forth over each other. The principle involved in the rotation method will be described later in a case in which it is clearly required, namely, in measuring the Zöllner illusion.

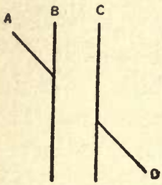


FIG. 13

The second supplementary experiment deals with such an illusion as that shown in Fig. 14, where the point is in reality equally distant from the two circles, but seems to be nearer to the large circle. In attempting to draw the two parts of this figure on cards for purposes of adjustment in a way analogous to that described for the earlier figures, a difficulty which has not been serious up to this point makes itself emphatically felt. The line of division between the two cards forms in reality an additional object in the field of vision, and its presence can not be ignored

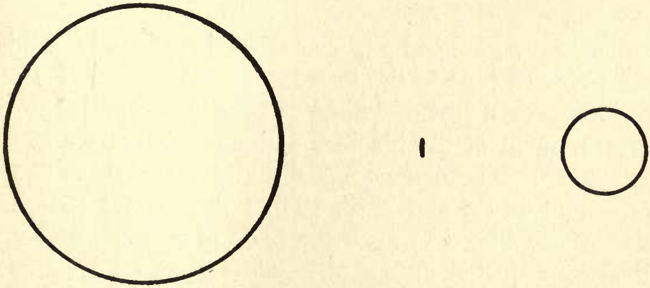


FIG. 14

in trying to locate a point between two figures. The method must, accordingly, be modified in such a way as to make it possible to present two circles in the field of vision with an intermediate point which shall in no way be associated with a line of division between cards.

The simplest method of meeting this demand is to draw the circles on a large card and then draw the point which is to be placed between them on the back of a glass which is large enough to cover the whole field. The glass with the point on its back surface may now be shifted over the fixed card until the point is in the desired position. The glass with the point may be fastened, if desired, to the adjustable strip *CC* of the apparatus shown in Fig. 9 (p. 18). The glass may be fastened by boring holes through it and screwing it to the board, or by fastening along one edge

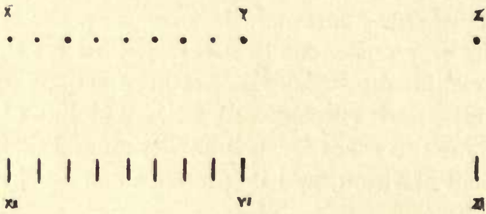


FIG. 15

either heavy gummed paper or electric tape, and fastening the paper or tape to the board.

The method just described can easily be applied to the measurement of the illusions of interrupted space shown in Fig. 15. The distances XY and $X'Y'$ of these figures are equal to YZ and $Y'Z'$. The point Z and the short line Z' may be drawn on the back of a glass, and may then be adjusted until XY seems equal to YZ, or $X'Y'$ equal to $Y'Z'$.

Another method of carrying out the experiments with circles of unequal size or filled and empty space consists in taking the observer into a dark room, and providing conditions of illumination which shall make it possible to manipulate the figures, without introducing any irrelevant object whatsoever into the field of vision. This can be readily done as follows: Provide a box, one face of which consists of a milk glass which will distribute the light falling upon it as uniformly as possible. This milk glass should be illuminated by a light placed within the box. A black square or circle may be produced upon this surface by means of an opaque figure which will intercept the light supplied to the milk-glass surface from within the box. In the same way a dark point at any desired distance from the figure may be produced by a black point on the milk glass. A second figure of any shape or size desired can now be introduced on the back side of the milk glass, and can be moved nearer to the fixed point, or further from it, by means of a rod which extends directly into the box in such a way as not to cast a shadow upon the milk-glass surface.

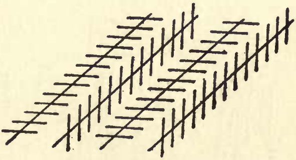


FIG. 16

The position of the adjustable figure can be measured either directly by means of a scale or by means of some recording device attached to the movable rod. This general method of escaping complicating objects in the field of vision by using illuminated surfaces and black objects can also be applied to other figures than the one in question.

One of the illusions of direction resulting from lines crossing the main line of the figure is that which appears in the so-called Zöllner pattern, Fig. 16. The apparatus for the measurement of this illusion is somewhat more complicated, because the direction of the line is to be measured and not its length. The simplest device is as follows: One of the long lines of the Zöllner pattern with its obliques is drawn upon a card, and at a suitable distance from the end of the long line and at the same horizontal level as the lower end of the line, a black silk thread is fastened to the white card. This thread should be 114.5 cm. (or some fraction) in length, in order to facilitate angular measurement. At a distance from the point of fastening which is equal to the length of the long line of the Zöllner pattern, the thread should be made to pass behind a screen, which will thus cut off a suitable portion of the thread to be compared with the long line of the Zöllner pattern. The thread should be kept under tension

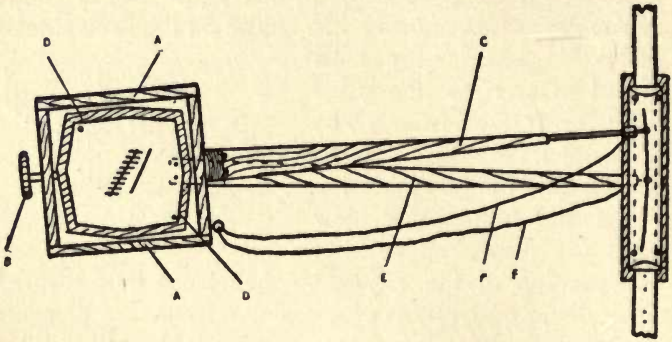


Fig. 17

at its remote end by a weight or rubber band. Let the position of the thread be adjusted by the observer until its direction seems to him to be exactly parallel with the long line of the Zöllner pattern. The deviation of the long thread from the position of true parallelism with the line of the Zöllner pattern can then be read on a scale. The amount of this deviation constitutes a measure of the illusion.

A piece of apparatus, which in a somewhat more elaborate form follows the principles already described, is shown in Fig. 17. An outer frame *AA* carries a piece of plate glass on the back of which is drawn a plain straight line. This line can easily be drawn on glass by means of an ordinary ruling pen and very thick India ink. The frame with the glass can be rotated, by means of the handle *B*, about a rod fastened to the frame at the back; and when the glass is so rotated it carries with it the long arm *C*. Held rigidly at the same center as that around which the glass and frame rotate is a wooden panel *DD*, to which is tacked any desired part of the Zöllner figure. The fixed panel has connected with it the long arm *E*. The observer is required to rotate frame *AA* with the arm *C* about the fixed panel *D*, until the plain line and the long line of the

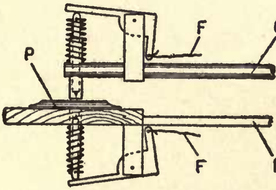


Fig. 18

Zöllner patterns seem to him to be parallel; the degree of rotation is indicated much enlarged at the ends of the arms *C* and *E*. At the extreme ends of these arms are placed pin-points, which may be used to mark a paper strip and leave a permanent record of the relative positions of the arms. The device for making the pin impressions is represented in Fig. 18, and operates by means of the strings *FF*, which are carried to a point within easy reach of the observer who is seated before the frame and panel. The arm *E* carries at its end a wooden plate over which is drawn a strip of paper seen at *P*. Above and below the paper are pin-points which are held back from the paper by coil springs. The pins are driven into the paper whenever the strings at *FF* are pulled by the observer. If with this attachment the distance is recorded between the pin-points attached to the fixed arm *E* and the movable arm *C*, and if, further, the distance of the pin-points from the center of rotation is properly chosen, as for example 114.5 cm., the apparent deflection of the line of the Zöllner pattern from its true position can easily be measured at once in centimeters and degrees of arc.

For the remaining supplementary experiments it is only necessary to make measurements with one or the other of the methods above described, and to tabulate the results fully as indicated in the table and curve given for such a practice series in the general introduction (page 13).

EXERCISE II

A—APPARATUS AND PROCEDURE

In all experiments dealing with monocular vision it is better to cover one eye with a loose shield rather than to bind the eye or require the observer to keep the eye closed by voluntary effort. A simple shield for the eye can be made of stiff cardboard covered with dark cloth. The shield should be large enough to cover the region from the eyebrows to the cheek bone, and from the bridge of the nose to the temple. It should be bent in its vertical axis and shaped at the sides so that the right and left edges will fit against the face as closely as possible. It can be held in position by means of a rubber band about the head.

A second general requirement in monocular experiments is a head-rest. If table clamps and S-clamps and rods (page 9) are included in the general equipment of the laboratory, a simple and satisfactory head-rest can be set up without special additions to the general equipment. Let a horizontal rod be supported on a table by two upright rods at the level of a seated observer's upper teeth. Since the head naturally tends to drop forward, and since the upper teeth are firmly fixed in the skull, it follows that any support placed under the upper teeth will give the head a firm rest. Any other point of the skull which might be used for the same purpose has the disadvantage of being covered with loose skin which permits more or less movement of the head against the rest. If it is desirable that the head be brought to the same position in a number of successive experiments, or if it is necessary, as in this exercise, to hold the head in the same position for a long time, the fixation of the teeth can be made much more complete by covering the supporting bar with a layer of sealing-wax into which the teeth may be pressed while the wax is warm. The mold of the teeth thus produced upon the bar can be used to bring the head back into its original position even after the observer has moved away for a time. Instead of the horizontal rods just described, a wooden strip small enough to be taken between the teeth can be supported by clamps from the table or from a chair, and the upper teeth can rest upon this wooden strip.

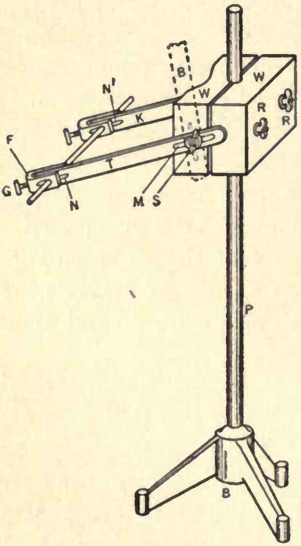


Fig. 19

It is frequently desirable to have a portable head-rest which can be set up in smaller space than the table-rest described. Fig. 19 represents a very convenient form of general head-rest. A piece of iron pipe *P* is screwed or driven into a heavy tripod base *B*. If it is desired, a number of pipes of different lengths may be provided for various purposes. A block of wood *W*, split into halves and having in its center a hole somewhat smaller than the iron pipe, can be clamped firmly to the pipe *P* by means of screws *RR*, which pass through the block and are provided with thumb nuts on one side. This block can be loosened by unscrewing *RR*, and can then be set at any desired level up and down on *P*. At the sides of the block are fastened adjustable strips of iron as indicated in detail at *S*, *T*, *M*. *S* is a thumb-screw which clamps the strip *T* against the block. By means of the slot *M* in the strip, the strip may be made to project to any desired distance beyond the block. This arrangement also makes it possible to set the strip at any desired angle, as at *B*. At the outer end of the strip is a device for clamping a cross rod. This device consists in a slot *N* in the strip *T*, and a bent piece of iron *F*, with a double slot corresponding to the slot *N* in the long strip. The bent piece *F* has a screw *G* passing through its middle. When now the bent piece is slipped over the strip, the three slots give an opening which may be regulated in size by means of the screw *G*. If this screw is set down against the end of the strip *T*, the opening left between the three slots can be reduced in size so as to hold a rod firmly in position. A second adjustable iron strip *K* is fastened on the opposite side of the wooden block. Between these two strips a bamboo rod can be fastened in the slots *N N′*, and on the rod a sealing-wax impression for the teeth can be made as described above. The rest can be used in two positions. Either the back of the head can be placed against the block and the rod with the teeth-rest be adjusted to hold the head back firmly against the block, or the iron strips can be set up from the wooden block, as in *B*, the block acting in this case as a standard on which to fasten the teeth-rest. In position *T* the space in front of the eyes is left entirely free; in position *B* the space around the ears is also left free.

A perimeter, which is the most convenient device for measuring positions on the retina and stimulating its different areas, can be constructed in very simple form from a child's hoop. The hoop should be as large as possible; it should be cut in two so as to give a half circle, and it should be graduated in degrees. The easiest method of graduating the hoop is to determine by measurement the total circumference of the hoop and then, after dividing this by 360, to mark off by direct measurement every $\frac{1}{180}$ of the half circumference. The half hoop should be fastened on some kind of firm upright standard, if necessary on the wall. Other points of fastening may be suggested. Thus, a heavy rod fastened to a table is a very good holder and gives the experimenter better opportunity of getting behind the perimeter. Even better is a special base similar to that described in connection with the head-rest. The point of fastening should be on the same horizontal level as the observer's eye. It is often easier to adjust the height of the observer than of the apparatus. The observer should be placed with one eye at the center of the circle of which the hoop forms the circumference; the other eye should be covered; and the observer should be required to look steadily at the point on the semicircular hoop at which it is fastened to the standard. This center should be marked with a spot of white paint in order to make it easy of fixation. The position of the perimeter will determine the part of the retina which is to be examined. The most convenient position is that in which the perimeter is placed in the horizontal plane. It may be placed vertically or obliquely. If the whole retina is to be examined, it must be placed successively in a number of these positions.

A small disk of colored paper two or three centimeters in diameter should be attached to a rod and should be held successively at various positions along the graduated circumference of the hoop. It is better that the color be exposed for a brief interval and then withdrawn, rather than exposed continuously, as the retina fatigues very easily, especially in its eccentric parts. The background against which the colored disks appear can be made either gray or black. It should, however, be uniform in its color tone. In certain elaborate experiments with the perimeter, uniformity of background is secured by going into a dark room and exposing the various colored papers by means of some artificial light which can be turned off when the apparatus is not in use. When the observer is thus taken into a dark room the condition of the retina is modified. It becomes dark-adapted and its sensitivity to colors is completely modified. The investigation when conducted in ordinary daylight gives results which are appropriate to an eye which is light-adapted. The disadvantage of trying an ordinary class experiment in a dark room is that dark-adaptation is not easy either to secure or maintain. In order that it should be complete, the observer must sit in a dark room for at least fifteen minutes and possibly more before the beginning of the experiment. Furthermore, every time the light is turned on there is a tendency to return to the condition of light-adaptation. The experiment must, therefore, proceed very deliberately. If the experiment is conducted in ordinary daylight, the background should not be so bright as to be dazzling, and this end is best secured by hanging about the perimeter either a gray paper or gray cloth. The color then appears on a uniform background.

A simple device which is easy to set up but complex in its measurements, consists in moving the eye rather than moving the object along the circumference of a circle. In this case the center where colors are exposed consists of a small circular opening in a cardboard screen. The eye can either fixate this opening directly or can look at some point at the left or right of this center. The distances to the right and left of the center of fixation being measured directly as straight lines, a trigonometric calculation is required to reduce the measurements to degrees. The simplest method of reduction is to fix an eye-rest consisting of a small ring at a known distance from the point where the color is exposed, and then after calculating the tangents for various degrees of circular movement, mark the scale to the right and left of the opening through which the color is exposed in linear extents which correspond directly to degrees. Such a graduated scale being prepared, the eye is turned say to a position 80° from the center at which the color is exposed; the color may now be exposed to the eye, and since the eye has rotated outward through 80°, the light will fall on the retina at a point 80° from the center of vision. The method of exposing the colored paper in this case consists in merely uncovering either a piece of colored paper or a source of colored light. The screen which has covered the colored light up to the moment of exposure should be of the same intensity of gray as the general background, which in this case consists of the screen upon which the graduations for the eye movement are placed. This form of apparatus, which is known as a campimeter, has the advantage over the perimeter that all sorts of colors can easily be placed under the opening in the screen. Color mixers of different forms, to which reference will be made in the description of the apparatus for the next exercise, can easily be used in connection with the campimeter, while they can not be used with any simple perimeter.

Colored papers for this experiment and the next can be secured from C. H. Stoelting Co., 39 West Randolph Street, Chicago, Ill., who are the American agents for Rothe, the mechanic of Professor Hering, of Leipzig.

Several systems of papers have been prepared by American manufacturers, notably those prepared by Milton-Bradley and the Prang Co., but these are inferior for purposes of scientific investigation to the selected German papers referred to above. Various devices for using transmitted rather than reflected light have been prepared. The most successful of these consists in colored gelatines, which are also of foreign manufacture and are to be had of Stoelting Co. A number of gelatines placed together can be so combined as to produce colors that are approximately pure. They are, however, by no means as bright as reflected colors from the Hering papers. Methods for the determination of the purity of colored fields and methods for the determination of the intensity of colored fields are unnecessary for anything except the more elaborate tests of the sort suggested in this exercise.

If it is desired to make these tests, the ordinary spectroscope methods employed by the physicists may be used for finding the quality of the colors. The establishment of the equations of like intensity of colors is of somewhat greater importance, and a simple method can be employed as follows: Two colors which are to be compared with reference to their intensity are brought into such a position that they stimulate the extreme periphery of the retina. At this part of the retina their color qualities are entirely lost and they are seen as gray. Their relative intensities can now be compared so as to determine which is the brighter. It is ordinarily not possible to change the character of the papers so as to make them equal in intensity, but the results of the equating of the color intensities can be recognized in evaluating the results of experiments with the papers.

One of the most common sources of difficulty in this experiment consists in the inability of the ordinary observer to describe with accuracy his color experiences. Slight differences in color qualities are not covered by the vocabulary of many observers. As a preliminary to this exercise it is therefore advantageous to spend some time exhibiting a series of color qualities and preparing a series of designations for them. For this purpose an excellent series of color specimens and color terminology will be found in the Standard Dictionary under the term spectrum. Otherwise the observer should be carefully instructed to follow the recommendation given in the *Laboratory Manual* of describing each succeeding color experienced in terms of its differences from the color which immediately preceded it. Observers can very frequently tell the direction of a color change when they have no adequate single phrase with which to designate the color itself.

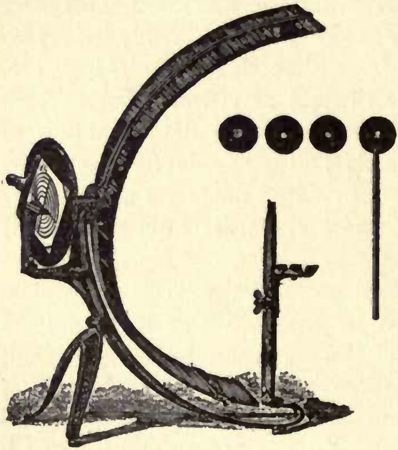


Fig. 20
From the catalogue of Meyrowitz

More elaborate forms of apparatus than those described thus far have been devised and are available for purposes of the experiment here under discussion. Perimeters are used by oculists for the determination of the retinal field without reference to the modification in the character of color vision. Elaborate frames carrying different devices for holding and recording the position of stimuli have been prepared. Several of the more complete forms of automatic recorders may be found by consulting the catalogue of E. B. Meyrowitz, 104 East 23d Street, New York City. (See Fig. 20, which shows one of these.)

The metallic half circle here used is supported on a heavy base. At its center the half circle may be rotated through every angle of the complete sphere. Its angular position is measured by a disk shown in the figure. This disk carries a printed chart of the retina, marked off in degrees. An automatic recorder indicates on this chart the position of any source of light which moves along the half circle. The observer, with his head fixed in the rest shown at the right of the figure, is seated in such a position that the center of his eye is at the center of the circle of which the half circle is a part, and in the same horizontal plane as the center of the perimeter.

It is desirable, as noted above, that the color which is to be exposed shall not be constantly visible to the observer. Various devices may be suggested, such as covering the color when it is being adjusted. Still better is the construction of a perimeter somewhat simpler than that shown in Fig. 20, but allowing the attachment of the light box represented in Fig. 21. A box shown in outline at *AAA* is painted black on the outside, so that it shall offer no positive stimulus. It is supplied inside, as shown at *E*, with an incandescent lamp. Some lamp which gives approximately white light, such as the tautalum lamp, is preferable to the ordinary incandescent lamp. The box is open at the point *F*, there being at this point a small circular opening 2 cm. in diameter. Just behind this opening and in such a position that it reflects the light from the lamp *E* is placed a colored paper *C*. Any color may be inserted at the point *C*, and when the box is closed and the lamp turned off the color will be invisible to the observer. By means of a simple switch at *S* the lamp *E* may be turned on, when the color will immediately be visible. If an ordinary incandescent lamp is used at *E* an additional feature must be introduced into the box because the color of the light from such a lamp is decidedly red. There must be introduced at *RR* a layer of colored gelatine which will modify the light so as to make the light less decidedly red. A combination of green and blue gelatine can be secured which, held between two sheets

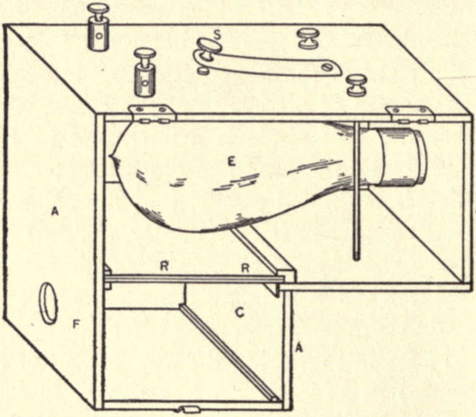


FIG. 21

of glass in the position *RR*, will modify the light from *E* before it reaches the colored surface *C*, and give satisfactory color effects with all papers.

The perimeter and its attachments may be of any size desired. The larger the circumference, the easier will be the readings for different positions of the color. Furthermore, if the base and circle are made heavy enough they may carry any desired additional apparatus, such as color mixers. In the larger forms a quarter circle counterbalanced at one end by a heavy weight serves better than a full half-circle.

B—RESULTS

The following table shows a very good series of observations. In general the observations are less consistent.

Observer A. B. C. Right Eye. Colors from Hering Papers. October 8.

	Red.	Green.	Yellow.	Blue.
90°	Nothing	Light, without color	Light, no color	Nothing
80°	Light, no color	Light, without color	Light, no color	Possibly red
70°	Possibly red	Orange, pale	Yellow, distinct	Pale yellow
60°	Yellow, distinct	Yellow, pale	Yellow, no change	Blue, distinct
50°	Yellow, toward orange	Orange	Yellow, no change	Blue, paler
40°	Orange	Yellow, pale	Yellow, brighter	Blue, brighter
30°	Red, distinct	Very pale, possibly green	Yellow, same as last	Blue, very clear
20°	Red, distinct	Green	Yellow, same	Blue, brighter
10°	Red, brighter	Green, brighter	Yellow, brighter	Blue, same
0°	Red	Green	Yellow	Blue, same

Fig. 22 shows graphically the results of a series of such observations for a class. The letters represent the various observers. The general result is here made obvious and agrees with the special table reported above. It will be seen from the figure that not all observers show so marked a difference as is shown in the table between red and green on one hand, and yellow and blue on the other.

C—SUPPLEMENTARY EXPERIMENTS

Among the additional problems described under Exercise II, is one for plotting the projection of the blind-spot. No elaborate apparatus is necessary for this experiment. Any means of holding the head in a fixed position before a large white surface will satisfy the requirements. A block of wood 25 cm. in length, placed upon a table, furnishes the simplest head-rest. If the teeth rest against the upper end of the block, and the eye is allowed to fixate

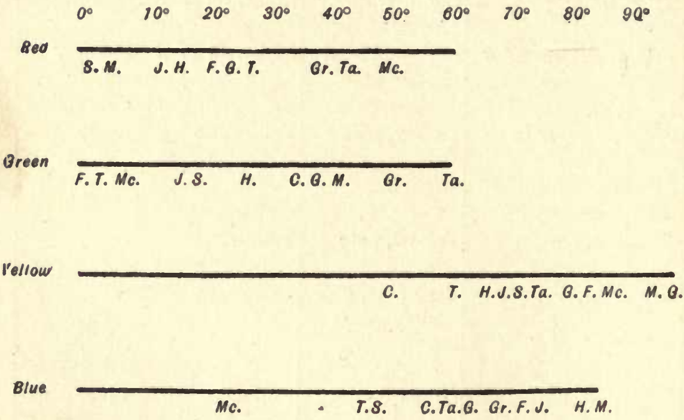


FIG. 22

a point on a sheet of paper lying flat on the table under the block, the eye can be held nearly enough in one position to permit the experiment to go forward. If the right eye is used, the point of fixation should be somewhat left of the center of the paper, and conversely, if the left eye is to be used, the point of fixation should be on the right. After the head has been brought into position and the eye fixed upon the point drawn on the paper, a strip of paper with a black spot at the end should be brought into the field of vision and should be moved about until the spot can not be seen. Evidently the spot is now within the area which casts its image on the blind-spot. In order to determine the boundary of this area the spot should be slowly moved to the right or left until it can just be seen by the observer. At the point where it becomes visible after being in the blind-spot, it is evidently emerging from the projection of the blind-spot and the fact should be recorded on the paper by means of a point. The movable strip of paper is now drawn back so that the spot falls in the blind area again; it is again moved gradually forward until it appears at some other point on the boundary of the blind area where a second point is marked. In this fashion a sufficient number of points may be definitely described on the edges of the area to indicate the outline of the projection of the blind-spot. Two cautions are necessary. It is better to determine the boundaries of the projection by drawing the point out of the area than by moving it into the blind area from some part of the field where it is visible. If the point is moved into the area from the parts of the field where it is visible, its movement can be seen and there is a strong natural tendency to follow its movement. Secondly, the eye must be steadily fixed on the point marked on the paper, otherwise the outline of the blind area will not be determined with exactness, for with every movement of the eye the position of the blind-spot changes.

If a convenient head-rest is at hand, such, for example, as that described on page 32, it should be used instead of the block above described, and the observer should be allowed to look at a large sheet of paper which has been hung vertically in front of the face. The further procedure is exactly the same as in the first case.

The second supplementary experiment under this exercise requires that the degree of apparent curvature of a straight line at the periphery of the field of vision be measured. As in the earlier parts of the experiment, let the head be held in a fixed position and the eye fixated upon a determined point. Arrange on the edge of the field of vision a series of points in such a relation that they will seem to the observer to extend in a straight vertical line. They will, in reality, describe an arc rather than a straight line, and the degree of the curvature can be readily determined.

The third supplementary exercise suggested on page 25 of the *Laboratory Manual* can readily be set up by drawing on white cards black geometrical figures. The figures should have a general diameter of about 3 cm., and should be exposed on a perimeter or with the aid of a campimeter, as indicated in the experiments with colors. If the results for these figures are tabulated and compared with the results for the various colors, it will be found that there are no intermediate zones of partial sensitivity for these figures. It will also be found that only the central parts of the retina which are highly enough developed to give complete color differentiation are highly enough developed to make possible the recognition of forms.

To determine the sensitivity of different parts of the retina for slight changes in illumination, prepare series of cards with gray circles of different intensities on a black background. Graded grays for this purpose can be obtained from Stoelting Co. The first card of this series should show very little contrast, the second more, the third still more, and so on. By successive trials one card can be found for each part of the retina which gives the just recognizable contrast. The procedure here is similar to that followed in exposing colors to the different parts of the retina. Beginning with a very slight contrast, expose it to various parts of the retina and determine where, if at all, it can be recognized. After this increase the contrast and again expose to different parts of the retina.

Another method of determining the sensitivity of different parts of the retina is to measure the amount of change in the intensity of light which is necessary to arouse in the observer the recognition of the fact that the intensity is changing. The observer may be allowed first to look at an area that is illuminated from behind by means of a certain source of light. If now the source of light is moved steadily away, the intensity of its illumination will be decreased in the well-known physical ratio according to which the intensity of a given light is inversely proportional to the square of its distance. If, therefore, we measure the distance through which such a light must be moved in order to give a just noticeable increase or decrease in the illumination, we have a measure for the sensitivity of that part of the retina. Care must be taken in such an experiment as this to move the light at a uniform rate. The experiment can be carried out most easily in a dark room. It is also advantageous where possible to introduce into the field of vision two illuminated areas, one of which is kept at the original intensity and the second one of which is modified in the manner just described. Such determinations may be carried out for different parts of the retina. The method here suggested is the regular method of photometry and will be described again in another connection. (See page 131.)

Experiments of this type give different results when the eye is dark-adapted than when it is light-adapted.

If the experiment is to be made for the dark-adapted eye and a dark room is not available, a substitute for the dark room can be provided by constructing a large box which can be made so as to exclude light except at the points where it is admitted for experimental purposes. Such a box should be painted black inside and should be provided at one end with a hood which can be thrown over the observer's head so as to exclude all light from that end. At the end of the box opposite the observer a screen may be provided which is perforated with any desired number of openings. The intensity of illumination which is allowed to come through these openings can easily be regulated. One convenient method of reducing the light is to hold in front of the opening a number of sheets of thin paper. The number of sheets of paper necessary to produce a just perceptible difference in the illumination of two neighboring points furnishes a rough but convenient method of measuring that difference. A more exact method is to interpose a series of plates of milk glass between the source of light and the observer, and to control the area of each of these glasses through which light may pass by means of an adjustable diaphragm such as that shown in Fig. 33, page 67. The successive plates of glass and their diaphragms may be enclosed in a box so as to secure light from one source only.

In all of these experiments it is highly important that fatigue and after-images should be avoided. These can be avoided by allowing sufficient intervals to elapse between successive experiments.

The last supplementary experiment deals with the matter of adaptation to light and darkness and requires no new methods.

EXERCISE III

A—APPARATUS AND PROCEDURE

The best introduction to this exercise consists in showing the observer a solar spectrum in which the different colors are exhibited in their natural intensity and order. Such a solar spectrum can be produced by allowing a pencil of sunlight to fall upon an ordinary prism. The rays coming from a prism may be projected upon a screen or may be examined directly by the observer. Still better, let the observer look into a spectroscope, which has the advantage over the prism of magnifying very much the color areas and of rendering the different qualities much more distinct.

For purposes of experiments with color, the light from a solar spectrum is very difficult indeed to control, and, except with the most elaborate equipment, it can not be used. For this reason recourse is commonly had to rays of light reflected from colored paper surfaces. The light which comes from colored surfaces can be controlled within wide limits, both in quantity and in position, and can easily be mixed. No special materials or methods beyond those described in connection with the last exercise are necessary to make possible the first part of the experiment.

The first and simplest method of mixture is to utilize such a reflection apparatus as is represented in Fig. 23. This apparatus consists of two boards placed at right angles to each other. Between these two boards is set a plate of plain glass which rests in the angle between the boards without fastening at the bottom. The glass can be supported by a string passing over the top of the vertical board and can be set at any desired angle by adjusting the length of the string. The glass should be of good quality so that it will have a uniform surface and will be as nearly transparent as possible. The observer should look down upon this plate of glass from above, as indicated by the diagrammatic eye, *O*, in the figure. If a sheet of colored paper is placed on the lower board on the

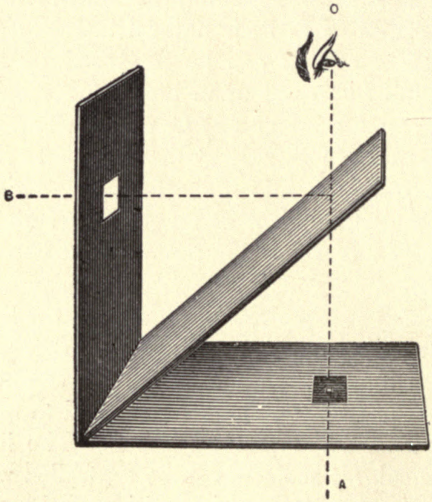


FIG. 23

line *OA*, rays of light from this colored surface will pass upward directly through the plate of glass into the observer's eye. A second colored surface placed on the vertical board in the line *OB* will send its rays to the plate of glass in a horizontal direction, and a part of these rays will be reflected from the upper surface of the glass and will enter the eye of the observer along a path which coincides with that followed by the rays from the colored surface on the horizontal board. The intensity of the light along the line *B* can be modified by changing the angle of the glass. By this means any desired colors can easily be mixed. The limitation of this method is that it does not permit of easy quantitative determinations. Furthermore, it does not permit a mixture of more than two colors at a time.

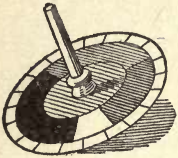


Fig. 24

A more common method of mixing colors consists of some system by which disks of colored paper can be locked together and rapidly rotated. The simplest device of this sort is a color-top (Fig. 24). A simple wooden shaft and tightly fitting ring hold in position small disks of colored paper. The whole is rapidly rotated by the fingers or by some string device, with the result that the colors, which are fastened to the top, pass so rapidly in succession before the eye that the

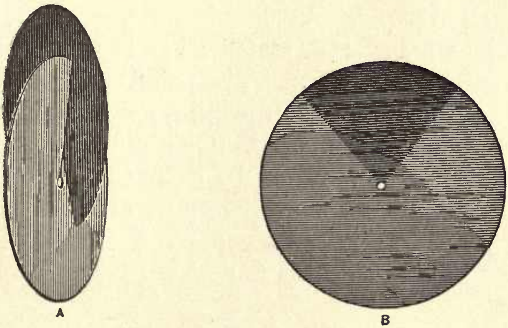


Fig. 25

effect produced by the different colored surfaces is practically continuous. The disks used with the top and other rotating devices have small circular openings in the center and are cut along one radius. Fig. 25, *A*, represents two such disks being slipped over each other so as to leave a part of each disk exposed. The final relation of the disks is represented in Fig. 25, *B*. Obviously the relation can be varied at will so as to expose as much as is desired of either disk. In like manner, several disks may be placed together. Furthermore, it will be easy to measure the amount of each colored surface exposed. For this purpose a protractor is placed over the disks and the area of each sector is recorded in degrees. A transparent celluloid protractor is a very convenient form for this purpose.

Colored papers suitable for this experiment have already been discussed on pages 36 and 37. If the papers are purchased for use in laboratories of moderate equipment, it will generally be found advantageous to purchase the prepared disks. If the papers are to be extensively used in a great variety of experiments, it is desirable to provide a cutter which will make it possible to prepare disks from large sheets of paper. A convenient cutter may be briefly described as follows: A metallic bar has at one end a handle and a sharp point. The point is driven through the paper into a board underneath; it now serves as a center of rotation for the cutter. On the bar is fastened a knife which can be adjusted by sliding it along the bar to any desired distance from the center of rotation. This knife is pressed against the paper and the disk cut out by rotating the knife so as to describe the circumference of a circle.

The color-tops described offer such small surfaces to the view of the observer that contrast and other distracting effects impair seriously the value of the measurements. A mixing device which utilizes colored disks of larger size made of cardboard, is included in Milton-Bradley's Pseudoptics.* This mixer takes advantage of a principle which is employed in a simple child's toy. Two holes pass through a small metal disk on opposite sides of the center of the disk. Through these two holes are drawn two strings. If now the extremities of these strings are held firmly in the fingers and the string is twisted about itself, the disk can be set in rapid motion by pulling at the ends of the string. Such momentum can be attained by the disk in its rotation that it will twist the string around itself in the opposite direction to that in which it was twisted at first, provided the operator relaxes the tension on the string after the momentum is well established. After the disk has wound the string around itself it will come to rest. It can now be set in motion in the opposite direction by again pulling on the ends of the string. The disk can be kept in successive rotation in one direction and the other by simply drawing and relaxing the ends of the string. The central perforated metallic disk through which the string passes is made in two parts in the color mixer, the two parts being screwed together. Between these two parts are clamped the colored disks to be used in the mixing. Pasteboard disks must be used in this case rather than paper, otherwise the successive rotation in opposite directions would result in air currents getting between the disks and tearing them. The mixer is shown in section in Fig. 26.

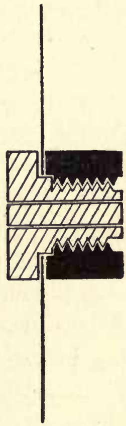


Fig. 26

* The Milton-Bradley Co., Springfield, Mass., issue a collection of charts and simple experimental devices for the illustration of a number of visual phenomena. It was announced, after this collection of charts and experiments had been in use some time, that it was devised by Prof. Münsterberg. The collection is extremely valuable as a means of demonstration and laboratory experiment. It should be in the hands of every teacher of psychology. The price of the three boxes is five dollars.

A third form of color mixer which utilizes colored disks consists of a combination of wheels driven by the hand. In order to secure the proper speed for mixing colors with such apparatus, it is necessary to have a series of cogs or belts between the handle and the rotating shaft on which the disks are held. A satisfactory mixer of this type is little, if any, less expensive than an electric motor to be described in the next paragraph. It should not be purchased unless it is quite impossible to secure proper electric connections for the motor. A good form of hand mixer made by Rothe in Leipzig is shown in Fig. 27. Most of the other hand mixers are unsatisfactory.

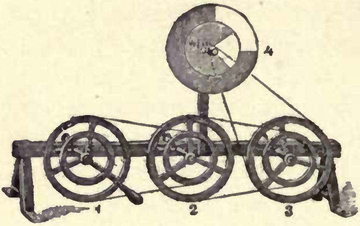


FIG. 27
From the catalogue of Rothe, Leipzig, Germany

A fourth device which is very satisfactory, consists in rotating the colored disks by means of an electric motor. An ordinary fan motor gives the rate necessary. The shaft of such a motor is supplied with an attachment, between the two parts of which the disks can be clamped. This addition to the shaft of the motor is known as an arbor and is the same in principle as the disk holder shown in Fig. 26. Care must be taken to place the disks in such a relation that when the motor rotates the air currents will not spread the disks apart. If paper disks are used, an uncut disk of cardboard should be placed behind the colored disks as a backing disk.

Some fan motors when once set in motion are likely to continue rotating because of inertia for an inconveniently long period of time. It is, therefore, desirable to provide some sort of brake for these motors. The most convenient brake consists in an electrical adjustment by means of which the current, which has been passing through the coils of the field magnet and the armature, may be made to pass through the coils of the field magnet only. By such a device the field magnet will act as a magnet and will attract the armature so as to bring it to a standstill. The connections required are represented in Fig. 28. When the key at K is open, the current passes through the series of connections 1, A, Z, F, 3, F', 4, that is, through the field and armature both. When K is closed, the current passes through the circuit $X1$, $X2$, K, $X3$, F, 3, F', 4, that is, through the field magnets only.

The method of procedure with the motor color mixer is to clamp in the arbor two sets of disks, one of large size, one of small size. The larger outer set may be, for example, in the first equation, red and yellow, the inner set should then be orange, white, and black. Or the reverse relation may be chosen by using small red and yellow disks and large disks of orange, white, and black. An arbitrary combination of such disks should be rotated, and then in successive trials the correct relation should be worked out by readjusting the disks until the same color appears in the inner and outer areas.

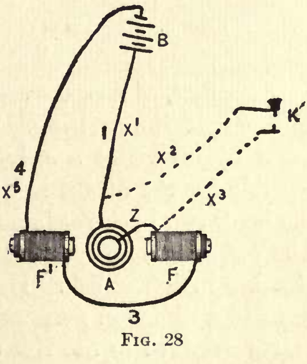


Fig. 28

There are certain devices by means of which the relation between disks can be changed while they are in rotation. These do not permit of fusion of two concentric sets of disks, the matching must accordingly be between two color surfaces placed side by side. The great advantage of changing the disks during rotation is that the effect of each change is immediately seen without stopping for the slow readjustment and trial necessary in ordinary mixers. The difficulty in constructing such a piece of apparatus as this is that there must be provision for the rotation of the disks, and at the same time there must be some fixed portion of the apparatus which can be easily moved by the experimenter so as to change the amount of exposure of the disks. A device constructed by Marbe which has these parts is shown in Fig. 29. It

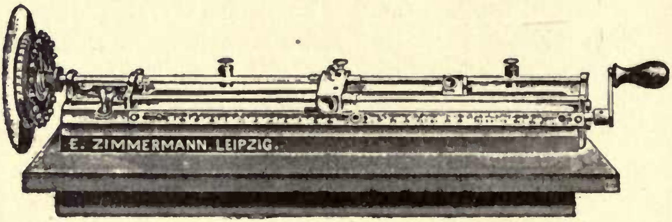


Fig. 29

From the catalogue of Zimmermann, of Leipzig, Germany

consists, first, of a screw which can adjust the length of a long catgut violin string. The string is fastened to this screw by means of a swivel joint which makes it easily possible for the catgut to rotate, while at the same time it can be drawn backward and forward by turning the screw. The catgut passes forward from this screw to the center of a hard rubber disk. Here it passes over a pulley and turns in a direction perpendicular to its first direction and passes outward to the rim of the disk. It is now turned on a second pulley and passes from this point over a number of pulleys describing a circle around the back of the disk. By passing over these pulleys, it describes a circle which has its center at the point of its first contact with the disk. After passing around the full circumference of this circle, the catgut is attached to a hard rubber ring which is held in position against the tension of the catgut by a spring. The hard rubber ring is capable of moving around the disk under the tension of the catgut in a clockwise direction, while by virtue of the spring it tends to return to its original position by moving counter-clockwise. This hard rubber ring has fastened on the surface opposite to that on which it is connected with the catgut, a colored disk, such as has been described in connection with the color-mixing motor. A second color disk is fastened firmly in position against the hard rubber disk around which the hard rubber ring is capable of rotating. The two color disks are interlocked along radii in the manner illustrated in Fig. 25. We have thus provided two colored disks, one of which is capable of being changed in its position by means of the catgut, the other of which is independent of the catgut. If now the screw which controls the length of the catgut is turned back, the catgut will draw the adjustable ring in a clockwise direction and will change the relation of the two colored disks to each other. If the screw releases the catgut somewhat, the adjustable ring will be moved by its spring in a counterclockwise direction and will reverse the relation between the two colored disks. The disk and ring to which the colored papers are attached are mounted in bearings and are made to rotate by means of a belt connected with an electric motor. The movement of this disk and ring with the colored papers involves a rotation of the catgut also, but this was provided for in the swivel joint described above. This complex apparatus is hardly necessary for ordinary laboratory work.

B—RESULTS

The following table presents in number of degrees the results of the mixtures required in the exercise:

169° Red	+ 191° Green	= 111° Yellow	+ 210° Black	+ 39° White	
153° Red	+ 207° Gr. Blue	= 228° Black	+ 132° White		
205° Red	+ 155° Blue	= 358° Purple	+ 1° Black	+ 1° White	
96° Red	+ 162° Green	+ 102° Blue	= 253° Black	+ 107° White	
138° Yellow	+ 168° Blue	+ 54° Green	= 247° Black	+ 113° White	
71° Orange	+ 127° Blue	+ 162° Green	= 248° Black	+ 112° White	

These equations are valid, of course, only for the particular colored papers used and for the general illumination under which the conclusions were worked out. The papers used in this case were the older Hering tissue papers, and the illumination was that of a large general laboratory in which the light was admitted from large windows about three sides of the room.

A convenient graphic device for representing the results of mixtures from a group of observers is represented in Fig. 30. The areas at the left represent, in each case, the relative amounts of colors necessary to match combinations of gray with the intermediate colors represented on the right. The areas given were secured by averaging the results obtained from a class of fifteen students. By comparing the various figures for the successive combinations with each other, it will be seen that the general law of color mixing is clearly brought out.

It will sometimes occur in a laboratory class that some member will exhibit a form of color-blindness which will appear from the abnormal character of his equations. Tests for such color-blindness have been carefully prepared, and it is better to use one of the regular tests than merely to try rough experiments. A rough test may, indeed, be made by collecting a series of commercial wools of different dyes. These being placed together in an unassorted mass, the observer is requested to take out those which seem to him to match even remotely some vivid green or red. If he successfully passes the test for red and green it is probable that he is not color-blind. The use of names for the color-blind test is very misleading, for many persons who have a clear recognition of the different simple colors are unable to give the names of these colors, while, on the other hand, persons who have

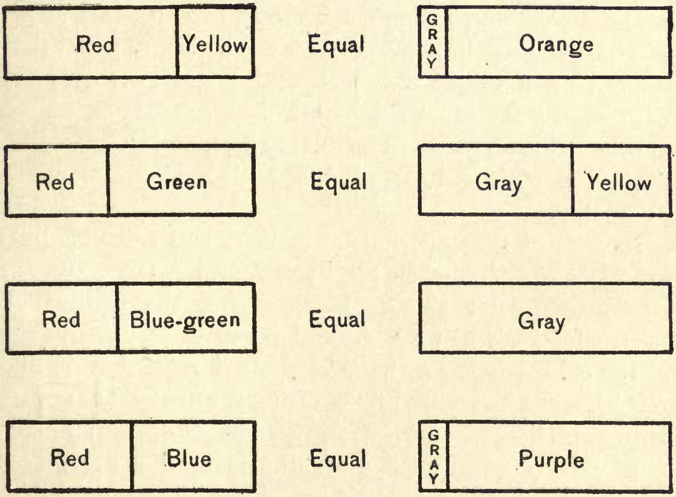


FIG. 30

some defect in color vision have learned enough of the relation between various color names and the experiences which they have derived from the different colored lights to stand a test even better than some normal individuals. The special tests are worked out by putting together a number of confusion colors which to the normal eye are clearly distinguishable, but to the abnormal eye seem alike. One of the best of these tests is that prepared by the physiologist, Nagel, who is himself color-blind. The cards may be had by addressing Professor Nagel, University of Berlin, Berlin, Germany, or will be supplied by the Yale Psychological Laboratory.

C—SUPPLEMENTARY EXPERIMENTS

The first supplementary experiment deals with the facts generally classified as light contrast and color contrast. To get a good illustration choose some complex color, such as a dark reddish brown. Place a small piece of paper thus colored on a bright red background and another piece with exactly the same color on a dark green background. On the red ground it will seem very dark and dull in color. On the green it will seem lighter and decidedly more red in quality.

In general the experiments in light and color contrast are most effective when the background is large and the contrasting color small. Furthermore, the contrast is most effective when the general intensity of illumination of the fields is not great. The desired reduction of illumination can be secured by covering the contrasted papers with thin tissue paper. Contrast effects appear, finally, most clearly when shades of little saturation are placed upon vivid backgrounds. One of the boxes in Milton-Bradley's Pseudoptics contains various gray and colored rings especially adapted to the demonstration of contrasts. Professor Witmer's *Analytic Psychology*, published by Ginn & Co. also exhibits contrasts in very striking forms.

A very good way of demonstrating contrasts is to set up a piece of colored glass so that the light from a window shall fall through it on a large white sheet of paper. Between the colored glass and the sheet of paper place some object which will cut off the light from the glass, thus leaving a part of the sheet of paper illuminated by the general diffuse light of the room. This uncolored area on the paper will seem by contrast with the general field in which it lies to be colored in the shade complementary to the background.

A very convenient method of demonstrating light contrasts is to prepare a disk such as is shown in Fig. 31, *A*. This disk, it will be seen, has around the center a complete circle of black. In successive rings toward the circumference of the disk the relative amount of black is reduced, but the relation of black and white in each ring is constant throughout the width of the ring. If such a disk as this

A B C

Fig. 31

is rotated by means of a color mixer, there will be produced about the center of the disk one black ring, and outside of this a series of gray rings differing from each other in intensity in such a way that each succeeding ring is somewhat lighter than that which lies nearer the center. The gray rings produced during rotation will not seem, as they are in reality, uniformly gray throughout their widths. That part of each ring which lies nearest to the inner, darker ring will seem relatively light, while that part of the ring which is nearer to the next outer ring will seem dark. These effects are due to contrast, for wherever a gray ring is in immediate contact with a light ring it will seem darker and, conversely, where it is in immediate contact with the darker ring it will seem lighter.

If a second disk is prepared, as shown in Fig. 31, *B*, with fine lines drawn between the successive rings, the contrast effect will be very much weakened if not indeed entirely destroyed. The lines of demarcation between the successive rings prevent the eye from traveling freely across from one ring to the other and consequently disturb the contrast.

Similar disks may be prepared to illustrate color contrast. Thus, as shown in Fig. 31, *C*, a disk may be prepared, the outer portion of which is blue, the inner portion of which is red. If now between these two large portions of the disk a middle ring be inserted which is made up of one-half of blue and one-half of red, there will be produced when rotation begins a central ring of purple. This central purple will seem very red on its outer circumference and very blue on its inner circumference, because at these two limiting circumferences contrast with the neighboring field is pronounced.

Reference was made a number of times in connection with the last exercise to the fact that the eye does not respond to colors in the same way after it has been for a time in the dark. It is true in general that all color mixtures and color contrasts are very much modified by a change in illumination. The general principle is that the reds and the closely related colors tend to disappear wherever there is a reduction in the illumination, before the blues and closely related colors. Consequently, if a mixture is made of red and blue and the general illumination is reduced, the mixture will show a stronger blue quality than it showed in the stronger intensity of light.

The third supplementary experiment requires that various cases of color experience shall be compared with each other. Such comparison can be made by matching each experience with a combination of standard disks placed in a constant illumination. Thus, if a red is to be compared with other reds, establish in each case an equation by matching the first red with a combination of standard disks and expressing the combination of disks in a formula. Then find the formula for the second red and so on.

The best method of demonstrating the difference between color mixture of the type which has been dealt with in this exercise and the type of mixture which is involved in combining pigments, is to prepare a disk which has been covered with a wash of pigments in the following manner: Let the outer portion of the disk be given a coat of blue over half of its surface. Let the other half of the outer portion of the disk be covered with yellow. Let the inner portion of the disk be painted with a mixture of the blue and yellow pigments. The result of mixing these two pigments is a vivid green. If the disk is now placed upon a color mixer and rotated, the central green portion will not be modified in any way by the fact that the disk is rotated. The outer portion of the disk will, on the other hand, show the regular complementary relation between blue and yellow; that is, it will show as a result of the mixture a decided gray.

After thus demonstrating the fundamental difference between pigment mixing and mixing by the method of successive stimulations, the nature of pigment mixing may be explained by the use of colored glasses, the results of such a test being exhibited in Fig. 32. Set up in a ray of sunlight a piece of blue glass. Examine with a prism, or, better, with a spectroscope, the light which passes through this blue glass. It will be found that the glass has deprived the white light of most of the red, orange, and yellow components which it originally contained. The blue, green, and violet components of the white light will be strong. It will thus he seen that the blue color of the glass is due to the fact that only a portion of the original white light is allowed to come through the glass. Similarly, it will be found on examining the light which comes through a yellow pane of glass that the orange, yellow, and green components of white light are strong. There is a great reduction in intensity of the reds, blues,

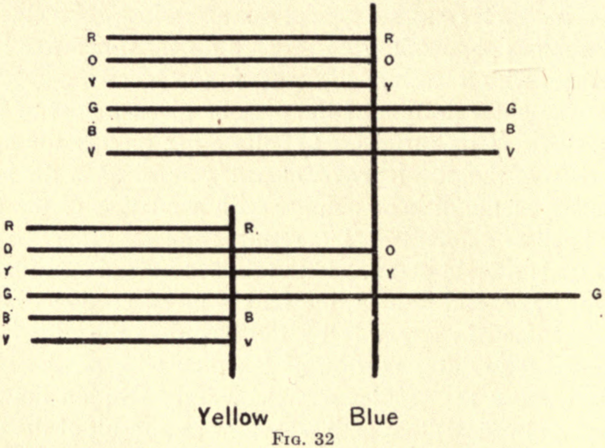


Fig. 32

and violets by the yellow glass. If, now, light which has been allowed to pass through the yellow glass passes afterwards through the blue glass, it will be obvious that only that color which passes easily through both glasses will survive the double process of absorption through the two glasses. The rays of light which thus pass through both kinds of glass are predominantly green in quality. Whatever other rays escape absorption are so completely submerged by the strong green rays that the light seems to be altogether green. This result agrees with the experiment of mixing yellow and blue pigments described above. Indeed, the blue and yellow pigment particles which were used in making the color washes may very properly be regarded as a series of small transparent particles of blue and yellow media, which deprive the light which passes through them of all rays except the green rays in the same way that yellow and blue glass would. The effect of these pigment particles is due to the fact that the light which falls upon the surface of the color wash is carried downward into the pigment particles for a certain distance and is then refracted back again after having been partially deprived of its rays. Combinations of pigments other than blue and yellow can be worked out in analogous fashion. It is to be noted in general, however, that most other pigments are not as transparent as the blue and yellow pigments. There is, therefore, in general a great reduction in the intensity of light whenever pigments are mixed with each other.

EXERCISE IV

A AND B—APPARATUS, PROCEDURE, AND RESULTS

Exercise IV requires very little apparatus. The head-rest which was described on page 32 may again be utilized in this exercise, or the simpler devices suggested in the same exercise will serve. The eye shield is described on page 31. The measuring rods can be conveniently held in clamps of the kind described in the general statement on page 9. In measuring distances on the rod it will be found convenient to have the experimenter move some bright object, like a strip of white card, along the rod until it seems to the observer to be in the right position to mark the boundary of the object which is being measured.

Drawing figures to scale is facilitated by the use of sheets of coördinate paper. This renders the reduction to any desired unit very easy. Thus, if the object is 24 cm. long and 12 cm. wide the successive measurements will be as follows:

At 3 M. . . .	18 cm.	long	by 9 cm.	wide
At 2 M. . . .	12 cm.	"	" 6 cm.	"
At 1 M. . . .	6 cm.	"	" 3 cm.	"

If now the scale chosen for the drawing on the coördinate paper is 1 mm. = 2 cm., the length and width of the object can be represented by two lines drawn one under the other, the first being 12 mm. long, the second being 6 mm. long. Perpendicular lines should then be drawn from the centers of each of these lines to represent the distance from the object to the eye. This distance will be represented in the figure as 20 cm. The form of the resulting figure is given in the author's *Psychology, General Introduction,* page 155.

The formula, which is easily derived from these results, is as follows:

$$\left.\begin{array}{l}\text{Any dimension}\\ \text{of the object}\end{array}\right\}\text{ is in the same ratio }\left\{\begin{array}{l}\text{to the corresponding dimen-}\\ \text{sion of its projection at a}\\ \text{nearer distance,}\end{array}\right.$$

$$\text{as}\left\{\begin{array}{l}\text{the distance of}\\ \text{the object from}\\ \text{the eye}\end{array}\right\}\text{ is to the }\left\{\begin{array}{l}\text{distance of the}\\ \text{projection from}\\ \text{the eye.}\end{array}\right.$$

The diagram and calculation can be directly related to the image on the retina by calculating how far back of the optical center of the lens the rays must be projected in order to reach the retina. In any given case the distance of the retina from the optical center can not be directly determined, but a general average of many eyes which have been measured justifies the general assumption that the diameter of the eye is 23 mm. and that the distance of the optical center from the front of the cornea is 7 mm. The full formula for the size of a retinal image is accordingly:

$$\begin{array}{l}\text{Dimen-}\\ \text{sion of}\\ \text{object}\end{array} : \begin{array}{l}\text{corresponding}\\ \text{dimension of}\\ \text{image}\end{array} :: \begin{array}{l}\text{distance of object}\\ \text{from front of}\\ \text{cornea} + 7\text{ mm.}\end{array} : 16\text{ mm.}$$

An excellent exercise for a class is to require the computation of the size of a house one hundred meters distant which seems just equal in height to one cm. held at a distance of 10 cm. from the eye. Also give the size of the retinal image of such a house. How large would the retinal image be if one moved away to twice the original distance?

Turning to the second part of the exercise, a well-defined after-image may be secured by cutting in a piece of black cardboard a cross with legs about ten centimeters in length and one centimeter in width. This cross should be held between the eye and the bright sky and the observer should look steadily at one point on the cross for a minute. If the cross can not be prepared, a gas jet or other bright object gives a very good image.

For comparisons of the apparent sizes of projections of the after-image, it will be found convenient to use a drawing-board on which has been tacked a sheet of paper marked off by heavy black lines into square decimeters. The drawing-board can be easily moved about from one position to others. If a drawing-board is not at hand, a similar drawing may be made on heavy cardboard.

The formula derived above will be found to hold for all of the distances to which the after-image is projected.

It may be found necessary, in order to bring out the after-image clearly as it is projected to the various positions, to wink the eyes rapidly.

The Aubert's diaphragm required for the third part of the exercise consists of two pieces of metal or wood each one of which has a right angle notch cut in one end, as indicated in Fig. 33, 1, 2 and 3, 4. 1, 2 may now be superimposed upon 3, 4 to any desired extent, and the result will always be a symmetrical diamond-shaped figure 1, 2, 3, 4. This Aubert's diaphragm should, for the purpose of the experiment, be mounted on a box. The box should be taken into a dark room and a light should be placed inside of the box. No other source of light should be present. Between the light and the Aubert's diaphragm should be a thick plate of milk glass which will thoroughly diffuse the light. The diaphragm will control the size of this diffusely lighted glass, which is the only object in the room visible to the observer. In addition to the preparations thus far described, the box should be mounted on runners so that it can be drawn backward and forward in the third dimension directly in front of the observer. Furthermore, a system of levers, represented in Fig. 33, should be attached to the parts of the diaphragm so as to permit a rapid adjustment of the diaphragm from both sides. Lifting the long handle *H*

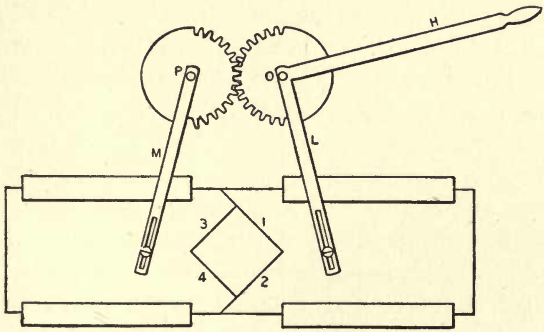


FIG. 33

produces a double effect. First, it throws the short arm *L*, which is rigidly fastened to *H*, outward away from the center of the diaphragm opening. The part of the diaphragm 1, 2 is drawn outward with *L*, for *L* is fastened to 1, 2 by means of a pin which fits into a slot in *L*. The second effect produced by lifting *H* is to rotate the small cog-wheel which is fastened at *O*, the center of movement in *H* and *L*. This cog-wheel in turn sets in motion a second similar wheel which has fastened to it the short lever *M*, at *P*. *M* is equal in length to *L* and is fastened by a pin and slot to 3, 4. By this means *M* is moved in a direction opposite to *L* whenever *H* is lifted, and 3, 4 moves in a direction opposite to 1, 2. When *H* is moved downward 1, 2 and 3, 4 are closed in on each other. The advantage of the whole system of levers is that the center of the opening always remains at the same point, and the effect, so far as the size of the retinal image produced by the area is concerned, is the same as the effect produced by moving the area in a direct line nearer to the eye or further away.

The result of this part of the experiment will be that the observer will make many mistakes, confusing change in distance with change in opening. The size of a retinal image will thus be shown to be complicated with interpretations of distance to such an extent that size and distance must be recognized as closely related forms of interpretation.

C—SUPPLEMENTARY EXPERIMENTS

The first supplementary experiment can be tried in a way to secure an accurate record, by taking a piece of cardboard about 10 cm. square and fixing on its under surface a pin. This pin should not be allowed to perforate the cardboard but should be fastened wholly on the under surface. A convenient method of accomplishing this is to pass the pin through a small piece of gummed paper. When the pin has been drawn through this paper as far as possible, leaving only the head on the gummed side of the paper, the whole may be fastened by the gum to the bottom of the pasteboard. The pin will thus be held firmly in position but will not be seen on the upper side of the pasteboard. The observer should now hold this pasteboard with the pin hanging down from its under side at the level of his open eye, the other eye being covered or closed. Let him now, by means of a lead pencil, indicate on the upper surface of the cardboard the point at which the pin seems to him to be located. A number of trials can be easily recorded in this fashion and it will be found that the distance of the pin from the eye is not accurately observed. After this let him make the same trials with both eyes open.

The reason why the threads required for the second supplementary experiment described in the *Laboratory Manual*, should be enclosed in a box is that it is important to exclude shadows and to cover up the fastening points of the threads. Any shadows which are allowed to fall upon the threads give an indication of the differences in position of the differently illuminated threads. Furthermore, unless some device is employed to prevent the observer from seeing the points at which the threads are fastened, he will be able to judge of the different distances of the threads from his eyes by means of the surfaces which lie between the different points of attachment. Let threads, preferably of different sizes and of different colors, be drawn vertically through a box which is 40 or 50 cm. cube. Let the upper and lower thirds of the opening of the box be covered with gray or black screens. The observer now looks through the middle third of the box and observes the threads which lie at different depths. He will be able to designate the different threads by their colors, and he will find, if he looks with only one eye, that it is almost impossible to give a correct judgment of their positions in the third dimension. Professor Jastrow has arranged a demonstration of analogous type by using cylinders of different degrees of curvature. A variety of blocks of wood were turned with different diameters, and these were placed in such a position that they were not covered with shadows as they would be in an ordinary environment. The light was thrown upon them from above. The result was that when they were viewed monocularly it was found to be very difficult to decide which one had the greatest degree of curvature.

The next supplementary experiment will give the following result. When the pin-hole is held very near to the eye it is inside the limit for near accommodation of the lens. The result is that the light coming through this pin-hole will not be focused upon the retina of the eye. It will come to a theoretical focus behind the retinal surface (Fig. 34, *F*). Since it is not focused upon the retina there will be an area of diffuse illumination on the retinal surface (Fig. 34, *RP*). The lower part of this diffuse area will

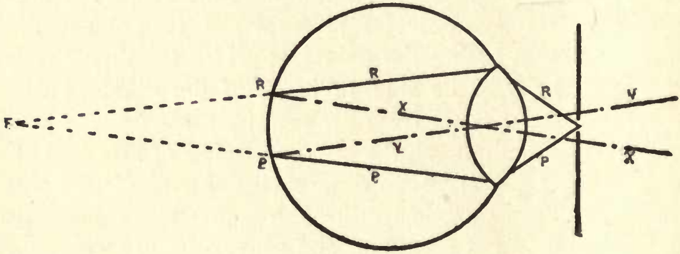


Fig. 34

derive its light directly from the lower part of the pinhole. If, now, a card is brought between the pin-hole and the eye and is gradually drawn upward from below so as to cut off part of the pin-hole, it will obviously cut off first those rays which come from the bottom of the pin-hole (Fig. 34, *PP*) and fall upon the lower part of the diffuse circle on the retina. It is a fact of general experience that all rays of light which affect the lower parts of a retinal image are under ordinary circumstances derived from the upper parts of objects. Put in other terms it may be said that the direction in which we refer all rays of light falling upon the retina is determined by a line drawn from any retinal point in question through the optical center of the lens (Fig. 34, *PVV*). Under the circumstances of this experiment to interpret the lower part of the retinal image as related to the upper part of the object is misleading, for the simple reason that the object has not been brought to a focus upon the retina as are the objects seen under ordinary conditions. Thus, as seen in Fig. 34, the light *PP* from the lower part of the pin-hole, and the light *RR* from the upper part of the pin-hole, come to the theoretical focus *F*, crossing the retina at the points *P* and *R*. The image will be interpreted according to the ordinary methods of interpreting retinal images as if *PP* came from the direction *VV* and will consequently be regarded as coming from the upper part of the figure, the ray of light affecting *R* being interpreted as though it came along the axis *XX*. A very convenient method of making this demonstration is to prepare a short tube about 4 cm. long, one end of which is entirely closed except for a small pin-hole. Directly in line with this pin-hole a small pin should pass through the wall of the tube in such a way that it can be pushed across the line of light coming through the pin-hole.

When the eye moves from a remote object to a point near at hand the observer will note that the apparent size of the remote object undergoes a change such that it seems to be somewhat smaller than when it was observed directly. If the new center of fixation is the finger or a pencil held near the face, a further experiment may be tried by keeping the eye fixed upon the pencil or finger as it is brought nearer and nearer to the eye. During this movement of the center of fixation toward the eye, the apparent size of the remote object will continue to grow noticeably smaller. An explanation which has sometimes been offered of these facts is that the finger or pencil as it moves toward the eye gives a larger and larger retinal image, whereas the remote object continues to give a retinal image of the same size as at first. Since the finger or pencil is the more clearly seen object it furnishes a standard of estimation, and since it is interpreted as constant in size in spite of the changes in the retinal image, the more remote object is by contrast interpreted as growing smaller. The fatal objection to this explanation is that exactly the same changes in apparent size in the remote object appear even when there is no movement of the near object. Merely looking from a remote object to a near point of fixation gives the result that the remote object seems to grow smaller. Indeed, the pencil or finger is merely a device for securing fixation upon a point near at hand. If the observer is capable through voluntary effort of fixating the eye on a series of points near at hand, he can, without the aid of a pencil or finger, secure all of the results described above. The contrast between the near object and the remote object can therefore not be the explanation of the facts observed. A more adequate explanation can be given by assuming that the center of near fixation is the point at which all objects in the field of vision seem to be located; that is, there is in monocular vision no clear discrimination of differences in depth. Consequently, when the eye fixates a near point, remote objects seem to be drawn up to this near point. Even if there is some suggestion of difference in depth because of shadows or other secondary characteristics, yet the remote object seems to be nearer to the point of fixation than it is in reality. Since the retinal image from the remote object is constant in size and since it seems to follow the movement of the near point of fixation, it will be interpreted as growing smaller and smaller as the near point of fixation approaches the eye. This experiment is very similar to the experiment described above, which dealt with the projection of the after-image, and the principle of interpretation is just the same.

The earliest experiments on monocular accommodation and its resulting sensations were tried by means of threads suspended in front of the observer. A uniform gray surface was spread out before the observer and he was allowed to look at this uniform surface through a shield which permitted only monocular vision. Across this monocular field was drawn a thread. The extremities of the thread passed out of the field of vision above and below. The thread was now moved backward and forward and the observer was required to state whenever he was able to distinguish its movement in depth and he was also required to state the direction of the movement. In some cases two threads were used, one being suddenly replaced by a second which was either nearer or further away than the first. This mode of experimentation obviated the necessity of pushing the single thread backward and forward, and it made possible more sudden changes in the position of the thread.

The difficulty with this whole method of experimentation is that the thread in spite of its small diameter is sufficiently large to give an appreciable retinal image. When now the thread is moved backward and forward, its retinal image changes in size according to the general laws of visual perspective. This change in size constitutes a secondary criterion which may be used by the observer in judging its relative position. It became evident in the course of experimentation that a method should be devised by which some sort of object should be presented in the field of vision that could be moved backward and forward without changing the size of its retinal image. Such an object can be produced if the line to be fixated is the boundary line between two areas in the field of vision. Since the boundary line is a geometrical line and has no width it will not change in width as it is moved backward and forward. If this line is made long enough so that it always extends through the whole field of vision in the vertical, it will obviously not change in apparent length. The method of producing such a line is as follows: Let a uniformly illuminated field be set up in a dark room. The illumination of this field may be either from shielded lamps which throw their light only upon the gray surface leaving other objects in the room dark, or by means of a plate of milk glass which is illuminated from behind. At a suitable distance in front of this illuminated field the observer is placed behind a screen through which he can look with only one eye. Such a screen as this should usually be provided with a tube through which the observer must look. The tube serves better than a single opening in the shield to limit the field of monocular vision so as to exclude all of the objects in the room except a portion of the uniformly lighted field. Half way across this circular monocular field of vision is projected a black screen with a sharp edge. This black screen should not be lighted at all on the side which is turned toward the observer. Since it cuts off one part of the observer's field of vision it leaves only a part of the former circular field visible, and gives a sharply defined line between the black field and the gray semicircular surface. If now this black shield is moved backward and forward, the boundary line between the black and light portions of the monocular field will constitute an object of invariable dimensions. The ability of the observer to recognize the position of this boundary line can be measured exactly, as in earlier experiments his ability to recognize the position of the thread was measured, by determining the distance through which the line must be moved in order that its change in position shall be recognized.

There is one criticism to be made of certain of the interpretations which have been given to the results of these experiments. It has sometimes been assumed that the covered eye is excluded as a source of sensation and that the experiment deals with purely monocular phenomena. The fact is that the closed eye exercises in many ways a large influence upon the open eye. Indeed, in certain individuals it has been shown that the kind and degree of influence exercised by the closed eye introduces very complex factors into the total situation. Thus, it has been shown that there is in some cases a tendency for the closed eye to relax somewhat in its muscular tensions and to take a position somewhat divergent from that which it would assume if it were open and fixating the same object as the uncovered eye. On the other hand, while there is some tendency toward divergence in the covered eye, there is unquestionably a tendency for this eye to fixate the same point as does the uncovered eye. All these tendencies of movement contribute sensory factors and also complicate the behavior of the open eye, as has been amply shown by photographic records of the eye's movement.

A great deal of experimentation was undertaken in the early years of experimental psychology to determine the *minimum visibile* or least recognizable distance between two points. The simplest method of making this determination was to draw two points or two parallel lines upon a sheet of paper and gradually move this paper further and further away from the observer. As the points were moved further and further away the retinal image of the intervening space gradually decreased in size until finally the two images seemed to flow together. The size of the image could now be computed by the formula given on page 65. By this method it was shown very clearly that the least perceptible distance between points or lines when seen in direct vision is very much less than the least perceptible distance between points or lines which are seen indirectly. The just perceptible distance is influenced in a measure by the amount of illumination. If the experiment is made by drawing black lines on a white sheet of paper and the white sheet of paper is relatively little illuminated, the lines will flow together much sooner than they will when the paper is brilliantly illuminated; that is, the intervening white space in such a case will be recognized much longer when it has a high light intensity than when it is very faint. It is probably true that if an intermediate area were illuminated with sufficiently great brilliancy it would never disappear between two bounding dark surfaces. Standard illumination is therefore quite as essential to the success of this experiment as any other condition.

The value of such experiments as these is very largely that they determine the acuity of the organ of sense. The importance of the results is that they throw light on the general problem of the differentiation of sensory surfaces. Since the tests are of value chiefly in determining the condition of the organ of sense they have been worked out in a much more practical form by those who are constantly called upon to use them for diagnostic purposes. The oculists have devised a number of methods for testing the acuity of vision. Charts made up of letters of different sizes are commonly utilized to test vision. These charts are placed in a given illumination and the observer is tested with reference to his ability to read the different sized letters. The greater the acuity of vision the smaller the letters which he will be able to recognize.

These visual charts have been modified sometimes in order to adapt them to use with illiterate persons. Instead of letters, lines drawn in such relation as to constitute the three sides of a rectangle are placed in various positions. Thus the open side of the rectangle is sometimes placed above, sometimes below, sometimes at the right, and sometimes at the left. The observer is required to indicate which side of the figure is open. These figures are printed in various sizes upon the chart, and the acuity of vision is tested by the observer's ability to recognize correctly the figures at standard average distances.

EXERCISE V

A AND B—APPARATUS, PROCEDURE, AND RESULTS

The student after observing double images, as directed in the *Laboratory Manual*, should represent the relations involved by means of a diagram.

Fig. 35 represents the relation between the two eyes and the two objects *N* and *R*, which are located at different distances in depth from the observer. Rays of light from *N* passing through the optical centers of the lenses of the

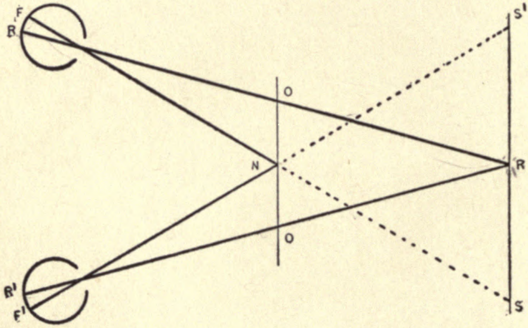


FIG. 35

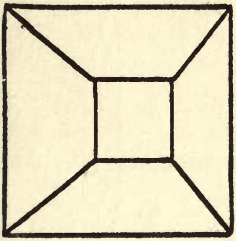
two eyes pass to the points *F* and *F'*, which represent the two foveas in the two eyes. The fact that the images from *N* fall on the foveas indicates that the two eyes are fixating this near point. The rays of light from the remote point *R* will also pass through the optical centers of the lenses and will fall upon the two retinas at the points *R* and *R'*. It will be noted that *R* and *R'* are both on the nasal sides of the retinas. Any point other than the point of fixation, if at the same depth, casts its image on the retinas of the two eyes in such positions that in one eye the image will fall on the temporal side of the fovea and in the other eye on the nasal side of the fovea. The condition which is represented in Fig. 35 is therefore one in which fusion of the two images can not follow as it would under ordinary conditions of observation of plane surfaces. The two retinal images *R* and *R′*, falling both on the nasal sides of the two retinas, do not fuse. The observer will consequently see these two images as separate. Some observers have difficulty in recognizing such double images. This is due to the fact that objects not in the center of the field of vision are vague because they are not clearly focused, and they are consequently for the most part neglected. Furthermore, there are a great many observers who habitually neglect to a greater or less degree one of their retinal images. If the double images *R* and *R′* are recognized as separate by the observer, it will be further noted that the image for the left eye appears to lie on the left side of the point of fixation. This can be clearly demonstrated by closing or covering the left eye. Correspondingly, the image for the right eye will seem to lie on the right side of the center of fixation. Under these conditions the double images are called uncrossed double images.

If the same diagram is used to represent the reversed condition where the eyes are fixated upon the more remote object *R*, the points *R* and *R′* must be treated as the two foveas. *F* and *F′* will therefore represent two points on the temporal sides of the retinas. These images will be seen as double and will seem to lie on sides of the center of fixation exactly opposite from the eyes to which they belong; that is, the image for the right eye will seem to lie on the left side of the center of fixation and the image for the left eye will seem to lie on the right. These double images are known as crossed double images.

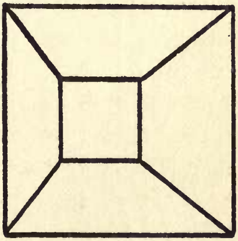
The clearest explanation of the apparent position of these double images is that the objects not at the center of fixation are attracted toward the center of fixation, as indicated in an earlier exercise, page 72. The points where the lines of light from the objects cross the plane of the point of fixation will accordingly determine the apparent position of the double images in space. In Fig. 35 the planes are represented by two lines OO' and SS'. If the center of fixation is the near point, the lines of light from the more remote object cross the nearer plane at the points O and O'. If the center of fixation is the more remote object, the lines of light from the near points must be projected, as indicated in the dotted lines, to the remote plane, which they will intersect at the points S and S'. Double images are essentially monocular phenomena. They appear in the binocular field but they are due to an absence of fusion of the images. They can be studied with reference to their characteristics, and it will be found in general that they do not give data necessary for localization in depth.

A very good introduction to the second part of Exercise V is to require the student to indicate by means of a diagram the form and position of the images on the retinas of the two eyes from a solid object. (See *Psychology, Gen. Intr.*, page 159, Fig. 48.) The student should also draw a similar figure indicating the character of the retinal images derived from a hollow object.

Any solid object will serve to show the difference between the images of the right and left eyes. It is desirable, however, that the object observed be small enough and simple enough so that the student can draw it for the later parts of the experiments, hence the suggestion of a truncated pyramid. Small blocks of wood should be sawn out with a square base of 5 cm. on each side. The pyramid should be from 4 to 6 cm. in height and the small truncated surface at the top of these models should be 2 cm. on each side. The figure will be much more easily used for the purposes of making drawings if the surfaces of the block are painted black and the edges are marked with a fine white line. The observer should now set this model on a piece of paper and should close one eye and examine the model with the single open eye. He should indicate by points on the paper, first the dimensions of



A



B

FIG. 36

the base, and then the apparent position of the edges of the small upper surface when this is projected to the plane of the paper. Without changing the position of his head, let him now open the eye which a moment before was closed and close the eye which was open. Again, let him plot the dimensions of his figure on the paper, noting especially the change in the apparent position of the projection of the upper square. He should now draw the figure in full with a result similar to that shown in Fig. 36, where *A* is the image for the left eye, *B* the image for the right eye.

The next step of the experiment consists in preparing the apparatus for the fusion of these two figures. The apparatus in its simplest form is a mirror stereoscope. Let two boards be set up as indicated in Fig. 37, 1 and 2. These boards are held most firmly in position by means of a common base *BB*. On the base *BB* should be set up two mirrors placed at angles of 45° with reference to 1 and 2, and at an angle of 90° with respect to each other. Rays of light from board 1 will now be reflected forward from the mirror 3, while rays of light from board 2 will be reflected by the mirror 4. If the two eyes of the observer

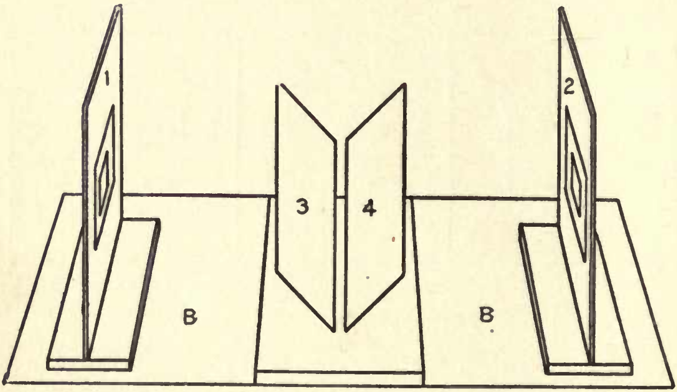


Fig. 37

are placed so as to look into mirrors 3 and 4, the observer will see the rays of light, which in reality come from the boards 1 and 2, as if they came from some point in space behind the mirrors. If, now, instead of plain boards 1 and 2, the figures drawn from the truncated pyramid are placed in proper position on these boards, the observer will see the images as if they came from a single object behind the mirrors and will fuse them into a single figure in space. Fig. 38 shows the fusion in diagrammatic outline.

A stereoscope of this form can be set up without any special construction of new parts if the laboratory is supplied with a sufficient variety and number of clamps and rods.

The mirror stereoscope suffers from certain defects which interfere somewhat with its use. In the first place, any ordinary mirror has three reflections from its surfaces. One reflection comes from the upper surface of the glass, a second from the lower surface, and a third from the silver surface. The latter two images are so near each other that

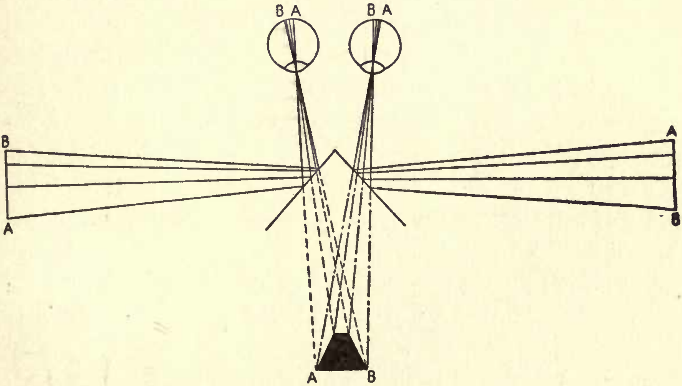


Fig. 38

they do not interfere noticeably with the experiment. The image from the outer surface of the glass, however, will disturb the ordinary observer very decidedly. There is no easy method of obviating this difficulty. A method which may be adopted consists in securing highly polished metal surfaces and using these for mirrors. Such metallic mirrors are, however, likely to tarnish, and it is difficult to keep them ready for use. A better expedient, if one is conveniently near a mirror-manufacturing establishment, is to secure small mirrors before the silver surface used on the back of the glass has been covered with paint, as it is in the finished mirror. The silver surface which is intended for use through the glass may be used in such unfinished mirrors on the side turned away from the glass, provided the mirror is carefully handled. From this unfinished surface only one reflection will be received. Such a mirror tarnishes very soon and can not be renewed without destroying the silver surface altogether. A new mirror, must, therefore, be provided for each series of experiments. A second limitation of the mirror stereoscope consists in the fact that it neglects a natural habit of adjustment which appears in all observers. In general it is true that the lenses in the two eyes are habitually adjusted in focus to the point of fixation; that is, if the two eyes are converged upon a point one meter distant from the eyes, the lenses will be so accommodated as to focus light which comes from the distance of one meter. This type of adjustment very often does not suit the conditions presented by the mirror stereoscope. Thus, if the center upon which the eyes are converged in looking at the stereoscopic object lies at a certain distance back of the two mirrors, the lenses may very frequently be called upon to focus light which comes from a distance very different from that of the point of convergence, because the light which enters the eye originates from the figures tacked to the boards of the stereoscope rather than from the point of fixation. The only condition under which the natural adjustments are the proper adjustments, are those under which the center upon which the two eyes are converged is at exactly the same distance from the eyes as the figures from which the images on the two retinas are derived. In order that this particular case may be attained, it is desirable that the simple form of stereoscope described above be elaborated so as to make the distance of the images from the two eyes variable. This can be done either by making the boards 1 and 2 (Fig. 37) adjustable in their distance from the mirrors or by making the angle between the two mirrors adjustable. An adjustment of the two boards 1 and 2 can be provided for by mounting these boards on wooden blocks, which in turn fit into runners placed along the base of the stereoscope, *BB*.

The mirrors 3 and 4 may also be mounted upon separate standards so as to be adjustable in their angle with reference to each other. In an even more elaborate form of apparatus, the base *BB* is divided into halves and so mounted that each half can be rotated about a single point between the two mirrors. In this way the angle of the mirrors with reference to each other can be changed without disturbing the relative angular positions of drawings 1 and 2 with reference to their respective mirrors. Experiments may in this way be made on movements of convergence without disturbing the other relations involved, especially those between the figures tacked to 1 and 2 and the mirrors which reflect their images.

The mirror stereoscope may be made in almost any desired dimensions. A very convenient size is one in which the base *BB* is 1 meter long and 25 cm. wide. The mirrors in such an apparatus should be 5 cm. square. Smaller stereoscopes may be made to give excellent results. The figures must, however, in such cases be made much smaller, and the student can not deal as easily with models in preparing the figures to be fused.

If the two drawings represented in Fig. 36 are fused in the stereoscope, the result will be that the observer will see a single solid truncated pyramid all sides of which are symmetrical. If, now, the wide side of one of the figures is covered, the fused figure of the pyramid will change somewhat in its character. It will no longer seem to be a symmetrical figure, nor will the side which is now seen monocularly be solid as in the original fused figure. There will be a continuous outline of the pyramid on the side for which one figure is covered, but this side will seem flat, and since it is the wide side of one of the drawings which was covered the figure seen will seem narrow. Conversely, if the narrow side of the figure is covered, the corresponding part of the pyramid will seem flat and wide. The fact that the monocularly seen parts of the pyramid are respectively too narrow and too wide shows that the binocularly seen figure has a width which is a compromise between the width of the two monocular figures. When both the wide and narrow sides are present, they give through fusion a compromise width, and they also yield the characteristic of solidity which was not present in either of the monocular elements which entered into the total figure. These observations give the clearest evidence that the fusion process is one in which all of the sensory factors receive due recognition, the resultant characteristics of the binocular figure depending upon compromises and fusions of the monocular elements.

Two figures with no lines in common can easily be prepared for the last part of this exercise by drawing on one card a series of vertical lines and on the other a series of horizontal lines. When the effort is made to fuse these two groups of lines the observer will see first one set of lines and then the other. In some cases the lines will not appear and disappear as a single group, but there will be a small area at which the vertical lines will appear in the midst of a horizontal field, and this area of vertical lines will gradually spread until the horizontals are for the most part submerged. Other figures can be prepared by using lines which extend in various directions. Surfaces of different colors may also be used to show the lack of complete fusion between entirely different kinds of fields.

C—SUPPLEMENTARY EXPERIMENTS

The stroboscope is an apparatus by means of which there is exposed to the eye of the observer a rapid succession of figures. These figures represent the successive stages of some activity, such for example as the flight of a bird or the movements of an animal or human being in walking or running. The essential condition for successful fusion of such a series of figures is that the eye shall see one image for an instant and shall then be supplied with an entirely different image, the first being covered so as to avoid any blurring or fusion of the two successive images. The stroboscope is usually made in the form of a cylindrical case in which a succession of vertical slits are cut. (For a simple hand stroboscope see Fig. 39.) Back of each of these slits is introduced a single figure. When now the eye looks through one of these slits it sees the single figure which lies behind it. As the cylinder is rotated this image is cut off after being seen by the observer, and as a new slit comes before the eye a second image is exposed to view, and so on.

FIG. 39
From the catalogue of M. Kohl, Chemnitz, Germany

A recent observer has described a very interesting experiment, in which by means of the stroboscope the successive views of a solid object, which would be seen by looking at the object with a single eye first on the right side, then from directly in front and finally from the left side, are fused when viewed successively in the stroboscope in such a way as to give the appearance of solidity. There can be no doubt that a person who has only one eye derives from his head-movements a series of images from solid objects which he uses for the recognition of solidity in a way very similar to that in which the normal individual uses binocular differences.

An elaborate apparatus which is in principle the same as the stroboscope is familiar to all who have seen the moving pictures or kinetoscope pictures which are commonly used to reproduce series of movements. The kinetoscope uses a series of photographs which correspond to the different stages of the movement to be represented and projects these photographs in rapid succession upon the same point on the screen.

When, as suggested in the second supplementary experiment, the angle between the two mirrors is changed, the center of convergence for the two eyes will move inward or outward—inward if the angle of the mirrors with respect to each other is decreased, and outward whenever the angle is increased. The angles through which the mirrors may be rotated are small. If these angles are made too large, fusion of the two images ceases and double images appear. With every change in the degree of convergence there will come a distinct perception of change in position of the object. There will also result a perception of change in size such that the object will seem to grow smaller if the angle of the mirrors is decreased and the point of fixation is made to approach the observer, while the object will seem to grow larger if the angle between the mirrors increases and the point of fixation recedes. If the changes here under discussion are extreme, double images will result, as indicated above.

Certain of the effects produced by changing the angles of the mirrors can be paralleled by simple experiments with natural objects when these are viewed in adjustable mirrors. Let two mirrors be held in exactly the same plane as shown in the full drawn lines *A*, *B*, in Fig. 40, and let some object *O* be observed at O^1 as it is reflected in these

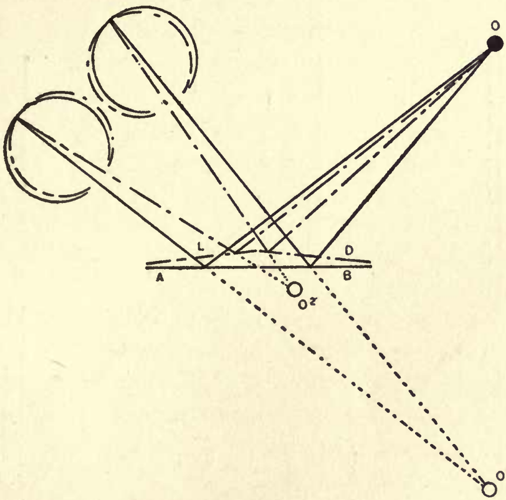


FIG. 40

two mirrors. The apparent distance of the object from the observer will be equal to the total distance through which the light has traveled from the object to the eye; that is, it will seem to be as far behind the mirrors as the object is in reality in front of the mirrors. If, now, the two mirrors are so arranged, as indicated at *A* and *B* in Fig. 40, that the reflected rays which enter the right eye come from the right-hand mirror, while the reflected rays entering the left eye come from the left-hand mirror, the angle of convergence can be modified without modifying the actual distance through which the light travels. This can be done by changing slightly the angle between the two mirrors, as indicated by the broken lines *L* and *D* in Fig. 40. Since the lines of convergence are changed by this inclination of the mirrors, the point of fixation will also seem to change, coming to the point O^2, and there

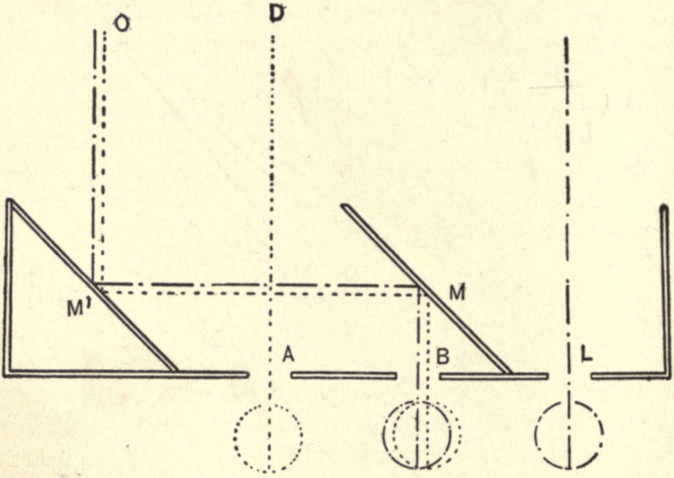


Fig. 41

will result an apparent modification in the position and size of the object. The apparent change in position will follow the rule that whenever the angle between the two mirrors on the side of the observer is greater than 180°, the object will seem to approach and at the same time to grow smaller. Whenever the angle on the side of the observer is less than 180°, the object will seem to recede and grow larger. Only very small changes in the angle can be made without producing double images. The angle shown in the figure is much exaggerated.

The third supplementary experiment requires the use of the pseudoscope. The simplest form of pseudoscope is one which was devised by Prof. George M. Stratton. It consists of a box, as represented in Fig. 41, which is supplied with three openings at *A*, *B*, and *L*. The distance between *A* and *B* and between *B* and *L* should be about the ordinary distance between the two eyes of an observer; namely, between 5 and 7 cm. In order to make the box useful for a great number of observers, the holes at *A*, *B*, and *L* should be made in the form of ellipses about 1 cm. in the transverse axis and 2 cm. in the axis lying in the line of the three holes. In front of the hole *B* should be mounted a mirror, as indicated at *M*, at an angle of 45° from the back of the box. A second mirror should be mounted at M′ in the corner of the box parallel to the mirror *M*. If now the two eyes of the observer are brought into position before the openings *A* and *B*, obviously the left eye looking through *A* will see any object at the point *D* directly in front of the opening. The right eye, looking through *B*, will not receive light directly from the object *O*, but will receive its light only after it has been reflected from the mirror *M′* into the mirror *M* and then through the opening *B*. (For convenience in drawing, the rays of light from the object *O* and *D* to the two eyes are represented as parallel, that is, as coming from a very remote object.) The effect of this double reflection is to throw into the right eye the image that would be received by the eye placed in the position of the mirror marked *M′*. The right eye, therefore, gets its image from a position at the left of the left eye and the relation between the two eyes is thus reversed; for the right eye gets its image from what is relatively the left-hand side of the object, and the left eye gets its image from what is relatively the right-hand side of the object. The result of such an interchange of the images in the two eyes will be that solid objects will appear hollow and more remote objects will appear near at hand. It will be very difficult for the observer trained in the ordinary observation of solid objects to get the interpretation of the hollowness from familiar objects. It will be easier to get the interpretation of changes in relative position, near objects appearing far away and remote objects near. The observation can be facilitated by using objects which are very little shaded, and by asking the observer to wink his eyes during the observation. This winking of the eyes makes the adjustment between the two eyes relatively easier.

The pseudoscope described thus far may be transformed into a telestereoscope by using the two openings *B* and *L* instead of the openings *A* and *B*. The right eye, which in this case is looking through the opening *B*, will get its image not from directly in front, but from the position *M'*. The distance between the two eyes will then be exaggerated by the double reflection through the mirrors, and the object will be seen under a greater parallax than when the two eyes are observing it in their ordinary positions.

There are a variety of forms of stereoscopes and pseudoscopes; perhaps the best known of the former is the lens stereoscope popularly known as a toy. The lens stereoscope is somewhat more complex in principle than the mirror stereoscope and for this reason is not as good for laboratory work. It can be used, however, and figures on a reduced scale can be prepared as required in the exercise. The lenses in such a stereoscope serve two distinct functions. From their shape and position they act first as prisms and deflect the rays. Secondly, in their capacity as lenses they assist the eye to focus the light from the figures. In order to make clear these two functions, Fig. 42 shows in full drawn lines two prisms in the positions occupied in the ordinary lens stereoscope by the lenses. It will be

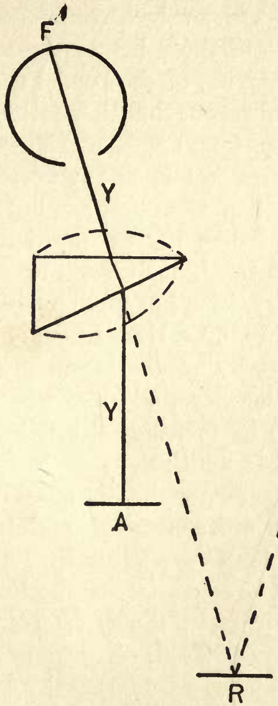


FIG. 42

noticed that the two faces of the prisms turned towards the two eyes are in the same plane. The surfaces of the prism more remote from the eyes are oblique. Rays of light from *A* and *B*, which represent the figures, will be deflected in passing through the prisms, as indicated in

XXF and *YYF′*. The two eyes receiving the rays *XXF* and *YYF′* will be converged, and the observer will interpret the two rays as if they came from the single point *R* behind the true figures. If the figures *A* and *B* are of suitable character they will fuse and the observer will see a single solid object at *R*. Obviously a conflict similar to that described in the case of the mirror stereoscope will arise between the reflex tendency of the lens of the eyes to focus upon *R* and the requirement that they focus the light from *A* and *B*. In this stereoscope the conflict is not overcome by the effort of the observer, but by placing lenses in the position of the prisms. The lenses are placed in the position indicated by dotted lines in Fig. 42. Here they serve all the purposes of deflecting prisms and, furthermore, aid the lenses of the eyes in focusing the light from *A* and *B*, which light comes from a position nearer than *R*, upon which the eyes are converged and for which the lenses are naturally focused.

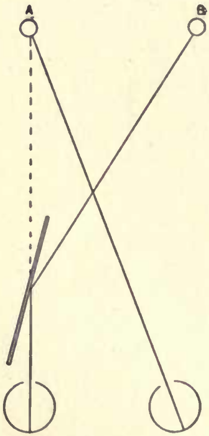
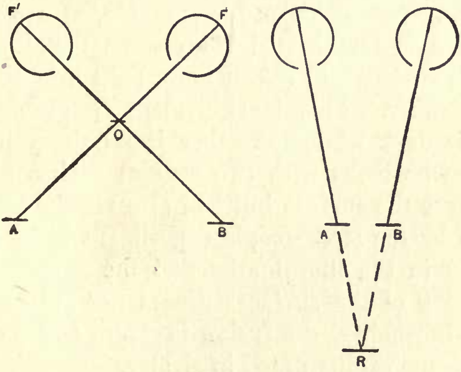


Fig. 43

A great variety of figures suitable for use with the lens stereoscope can be purchased of any one of the stereoscope supply companies. Underwood & Underwood of New York City, 19th Street and Fifth Avenue, have a collection of sterograms which cover most of the important phenomena of binocular vision.

Another form of stereoscope is illustrated in Fig. 43.

With some training an observer may accustom himself to the fusion of figures of the kind usually used in stereoscopes without the aid of any apparatus whatsoever. If, for example, the image appropriate to the right eye is drawn on a card and the image for the left eye is drawn on a second card, and these two cards are placed in the positions *A* and *B*, Fig. 44, *A*, and the two eyes are voluntarily crossed so that the axes of vision are along the lines *AF* and *BF′*, there will be seen at *O* a single solid object which results from the fusion of the two images derived from *A* and *B*. If the two cards *A* and *B* are appropriate in form and nearer than the two eyes, fusion may take place as indicated in Fig. 44, *B*. The fused image will



A FIG. 44 *B*

in this case appear at *R*. Such fusion requires practice in order to dissociate convergence and accommodation, for obviously in both cases the lenses of the eyes must focus light coming from a point other than the point of fixation.

The whole matter of retinal rivalry is a fruitful field for investigation. There are undoubtedly great individual differences in observers in the ability to fuse different colors, and the strain which is produced by the effort to fixate two objects undoubtedly influences the rate of rivalry. Dr. Breese in his paper "On Inhibition," Monograph Supplement of the *Psychological Review*, No. 11, reports a number of experiments on retinal rivalry in which he has shown that the movements of the eyes are important elements in determining the degree of fusion of two rival fields. There is one special case of partial fusion which properly belongs under the general head of retinal rivalry. If two fields which are otherwise suitable for fusion are different from each other in that one is black and the other white, there will be a unique type of fusion resulting in metallic luster. This metallic luster corresponds directly to what is seen in ordinary experience under similar conditions. If one looks, for example, at a metallic surface which is illuminated from some definite source of light, this surface will reflect more light into one eye than into the other. This is equivalent to saying that one surface is dark while the other is relatively light. The observer who looks with two eyes at such a surface will not only see the surface but will also see the luster, which is shown by the stereoscopic experiment to be due to the inequality in the illuminations of the surfaces. If now the coloring of the surfaces differs not only in intensity but also in quality, the fusion becomes still more incomplete with the results noted in rivalry.

Methods of recording the rate of rivalry will be described in connection with Exercise XXII. These methods involve certain recording apparatus which will be in constant use in the second part of the course, but is not needed in general in this part.

The exact point upon which the two eyes are converged when two images are fused by means of a stereoscope is impossible to define from direct introspection. It can be determined by finding out the positions of the lines of regard. The method of procedure, if one is using a mirror stereoscope, is to find on the two mirrors the points from which the rays enter the two eyes from what seems to be in the fused image a single point. This can be done by moving a lead pencil successively across the two mirrors until its point seems to coincide with the point chosen. The distance between the two points on the two mirrors should now be measured; the distance between the two eyes should be measured, and the distance between the eyes and the mirrors. If the distance between the two eyes is regarded as the base of a triangle at whose vertex the point of fixation lies, the distance of this point of fixation can readily be plotted by recognizing that the distance between the two points on the mirrors is the base of a second similar triangle which also has as its vertex the point of fixation. The distance between the two bases of the two similar triangles is the known distance between the eyes and the mirrors. The whole matter can be plotted as shown in Fig. 38 (page 83). When the lens stereoscope is used instead of the mirror stereoscope, it is somewhat more difficult to determine the point of fixation, because the lenses are so near to the eyes. In this case some object should be interposed between the lens of the stereoscope and the eye. The two points on the surfaces of the lenses near the eyes can now be ascertained which correspond to a single fused part of the object. Further procedure is similar to that followed in the case of the mirror stereoscope.

EXERCISE VI

A—APPARATUS AND PROCEDURE

The head must be held in a fixed position in this experiment. To this end the head-rest described on page 32 may be used, or rods may be clamped to the chair in which the observer sits. In either case the space back of the head and around the ears must be left free.

Any means of producing an easily controlled sound of small intensity will serve the purpose of this exercise, though telephones are so much better than any other form of sounder that they are explicitly referred to in the text. There is a child's toy known as a snapper, or sometimes called a telegraph sounder, which is very convenient. This toy can be made to produce a sharp single click by pressing upon a spring. The noise produced by this snapper is especially advantageous for this experiment, because it is simple in quality and is very little modified by the position of the snapper in front of the ear or behind it.

The greater convenience of telephones as sources of the sounds consists in the fact that telephones can be easily controlled in their positions and the sound can be produced in two or more telephones at exactly the same instant. In the parts of the experiment which require more than one sound at the same time, the use of two snappers is difficult, because the experimenter must depend upon his own ability to produce the sounds at exactly the same instant. Two or more telephones can be utilized by passing the same electric current through them. When this electric current is made or broken both telephones will act in exact harmony. The watch case telephones, so called, are better than the larger receivers for the purposes of this experiment. They are smaller and can therefore be better held in position. As many of these telephones as are necessary for the experiment should be put in circuit with one of the batteries referred to in the general introduction as yielding about one ampere of current. In the circuit should also be placed a mercury switch; this can be used in making and breaking the circuit and does not interfere with the experiment by itself producing a click. The simple method of using the make-and-break current to sound the telephones has one disadvantage. Unless the telephones are tuned exactly to the same pitch, it is sometimes possible to distinguish them because of their difference in quality. This difficulty can be overcome by putting into the circuit a simple interrupter. When the interrupted current is allowed to pass through the telephones, the result will be a series of vibrations of the telephone diaphragm rather than a single click. Minute differences in the pitch of the telephone diaphragm will then be entirely overcome, and the sound will be somewhat clearer and easier to locate than with the single clicks.

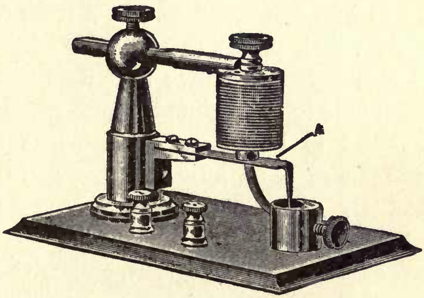


Fig. 45
From the catalogue of C. H. Stoelting Co., Chicago

The principle of the interrupter is one which is used in a great many pieces of apparatus employed in the laboratory, and it may be described at this point in some detail. The rod *A*, Fig. 45, is held firmly in position by the heavy post shown at the left of the figure. The rod carries at its right end a long platinum needle which extends downward into a mercury cup. From the mercury cup a wire extends to the electromagnet which is held above the rod *A*. The electromagnet is insulated from the rest of the apparatus and is connected at the end of its coil opposite to that at which it is connected with the mercury cup, with the battery. The other pole of the battery is connected with the rod *A* through the metallic post. As soon as the platinum needle is pushed downward so as to dip into the mercury cup a complete electric circuit is made which passes through the magnet. As soon as the magnet becomes active it pulls the rod *A* upward and thus tends to draw the platinum needle out of the mercury cup and to break the circuit. As soon as this is done the magnet is no longer active, and the rod *A* by its own elasticity oscillates back again so as to make a contact between the mercury cup and the platinum needle. This renews the electric current, causes the magnet to pull the bar *A* up again, breaks the circuit, and the whole operation is again repeated. The rate at which the electric current will be interrupted depends upon the rate at which the rod *A* oscillates. In some other forms of interrupters the contact here provided by the mercury cup and platinum needle is made by means of an elastic platinum wire and a fixed metallic plate. The use of platinum in all of these contrivances is necessary because there is an electric spark each time the current is broken, and this spark would very soon burn any other metal. Furthermore, in the mercury contact it is desirable that the mercury surface be covered by a drop of alcohol or water which will take up the fumes from the burning mercury.

Contrivances for holding the telephones in position may be made as elaborate as desired. The most convenient method of fastening the telephones and measuring their positions is to prepare an auditory cage. In its simplest form this cage may be made of wooden hoops. A somewhat more elaborate form of auditory cage is represented in Fig. 46. The simpler form made of wooden hoops is constructed on the same principle and will be

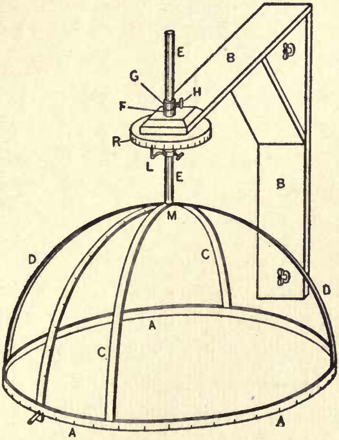


Fig. 46

readily understood from the following description of the more elaborate form. A circular metallic ring *AAA* is supported by similar metallic semicircles *CC* and *DD*. These semicircles cross each other and are fastened firmly at a point *M* just over the middle of the circle *AAA*. From this point *M* a bar is carried upward, as shown at *EE*. This can be held at any point that may be convenient. In the figure, *EE* passes through the tube *F* which is held in the bracket *BB*. *EE* is held in position by the collar *G* which is clamped to it by means of a set screw *H*. If the collar *G* is loosened the shaft *EE* may be adjusted so as to bring the cage to a higher or lower point to suit a given observer. The whole cage may be rotated within the carrier *F*, so that any point on the circle *AAA* may be brought into any desired horizontal position. A circular disk *R* is clamped on the outside of the carrier *F* by means of a screw. This disk has graduations marked upon it to indicate degrees, and a pointer is brought up from the shaft *EE*, as indicated at *L*, so that the position of the pointer and therefore of the whole cage can be read on the circular disk *R*.

The telephones are now fastened on the frame *AAA*, or on the side pieces *C* or *D*, and the cage can be rotated as the experimenter desires. A convenient method of fastening the telephones to the frame is represented in Fig. 47. *C* represents a section of the frame. The bent metal plate *A* hooks over the top of the frame. Below there is a screw *S*, which controls an adjustable tooth *H*. When *H* is screwed against *A*, the whole is firmly clamped to *C*. When, on the other hand, *S* is loosened, *H* falls down and permits *A* to be carried to any part of the frame desired. *A* is riveted to the back of a telephone which is by this means easily clamped to any part of the cage.

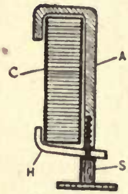


Fig. 47

A simpler form of holder can be devised by using a piece of spring brass which can be bent into a clip and slipped over the frame.

Another attachment necessary for the first part of the experiment is a rod which can be fastened to the cage in a horizontal position. Along this rod slides a carriage to which a telephone may be clamped.

The various parts of the frame of the cage should be graduated in degrees and the rod should be graduated in centimeters.

The whole cage can be supported in various ways. It is desirable to support it at a distance from any large surface which could serve to give an echo of the sounds. The best device for supporting any cage is a high stand made of a heavy base and a piece of iron pipe, such as is used for steam or water connections. For ordinary purposes of class work, it is possible to fasten the cage to a bracket extending from a wall of the room. The experiment will be somewhat interfered with by the echo from the wall, but if the sounds are not too intense the disadvantages of this method will be reduced to a minimum.

Any form of cage which offers large reflecting surfaces of wood or metal is objectionable; the metal strips used for the cage should, therefore, be as narrow as practicable. The fact that the experimenter must stand near the cage is also an objection to the device thus far described. This difficulty can be overcome by more elaborate devices for adjusting the cage by means of strings carried to a distance from the cage.

A very elaborate auditory cage is described by Professor Seashore in the *Psychological Review*, Vol. X, pp. 64–68, and in Monograph Supplement of the *Psychological Review*, No. 28, pp. 1–5.

B—RESULTS

The following series of observations was reported for the first part of the experiment, when one telephone was kept in a fixed position 50 cm. from the left ear in the same horizontal plane as the ear and in a line passing through the two ears, and the other telephone was moved in the same line through various distances from the right ear.

Distance of second telephone from right ear in cms.	Apparent position	Apparent distance from head
10	Right, about 5° to rear	Near head, 10 cm. distant
20	Right, about 20° to rear	Further away, perhaps 20 cm.
30	Right, about 50° to rear	Still further, 30–40 cm.
40	Rear, about 10° to right	Still further, 40–50 cm.
50	Rear, perhaps 5° to right	Still further, 50 cm.
60	Rear, about 10° to left	50 cm. distant
70	Rear, about 25° to left	Same as last
80	Left, about 45° to rear	Same as last
90	Left, about 30° to rear	Same as last
100	Left, about 20° to rear	Same as last

In the second part of the exercise the distances through which the telephones must be moved were found by various observers as follows:

	Starting in median plane in front or behind and moving to right or left		Starting opposite one ear and moving forward or backward	
Observer	Avg.	M. V.		M. V.
A	3°	0.4	Avg. 25°	4.3
B	5°	0.3	15°–20°	
C	6°	0.7	30°–40°	
D	8°	0.6	Avg. 40°	6.0

C—SUPPLEMENTARY EXPERIMENTS

If complex tones are used it will be found that there is much more complete discrimination of positions in front of the head and behind. This is probably due to the fact that the pinna in reflecting the sound into the ears modifies the sound somewhat by reinforcing certain of its components. This action of the pinna as a resonator is different according to the direction from which the sound comes.

The second supplementary experiment which uses tuning-forks in direct contact with the head is of some interest because the bones of the skull transmit the sounds directly to the two inner ears. The apparent localization of the fused resultant is often inside of the skull.

Oblique positions give complications of the results reported for horizontal positions. Variations in the quality of components have been reported as giving variations in the vertical or oblique positions of the fused resultant. Variations in the pitch can be produced by using diaphragms of different thicknesses in the telephones, or by loading an ordinary diaphragm with lead. If the difference between the two sounds is too great they will not fuse.

If reflectors are fastened to the ears the effect of the pinnas as resonators is entirely changed, and as a result the apparent location of the sound will be modified.

Improvement of auditory localization through practice is reported by Pierce in his "Studies in Auditory and Visual Perception."

The use of three telephones complicates the problem by introducing one factor which may dominate the whole experience (if, for example, one source of sound is outside of the median plane and the other two are in that plane). This is a case which differs radically from color and light fusions.

EXERCISE VII

A—APPARATUS AND PROCEDURE

The simplest method of producing tones for the purposes of this exercise is by means of a set of Quincke tubes. A Quincke tube is represented in Fig. 48. It consists essentially of a blower *B* held by means of a wire in front of a sounder *S*. The sounder is stopped at one extremity by means of a cork. If the blower is held in the right position at the mouth of the tube, a fairly pure note may be produced by blowing through *B*. The air for the blower can be supplied most readily by the mouth. If it is desired to blow more than one tube at a time, as in the experiment, a mouthpiece can be made from tin with a single opening at one end to be inserted in the mouth, and two or more openings of appropriate size to fit over the blowers of the desired number of tubes at the other end. Quincke's tubes can be made to produce tones of relatively high pitch.

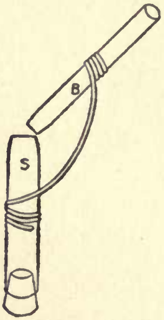


FIG. 48

A second simple means of producing musical tones of desired pitch is to employ two or more chromatic pitch-pipes. The form of pipe diagrammatically represented in Fig. 49 serves the purpose very well. The reed pipe *PP* is supplied with a sliding damper *DD*. The foot of the damper rests on the reed *RR* and may be drawn up or down so as to make the reed longer or shorter, and the note of the pipe consequently lower or higher. If a scale is attached to the damper at some point, any desired note may be produced and read on the scale. Two such pipes with a combination mouthpiece, such as that de-

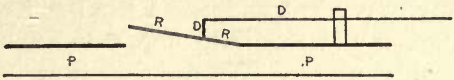


FIG. 49

scribed in connection with the discussion of the Quincke tubes, will serve very well the purposes of the exercise.

Even with the simple devices thus far described, it is desirable to provide an air supply which shall be more constant in intensity than that which can be produced by

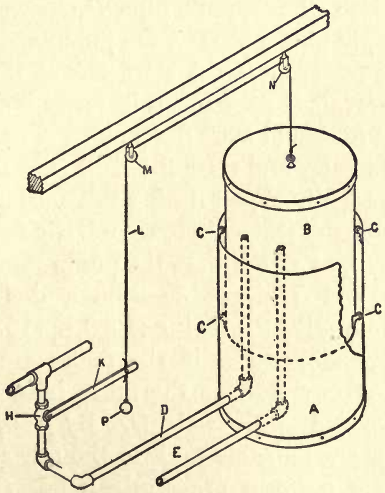


FIG. 50

blowing with the mouth. A simple type of air reservoir consists of a large vessel indicated in Fig. 50. This outer vessel *A* should be two-thirds filled with water. A second vessel of like form should be inverted in the position *B*, and tubes *D* and *E* should be introduced through the outer vessel and led upward into *B* above the level of the water. Air may be introduced into the vessel *B* through the tube *D* from any convenient source. A hand or foot bellows, a foot pump, or a mechanical pump, may be used to supply air for this purpose. When the air is needed to blow the pipes it should be drawn from the second tube *E*. The reservoir *B* will act as a storage reservoir and through its weight it will also tend to force the air out under a constant pressure. The pressure can be increased by placing on top of the reservoir various weights.

If it is desired to use a current of air for any lengthy experiments, automatic mechanical contrivances can be introduced into the supply pipe *D*, so as to open or close the supply pipe and start the pump according to the height of the reservoir *B*. A stop-cock at *H* should open when the reservoir *B* approaches its lower limit and a connection from *K* should start the pump. The air will then be allowed to enter and raise the tank *B*. The stop-cock should be gradually closed during this raising of the tank *B*, until finally the reservoir is completely filled ready for the experiment, at which time the pump may be stopped.

Titchener and Whipple describe a double reservoir (*American Journal of Psychology*, 1903, pp. 107–112). Two tanks corresponding to *B* in the figure are chained together so that one rises as the other falls. The falling tank is provided with weights. By transferring the weights from one movable tank to the other, a stream of air under very uniform pressure can be supplied with no interruption except that involved in transferring the weights.

A mechanical pump can be used with a storage reservoir without the pressure tank here described. In that case, since the air is delivered from the storage reservoir at an irregular pressure, a double regulator valve should be secured which will so regulate the outflow that the air can be delivered at the point of use at a uniform low pressure. Such valves are to be had through any mechanics' supply house. They are manufactured by Wm. Boekel & Co., 518 Vine St., Philadelphia. (Catalogue E.)

Even when blown steadily by means of an automatic air-pump, Quincke's tubes and chromatic pitch-pipes are

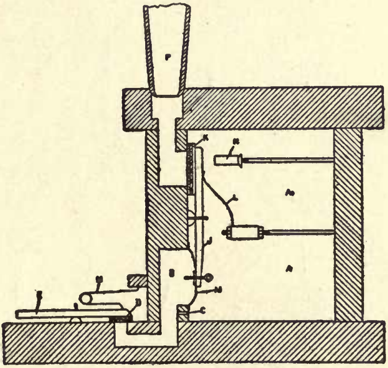


Fig. 51

less constant in their qualities than organ pipes. A system of organ pipes mounted on a keyboard will be found to be a very satisfactory means of supplying tones. The practical difficulty in securing this kind of equipment consists usually in getting the keyboard for sounding the pipes rather than in securing sets of pipes. Fig. 51 shows the mechanism of a keyboard, such as is commonly used in pipe organs. The air chest *AA* has two openings, one very small one at *C*, and a large one at *K*. The one at *C* is always open and tends to keep the air in the small outer chamber *B* with which it communicates at the same pressure as the air inside the air chest *AA*. The opening *K* is closed by the valve *KJ*. This valve consists of an arm *J* with a fulcrum at its center. At the end *K* is a felt foot fitting over the opening which leads out of the air chest. At the opposite end the arm *J* is fastened to a piece of flexible sheepskin *M*. The valve *KJ*, is held in position

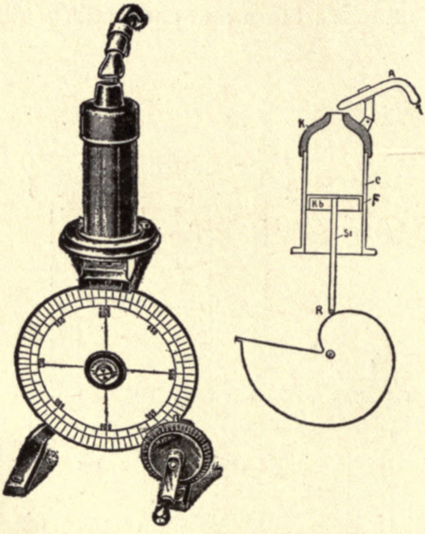


FIG. 52
From the catalogue of Kohl, Chemnitz, Germany

by the pressure of air within the air chest and by the small supplementary spring *L*. The valve *KJ* is opened indirectly by reducing the pressure on the outside of the sheepskin *M*. This is accomplished by opening the valve *D* which communicates with the outer air. The valve at *D* can be opened by pressing on the finger piece *E*. As soon as the pressure in *B* is reduced, the sheepskin *M* is forced outward and opens the valve *K*. This allows the air to pass out of the air chest *AA* into the organ pipe *P*.

Elaborate instruments for producing series of tones are manufactured. Appunn's "tone messer" is a reed pipe in which the successive pipes differ from each other, not by the conventional intervals, but by two vibrations in each case.

Stern has worked out an apparatus called a "tone-variator" for producing continuous series of variations in tonal quality. This is represented in Fig. 52. The metallic cylinder *C* has a piston *Kb* which is raised and lowered from below by a cam. The volume of air within

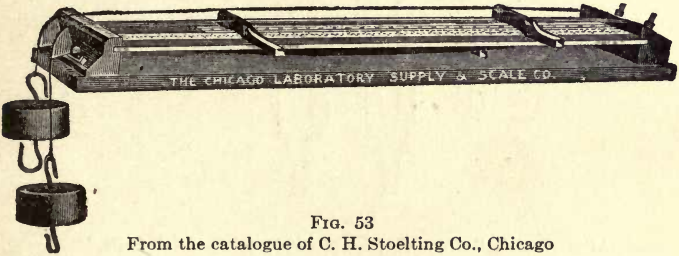


FIG. 53
From the catalogue of C. H. Stoelting Co., Chicago

the cylinder is thus varied by any desired amount, and the change can be read directly on the scale connected with the cam. A pipe, *A*, which extends obliquely down to the mouth of the cylinder, excites the cylinder whenever an air current passes through it. This apparatus has the advantage of producing not merely a variety of tones, but every possible modification of pitch. The range of a single cylinder is limited and a series of cylinders must be provided for any extended experiments.

Instead of wind instruments such as have been described up to this point, string instruments may be used. The most available instrument of this sort is the sonometer represented in Fig. 53. Over a resonator box are stretched wires. Under these wires are adjustable bridges which may be placed in various positions along scales marked on the resonator. The wires are kept under tension either by weights, as shown in the figure, or by means of screws. The tones from the wires are clear and of long duration. They differ in timbre according to the point at which the wires are plucked or bowed when excited.

Another means of producing continuous series of tones is by means of weighted tuning-forks such as are shown in Fig. 54. Tuning-forks give very much more reliable tones than any other type of apparatus, and the tones are simpler in quality than any that can be secured either

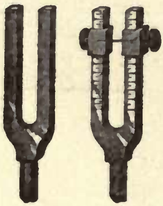


FIG. 54
After Wundt. "Grundzüge der physiologischen Psychologie," 5th Ed., Vol. II, p. 82

from reeds, organ pipes, or string instruments. On the other hand, the tone from a tuning-fork is by no means as intense as the tone from a wind instrument. The intensity of the tone can be increased by mounting the forks on resonating boxes.

The simplicity of the tones from tuning-forks is a matter of importance for the complete success of the experiment with the fused tones. If the tones are at all complex, the degree of fusion will depend quite as much upon the other components as upon the chief or fundamental tone. For this reason the use of organ pipes or stringed instruments is likely to result in a discrimination of tones even when they would fuse completely if they were simple. The production of pure tones requires the very best tuning-forks. It is relatively easy to produce a tuning-fork which shall give a fairly pure tone, but if the material in the tuning-fork is irregular in its temper or in its density, the fork will vibrate in different ways in its different parts and there will result a complex tone. For this reason the best quality of tuning-forks will be found indispensable for reliable scientific work with tones.

If such tuning-forks are secured, the second problem

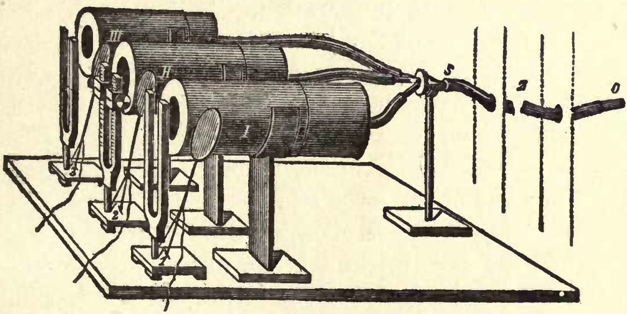


FIG. 55
From Wundt's "Grundzüge der physiologischen Psychologie," 5th Ed., Vol. II, p. 82

is to provide for the transmission of the sound from these forks to the hearer. It is not a satisfactory method to excite the two forks successively and then attempt to judge of their fusion, for the successive sounding of the forks will give the observer opportunity to discriminate the sounds more completely than he could if the sounds had been presented to him together. The arrangement shown in Fig. 55 makes it possible to excite the forks without giving the observer an opportunity to hear them until they are both in vigorous action. A rubber tube

(*S Z O*) should be carried through a heavy wall from one room into the next. Indeed, it is preferable that the tube be carried through a still greater space. In any case it should be of rubber rather than of rigid material. At the end *O*, should be seated the observer with the tube placed against the ear. For this purpose a glass tube may be carried from the rubber to the ear of the observer, this glass tube being shaped so as to fit the ear of the observer. At the other end of the rubber tube there may be, in addition to what is shown in the figure, a stop-cock by means of which the tube can be completely closed while the experiment is in preparation. This tube should be connected with two or more resonators, such as are shown at I, II, and III. A very convenient method of procedure is to have two resonators, one of which is fixed in size, the other of which has a piston so arranged that it can be adjusted within the resonator, reducing it to the proper size for any one of the forks of a given octave. In front of the resonators should be clamped the forks which are to be used in the experiment. When all is in readiness for the experiment the observer should be warned that he is to hear the sound in a few seconds. The tuning-forks should be excited either by striking them or by bowing them with a violin bow. The shutters in front of the resonators should be drawn aside; the rubber tube should be opened so as to transmit the sound to the observer. It may be found necessary, if the wall between the observer and the apparatus is not thick, to completely disconnect the rubber tube from the resonators during the preparation for the experiment. Furthermore, in order to prevent the sound from being transmitted by the solid walls, it is sometimes necessary to suspend the resonators and the tuning-forks from springs so that the sound may be produced upon an isolated bridge.

The intensity of the tones can be varied by exciting the source less vigorously or by cutting off part of the conducting channel to the observer. If the source is a Quincke tube or reed-pipe the tube which carries the air into the tube can be partly closed. The effort to cut down the intensity of a sound after it has been produced is always complicated by the fact that the walls of the conductor are as likely to carry the vibrations as the columns of air inside of the conductor. It is better, therefore, to regulate the sound at its source.

For the third part of the experiment two chromatic pitch-pipes or two Stern's variators are the best devices.

In working with intervals, the simplest procedure is to have one source adjustable (for example, either a chromatic pitch-pipe or a tone-variator) and the other fixed. Now sound the interval between the two, and immediately after vary one of the sources slightly and repeat. It will be found that the ability to recognize intervals is in general very highly developed.

B—RESULTS

A table showing the distribution of judgments in the first experiment of the exercise with three untrained observers is as follows:

Judgments

Combinations	Certainly one tone			Probably one tone			Doubtful			Probably two tones			Certainly one tone		
CC	3	4	3	1	1	1	1	0	0	0	0	0	0	0	1
CB	0	0	0	0	0	0	1	0	0	1	0	0	3	5	5
CA	1	0	1	2	0	0	0	0	1	0	2	2	2	3	1
CG	1	1	1	3	1	2	0	1	1	1	0	1	0	2	0
CF	1	0	0	1	0	1	2	1	3	1	2	1	0	2	0
CE	0	1	0	0	2	1	1	0	2	3	2	1	1	0	1
CD	0	0	1	0	0	0	0	0	0	1	0	4	4	5	0
Observers	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C

The degrees of fusion here indicated do not agree in detail with Stumpf's table, but they give a sufficiently clear indication of the difference between *CC'* and *CG* on the one hand and such combinations as *CB* and *CD* on the other hand. Stumpf recognizes five degrees of fusion: from the most complete in the octave, *CC'*, through 2d) the fifth, *CG*, 3d) the fourth, *CF*, 4th) the pure thirds and sixths, *CE* and *CA*, to 5th) minor sevenths and other combinations, *CB* and *CD*.

When one tone is stronger than the other, fusion is more complete, the stronger tone dominating the whole percept.

The ability to discriminate tones differs greatly with different observers, ranging from one vibration to half a tone. If will be found in some cases that the observer can discriminate tones before he can tell which is higher.

The recognition of intervals, as pointed out above, is often better than the recognition of tonal differences.

C—SUPPLEMENTARY EXPERIMENTS

The apparatus for developing combination tones is the same as that described. Quincke tubes serve very well for difference-tones, adjustable forks for beats. For purposes of demonstrating difference-tones the double whistles which are supplied as bicycle warning whistles sometimes give a very marked difference-tone.

The last supplementary experiment which deals with highest and lowest tones requires apparatus not described thus far.

Series of steel cylinders of different lengths are manufactured which make it possible to secure, by simply striking the different cylinders, very high metallic tones which are pure in quality because all of their overtones are much beyond the range of ordinary hearing.

The apparatus most convenient for securing high tones is Galton's whistle, the most elaborate form of which is shown in Fig. 56. This whistle consists of a pair of small tubes, *D* and *E*. The air is forced into *D* and so against the tip of *E* from the rubber bulb. Vibration is set up in *E*. The length of the air column in *E* is regulated by means of a piston controlled by the graduated screw *G* and *F*. The rate of the vibration will be determined by the length of the air column in *E*. In order to prevent transverse vibrations, the opening between *D* and *E* is regulated by the graduated screw *B*. There is a simple form of this whistle which is subject to certain errors. The more elaborate form supplied by Edelmann obviates these errors and gives a very accurate measurement of the highest tones.

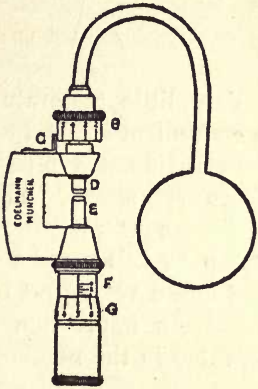


FIG. 56

From the catalogue of Edelmann, Munich, Germany

For the lowest audible tones, simple rods may be used. These may be held firmly in a vise and shortened or lengthened until the limits of audibility are reached. A simple rod made for this purpose is supplied by Appunn.

EXERCISE VIII

A—APPARATUS AND PROCEDURE

Very little apparatus is required for Exercise VIII. A convenient method of marking the arm at the outset of the experiment is to provide a rubber stamp, or, better, an electrotype stamp, which has on its face a figure marked off into squares two millimeters on each side. Such a stamp as this can be used with the ordinary stamping pad and a very good impression can be produced on the skin. An impression from the same stamp should be repeated in the notebook of the experimenter as a means of making a record of the differences in sensitivity discovered during the exploration of the skin. Fig. 57 shows the impression from such a stamp.

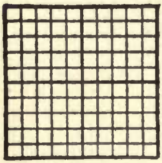


Fig. 57

Points for the exploration of the skin can be provided in the simplest fashion by beveling the end of a short brass rod to a blunt point. The point should not be too fine, as it will be likely to prick the skin and cause discomfort during the experiment. On the other hand, it should not be so blunt as to spread the stimulation diffusely over the skin so as to affect a series of points at the same time.

In order that the hand of the experimenter may not come into direct contact with the metal rod and thus serve as a means of rapidly cooling or warming it, the rod should be passed through a cork and the experimenter should handle the rod by means of this cork. Such a metallic point as this may be placed in ice water if it is desired to experiment with cold spots, and in water of various other degrees of temperature if it is desired to work with warm spots.

More convenient forms of temperature points can be made as indicated in Fig. 58. The handle furnishes a means of holding the point which may be renewed as often as desired from a supply which is kept in cold or warm water.

Instead of the solid points, cylinders may be used. These can be filled with water of any desired temperature and will hold their temperature longer than the rods. In the most elaborate forms of temperature cylinders, a current of water is drawn from a remote reservoir, where it is kept at the desired temperature, and passed continuously through the cylinder.

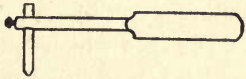


FIG. 58

For work with pressure spots, bristles of various sizes may be fastened to wooden handles by means of sealing-wax, or they may be held in screw clutches which fit into the handle shown in Fig. 58. A clutch for this purpose is made by splitting a screw and putting the bristles between the two parts of the screw. The screw should be made in the form of a cone. When a nut is screwed up on this taper, the sides of the screw will be drawn together and will firmly grasp the bristle.

C—SUPPLEMENTARY EXPERIMENTS

Experiments dealing with the relativity of temperatures can be readily prepared by using dishes of warm and cold water. The observation is so closely related to the facts of common experience that no detailed discussion of the matter is necessary.

For the second supplementary experiment, prepare a series of light corks which are equal to each other in weight but differ in size, and ascertain by tests which one will give the greatest apparent pressure.

Experiments on the tongue can be made by drying the surface thoroughly and afterward applying drops of the substance with which the organ of taste is to be stimulated by means of a camel's-hair brush.

One test for sensitivity of the skin to which reference is not made in the *Laboratory Manual* is the test for sensitivity to pain. The apparatus for such a test is known as an algometer. It is virtually an inverted spring balance, and consists in a hollow wooden cylinder which has a coiled spring inside. Against this coiled spring there is a piston which extends out beyond the end of the wooden cylinder. The end of the piston is held against the part of the skin which is to be tested, and the wooden cylinder which serves as a handle is now pressed downward toward the skin. The pressure on the cylinder acts upon the piston through the spring and tends to push the piston against the skin with as much force as is exerted by the coiled spring within. If a scale is marked on the wooden cylinder and a pointer is attached to the piston, this pointer will tend to travel up the scale as the pressure is exerted on the piston, showing how much the spring is brought into play. The amount of pressure necessary to produce pain at any given point can thus be read off directly from the scale as it would be read on a spring balance.

EXERCISE IX

A—APPARATUS AND PROCEDURE

For the first part of this exercise a simple tracing may be made by laying the hand on a piece of paper and outlining its form with a pencil. The outline should be supplied with lines to indicate the positions of the knuckles, and certain of the prominent features of the hand and arm. If it can be had, a still better map with which to work is a life-sized photograph of the arm. A more elaborate method yet is to secure a plaster of paris cast of the arm and hand. The latter device is necessary only when a long series of experiments is to be tried. A photograph as a substitute for the rough outline is advantageous even for simple demonstration experiments.

For producing the sensations in the first part of the exercise a simple wooden point can be used. The points can be marked by ink made of aniline dye and water.

As a means of supplying the stimulation at two points on the skin an ordinary drawing compass may be employed. It is not absolutely necessary, as prescribed in the text, that the points should be made of hard rubber, but if they are not so made there is large possibility that the observer will be distracted from time to time through the excessive stimulation of temperature spots on the skin. Even with a compass, additional points of rubber or bone or wood may easily be fastened over the metallic points, and thus the difficulty which might otherwise arise through excessive stimulation of the temperature spots may be eliminated. If drawing compasses are employed, it will be necessary for the experimenter to measure the distance between the points by comparison with a scale.

It is obviously more convenient to have the measure directly connected with the points, so that when an adjustment is made a direct reading of the distance of the points from each other can be seen at a glance. Fig. 59 represents a simple apparatus very similar to the one that was employed by Weber in his experiments. The long bar *A* is graduated into millimeters. One point is directly connected with the extremity of the graduated bar. Over the bar there travels an adjustable arm which can be placed at any desired distance from the fixed point. The

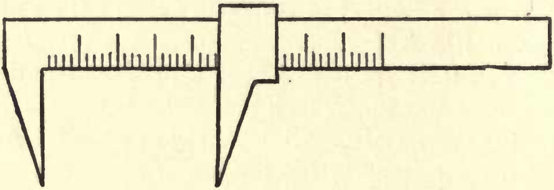


Fig. 59

distance between the two points can now be read directly on the scale. Such an apparatus is known as an æsthesiometer.

Certain refinements can be introduced into an apparatus of this sort. Thus, instead of using hard rubber points Von Frey has suggested that bristles be used which shall be of equal thickness, so that the two points can be pressed against the skin with equal intensity. Such an addition as this to the æsthesiometer makes impossible any inequality of pressure at the two points. Others have suggested that the æsthesiometer points be held in some kind of sliding handle so that they will always rest against the skin with the weight of the apparatus. These refinements, however, are unnecessary.

With a little practice the experimenter can learn to set the two points down with equal pressure and with the greatest precision in the matter of the time of contact of the two points.

In the course of a series of experiments with the two points it is customary to introduce what has been called a confusion experiment. This consists in stimulating the observer with a single point. It is sometimes found that an observer gives a judgment two points when, as a matter of fact, he is being stimulated only with a single point. This is doubtless due in many cases to the fact that other points on the skin are more or less irritated by internal conditions or by after-images of early tactual stimulations. Indeed, after one has been experimenting for some time with a given region of the skin it is almost impossible to decide whether a given experience is the result of a present stimulation or an after-image. These confusion results will be found to be sources of constant error especially with untrained observers. It is generally well, in case these errors become too numerous, to begin with a distance between the two points so large that the observer has no difficulty whatsoever in recognizing it, and then to gradually reduce the distance until the two points are no longer clearly recognized. The degree of certainty in the observer's judgments of the separateness of the two points may also be considered in determining the threshold for two points. One fact which comes out very clearly from these results is that the skin threshold is not a definite sensory matter, but is rather the result of a complex perceptual discrimination.

If in addition to the judgment of separateness the observer is required to judge the direction of two points or a line upon the skin, it will be found that this judgment of direction is vague in the extreme. especially in untrained parts of the skin. More investigation of this matter can readily be made by the methods here described.

In the part of this exercise where it is required to use lines instead of points, the simplest means is to prepare a series of cardboard lines. These lines should be cut at lengths varying from a single millimeter to any desired length. More convenient than cardboard lines will be found a system of thin lines made of hard rubber, varying

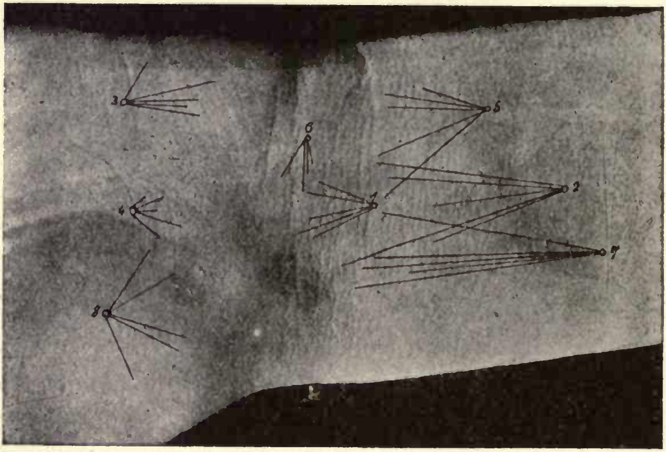


Fig. 60
From an article by Henri, in the "Archives de Physiologie," 1893, pp. 619–627

in length, as do the cardboard lines, from a single millimeter to lengths of from 5 to 6 centimenters.

B—RESULTS

Results of experiments in localization when single points are touched are shown in Fig. 60 and also in the article by Pillsbury in the *American Journal of Psychology*, 1895, pp. 42–56.

The results in millimeters of the æsthesiometer experiment on three observers were as follows:

	Observer A			Observer B			Observer C		
Arm...........	24	27	30	14	13	15	31	27	32
Thumb.........	7	6	8	5	5	4	8	9	10
Finger.........	2	1	1	3	1	2	2	2	2

When a continuous line is used, it will be found that it is distinguished from a point when it is less than half as long as the distance which must lie between two points in order that they may be distinguished as two.

C—SUPPLEMENTARY EXPERIMENTS

Distances across the arm are always recognized earlier than distances in longitudinal directions.

The supplementary experiments on different parts of the body and on the effects of practice require no new apparatus or methods of procedure.

If a point is moved across the skin it will be found that the fact of movement can usually be recognized before the point has moved over the distance required for the discrimination of two æsthesiometer points. The fact that perceptual discrimination of different stimulations can be more readily made during the movement of the point has been dwelt upon by certain writers as clear evidence that the perception of motion is a separate process from that of general spatial discrimination. Elaborate devices have been constructed for moving points across the surface of the skin at a uniform rate. These devices have usually been supplied with means of varying the rate from very rapid to very slow. They consist in principle of a moving carriage that carries a pointer which rests with its full weight upon the skin. The weight of such a point can be regulated by adding to the natural weight of the pointer or by counterbalancing it so as to make it lighter than it would be if it rested with its full weight upon the skin. For the purposes of ordinary experimentation much productive observation can be made by using a wooden point and moving it with the hand, not attempting to employ the more elaborate forms of apparatus.

Many experiments with the semicircular canals have been tried upon animals. The canals have been destroyed in various ways and the animal's behavior after the disturbance of its canals has been carefully observed. Certain pathological human cases also serve for similar experiments. Experiments with normal human beings can be tried by directly stimulating the canals. If an electrode is applied to the outer surface of the skull directly back of the pinna, effects may sometimes be produced of slight dizziness or in some cases movements of the head may be induced which are analogous to the corrective movements on the part of animals when abnormal conditions of stimulation are produced through vivisection in the canals. Such experiments by stimulation are, however, not agreeable and are hardly suitable for general experimental courses. A better method of demonstration and experiment for general classes consists in observing the effect upon the general recognition of bodily position when the excitation in the canals is unusual. Thus, let an observer stand with closed eyes, and point directly in front of himself. Now let him take three or four steps to a neighboring wall or blackboard where he is required to indicate the point which seems to him to be directly in front of the original position from which he started. This experiment should be repeated several times in order to determine the variations which will appear under these undisturbed conditions. After the average error of pointing out a position which is directly in front has been ascertained, let the experiment be repeated by the same observer with the head turned sharply in some unusual direction. Thus, let the observer hold the head with the left ear as near to the left shoulder as possible or, conversely, with the right ear near the right shoulder, or let the head be thrown back as far as possible, or let the neck be bent forward as far as possible. It will be found in these cases that the points selected on the blackboard after several steps forward differ decidedly from the points indicated in the earlier experiments. There may be involved in these experiments factors other than the sensations from the semicircular canals. The strain upon the muscles of the neck and the effect of a changed position of the whole head are undoubtedly to be considered in explaining the unusual direction of movement.

Measurements of the ability to recognize changes in the position of the body can also be made by means of a tipping and rotating table. The observer lies on such a table and is gradually tipped so that the head rises and the feet are lowered, and record is made of the point where he first recognizes the change in position from the starting-point. Again the table is rotated so that the observer's head moves clockwise or counter-clockwise, and the angle is measured through which he must move in order to recognize the fact of movement and the direction. Such measurements as these probably deal with changes in the pressure of the lymphatic fluids in the semicircular canals. They may also include certain skin sensations. Much will depend upon the rate at which the movement is made.

EXERCISE X

A—APPARATUS AND PROCEDURE

The simplest means of securing weights for this experiment is to take cartridge shells and ordinary shot and load the shells so that they are as heavy as desired. Other forms of cylinders can be prepared consisting of hard rubber cylinders or metallic cylinders. The cylindrical form is distinctly advantageous for all of the work because cylinders can always be picked up in the same way by the observer. Hard rubber is better than metal as the latter introduces temperature sensations.

These weighted cylinders can be most readily presented to the observer by means of a small rotating table. The arm of the observer is supported above this rotating table within easy reach of the weights placed upon it. The experimenter operates the table, bringing first one weight and then the other under the observer's hand. If no such rotating table as this is provided, the experimenter may place the arm of the observer in a convenient position and set the weights successively under the hand.

Methods of treating the results of such tests are given in the text of the *Laboratory Manual.*

Faint sounds can be most simply produced by means of a small body which is allowed to fall against a plate of glass or metal. A convenient body for this purpose is a small pith-ball. A suitable scale may be fastened at the side of a glass plate, and the pith-ball held in a funnel or taken in a pair of forceps which can be brought to any desired height on the scale. When the funnel or forceps are opened, the pith-ball will fall through a known distance to the plate of glass or metal below. The sound which it produces will be sufficiently faint to allow a considerable range of variation either in the height of the fall or in the distance of the object from the ear, and a measurement can thus be secured of the intensity of sound just necessary for auditory recognition. If the apparatus is moved further and further away from the ear in order to produce a fainter sound, it is not necessary to have a scale connected

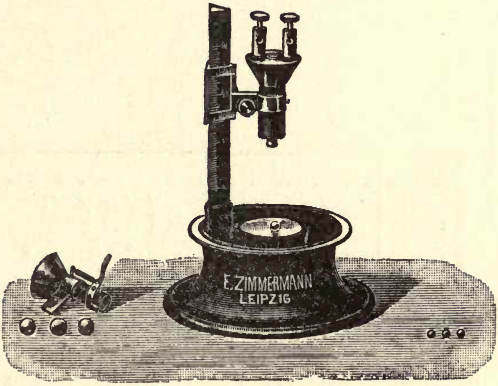


FIG. 61
From the catalogue of Zimmermann, Leipzig, Germany

with the glass plate. The forceps or funnel may he held in a fixed position at a certain height above the glass. The distance through which the pith-ball falls will thus be in every case the same, the variation in intensity of sound being produced by the distance of the apparatus from the observer's ear. Fig. 61 shows an elaborate device of this kind.

A second form of audiometer consists in a telephone which is connected with the secondary coil of an induction coil. The secondary coil is made adjustable so that it can be varied in its position with reference to the primary coil. The current which is to pass through the primary coil is controlled by means of a make and break key. If now the secondary coil is placed at a given distance from the primary, and the current in the primary is made and broken, a sound will be produced in the telephone. If the sound is of sufficient intensity for the observer to recognize it, the intensity of the current in the secondary coil should be reduced by moving this coil further away from the primary,

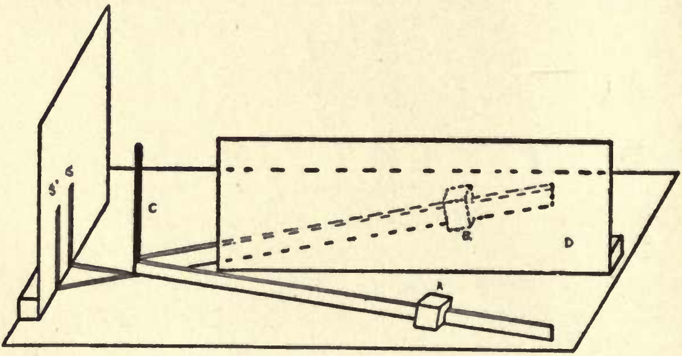


Fig. 62

and the experiment should be repeated until the distance is found at which the observer is unable to recognize the faint sound produced in the telephone. The distance between the coils constitutes a measure of the auditory sensitivity.

Physicians use a much simpler test than either of these in determining for diagnostic purposes the sensitivity of the ears. They use the tick of a watch or a faint whisper, and measure the threshold in terms of the distance to which the sound must be removed from the ear in order that it may become too faint to be recognized.

A simple form of photometer is shown in Fig. 62. Two sources of light are set up on the blocks *A* and *B*. Convenient sources of light for this purpose are candles. Between the two sources of light is a shield *D*. There is set up at *C* a rod which will cast shadows on the screen as shown at *S* and *S'*. The blocks *A* and *B* should be moved by the experimenter until the shadows *S* and *S'* seem to the observer just noticeably different in intensity. The difference in the distance of the two blocks from the rod can be determined, and this distance constitutes a measure of the just perceptible difference in illumination necessary for the observer's recognition. If now the total illumination of the room is changed, it will be found that the distance of the blocks from the rod necessary to produce a just perceptible difference in the shadows has also changed. In order to control easily the total illumination of the room as required in this experiment, the apparatus should be set up in a room that can be darkened.

Other photometers are constructed in such a way that light from different sources falls upon two neighboring plates of milk glass. Such plates of milk glass should be separated from each other by an opaque metal strip. They should be placed so that they can both be seen by the observer at the same time. The sources of light should now be so adjusted that the illumination of one plate of glass can be recognized as just noticeably greater or less than the illumination of the other plate. The principle here employed consists in a direct examination of the illuminated surface, rather than in the comparison of shadows as in the photometer shown in Fig. 62. In the second form of photometer, as well as in the shadow photometer, the measurement is made in terms of the distance of the sources of light. These measurements can be reduced to an absolute physical basis by recognizing the general physical formula that the intensity of lights is inversely proportional to the square of their distances.

Other forms of photometers are numerous and can be arranged without difficulty. The principle of all such instruments is sufficiently illustrated in the one or the other of the forms described.

C—SUPPLEMENTARY EXPERIMENTS

In the first supplementary experiment the comparison of differences is suggested. Such a comparison can be worked out with auditory sensations by arranging four balls so that they can be dropped from different heights. A certain difference in height between balls 1 and 2 will produce a known difference in the intensity of their sounds. Balls 3 and 4 are also dropped from known heights, the difference between their heights being adjusted in the course of successive trials to satisfy the listening observer. The difficulty in carrying out this experiment arises from the great difficulty of providing balls that are just alike and uniform plates on which the balls may fall. Furthermore, the balls must be dropped by some sort of mechanical device which shall prevent them from rotating and shall be noiseless. Such an elaborate apparatus has been worked out in the Leipzig Laboratory and is described in

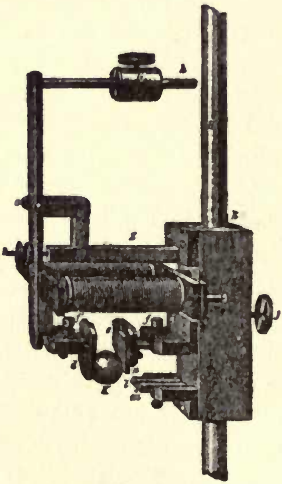


FIG. 63
From Wundt's "Grundzüge der physiologischen Psychologie," 5th Ed., Vol. I, p. 513

full in the *Philosophische Studien*, 1892, Vol. VII. The essential part of the apparatus, namely that by means of which the ball is dropped without rotation, is shown in Fig. 63.

It is much simpler to determine the threshold for just perceptible difference in sounds. Fig. 64 represents a pendulum apparatus designed for this experiment. Two pendulums with ivory bulbs at their ends are so pivoted that they can be lifted to suitable distances in front of scales and then allowed to descend against a block. As the pendulum rebounds it is caught either by the hand or

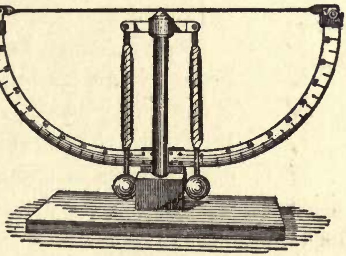


FIG. 64
From the catalogue of Diedrich, Goettingen, Germany

by a felt catch. The second pendulum is dropped in like manner through a slightly different distance, and the second sound thus produced is to be compared by the observer with that produced by the first fall. If the difference is not perceived, the experiment should proceed, the difference between the two distances through which the pendulums fall being slightly increased.

An apparatus known as an olfactometer is used for experiments with intensities of odors. Let a glass tube TT be supplied with a nasal bulb as represented in Fig. 65 at N. This tube is held by a handle. Over the tube T is slipped a second larger tube MM, which is lined on the inside with a layer of paraffin. The tube *T* is represented in the figure with its outer tube *MM* in such a position that the air drawn into the nose during inspiration will have been exposed for a time to the paraffin surface of *MM* and will have taken up any odor which *MM* tends to give out. If *MM* is drawn further along *T*, a greater surface will be exposed and the odor will be relatively more intense. The amount of surface exposed in *MM* is accordingly a measure of the intensity of the odor entering the nose.

Experiments on taste have been carried on by stimulating the tongue with solutions of various degrees of saturation.

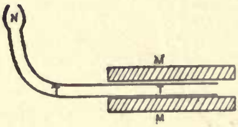


Fig. 65

Experiments have sometimes been tried with stimuli which are undergoing very gradual change; that is, instead of requiring the observer to compare two clearly different intensities of pressure, a given pressure is modified gradually. The threshold of discrimination will be different from that which results from a sudden change. The same type of experimentation has been worked out for gradually varying sounds. The devices for producing gradual variations in weight are in principle a form of balance upon which weights of greater intensity are gradually imposed. Flowing water has been used to increase the weight of the pressure gradually; the sliding of a weight along a counterbalance arm has also been employed. For purposes of change in the quality of tones the tone-variator of Stern, described on page 111, may be employed.

The determination of pressure thresholds has been touched on in discussing pressure points (page 119). An elaborate piece of apparatus for producing and measuring pressures is shown in Fig. 66. The small ivory point *St* is brought into contact with some part of the skin by raising the arm H_2. This lever may be raised by some form of clockwork which will determine its rate. As the lever H_2 rises it brings into action the coil spring M_1 gradually increasing the pressure at *St*. By means of the scale the degree of pressure can be directly read. The initial position of the lever H_2 can be regulated by the screw *S* and the height of the apparatus after it is clamped in position can be adjusted by means of the screw M_3.

A principle similar to Weber's law can be demonstrated

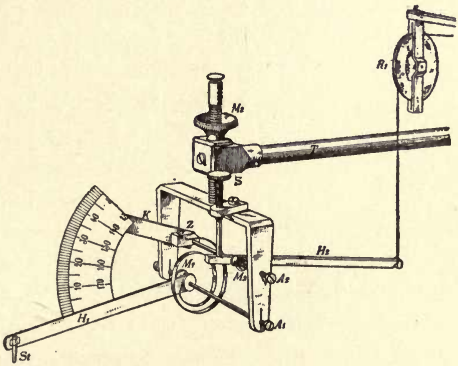


FIG. 66
From the catalogue of Zimmermann, Leipzig, Germany

for the recognition of the length of lines. If a series of lines differing from each other in length is prepared in a manner analogous to that described above for the weights, experiments by the method of right and wrong cases may be carried out. Thus, if a line 10 cm. long is compared with a line 10.5 cm. long, and a line 2 cm. long is compared with one 2.1 cm. long, the methods and results will be analogous to those described above for weights.

Another method may be used for lines which can not be employed for weights. In this case the observer may be required to draw a line which seems to him to be equal to a given line, or he may be required to draw a line which is just noticeably shorter or just noticeably longer than the given line. Again, the observer may be given a certain line and may be asked to cut off that portion of the line which seems to him to be equal to a standard. This experiment has been elaborated as a typical experiment in quantitative determination of psychical processes in the introduction of the *Laboratory Manual* and need not be worked out further at this point. (See *Laboratory Manual*, pp. 3–10.)

EXERCISE XI

A—APPARATUS AND PROCEDURE

A simple tambour is represented in Fig. 67. A bowl *B* opens at the side into a tube *S*. The bowl is covered over the top by means of a thin rubber membrane which is held in position in this form of tambour by a tightly fitting metallic ring *R*. Rubber suitable for tambours can be secured at any place where dentists secure their supply of rubber dam. The rubber is sometimes tied around the bowl which is constructed with a groove below its edge. In order to insure an air-tight contact, the edge of the bowl may be prepared for the reception of

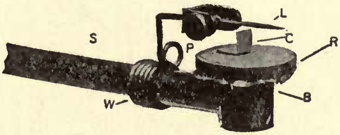


FIG. 67
From Professor Porter's catalogue of Harvard Physiological Apparatus

the rubber membrane by giving it a thin coat of wax. Ordinary beeswax serves the purpose very well. The rubber should be stretched as little as possible so as to leave it free to move with the least possible resistance. From the hollow stem *S* a thick walled rubber tube may be carried to any point desired and a second tambour may be attached to the other end of the conducting tube, the two acting in harmony, one to receive, the other to record the movement. In order to avoid loss of energy through the elasticity of rubber tubing, it is advantageous where the connection is a long one, to insert a glass tube in place of the rubber wherever possible. Any pressure which is exerted on the rubber surface of one of the tambours will force air into the other tambour and will produce a movement in the rubber of this second tambour. The advantages of this arrangement are that movements may be taken on one tambour at any point desired and may be conveyed to a second point where they can be

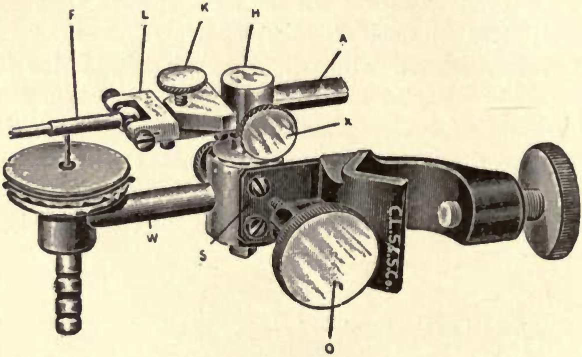


Fig. 68

From the catalogue of C. H. Stoelting Co., Chicago

recorded on suitable surfaces prepared to receive the record.

A record of the movement of a tambour surface can be made by means of a lever attached to the surface of the rubber as shown in the Fig. 67 at *W*, *P*, *L*. This lever may be of an extremely simple form. A wire coil *W* may be wound around a pipe *S*. At *P* the wire carries a fulcrum and a lever *L*. This latter is connected with the rubber of the tambour by a light angle of metal, *C*. Any movement of the rubber surface will be transmitted to the lever and magnified at the end of the lever. The degree in which the movement is thus magnified will depend on the distance between *P* and *C*, and *C* and the end of the lever. *PC* may be varied by sliding *W* along *S*.

A more satisfactory form of lever is shown in the tambour represented in Fig. 68. It consists of a post *H* which carries a horizontal bar *A* which can be set backward and forward by means of the set-screw *X*. The horizontal rod *A* is supplied at its end with a fork *L* and a pair of point bearings. The fork can be adjusted up and down by the set-screw *K* which acts against a spring. The point bearings in *L* carry a cross rod to which the lever is attached, as represented at *F*. The lever *F* is fastened to the rubber surface of the tambour by means of a light metal rod which has fastened at its bottom a thin metallic plate. In some cases the rod which connects the lever with the rubber is forked at the top. The lever is held in position in this fork by means of a small rubber band which passes around the prongs of the fork and over the lever. Suitable rubber bands for this purpose may be made from a small, pure rubber tube. Such a small, pure rubber tube may be cut off in thin sections with a pair of scissors, and these sections will supply the band desired. The plate at the bottom of the rod is fastened to the rubber by means of a drop of wax. This wax can be melted by bringing a hot metal bar in contact with the upper surface of the plate.

It will be found convenient to mount the tambour on a standard which is quite separate from the bowl or from the recording lever. This can be done as indicated in Fig. 68, where the bowl is connected with a standard by means of an arm *W*. This arm can be mounted on a spring *S*, which is fastened at the end opposite the point where it carries *W* in a clamp by means of which it can be fastened to a standard. Connected also with the clamp there may be a set-screw O, which presses against the spring S. If now the clamp is held firmly in position and the set-screw is operated backward and forward, the whole tambour with its recording points can be adjusted back and forth so as to be brought nearer the surface on which the record is to be made, or removed further from this surface. The advantage of such a screw adjustment is that the recording point can be delicately adjusted to any required degree of pressure upon the surface upon which it is to record. Such delicate adjustment will be found to be indispensable if the records are to be taken with as little friction as possible.

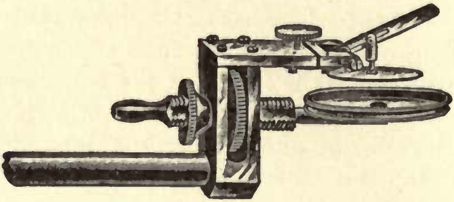


FIG. 69
From the catalogue of Verdin, Paris, France

A great variety of tambours are supplied by makers. Fig. 69 represents a form in which the bowl instead of the lever is adjusted. This figure shows very well the plate which connects the lever and the rubber.

It is desirable that the levers used with tambours should be as light as possible. Most very light rods have the disadvantage of vibrating whenever they move. A hollow cylindrical rod is least subject to this objection, and fortunately nature has provided light hollow cylindrical rods in abundance in straws. The best straw for tambours is fine, clean rye straw. If this can not be easily secured, a substitute can be found at almost any florist's where sheaves of an Italian grain will be found. This imported Italian grain is used as a miniature substitute for sheaves of wheat. The straws are fine and straight. They are somewhat heavier than rye straws but serve very well.

An important part of a tambour is its recording point. This should be at once flexible enough to insure so far as possible a reduction of the friction against the record surface, and it should be rigid enough to insure a clear mark. As will be stated later, the form of surface most commonly used in making records is a surface of smoked paper. Points for tracing on such surfaces may be made of parchment. The parchment should be cut with sharp scissors to a point, and the point should be slightly curled, so as to press against the smoked paper surface with the elasticity of its curve. Such a parchment point may be fastened to the end of the straw by a drop of wax. Or the end of the straw may be split, the parchment inserted in the slit thus prepared, and the whole bound with a fine silk thread. Another very satisfactory point can be made by using celluloid, which can be treated in the same way as the parchment. Pendulum ribbon makes a good metal point. Heavy tinfoil may be used.

Tambours can be used in various combinations. It will be convenient to speak of a tambour supplied with a lever and a recording point as a recording tambour. Tambours which have no levers attached may be variously attached to the finger or head or other part of the body and will be called, because of their function of receiving the movement, receiving tambours.

It is often convenient in practical work to be able to introduce air into a tambour without pulling apart the connections. A convenient device for doing this is a short metal tube which is inserted in the rubber tube leading from receiving tambour to recording tambour. Such a tube is represented in Fig. 70. At *A* is a fine opening communicating when open with the outer atmosphere and the air system inside of the tambours. Under ordinary circumstances *A* is kept closed by the small stopper BB^1B^2, which is pressed down against it by the spring *S*. When it is desired to open *A* the finger presses at B^2.

One of the most fertile sources of annoyance in working with tambours is to find that they are not air-tight. It is frequently necessary for the student who is to use tambours to renew the rubber covering. Indeed, it is usually better for him to begin any experiment with an entirely new rubber on the tambour. It will be found

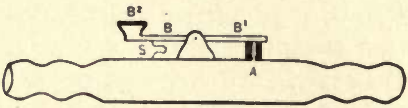


Fig. 70

advantageous in every laboratory to have the material necessary for setting up tambours at hand in such form as to be easily accessible to the student. A box can be prepared containing the smaller parts of the tambours, a supply of rubber, a supply of strong thread, a pair of scissors and beeswax. If the tambour is to be used only a short time it is often convenient to fasten the rubber tambour by means of a wire instead of thread. A fine wire and a pair of pinchers should accordingly be added to the equipment. If the wire is drawn firmly around the tambour it can be fastened by twisting it up with the pinchers. The disadvantage with the wire connection is that it very soon cuts through the rubber.

After securing a recorder, a surface must be provided for taking the record. In order that the movements of the tambour levers may be fully recorded, the surface must offer as little friction as possible and it must be moved forward so that when one part of the record is completed an unused portion of the receiving surface may be substituted for the part on which the recorder has been tracing, and a new phase of the movement be recorded. The movement of the surface also aids in reducing the friction. We may, therefore, begin our description with the moving device which is known as a kymograph.

A variety of kymographs are in use. The simplest consists of a large brass cylinder about 15 cm. in diameter. Such a brass cylinder or drum, as it is called, should have as smooth a surface as can be provided. It should be turned in an accurate lathe so as to be a perfect cylinder, and it should be kept polished by means of buffing apparatus so that its surface may at all times be as nearly as possible free from irregularities. It is desirable that this drum should be rotated at a uniform rate. The problem of securing regularity of movement is a problem which has resulted in a number of clock-work devices and electrical devices. If one wishes the highest degree of accuracy he will find that all these devices are subject to some variations; the effort to drive the drum at a uniform rate is therefore at times abandoned, in which case it becomes necessary to trace upon the receiving surface a standard time-line. Any irregularities in the movement of the drum will be indicated by means of this standard time-line, and the results of the record to be studied can be measured in terms of the standard time-line rather than in terms of the movement of the drum.

Of the devices for driving the drum at a uniform rate, the clock-work devices are the simplest. A cheap and very satisfactory clock-work device was prepared by Professor Porter of the Harvard Medical School, in the kymograph which is supplied with the Harvard physiological apparatus. It consists of clock-work shown in the accompanying Fig. 71. The drum is carried in a vertical position and driven by a friction contact between the foot of the drum and the shaft which is connected with the clock-work. The whole is regulated with reference to its speed by a fan governor shown in the figure. The fan governor consists of a flat piece of metal which, in its rotation, strikes the air and offers, because of the constancy of the pressure of the atmosphere, a uniform resistance to the clock-work. Fans of various sizes are provided with the apparatus.

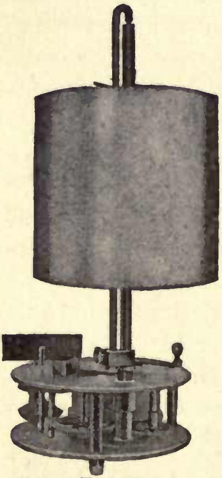


FIG. 71
From Professor Porter's catalogue of Harvard Physiological Apparatus

More elaborate kymographs are made, the best clock-work kymograph being that which bears the name of the physiologist Ludwig. This kymograph is supplied by Zimmermann, in Leipzig, Germany. It is represented in Fig. 72, and consists of an elaborate clock-work, which by means of the coupling and uncoupling of certain of its gearings gives a wide range of adjustment of speed. The speed of the drum may also be regulated by means of a fan governor which consists in this case of a pair of wings which spread out against springs because of the centrifugal force exerted during rotation. When springs of a given strength are placed in position in this governor, the fans of the governor tend to spread out to a certain extent, depending upon the balance between centrifugal force and the tension of the springs, and thus maintain a uniform rate of movement in the kymograph. The drum may be placed either in the vertical or horizontal position as is most convenient for the record. The figure shows at the left a tripod standard with a disk and rotating arm and contacts to be used in securing regular time intervals for

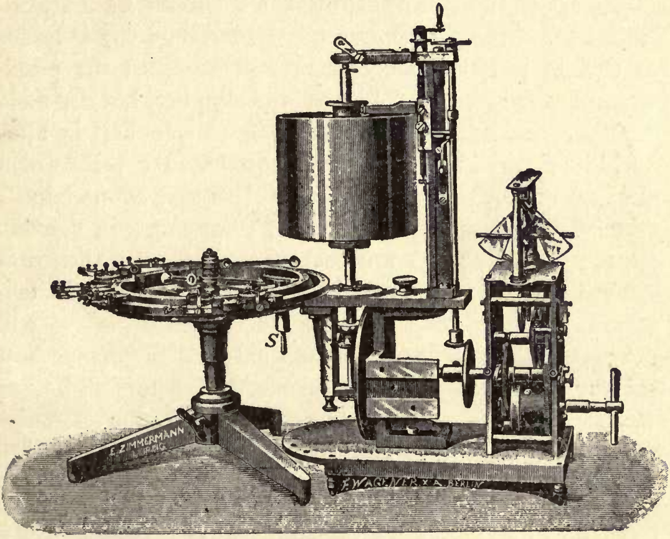


Fig. 72
From the catalogue of Zimmermann, Leipzig, Germany

the purposes of experimentation with time perception. This part of the apparatus will be referred to again in connection with the supplementary experiments under Exercise XXIII.

For ordinary laboratory purposes it will be found convenient to use a simple drum not connected with clockwork and to drive this with an electric motor. Such an arrangement can not be relied upon, it is true, to give as uniform speed as clock-work, but it does not need to be wound during the course of the experiment and it is a very much cheaper arrangement than any which is driven by clock-work. It is capable of a great variety of modifications, and two or three drums of this sort will make possible a very large number of combinations for recording purposes. The drum-shaft should be supplied with either a belt-wheel or a cog-gear. The cog is better for certain purposes since it provides against the possibility of any slipping, but for most purposes the simple belt is altogether adequate. By means of a series of pulleys and countershafts such as are represented in Fig. 73, any rate of movement in the drum can be secured. Commonly two or three intermediate pulleys will be placed between the drum-shaft and the electric motor. The fan motor referred to under Exercise III, (page 52) serves very well to drive this drum.

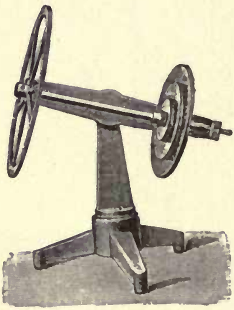


FIG. 73
From the catalogue of Zimmermann, Leipzig, Germany

A number of motors have been devised which are so regulated that they move at uniform speed. The oldest of these was designed by Helmholtz and is known as the Helmholtz rotation apparatus. It consists of the ordinary parts of an electric motor with an additional part which regulates the amount of current that is supplied to the motor. This regulator consists of an arm which can move outward by centrifugal force wherever the shaft of the motor is set into rotation with sufficient speed. As soon as this centrifugal arm moves outward from the shaft it breaks an electric contact and introduces a certain amount of resistance into the electric circuit which drives the motor. The reduction of the current tends to reduce the speed of the motor. As soon as the speed is reduced the centrifugal arm falls back again against the shaft and the extra resistance is cut out. The motor once more begins to move more rapidly, the centrifugal arm again moves away from the shaft and introduces the resistance, and so on. The point of regular rotation in this apparatus is reached when the centrifugal arm makes a continuous light tapping due to its constant movement away from the shaft and back again. Recently devices have been worked out for regulating a motor by means of a tuning-fork.

The drum and its motor being provided, the next step consists in the preparation of a suitable surface for taking the record. A strip of heavy glazed paper, no wider than the drum, should be pasted around the drum. In doing this care should be taken to bring the paper as smoothly in contact with the drum at all points as possible, and to paste it under such tension that it shall be held firmly in position against the metallic surface. The paste should not be applied to the surface of the drum but along the line of contact of the two ends of the paper. Instead of pasting a sheet of paper on a single drum, it is very convenient, especially if a long record is to be taken, to carry a belt of paper between two drums, as indicated in Fig. 74. If a drum *A* is driven by means of clock-work or by means of an electric motor, it will drive the drum *B* which does not need to be connected with the driving device except through the belt of paper *C*. In practical operation this belt of paper can be made as long as the strength of the paper will permit. Belts of paper 70 feet long have been utilized, although care must be taken in the use of such a long belt not to bring too great a strain upon it at any part of the belt during the process of taking or fixing the record. The adjustment of the belt of paper on these

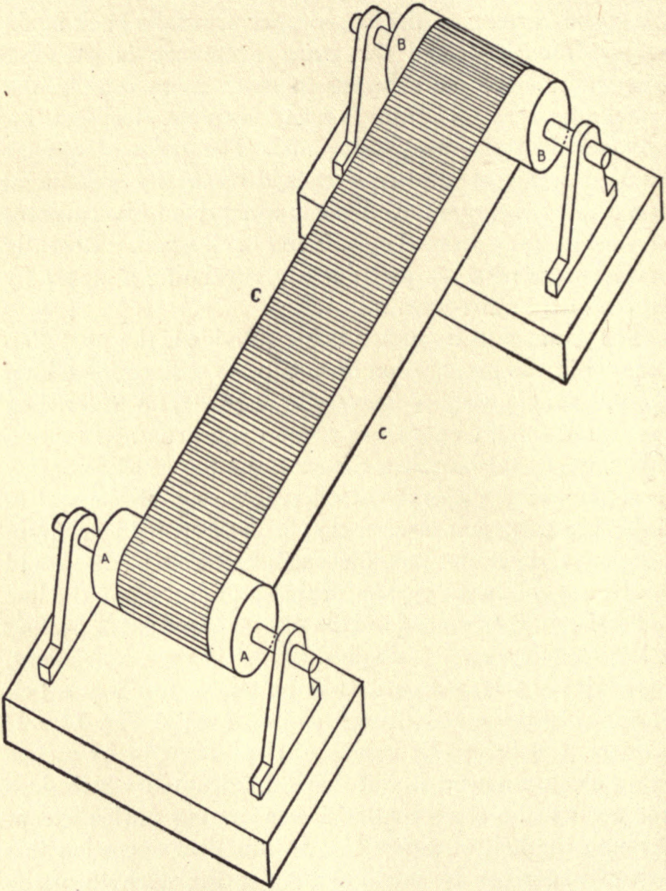


Fig. 74

two drums requires some manipulation. In the first place, the two drums must be in alinement and the ends of the paper must be carefully pasted so as to make a true joint in the paper. The two drums will probably need to be adjusted after being set up. They may be brought into approximate position and the belt slowly rotated. If the belt tends to run off the drums, the drums should be readjusted with reference to each other on the following principles: If the belt tends to run to the right or left on the remote drum, the near drum should be set in a direction opposite to that in which the paper tends to run. Thus, if the paper runs toward the right of the remote drum, the drum near at hand should be moved gradually toward the left. If the movement is made gradually, the paper can usually be brought into a position of equilibrium very readily. Rapid movements are unfavorable to the adjustment. If instead of running off of the remote drum, the paper tends to run to the right or left on the drum near at hand, this tendency may be corrected by moving one or the other end of the drum toward or away from the remote drum. The belt travels in the direction of least tension, so that if the belt tends to run off at the right side of the drum near at hand, it indicates that there is less tension on the right-hand side of the belt than on the left-hand side. The right-hand end of the drum should, therefore, be drawn away from the more remote drum so as to increase the tension of the belt on the right side. With a little practice the experimenter can learn to manipulate the belt easily, and to adjust it so that it will run smoothly and in a given part of the two drums. The most important condition for this desirable result is the careful pasting of the strip of paper at the outset of the experiment.

When the belt is adjusted or the paper pasted upon the kymograph, the next step is to lay on a coat of lampblack. A variety of forms of combustion can be employed for producing a layer of lampblack. In every case the heat should be applied to the paper only where the paper is in contact with the drum. The metal drum serves to conduct away the heat and prevents the paper from burning.

The finest grade of lampblack can be produced by burning camphor under the paper and rotating the drum at a considerable speed, carrying the paper through the smoke. Camphor is more expensive than some of the other substances which can be employed. Ordinary illuminating gas gives a very good fine layer of lampblack. The form of flame which is most advantageous is one which gives the least possibility of complete combustion of the illuminating gas. A wide flame supplied with gas through large holes is the most desirable flame for this purpose. The drum should be rotated so as to draw the flame underneath the drum, and the flame should be held in such a position that it is in contact with the paper only at the red, upper part of the flame. Coarser and less desirable forms of lampblack may be produced by burning under the paper kerosene or even turpentine. The latter produces very rapidly a thick layer of lampblack, but it is coarse and therefore not so advantageous for delicate work as some of the other forms mentioned. Automatic devices for smoking strips of paper have from time to time been described; they are all very complicated and can be dispensed with, especially if one uses belts instead of single sheets of paper.

When the tambour point has been allowed to trace on this lampblack surface and the record has thus been secured, it may be made permanent by shellacing or varnishing the lampblack surface. The most convenient device for shellacing or varnishing consists in the apparatus represented in Fig. 75. A tray *T* is mounted in a table *S* and may be covered when not in use by a cover. At the bottom of the tray a rubber tube is carried, as indicated by

R, to a bottle which contains the liquid varnish or shellac. This bottle should be suspended by means of a string which passes through the pulley *P* and is fastened at the bottom to a pedal *M*. When it is desired to shellac a strip of paper, the foot is placed upon the pedal *M*, and the bottle containing the varnish or shellac is raised to a level higher than the tray *T*, and the varnish runs into the tray *T*. As soon as the foot is removed from the pedal, the

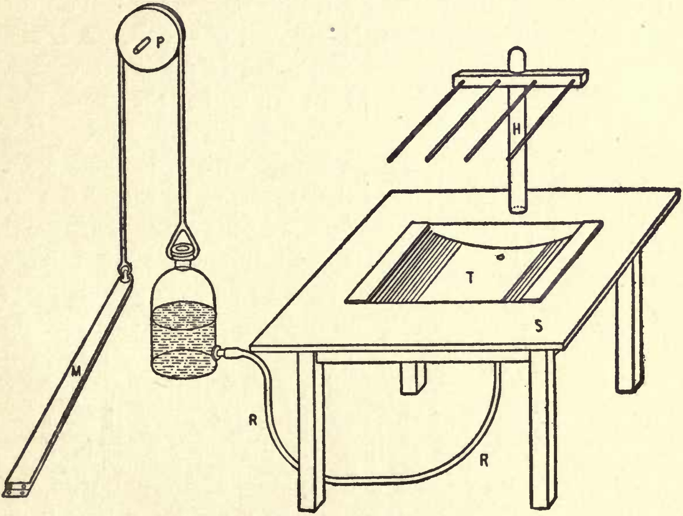


FIG. 75

bottle sinks to a level lower than the tray and the varnish runs back into the bottle. It is not necessary to immerse the paper taken from the kymograph in the varnish or shellac. It is enough that the varnish or shellac be brought into contact with the back or unsmoked surface of the record. This is accomplished by drawing the strip of paper, after it is removed from the drum, through the tray so that its unsmoked surface comes in contact with the shellac. The shellaced paper may be hung in a holder above the tray and allowed to drip into the tray, thus saving all the unused fluid. If it is desired to keep the records as permanent records, it will be necessary to provide a good quality of shellac. If the record is merely for temporary use any thin transparent varnish will serve the purpose.

If the record is made on a long belt as shown in Fig. 74, the simplest method of fixing it is to shellac the belt on the unsmoked surface while it is still on the drums. A bottle of shellac is provided with a bent tube in the cork, as shown in Fig. 76. From this a small stream is poured on the back or unsmoked surface of the long strip and spread by means of a large brush so as to cover all parts of the paper. If this process of shellacing is undertaken with some deliberation there will be no danger of the paper being torn or of covering the drums with wet shellac. If the work must be done hurriedly, the drums are likely to be covered with the shellac and it will be necessary to clean the drums from time to time by buffing them. It will be especially necessary to guard against the tearing of the paper, which is, of course, very much weaker when wet with the shellac than it is when dry.

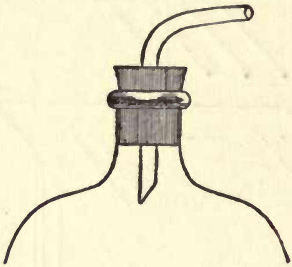


FIG. 76

The record which is secured by allowing a tambour point to trace upon a moving surface will depend for its length upon the length of the movement recorded and the rate of movement of the record surface. If this surface is moving rapidly, the record of a given movement will be long drawn out; if the surface moves slowly, the record will be much condensed. If the surface moves at a uniform rate, the various parts of the record will be directly comparable; if the surface moves at an irregular rate, comparison of the various parts of the record can not be directly made. It is often desirable to state the results from records obtained in this way in absolute terms and to provide, as indicated in an earlier paragraph, against the possible irregularities in the movement of the receiving surface. In such cases, a time-line from a vibrator of known rate may be traced on the paper along with the tambour record.

The simplest method of securing a standard time-line

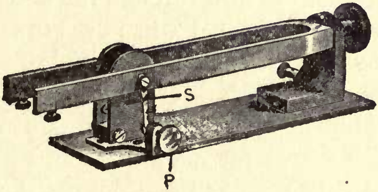


FIG. 77
From the catalogue of C. H. Stoelting Co., Chicago

is to use a Jaquet chronometer manufactured by Verdin, in Paris. This is a small stop-clock with a lever attachment which moves every second or every fifth of a second according as it is set for the one interval or the other. The lever can be made to trace directly on a kymograph.

Another method of securing a time record is to attach a point of pendulum ribbon, similar to that described in connection with the tambour, to a tuning-fork or other vibrator and hold this point during the vibration of the fork or rod against the record surface. If a very short unit of time is desired, a 100-vibration fork or a 500-vibration fork may be used. The difficulty with such a contrivance is that the time record is very short, or else the experimenter must devote himself to keeping the fork in motion. A device for keeping the fork in motion is provided in the electric fork, which operates on the same principle as the vibrator described on page 99. Such a fork is represented in Fig. 77. It consists of an ordinary fork mounted on a frame and having between its prongs an electromagnet. The current for this electromagnet enters through the fork and passes from the fork to the magnet, whenever contact is made between the spring *S* and the plate, which can be adjusted by means of the screw *P*. *S* and *P* will be in contact whenever the prongs of the fork vibrate outward. As soon as *S* and *P* come together, the current passes from the fork through the magnet and back to the battery. The magnet will now attract the prongs of the fork inward with a strong impulse. The rate at which the prongs of the fork respond to the attraction of the magnet will be determined by the fork's natural rate of vibration. The energy for the movement will be supplied by the magnet. As soon as the prongs of the fork vibrate inward in response to the attraction of the magnet, the contact between *S* and *P* will be broken, the electromagnet will cease to attract the fork, and by its own elasticity the fork will tend to vibrate outward again. In vibrating outward the contact at *S* and *P* is established again and the process is indefinitely repeated.

An electric fork has two uses; it may be used directly to make a tracing on a kymograph or it may be used indirectly to make and break an electric current, this current in turn being used to make the record on the drum.

If the fork is to be used directly, a point is attached to the end of one of the prongs, and the fork is held in contact with the drum. A convenient means of holding the fork is the clamp shown in Fig. 78. The shaft *R* passes through a hole drilled through the base on which the electric fork is mounted. The fork is held firmly on this shaft by means of the screw *S*. This rod *R* is clamped by the screw *I* to a second rod *P*, which is hollow and fits over the third rod *T*, which is held by the standard. From *P* and *T* two arms project, as shown in *O* and *Q*. Between these arms is the set-screw *N* which controls the distance between them. *T* is clamped to a holder. the fork is fastened at *RS*, and by means of *N* the position of the fork may be nicely adjusted up or down so as to regulate the pressure of its point against the smoked paper.

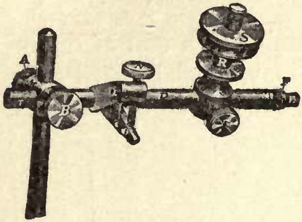


FIG. 78

From the "Studies from the Yale Psychological Laboratory," Vol. IV

If the fork is to be used indirectly, a marker is required. A simple marker is represented in Fig. 79. An electromagnet *m* is connected in series with the electric tuning-fork. A current passes through *m* every time a contact is made at the fork. Directly in front of the metallic core *e* of the magnet *m*, is placed a spring point *a*. The marker *a* is held by its own elasticity away from the magnet, but not far enough away to be beyond the range of attraction when the current passes through the magnet. As a result, the marker *a* moves toward the magnet whenever a current passes through the coil and oscillates in the opposite direction when the current in the coil is interrupted. Very often the spring which draws the marking point away from the magnet is a coil spring. The moving point *a* is made to trace on the smoked paper surface.

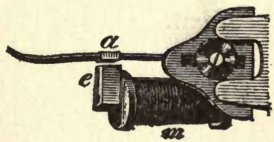


FIG. 79

Various forms of markers have been devised. In general if one's equipment is limited, it is better to procure a small marker. This can be used for either a slow or a rapid record, whereas a heavy marker has too great inertia for rapid vibrations.

The principle of the electric tuning-fork and of the interrupter described on page 99 may be elaborated so as to give any desired rate of motion and any desired strength

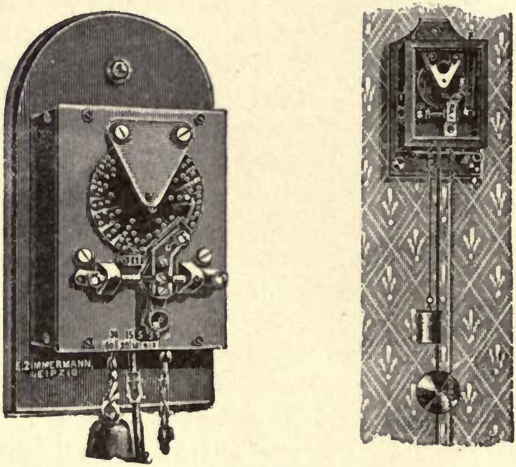


Fig. 80

From the catalogue of Zimmermann, Leipzig, Germany

of current. One of the most elaborate instruments constructed on this principle is the Kronecker interrupter. This interrupter is supplied with mercury contacts for making and breaking the current. It is also supplied by means of an additional pair of contacts with the means of making and breaking a current entirely separate from that which drives the vibrating rod. It is supplied with a system of tubes by means of which the mercury contacts are kept clean by a flowing stream of water that passes over these contacts. This stream of water is supplied from a small reservoir which stands a little above the mercury contacts. From this reservoir the water is conducted by tubes directly across the mercury. The platinum needles pass through the water and into the mercury, the contact not being completed until the needles reach the mercury. If it is desired to secure intervals of time of a second or longer, a pendulum may conveniently be used. A contact pendulum manufactured for this purpose and giving series of contacts for any interval from one half of a second to a minute is shown in Fig. 80. With each oscillation of the pendulum the dial is advanced one degree. An outer series of metallic posts is so arranged that with each movement of the dial a post comes in contact with the catch. Other series of posts on the dial are separated by longer intervals. The catch may be adjusted so as to connect with any series desired. The catch controls an electric current which is thus regulated by the clock for any long interval desired. A simple contact may be arranged with any pendulum by allowing it to sweep through a meniscus of mercury. In such a case one wire should be connected with the pendulum, the other with the mercury.

It is sometimes possible and desirable with markers which record long intervals and consequently move slowly, to make a record by means of a pencil or pen on a paper which is not smoked. The pencil used for such purposes is mounted at the end of a flexible metal strip which presses it against the paper and is at the same time sufficiently elastic to avoid excessive friction. A pen may be similarly mounted. The best form of pen is one which feeds out the ink through a capillary opening. A glass tube drawn to a fine point makes a very good pen. Metallic pens with holes of very small caliber can also be used.

The records which are made by a tambour can be used not merely for the purpose of determining the duration of movements but also for the purpose of studying the intensity and form of these movements. The intensity and form are, however, by no means as directly recorded as the rate, for the tension of the tambour rubbers increases rapidly after the rubber has been stretched even very slightly. The last part of the movement of a tambour lever represents not merely the energy necessary to lift the lever itself, but in addition the energy necessary to stretch the rubber. For this reason the quantitative use of a tambour record to show the amount of movement in-

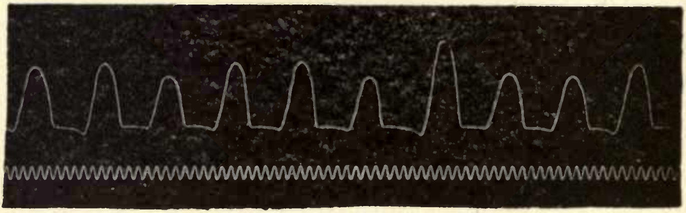


Fig. 81

volves complex corrections. In a general way a higher movement means a greater amount of energy of movement, but the amount of energy expended is not directly proportional to the movement of the tambour recorder. A record is presented in Fig. 81 showing a regular time-line from a 100-vibration fork. A second line shows the tambour record of an upward and downward finger movement which is executed as rapidly as possible. It will be seen that the successive finger movements differ from each other in intensity and in regularity of form as well as duration.

It remains to mention in connection with the kymograph and its accessories, standards for carrying the various recording pieces. The simplest standards consist merely of heavy metallic bases into which are set rods. The best bases for such standards are heavy tripods. More convenient than these simple standards is one which can be raised or lowered by means of a screw. Such screw standards may be connected with kymograph drums so as to move the tracing points automatically as the drum revolves.

EXERCISE XII

A—APPARATUS AND PROCEDURE

The simplest contrivance for securing records of the rate of the heart-beat consists in a recording tambour, such as was described under the last exercise, and a rubber tube connecting this recording tambour with a thistle tube such as is shown in Fig. 82. The large end of the thistle tube should be placed against the skin of the neck just over the carotid artery and should be held in position by rods and clamps fastened to a table or portable base. The skin of the neck serves as a cover for the thistle tube, which is thus converted into a tambour, and the pulse of the carotid artery will at intervals compress the air in the thistle tube, with the result that the recording tambour will be set in motion at the same rate as the pulse. The difficulty with this arrangement is that any movement of the reactor's head and any motion of swallowing or unusual breathing will change the pressure of the air within the thistle tube and complicate the pulse record. The first difficulty can be very largely overcome by fixing the head in the head-rest already described under Exercise II, page 31. No easy means of overcoming the difficulty that arises from swallowing can be provided. It is better for this reason to utilize the pulse in the radial artery.

FIG. 82

The radial pulse is not strong enough and the skin of the wrist is not smooth enough to allow the use of a thistle tube, and a special contrivance must be provided for recording this pulse. The simplest contrivance that can be used is a cork fastened to an ordinary recording tambour. If one end of the cork is fastened to the rubber surface of the tambour by a drop of wax, and the whole tambour is held in a clamp in such a position that the free end of the cork

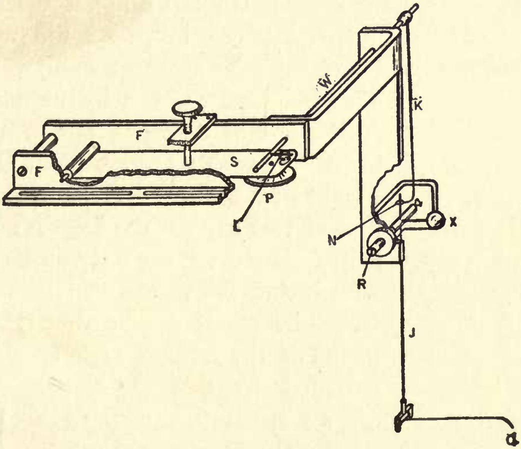


FIG. 83

presses against the radial artery, a record may be taken with a recording tambour which will correspond in rate and in intensity to the rate and intensity of the movement induced in the receiving tambour by the pulse.

Fig. 83 shows a more elaborate contrivance for recording the radial pulse. A spring *S*, with a small plate *P*, is brought by means of a frame *F* into contact with the radial artery at the point *P*. Bands are provided which will hold the frame firmly against the arm. These bands are not represented in the figure. Passing through a wire hook *L* connected with the spring is a small rod which is fastened perpendicularly to the long bar *W*. At the other end of *W* is a long arm *K*, which serves to magnify the movements communicated by the spring at *L*. This enlarging lever may be made to carry a point which will trace directly upon a smoked surface, or it may be connected with other enlarging devices before the tracing is made. A very effective enlarging device is represented in Fig. 83. The end of the lever *K* is made into a loop as shown at *N*. Through this is allowed to pass a rod which is weighted on a short perpendicular arm by a small weight *X*. This weighted rod has its fulcrum at *R*. At the end of its lower long arm *J* is a loose joint with a tracing point *O*. The weight draws the rod *RJ* into the position of rest against the loop *N*. If the loop *N* is moved, the rod will be moved with it and the record can be taken at *O*. The result will be that the movements of the lever K are a second time enlarged by this additional leverage. In the use of such an apparatus, which is technically known as a sphygmograph, care must be taken to have the relation between the arm and the recording surface perfectly constant. If the arm is allowed to move in any degree, the tracing at the end of the pointer will be affected by the arm movement as well as by the movement of the pulse, and a source of error will thus be introduced in the readings.

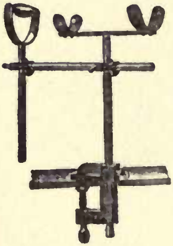


FIG. 83*a*

A simple device for holding the arm in a fixed position consists of an arm-rest made up of two U-shaped brackets shown in Fig. 83*a*, through which the arm is allowed to pass and lie in a comfortable position. The hand should clasp firmly the holder, which can be adjusted by means of a rod to any desired level. A sphygmograph attached to the arm held in such a rest as this can be adjusted so as

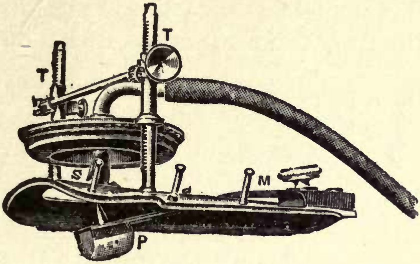


Fig. 84
From the catalogue of Zimmermann, Leipzig, Germany

to trace upon a drum, which has been set in the proper position with reference to the arm-rest.

There are other sphygmographs. In some of them the movement of the spring which presses against the pulse is communicated to a tambour and thus recorded on a kymograph. Such a sphygmograph is shown in Fig. 84. *P* presses against the artery with a pressure controlled by

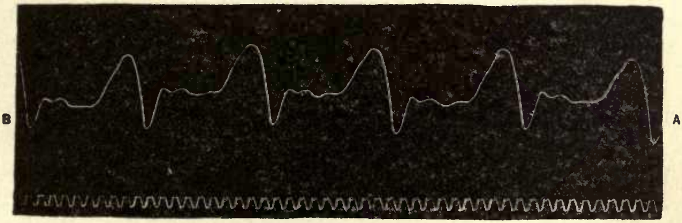


Fig. 85

the spring *M*. As *P* moves up and down it acts upon the tambour shown in the figure. The frame is to hold the apparatus on the arm.

B—RESULTS

Fig. 85 shows a typical record from the sphygmograph. The following table shows the change in heart-beats resulting from the various forms of excitation:

1. Multiply 31 by 17.
2. Multiply 27 by 13.
3. Strong disagreeable odor.
4. Pleasant odor.

	Average number of heart-beats in 5 selected periods of 10 seconds during 2 minutes preceding stimulus		Average number of heart-beats in each 10 seconds during 30 seconds immediately after stimulus		Average number of heart-beats in 5 selected periods of 10 seconds during 2 minutes following stimulus	
		M. V.		M. V.		M. V.
1	14.1	0.4	15.6	0.7	15.2	1.4
2	14.6	0.7	14.7	0.9	14.8	1.0
3	14.3	0.3	17.3	1.1	16.1	1.3
4	14.0	0.5	16.2	1.2	15.5	1.1

C—SUPPLEMENTARY EXPERIMENTS

A second type of apparatus for securing records of vasomotor changes is the plethysmograph. This is made to enclose some part of the body and record changes in the volume of a part of the body which it encloses.

The simplest plethysmograph is made for the finger. It consists in a small glass cylinder. This cylinder has a thin rubber hood extending into it to receive the finger. This rubber hood is fastened to the edge of the cylinder so that the whole makes what may be called a hollow tambour. The finger of the reactor can now be inserted in the rubber hood, and the finger and cylinder are held firmly in position by means of the necessary arm-rests and clamps. If the volume of the finger increases or decreases, as it will with each pulse-beat, or if it undergoes more gradual changes through the withdrawal of the blood, or through an excessive flow of blood to the finger, the air between the wall of the cylinder and the rubber hood will be driven out or drawn in each time there is an increase or decrease in the volume of the finger. If a recording tambour is connected with the cylinder, changes in the volume of the finger will be recorded.

The principle employed in this finger plethysmograph

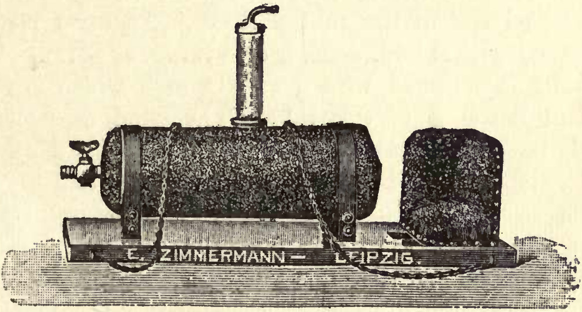


Fig. 86

From the catalogue of Zimmermann, Leipzig, Germany

can be applied to a larger apparatus for the arm. Fig. 86 represents an arm plethysmograph supplied by Zimmermann. The arm is inserted in the large cylinder and held in position by the elbow rest. The cylinder contains a large rubber sleeve, and the space between this sleeve and the walls of the cylinder is filled with water. The water rises into the glass tube extending vertically out of the cylinder, and from this glass tube connections are carried to a recording tambour. Rubber sleeves for this plethysmograph can be made at any rubber establishment by using a mold of proper size made of polished wood or, still better, of glass. The objection to this form of plethysmograph is that the rubber sleeve or sack does not fit closely around the hand, especially at the end, and error is likely to be introduced into the record through involuntary movements of the fingers. Such movements result in changes in the volume of the rubber sack, which are in no way due to changes in the volume of the arm. One method of reducing this error to its minimum is to close the hand firmly about some solid object and keep it clenched inside of the rubber sleeve.

A still better device consists in eliminating altogether the closed end of the rubber sleeve. An outer metallic cylinder, open at both ends, is drawn over the arm. This cylinder is supplied with a rubber sack which is made fast at the ends of this tube. The hand thus extends freely beyond the rubber sack. If, now, water is allowed to fill the cylinder between the rubber sack and the wall of the cylinder and to rise for a short distance in a vertical tube, similar to that shown in Fig. 86, a record can be taken as in the other cases by means of a recording tambour. This form of plethysmograph has the advantage over the finger plethysmograph of including a larger part of the body and, therefore, insuring a greater change in volume. It has a decided advantage over the Zimmermann plethysmograph in that no involuntary hand movements will change the volume of the arm.

A form of apparatus which has recently been described by Professor Henderson could be used to great advantage in experiments on the relation of circulation to conscious processes. The apparatus, called a recoil table, consists of a table on which the reactor lies. This table is suspended or supported on flexible supports so that it may readily swing through a small distance. Levers are connected with the table so as to record any movement.

Whenever the heart of a reactor drives the blood into the aorta there will be a recoil of the body, in accordance with the familiar physical principle of action and reaction, in a direction opposite to that in which the heart forced the blood. This recoil of the body is communicated to the table on which the reactor lies and through the leverage is recorded on the kymograph.

A form of apparatus required in the third accessory experiment of this exercise for measuring changes in the rate of intensity or respiration is known as a pneumograph. A very satisfactory pneumograph is represented in Fig.

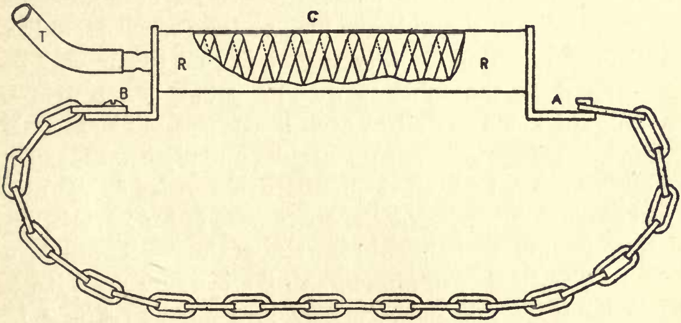


FIG. 87

87. It consists of a coiled spring *C* twenty-five to forty centimeters in length, covered with a light rubber tube *RR*, which is entirely closed at one end and at the other end is fastened firmly around a small metallic tube which permits connection with a rubber tube leading to a recording tambour. From the ends of the coiled spring *A* and *B* extends a chain which is fastened about the thorax of the reactor. When the pneumograph is in position, the coiled spring *C* should be under slight tension. Any change in the volume of the thorax will result in a change in the expansion of the coiled spring *C*, and as a result the volume

of the air column within the rubber tube *R* will be modified and the changes in this air column will be recorded at the recording tambour. By using more than one pneumograph, tracings can be made for different parts of the thorax during a single act of respiration. By using at the same time a pneumograph and a plethysmograph or sphygmograph, parallel tracings can be made for respiration and the heart action.

For reasons which were pointed out in the earlier discussion of tambour records (page 158), the records from sphygmographs, pneumographs, and plethysmographs can not be regarded as direct quantitative records of the amount of movement of the pulse or lungs. The recoil table has a distinct advantage in this respect, in that the amount of movement of the table is directly proportional to the amount of blood moved at each heart-beat. The records from sphygmographs, pneumographs, and plethysmographs may, however, be treated quantitatively so far as the rate and general intensity of the movement is concerned.

For a study of changes in the size of the pupil of the eye the best method is to photograph the eye in a good light. The light for this purpose may be sunlight reduced in intensity by passing it through a screen of blue glass, the screen being of any thickness necessary to prevent discomfort on the part of the reactor.

If the eyes are not photographed, measurements may be taken by observing the eyes of the reactor through a reading telescope placed at some distance in front of the reactor.

EXERCISE XIII

A—APPARATUS AND PROCEDURE

The steadiness of the finger can be measured by allowing it to rest upon the rubber surface of a receiving tambour, any movement of this tambour being carried to the recording tambour and there traced upon smoked paper. The only precaution required is that the pressure shall not be so great as to bring the finger into contact with the bottom of the tambour, nor so light as to make no impression on the rubber. Another somewhat simpler device is to allow the finger to rest on one end of a lever which is held in position by means of a fulcrum and traces at the end opposite that which is in contact with the finger, on a kymograph. Slight movements of the finger can be magnified in this way as much as desired. In like fashion, head movements may be recorded by connecting the head by means of a rigid rod with a receiving tambour or with a tracer which marks directly on a recording surface.

Various forms of planchettes have been devised. The simplest consists of a board hung from the ceiling of the room by a long string or wire. A board thus suspended by a long string can be moved very freely, and its movement will be practically in a straight line through any ordinary distance such as would be required for the experiment. Another device for furnishing a recorder for hand or arm, which can be moved with very little friction, consists of a glass plate supported on a second glass by large balls, such as are used for ball bearings. After securing by

Fig. 88

one of these means a surface which can be moved with relatively little friction, it is necessary to provide a tracing point. This tracing point should add as little as possible to the friction of the movement. In some cases a pointer has been allowed to trace upon smoked paper. The paper is smoked on a kymograph and is spread out on a flat surface under the pointer. The pointer may be of the simple sort described in discussing tracing points for tambours or it may be a stylus especially designed for use with the planchette. A very convenient form of stylus consists of a rod which passes freely through a glass or metal tube. Such a stylus always rests on the receiving surface with its own weight. The metallic or glass tube through which it passes is fastened to the planchette. As the planchette moves backward and forward the pointer will trace its movements on the smoked paper. The smoked surface may be dispensed with if the stylus is made in the form of an ink pen. For this latter purpose a special pen-point must be provided which will trace equally well in any direction. The ordinary pen-point will not serve because it traces freely only in one direction. Fig. 88 represents a form of pen-point which answers the purpose. It consists of a small metal rod turned down to a point into which a groove has been sawed as represented at *G*. The two points *P* and *P'* have been bent together so that they are nearly in contact. A hole which serves as a reservoir for ink is drilled at the upper end of the slit between the points. The size of this reservoir is determined by trial. If it is too large the ink is forced out too rapidly. If it is too small it requires very frequent refilling. Such a pen as this should be prepared for making the record by being filled with some thin fluid ink. The best ink for the purpose consists of a water solution of one of the aniline dyes. Such a pen as this will mark freely in any direction, and the amount of ink it will carry is quite adequate for an ordinary record.

B—RESULTS

A number of very striking records of involuntary hand movements are reported in Jastrow's *Fact and Fable in Psychology,* pp. 307–336. One of these figures is reproduced in the author's *Psychology, General Introduction,* page 187.

C—SUPPLEMENTARY EXPERIMENTS

The apparatus necessary for the supplementary experiments suggested in connection with this exercise is usually some form of tambour. Thus, if a tambour is pressed against the cartilages of the larynx, a record will be secured of the movements of the muscles of the larynx. Special frames have been devised for holding the tambour in position upon the larynx or against the other parts of the neck. One such, devised by Rousselot for recording upward and downward movements of the larynx, is represented in Fig. 89.

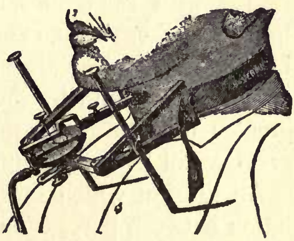


Fig. 89
From the catalogue of Verdin, Paris, France

In experiments with the tongue, it is desirable to provide some means of inserting the whole receiving tambour in the mouth. For this purpose rubber bulbs have been devised of the form shown in Fig. 90. These can be taken into the mouth and can be held between the tongue and he roof of the mouth or between the tongue and the teeth.

Such rubber bulbs are in essence tambours in which all of the surfaces are more or less flexible. Any compression of the bulb will drive the air out into the recording tambour.

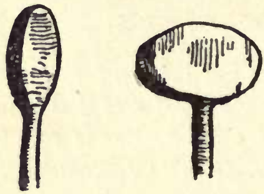


FIG. 90

From Rousselot's "Principes Phonétique Expérimentale"

Dynamometers for measuring the strength of movements are of various forms. One of the simplest forms consists in a double spring and recording dial shown in Fig. 91. This is grasped in the hand and pressed together as the hand closes.

Instead of taking merely the record of a single compression, devices may be attached to this dynamometer for adding up the movements made in a number of successive efforts; or instead of a recording device directly connected with the dynamometer, a pointer may be carried to a recording surface and the amount of work done may be recorded by tracings on smoked paper.

It will be found by the use of such apparatus that the greater the stimulus affecting the organs of sense, the greater will be the amount of work which can be done.

An illusion which serves very well to illustrate the relation between perception and change in muscular tension appears whenever one lifts two blocks which are of the same objective weight but are of unequal size. Quantitative methods of determining the amount of this illusion can be worked out by presenting to the observer a series of weights intermediate in size between the large and small weight. The intermediate series should range in objective weight by short stages from 30% less than the weights to be

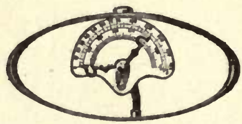


FIG. 91

compared to 30% above. Ten to fifteen weights of this sort being presented to the observer, he should be allowed to select those of the intermediate weights which seem to him to be equal to each of the two weights which constitute the illusion. In one case, for example, where the primary weights were 55 grams, it was found that the large weight seemed to the observer to be equal to 45 grams, whereas the small weight seemed to be equal to 65 grams. The illusion must therefore be equal in this

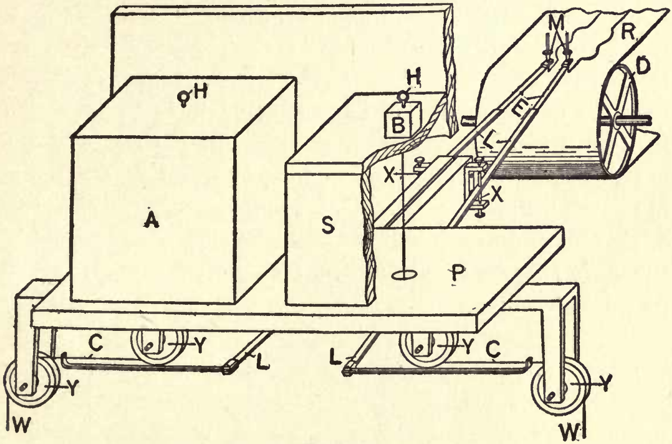


Fig. 92

case to 20 grams, which is somewhat more than 36% of the objective weight.

A more productive method of dealing with this illusion is to attach to each of the two weights, levers which will record the way in which the observer lifts the weights when he judges of their intensity. Fig. 92 shows an elaborate apparatus for recording the movements of the observer in testing these weights. A large weight *A* stands upon a platform *P*. By the side of *A* is a shelf *S* upon which is placed a small weight *B*. The purpose of this shelf is to bring the small weight *B* to the same level as the large weight *A*. Each weight is supplied with a screw-eye *HH*, so that when the subject lifts the weights he may have the same type of contact in both hands. Strings pass down, as shown on one side, from each of these boxes over pulleys *YY*. These strings are held in position by weights not shown in the figure but fastened at the ends of the thread at *WW*. The threads are connected with compound levers *LL* which, as seen in the figure, trace lines upon the paper, giving a record as indicated at R. This record makes a comparison between the two movements very easy. When both boxes are at rest the two levers make straight, parallel lines as indicated in the drawing. When they are lifted they describe curves which in form and in time indicate in detail the mode of lifting the weights. Typical records from this apparatus are described and discussed by Mr. Loomis in the *Yale Psychological Studies*, New Series, Vol. I, No. 2, pages 334–348.

EXERCISE XIV

A—APPARATUS AND PROCEDURE

The simplest device for securing a record of rapid movements of the fingers is a contact key such as that represented in Fig. 93. This spring key has a metallic connection at the wires W^1 and W^2 with a battery which supplies a current and with a marker which records on a kymograph whenever a contact is made at the two points on *P* and *R*. The distance between *P* and *R* should be made as small as possible so that the electrical contact may be made as soon as the fingers press down upon the plate *R*. The record of the movement of the fingers obtained at the marker should be compared with the standard time-line derived from some vibrator, either a tuning-fork or a vibrating electric rod.

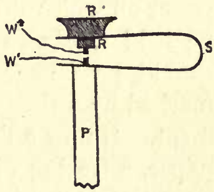


Fig. 93

The apparatus for measuring the rate at which plain lines are drawn by a reactor, consists in a wide strip of paper which is drawn forward by a kymograph under a platform upon which the hand of the reactor is supported. The rate of the paper should be indicated by means of a time-line which is traced on the edge of the paper by means of a pencil or ink marker such as that described on page 155. If, while the paper is moving, the reactor draws on the paper with a pencil lines perpendicular to the direction in which the paper is traveling, each line which is drawn on the paper will be drawn out into a record which is in its form a resultant of two movements—the movement of the paper, which is of known rate, and the movement of the hand, which is to be measured. A determination of the rate of the hand movement from this record is very simple so long as the hand movement is strictly perpendicular to the line in which the paper is traveling. If the movement of the hand is in some other direction, it will be necessary to complicate the arrangements thus far described by inserting above the moving paper, first, a piece of carbon paper or a typewriter ribbon, and second, a piece of paper on which the line is to be drawn. The paper on which the line is to be drawn, should in this case be held firmly in a fixed position. The moving paper should pass beneath the carbon paper and should be marked by a time marker to indicate the rate of its movement. If now a line is drawn freely upon the upper fixed paper, a tracing will be produced by means of the carbon paper or typewriter ribbon on the moving paper. The line thus traced on the moving paper will, as before, be the resultant of the hand movement and the rate of the movement of the paper. The line drawn on the fixed paper will show the length and direction of the hand movement. Comparison between the line on the fixed paper and the line on the moving paper can now be easily instituted, and the rate of the hand movement can be determined.

An elaborate apparatus constructed on the principle just described is reported as follows by Mr. Freeman in the *Yale Psychological Studies*, Vol. I, No. 2, pages 303–307.

"Fig. 94 gives a general view of the apparatus. Two bars extending from the metal base *A* support the roll of paper and the spool of ribbon from which the strips *B* and *F* are unrolled. *B* and *F* pass across plate *A* to the drum *C* and the spool *S*, the latter being supported by the post *Q* and one not shown in the figure. The drum and spool are driven through spur-gear connections by the shaft *G*, which is in turn connected with a driving shaft. The apparatus is coupled into the driving shaft and uncoupled by a friction clutch

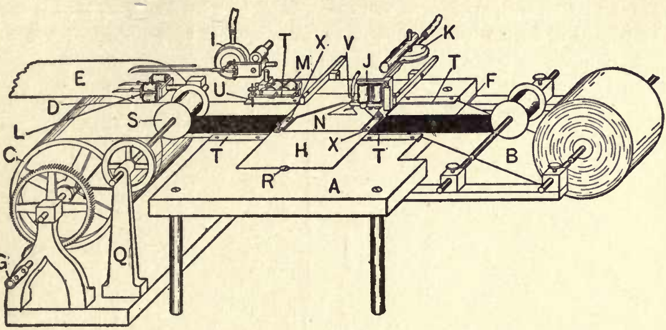


FIG. 94

of the type shown in Fig. 95. This consists of a large balance wheel *F* which is driven by an electric motor. The heavy balance wheel is necessary in order to maintain uniform motion when the apparatus is thrown into gearing. The balance wheel carries a hollow cone into which a solid cone (*W*) may be firmly set from above. The solid cone is in turn connected with the shafting (*S*) which drives the drum. By means of the handle (*H*), which holds the solid cone in a ball-bearing collar, the solid cone may be lifted out of the hollow cone, when the shaft (*S*) will be uncoupled from the driving wheel. On the other hand, when the solid cone is set firmly into the hollow cone, the shaft (*S*) will immediately be set in operation at the full speed of the driving wheel. The upward and downward movement of the shaft is taken up by a slot device at the upper end of the shaft. By means of this clutch the apparatus shown in Fig. 94 can be set in motion at full speed, and it can also be instantly set free when the record is complete.

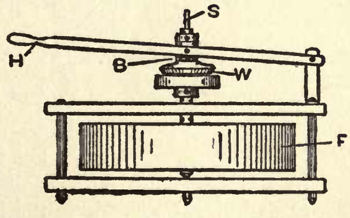


FIG. 95

"In order to hold in position the primary sheet of paper on which the reactor writes and to support the hand, a plate, *H*, is placed over the primary sheet. A rectangular opening, *N*, is made in this plate to expose a writing surface on the primary sheet. The plate, *H*, is hinged at the back of the main base by two bars, so that it may be raised to insert the paper. Fig. 96 shows it raised from the base.

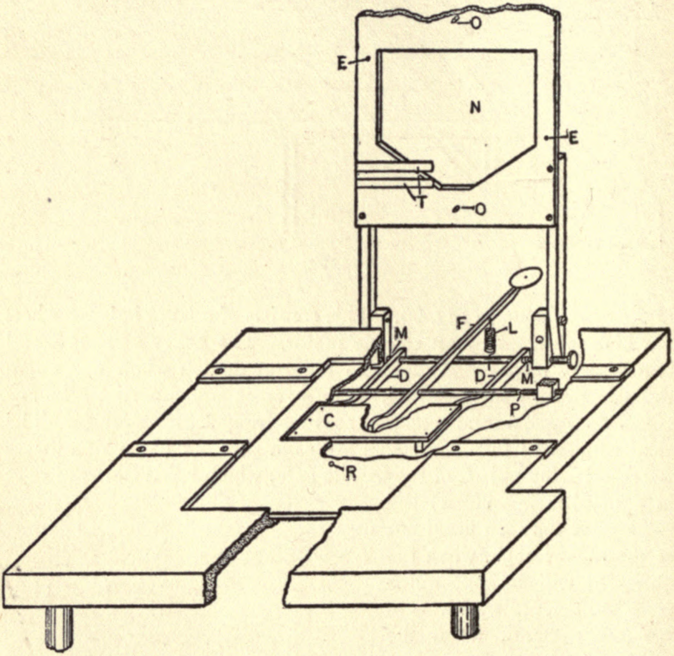


FIG. 96

Two small pins, *O*, *O*, pierce the primary sheet of paper and fit in the hole *R*, and one not shown in the figure, and keep the primary sheet from slipping when the strip and ribbon pass beneath it. These pins are above and below the moving strip. In order to get an even writing surface the plate is set into the main base, so as to lie flush with the general surface, and is held down by a screw, *R*, Fig. 94. The moving strip of paper and ribbon are also set below the surface in a channel which is cut in the main base. Two guides, *T*, *T*, on each side of the moving strip keep it straight. The upper ones are slightly adjustable, so as to suit minor differences in the width of the paper.

"In order to obtain a record of the relative position of the primary sheet and the moving strip, two pencil points are set through holes in the hinged plate, *H*. These pencil points make two dots upon the primary sheet and two lines on the strip. The points are shown in Fig. 94, *X*, *X*, and the holes through which they project in Fig. 96, *E*, *E*. The points are set on two flat springs and are adjustable with screws, so that they may be set against the paper with varying degrees of pressure.

"Since the speed of movement of the strip is not perfectly uniform, an electric marker writing tenths of seconds, *J*, Fig. 94, is pivoted to a post set on the hinged plate, *H*, and is adjusted by a screw so as to bring the writing point against the paper. It writes through an opening in the primary sheet upon the moving strip beneath. In order to keep the primary sheet from blotting this line, it is held up from the moving strip by two small brass clips, *T*, Fig. 96, and the time-line passes between these clips.

"The glass pen, *V*, Fig. 94, which is used for the time record, is a form of capillary pen. To prevent clogging and uneven flowing, the opening in the point is made fairly large and the flow of ink controlled by a regulating air chamber. The upper end of the glass tube is inserted in a rubber tube which allows the point to move freely, and the tube is connected with a tambour. The rubber head of this tambour can be raised or lowered by a screw, and the ink thus made to flow slower or faster.

"Besides the speed of the reactor's movements, it is desirable that the variations in the pressure of the pencil against the paper should also be recorded. The arrangement for securing a record of the pressure is shown in Fig. 96. Under the paper upon which the reactor writes is a small table *C*, set into an opening in the base. The opening in which this table is set is situated immediately below the opening, *N*, of the hinged plate, so that the table occupies all of the writing space. The table is capable of an upward and downward movement, for it is fixed to the two bars, *D*, *D*, which are in turn fixed to the axis working in the pivot joints, *M*, *M*. The radius of movement of the table is, accordingly, the length of the bars *D*, *D*, or 17 cm., and the direction of movement during a slight displacement is practically in a vertical line. The extent of movement of the table is magnified five times by means of the lever, *F*, which has its fulcrum at *P*. A disk on the outer end of this lever is in contact with the rubber of the tambour *K*, Fig. 94. The inner end of the lever, which is rounded, bears up against the table, making a sliding contact. In order to lessen the weight and consequent inertia of these parts, the table and its connections are made of aluminum. The long arm of the lever nearly balances the weight of the short arm together with the table and its supporting bars. The slight residue is counterbalanced by a light spring, *L*. This can be adjusted so that it will bring the table quickly back to position, but will not prevent a delicate response of the lever to a very light pressure on the table. The spring, *L*, as well as the tambour, with which a disk on the end of the lever is in light contact, are supported by a rod, shown in Fig. 94, fastened to the main base. The tambour is adjustable so that its head will just touch the lever when the table is in position. This apparatus responds with delicacy sufficient to easily record all the ordinary changes in pressure during writing. Tests with weights show that it will record changes in pressure of from 20 to 300 grams.

"The remainder of the apparatus for recording pressure is shown in Fig. 94. The receiving tambour, *K*, is connected with the recording tambour *I*, which writes on a long strip of smoked paper, *E*. This strip travels over the drum, *D*, and another drum 3.5 meters away. The drum *D* is clamped by an adjustable screw to the same shaft as the drum *C*, so that both of them can be driven together, or either one can be run separately by loosening the screw which clamps *D* to the shaft. Above the tambour pointer is a fixed pointer which traces a straight line with which to compare the pressure curve. The pressure curve is correlated with the speed curve on the moving strip, *B*, by means of one pointer of the double marker, *L*, which is in circuit with the marker *J*, on strip *B*."

For a full account of records obtained from this apparatus, and methods of measuring the same, Mr. Freeman's article should be consulted.

B—RESULTS

The following table shows in sigmas the time of contact of the various fingers with the key, and also the length of the interval between each of the contacts. The quantities in the table are averages from twenty-five cases.

Finger I (Index)		Interval after I		Finger II		Interval after II		Finger III		Interval after III		Finger IV	
Avg.	M.V.	Avg.	M.V.	Avg.	M.V.	Avg.	M.V.	Avg.	M.V.	Avg.	M.V.	Avg.	M.V.
NATURAL ORDER													
85	1.0	37	5.3	80	5.0	40	6.2	100	2.2	45	7.0	100	1.8
REVERSE ORDER													
75	1.2	116	9.8	82	1.1	89	1.5	127	3.1	51	2.3	99	2.0

The following table shows the average length of line drawn in twenty trials in successive tenths of a second.

1st 1/10		2nd 1/10		3rd 1/10		4th 1/10		5th 1/10	
Avg.	M. V.	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.
RIGHT HAND									
2.1	1.3	17.2	4.1	43.5	6.7	37.2	7.9	12.2	5.1
LEFT HAND									
1.7	1.2	11.3	6.2	31.1	7.9	36.4	8.1	9.4	3.2

C—SUPPLEMENTARY EXPERIMENTS

The experiments here suggested are referred to again in later exercises, especially in Exercise XIX. The apparatus is not different from that required in general for recording movements and measuring their characteristics.

EXERCISE XV

A—APPARATUS AND PROCEDURE.

The apparatus commonly used for measuring reaction time is, first, a timepiece that will measure very short intervals of time, and second, the accessories which make it possible to measure by means of this timepiece the interval which elapses between the signal to react and the reaction movements.

The simplest arrangement for measuring reactions requires no other apparatus than that which has already been described. Let a contact key, such as that used in Exercise XIV, be connected with an electric marker which records on a kymograph. The marker should be allowed to trace in parallel with the record of a tuning-fork. In this case the tuning-fork record should be made if possible from a fork vibrating at the rate of 500 times a second. Another marker should be introduced to record the moment at which the stimulation for the reaction is given to the reactor. This marker should be connected with a second key, which makes a sound that serves as the signal to react and at the same time completes the electric circuit passing through the marker. With these three records—that of the reaction key, that made by the tuning-fork, and that made by the apparatus which gives the signal for reaction—it is possible to determine the number of tuning-fork vibrations which lie between stimulus and reaction. Such determinations as would be possible with the arrangement just described involve a great deal of counting of tuning-fork vibrations; consequently, other forms of apparatus have been devised and are in common use, which obviate the necessity of such elaborate counting.

A simple and very convenient form of chronoscope which can be used in connection with a tuning-fork to obviate counting is the Ewald Chronoscope, which is represented diagrammatically in Fig. 97. Its essential parts are a pair of small electromagnets *M* which can be put in the circuit of an electric current which is made and broken by a 100-vibration fork. This pair of electromagnets, being supplied with an electric current every 1–100 of a second, can be made to set in oscillation a little plate *P* which hangs in front of the magnets and is drawn away from them by the spring *S* whenever the current is broken. The plate thus set in vibration is connected by means of a short rod with a fine toothed wheel which has the form of an ordinary clock-work ratchet. Each time the rod is thrown forward into this wheel it advances the wheel one tooth, so that the rate of the movement of the wheel will be one tooth in every 1–100 of a second. Connected with the ratchet wheel is a hand *T*, which moves across the face of a circular dial, graduated so that one graduation is equal to each tooth of the ratchet wheel. If now the electric current from the tuning-fork is allowed to pass through the electromagnets for any length of time, the hand on the dial

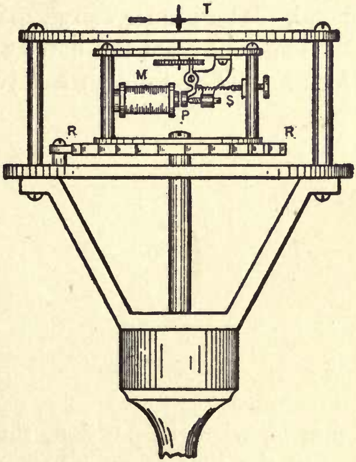


FIG. 97

of the chronoscope will travel over a number of graduations equal to the number of vibrations of the fork which occur between the beginning and the end of the introduction of the current into the electromagnets. In order to measure reaction times, connections should be provided such that the current from the fork will begin to pass through the electromagnets at the instant that the signal for the reaction is given, and will cease to pass through the electromagnets the instant that the reactor moves his hand. The proper connections are indicated in Fig. 98. The current from the battery *B* passes at *F* through the fork and at *K* through a key. This key is a break key;

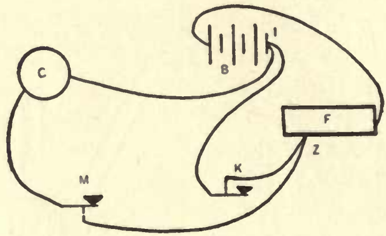


FIG. 98

that is, when in position, the current passes through it, when the experimenter presses down on it the current is interrupted. From the points *I* and *Z*, at which the wires from the battery and fork connect with the key *K*, a second circuit leads through the Ewald Chronoscope *C*, and a second key *M*. The key *M* is the reactor's key and at the beginning of the experiment is closed. This second circuit supplies the path for the current when the contact at *K* is broken. If the circuit is broken by taking the finger off the key *M*, as it is when the reactor raises his hand, the current will no longer pass through the chronoscope.

A reaction time experiment in its simplest form can be carried out with this apparatus by requiring the reactor to prepare for the experiment by pressing down upon the key *M*. The making of this contact without a breaking

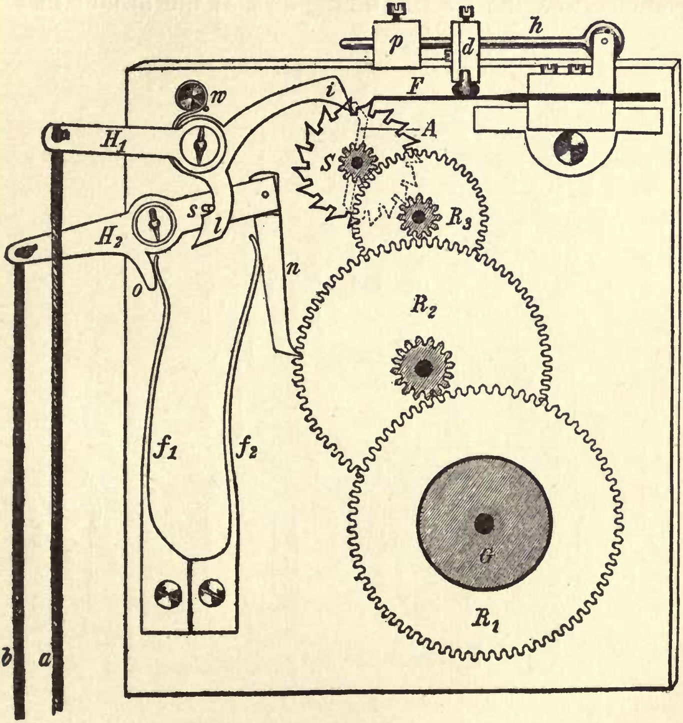


Fig. 99
From Wundt's "Grundzüge der physiologischen Psychologie," 5th Ed., Vol. III, p. 339

of the current at *K* is not sufficient to drive the current through the Ewald Chronoscope, because of its relatively high resistance. The reactor may, accordingly, make preparation in this way for the experiment without starting the chronoscope. The signal to react is given by the experimenter by striking the key *K*. The simplest signal for reaction is the sound thus produced at the key *K*. The Ewald Chronoscope will be set in motion by the current coming from the electric tuning-fork at the instant that

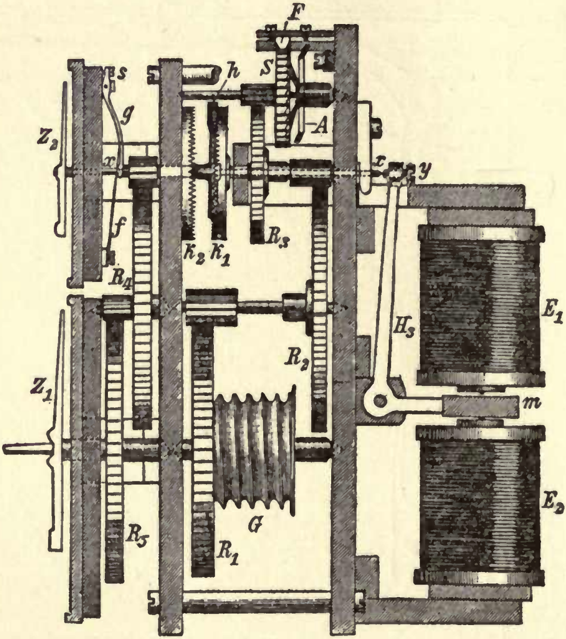


FIG. 100

From Wundt's "Grundzüge der physiologischen Psychologie," 5th Ed., Vol. III, p. 392

K is depressed, and it will continue in operation until the hand of the reactor is lifted from the key *M*. The number of 1–100's of a second that the chronoscope was in operation can now be read on the scale and this is the reaction time.

A more elaborate chronoscope is that which is known as the Hipp Chronoscope. This chronoscope consists of three essential parts. First, there is a clock-work which is represented in outline in Fig. 99. Instead of being controlled by a pendulum as is an ordinary clock, the works of the Hipp Chronoscope are controlled in their rate by the vibration of a fine metallic rod, *F*, Fig. 99. This rod vibrates at the rate of 250 times per second, and releases the clock-work at a high rate of speed, and at the same time regulates that speed so that the clock-work moves uniformly under its control. The same works which are seen from in front in Fig. 99, are shown from the side in the middle section of Fig. 100. The clock-work drives the toothed wheel K_1 (Fig. 100) but not the similar wheel K_2.

The recording pointer and dial constitute the second part of the chronoscope. The dial is made up of two scales, the upper one of which indicates when the pointer moves over a single graduation one one-thousandth of a second, or a sigma as it is called. The lower dial and pointer which are connected with the upper by proper reducing gears, record tenths of a second. When the shaft of the recording parts is thrown into the clock-work so as to move at the same rate as the clock-work, as it is when the stylus *h* is held in the wheel K_1, the period of time that elapses between the beginning of the movement of the recording apparatus and the end of that movement can be read on the dial.

The third part of the Hipp Chronoscope consists of a pair of electromagnets E_1, E_2 (Fig. 100) which make it possible to control the reading part of the apparatus so that it will move with the clock-work or come to a standstill. Between the electromagnets is placed a metallic plate *m*, which is also controlled in some cases by means of springs not shown in the figure. This metallic plate can be drawn up or down by the magnets, according as the one or the other carries an electric current. Whenever m moves downward it acts through H_3 so as to throw h into the wheel K_1. When m moves upward it throws h into the wheel K_2 and prevents the hands of the dials from moving. The accessory connections are very similar to those shown in Fig. 98, and are shown in full in Fig. 101. Two keys, K^R and K^E are placed in circuit with the lower magnet of the chronoscope. For the sake of simplicity let it be assumed that the plate m is in this case held away from the lower magnet by a spring. If now either key is opened no current will pass through the chronoscope. The clock-work may be set in motion without carrying the recording arms on the dials with it. Preparation for

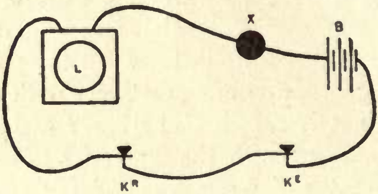


FIG. 101.

the experiment may be made by requiring the reactor to press down the key K^R. By pressing down upon this key, the reactor closes one of the breaks in the electric circuit, but there will still be a break at the key K^E, and the current will, therefore, not pass through the electromagnet in the chronoscope. After the reactor has prepared for the experiment by closing the circuit at K^R, the experimenter may start the clock face by pressing upon key K^E. This pressure upon key K^E allows the current from the battery B to pass through the electromagnets in the chronoscope (L) and sets the recording arms on the dial in operation. The movement of the recording face will continue until the reactor again breaks the circuit by lifting his finger from K^R. The reading on the dial will, therefore, correspond exactly to the interval that elapses between the pressure upon K^E and the breaking of the circuit at K^R. X is a commutator which changes the direction of the current after each reaction.

The experiment may be made more elaborate by introducing other pieces of apparatus into the circuit. Thus, instead of allowing K^E to close the circuit through the clock, the experimenter may arrange a secondary circuit whereby his pressure upon K^E will cause an electric hammer to sound. The electric hammer-head can be made to close the circuit through the clock, other connections remaining the same

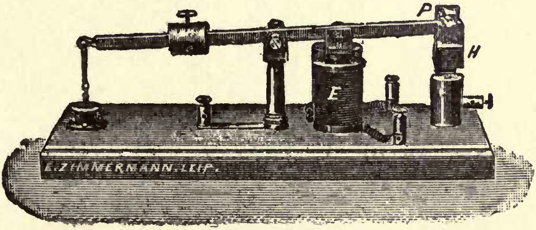


Fig. 102
From the catalogue of Zimmermann, Leipzig, Germany

as in the first case described. Fig. 102 represents an electric sound hammer. The sound hammer consists of a long handle P and a metallic hammer-head H. An electromagnet E is so placed that it may draw the rod P downward and thus cause a sound by the forcible contact of H upon the metal plate under it. Electric connections for sounding the hammer are made through the magnet. The necessary contacts for starting the clock may be made by connecting one wire with H through the rod P and a second wire with the plate upon which H strikes. The current will now pass through the two wires when H and the plate under it are in direct contact. A convenient substitute for a sound hammer is the common telegraph sounder. This is essentially a sound hammer in principle and has adjustments for controlling the extent of the movement and the consequent intensity of the sound.

In practical use the Hipp Chronoscope requires very careful handling. In the first place, care must be taken to keep the magnets from becoming permanently magnetized. If the current is allowed to pass through the magnets in the same direction a number of times in succession

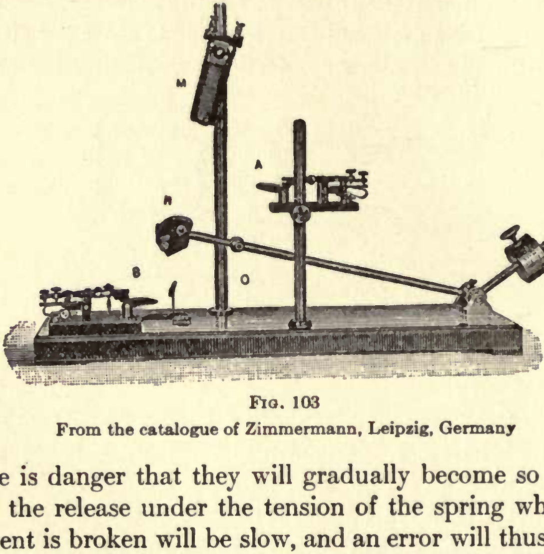


FIG. 103
From the catalogue of Zimmermann, Leipzig, Germany

there is danger that they will gradually become so strong that the release under the tension of the spring when the current is broken will be slow, and an error will thus be introduced into the readings of the chronoscope. For this reason the current should be changed in direction each time it is sent through the electromagnets of the chronoscope. This can be readily done by means of a simple mercury commutator.

In the second place, the relation between the strength of the current and the tension of the springs should be so adjusted that the chronoscope acts uniformly. The best method of establishing and maintaining this relation is to adjust and test the chronoscope by comparing it with a mechanical device which will operate the clock during the time which elapses between the beginning and the end of the movement of a heavy falling body. One of the most common forms of control apparatus is the control hammer, represented in Fig. 103. This makes and breaks two electric contacts at *A* and *B* in the course of its fall. The hammer *H* is held in position by the magnet *M* until the clock is started, when it is released. As *O* passes *A* in the descent of the hammer the clock is started. When *H* strikes *B* the clock is stopped. The chronoscope should not vary in successive trials with such a mechanical device, if it does it needs readjustment. Other forms of control apparatus may be made to operate contacts, or a freely falling body may be used.

There are a number of pendulum chronoscopes which have been devised as substitutes for the various clocks and electrical apparatus described. The range of usefulness of these pendulum chronoscopes is by no means as large as that of the various types of apparatus described. Reference may be made, if one desires to become familiar with this type of apparatus, to descriptions by Professor Scripture in his *New Psychology*, Chapter IX, page 155, and Professor Sanford in the *American Journal of Psychology*, Vol. XII (1901), pp. 590–594.

The procedure in reaction experiments is complicated by the necessity of securing the maximum attention of the reactor just before the signal is given. It has been found advantageous to warn him two seconds before the stimulus in order that he may be fully prepared. If the warning is given less than two seconds in advance, the period of preparation has been found to be in general inadequate. If it is given more than two seconds in advance, attention flags before the arrival of the signal to react.

It is advantageous, where this is possible, to remove the reactor far enough from the apparatus so that he will not be distracted by preparations.

In all of the earlier investigations of reactions the equipment which has been described up to this point was regarded as entirely adequate. It was assumed that the hand reaction under the simple conditions presented was uniform. It has been made very clear by recent investigations that this is not the case, and that there is much productive information to be gained from an examination of the form of hand movement involved in simple reactions. In the simplest case this investigation of the form of movement may be altogether dissociated from the measurements of duration. The finger of a reactor may be placed on a receiving tambour or on a lever which is so placed that it records directly on a kymograph, and the reactor may be required to react to a signal. If the record thus secured is accompanied by a standard time-line, the time of the various phases of the movement may be measured by counting the vibrations in the time-line.

If an electrically controlled chronoscope is at hand, a graphic record may be taken from a tambour, and at the same time the chronoscope may be used to measure the reaction time. In this case the tambour should be supplied with a metal sheet and the reactor should have a metallic cap fixed to his finger. Fine wires should be led from the metal plate of the tambour and finger cap to the chronoscope and the battery that supplies the current for the chronoscope magnet, just as in Fig. 101 connections passed through the clock from the reactor's key, K^R. The reactor should bring the two metal plates into contact in such a way as to depress the rubber of the tambour. If this tambour is connected with a recording tambour, any change in the pressure of the finger will be recorded by the recording tambour. The reaction from this apparatus will proceed exactly as in the earlier cases by the lifting of the reactor's finger. Some care must be exercised to make the tambour sufficiently large so that the rate of movement of the rubber surface in its recovery will not be equal to, or greater than, the rate of the finger as it is raised in reaction. If the movement of the rubber is equal to, or greater than, that of the finger, the plates of

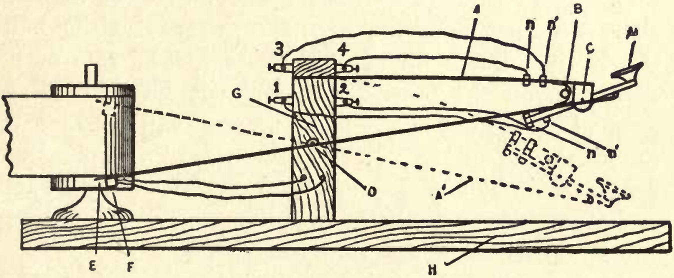


Fig. 104

the tambour and finger cap will be kept in contact even after the reactor begins to raise the finger. The reaction time will, by this purely mechanical process be somewhat exaggerated in length. This difficulty may be overcome by making the rubber face of the tambour relatively large, when the rate of its movement will be slow.

An especially devised apparatus, which gives great range to this type of experiment, is shown in Fig. 104. On a heavy table *H* is erected a firm post *G*. This post should be about 15 cm. high and has screwed into its top a long strip of spring brass seen from the side in the figure at *A*. This strip of spring brass is 25 cm. long and 5 cm.

wide. The spring when in use is depressed with its attached parts to the position indicated by the dotted lines. The dimension of the spring may be determined empirically. It must be made of such size that its rate of oscillation, when set free from its depressed position, is slower than the rate at which the hand or finger of a reactor is lifted in making a rapid reaction movement. The method of determining the proper rate of the spring is very simple. Several reactors are required to record on a kymograph by means of a simple lever the rate of their movements when lifting the hand as they would in an ordinary reaction. The spring is then made enough slower than the slowest of these hand movements to insure its rising more slowly than the hand of any reactor. The rate of the spring is, on the other hand, fast enough so that any gradual movement of the hand upward will not separate the finger and spring. Put in other terms, the spring will follow faithfully any slow upward movements of the hand, and it can, of course, be pressed downward by any downward movement of any rate whatsoever.

At the end of the spring *A* there is attached at a fulcrum *C* the reaction key *M*. This key is closed by pressing downward at *M*. The contacts *n n*, *n′n′* are brought together by such a downward pressure. There is a small spring at *B* against which the downward pressure applied by the finger at *M* is exerted. This small spring *B* tends to separate the contacts *n n*, *n′n′*. If *A* were a rigid rod instead of a spring, the small spring *B* would be brought into action at the slightest movement of the finger upward from *M*. But since *A* is a heavy slow spring and *B* is a small rapid spring, we have the following complex results of finger movements at *M*. When the finger is pressed downward at *M* it overcomes the spring *B* and brings together the contact *n n*, *n′n′*. At the same time it flexes the spring *A* for a short distance. As soon as *n n*, *n'n'* are firmly closed, any further downward pressure will be expended altogether in the flexion of *A*. In practical use the spring *A* is flexed for some distance after the contacts are firmly closed. This flexion of *A* beyond the point of closing the contacts may be described as the surplus flexion of *A*.

If now the finger rises at a rate which is slower than that at which the large spring *A* would naturally recover its position of rest, the contacts *n n*, *n'n'* will remain closed through the whole of what has been called the surplus flexion of *A*. If the finger is pressed downward at any rate whatsoever, the contacts will remain closed. There is one case of movement in which the contact will be immediately broken. That is the case of a rapid reaction movement upward. If the movement upward is more rapid than the rate of the spring *A*, as it is for example in a reaction movement of the ordinary type, then the lifting of the finger from *M* will immediately call into play the small rapid spring *B*, and *n n*, *n'n'* will be separated by *B* without reference to the slow upward movement of *A*.

This combination of springs gives us all the conditions necessary for maintaining a contact at *n n*, *n'n'* until the reaction takes place, while it leaves the hand free to move downward at any rate whatsoever, or to move upward at any rate slower than that of the spring *A*.

The method of recording any upward or downward movements of the reacting hand is to attach a long lever to the post *G* at *O*, and place one end in contact with the key *M* while the other end traces on a kymograph at *E*. This connection may be of the form shown in the figure or it may consist in some other form of lever connection. A marker may be attached to the lever as at *F* and may record the signal to react and, if desired, the reaction itself.

The extent of the hand movement to be recorded and the necessity of trying long series of experiments in rapid succession make it convenient to use on the kymograph the long belts of paper described under Exercise XI. The adjustment of a belt running in the vertical differs from the adjustment of a horizontal belt somewhat, but will be easily mastered by one who has learned to adjust horizontal belts.

B—RESULTS

Table of reactions expressed in one-hundredths of a second.

Reactor	Sensory		No. of determinations	Motor		No. of determinations
	Avg.	M. V.		Avg.	M. V.	
A	19.5	4.3	10	17.4	1.7	10
B	15.5	1.5	10	15.0	2.0	10
C	22.6	5.9	10	14.3	5.0	10

For complete statement as to forms of reaction, see *Yale Psychological Studies,* New Series, Vol. I, pages 141–184.

C—SUPPLEMENTARY EXPERIMENTS

If the reaction is to be to visual stimuli a very simple exposure apparatus may be set up as follows. Connect with the key which is to make the contact a long lever. Let the end of this lever be hidden from the reactor behind a screen when the key is not in use. Behind this screen various colors, letters, or other visual stimuli may be attached to the lever. The screen should be of such a size that when the key is closed the end of the lever with its attached visual object will appear through an opening in the screen, and this become visible to the reactor. A simple form of shutter on this principle is shown in Fig. 105. In this figure the opening in the screen and the key are shown. The reactor is placed on the opposite side of the screen.

A simple visual exposure apparatus consists of a board which can fall between two guides and which has in its center a hole through which a series of letters or figures can be exposed. In its first position the board covers these letters, in its last it exposes them to view and

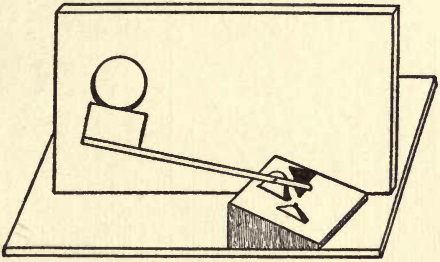


FIG. 105

at the same time by means of metallic strips at the side makes any desired electric contacts.

The disadvantages with the fall apparatus and also with the simple shutter shown above are: first, both pieces produce a sound as well as expose letters to view; and, furthermore, since there is a general movement of the whole field during the exposure there is large probability that the observer will be distracted by the general movement in the field. An ideal visual exposure apparatus is one which presents the visual object to view without any apparent motion in the field. In order to obtain these ideal conditions the light which falls upon the visual field should be cut off and turned on, rather than the field itself either moved or exposed by a falling shutter.

It is very easy to control the light which is to fall upon a given visual field provided this light is brought to a focus as indicated in Fig. 106 *A*. By means of the small bright light *L*, the lenses *I* and *N*, and the diaphragms S^1, S^2, and S^3, the field *O* is easily illuminated or darkened by a shutter placed at *H*. The visual field *O* is enclosed in a dark box and is so placed that when the rays of light are cut off by the shutter *H* the field is entirely invisible because it stands in the dark. When the shutter opens, the field is exposed and its whole area will be visible at the same time. There will be no movement anywhere visible in the field. The exposure shutter may in this case be of a very simple type, consisting of a metallic wheel shown in detail in Fig. 106 *B*. At its outer part this disk is made adjustable so that openings of different sizes may be made at *T*. The shutter is made to rotate by attaching a weight *W* to its axis. The shutter is stopped by means of a brake, which consists of a wedge (*R*) attached to the shutter and a felt pad *D* which is held in position by a

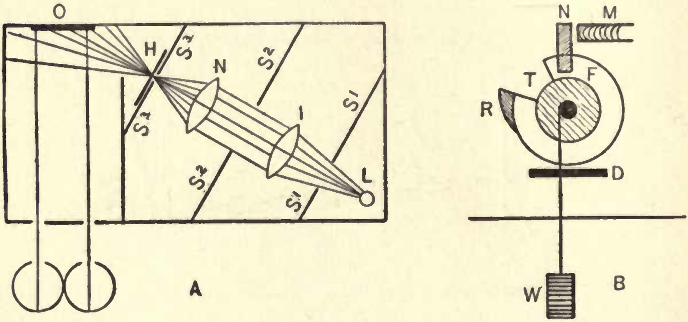


FIG. 106

spring not shown in the figure. This break holds the shutter firmly in position after it has exposed the visual field.

Fig. 107 shows a key designed by Professor Scripture to give tactual stimulations. A heavy rod *H* is set into a handle and is connected with a wire. The flexible rod *N* is placed above *H* and in electrical contact with it. At the end of *N* is a small hard rubber point with which pressure is to be exerted on the skin. When this point is brought against the skin, it breaks the contact between *N* and *H*.

It is frequently desirable to make a number of different contacts simultaneously in order to set different pieces of

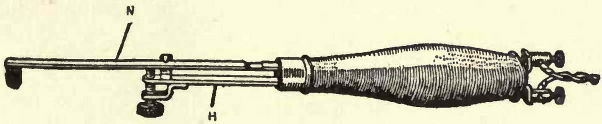


FIG. 107

From the "Studies from the Yale Psychological Laboratory," Vol. III.

apparatus in action at the same instant. A very good means of securing simultaneous contact has been devised by Professor Angell. It consists of a large wooden cylinder upon which are fastened at certain points metallic strips which extend over only a part of the circumference of the cylinder. Adjustable brushes are set against the surface of this cylinder. When in contact with the wooden cylinder these brushes make no electric contact. If now the cylinder is turned until the brushes come in contact with the metallic strips referred to above as fastened to the surface of the cylinder, a contact will be made between each brush and the metallic strip with which it comes into contact. By carefully adjusting the brushes so that two or three come into contact with their respective metallic strips at the same moment, a series of contacts can be made simultaneously. The advantage of the large cylinder is that the contacts can be adjusted to secure absolute precision in the making or breaking of the contacts.

The supplementary experiments which require records of hand movements are closely related to the experiments required in Exercise XVII. The apparatus there described in full may be used for these experiments.

EXERCISE XVI

A—APPARATUS AND PROCEDURE

Most of the apparatus necessary for this exercise has been described. For choice reactions the colors or sounds may be produced by means of one of the exposure screens or by means of two or more hammers placed in various

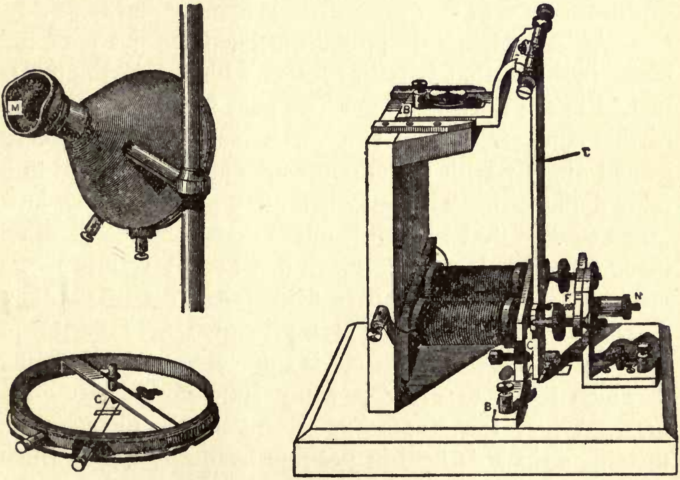


Fig. 108

From Wundt's "Grundzüge der physiologischen Psychologie," 5th Ed., Vol. III, p. 403

positions. Reaction keys for more than one finger can be constructed by bringing together in compact form a series of finger pieces which control electric contacts.

For recording the reactions of articulation the simplest device is to require the reactor to move his hand at the same time that he utters the word. This method is not satisfactory because some error arises when the reactor attempts to make two simultaneous movements. The only satisfactory method is to secure a record from the articulation movement itself. For this purpose a special voice key may be used. The most satisfactory form of voice key is represented in Fig. 108. A large mica plate is placed at the end of a funnel. The mouth is placed against the opening of this funnel *M* and a word is sounded into the air chamber. The vibrations, as well as the change in the pressure of the air, set the mica plate in oscillation. On the surface of this mica plate is a small platinum contact *C*. An adjustable point controlled by means of the screw is set so that it is in contact with the platinum attached to the mica plate. Wires pass from the two poles of this contact. These two wires, instead of being connected directly with the chronoscope, are first carried to a relay apparatus. The relay is a piece of apparatus which may be set so that when it is once released by means of an instantaneous electric current, it will not return to its original position unless it is deliberately set in position. A simple form of relay is represented in Fig. 108 at the right. A metallic strip *T* is connected with the spring *F* which tends to draw it away from the electro-magnets. When the apparatus is set ready for use, the metallic strip *T* is held in position by the magnets which are supplied with a current through the mouth-key described above. If now the current is broken even an instant by vibrations in the voice key, the metallic strip *T* is released by the magnets and responds to the tension of the spring *F*. When once it is drawn away from the magnets it does not return with the reestablishment of the current in the magnets. At the lower end of *T* are electric contacts which are broken or made with the movements of the strip. In this way an intermittent make and break, such as that which results from the vibration of the voice key above described, is converted into a permanent break the moment the current in the voice key is interrupted. From this point the connections from the chronoscope are as from the regular break key and require no special description.

B—RESULTS

The following discrimination times are reported for reactor *B*, for whom simple reaction times were reported on page 196. These times are long. They are expressed in one-hundredths of a second.

	Avg.	M.V.
10 Discriminations of Green and Yellow	44.7	3.6
10 Discriminations of Red and Blue	52.8	13.8

Articulation times from reactors who pronounced printed words exposed to view are given in sigmas as follows: Train, 560; boat, 570; blot, 440; tank, 1100; dark, 540.

Association times for free associations are as follows: Boat—water, 980; train—smoke, 850; bank—money, 1270.

C—SUPPLEMENTARY EXPERIMENTS

A very good discrimination experiment consists in presenting to the reactor a number of different pairs of colors which differ qualitatively from each other in various degrees. Thus, one pair should be made up of a certain red to be designated as *R* and a second red slightly different from the first and designated as *R′*. A second pair of colors should be made up by using *R* and a quality of red which differs from it more than R'. This third red will be designated as R''. In this way a series of reds can be made up, all of them differing from the original red R but in increasing degrees. R and R' should now be shown to the reactor with R sometimes on the right-hand side and sometimes on the left, and he should be required to react in every case with the hand corresponding to R. It will be found that the time required for discrimination decreases as the difference between the two qualities increases.

Various types of associations between words may be measured. The time for so-called free association is the shortest of the association times. If a word is presented and the reactor is required to associate some other word with it but no restrictions whatsoever are placed upon the direction of this association, we shall have such pairs as chair—desk, chair—floor, chair—table. A variety of restrictions may be imposed upon the reactor. Thus, he may be required to name a second object belonging to the same class as the first object or he may be required to mention a part of the object named. He may be required to name the general classes to which the object belongs. These restrictive associations require much longer time than the free associations and they vary a great deal as compared with each other.

The experiment of striking out a's may be made with any page of printed matter that is conveniently at hand. For purposes of comparison in a series of experiments, it is desirable that the distance over which the hand must travel in marking out a given number of a's shall be uniform. For this reason it is better to prepare tables which are composed of letters of the alphabet irregularly arranged and containing a standard number of each one of the letters.

A convenient method of preparing such tables was suggested by Dr. Whipple. Let 100 printer's types of each of the letters to be used be "pied" and then set up as a regular press form. The form may need a little editing to prevent letters from being repeated in close proximity to each other, but in general the chance order of the letters can be accepted without further change.

EXERCISE XVII

A AND B—APPARATUS, PROCEDURE, AND RESULTS

For the measurements of the duration of writing activities the apparatus and method described on pages 176–180 are to be used. A very simple form of this apparatus can be set up by merely writing over a moving strip of paper through a sheet of carbon paper. The moving paper

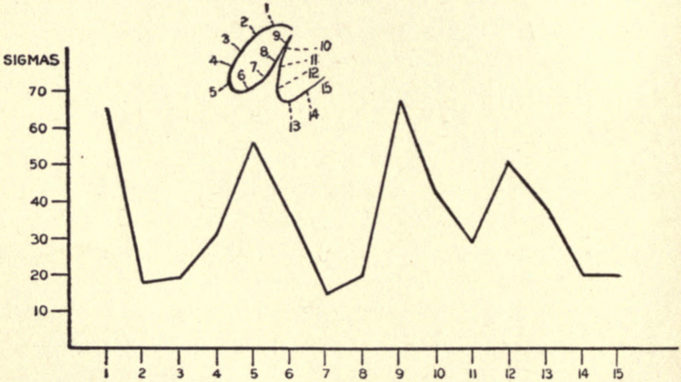


FIG. 109

which receives the record can be drawn along as suggested on page 175 by a kymograph, its rate being recorded by a time marker. Figures 109 and 110 show fluctuations in the rates of movement during the writing of different parts of the letters *a* and *b*.*

A recorder which will very conveniently show the move-

* These two figures have been supplied by Mr. F. N. Freeman from a general study in which he is engaged. The letters *a* and *b* in the figures are marked off in sections which correspond to distances of 1 mm. in the original written letter.

ments of different parts of the hand during writing is represented in Fig. 111. It consists of a spring *A* which fits closely on the hand and carries the rod *BB*. This rod runs forward far enough so that the distance of its end from the wrist and elbow is the same as the distance from the wrist and elbow to the pen held between the thumb and fingers. This equality in length insures a record of the hand and arm movement which is on the same scale as the writing done by the pen, and thus comparison is made

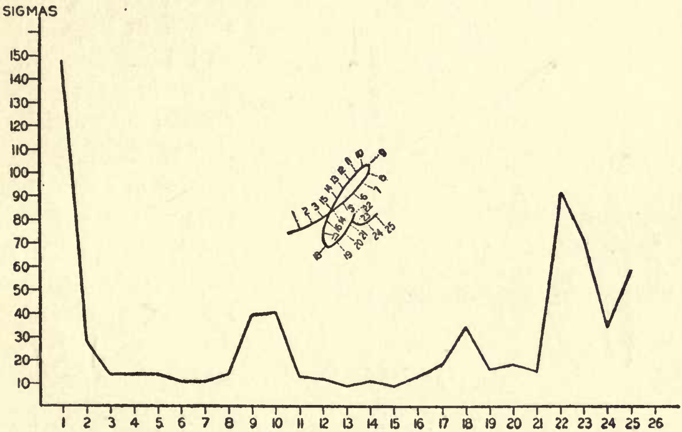


Fig. 110

direct and easy. At the end of the rod *B* is placed a metal or glass tube *C*, and through this falls a tracing point *DD* of the same form as that which has been described under Exercise XIII, page 170. The record is made by allowing the reactor to write naturally on the paper with the pen held between the thumb and fingers; the tracer in the meantime making a record of all of the movements which the hand makes during the writing. The written letters are the records of the finger movements plus all of the hand

and arm movements, except such hand and arm movements as are made during the intervals between the words, when, of course, the writing pen is raised from the paper. The tracer is carried on the paper by its own weight and records all that the hand and arm do, but gives nothing of the pure finger movement. By a comparison of the written letters with the tracer record it is easily possible to determine what part of the whole work is done by the hand and arm and what is done by the fingers. Two records of writing with their corresponding tracer records are shown in Figs. 112 and 113.

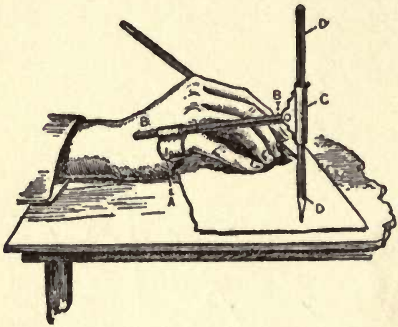


Fig. 111

In order to secure the moving point which is required in the third part of the experiment, the following combination of apparatus already described may be arranged. A belt of paper is carried between two kymograph drums. On this belt of paper a line is drawn obliquely across the paper. The belt is set in rotation by means of the drum, and the reactor is allowed to look at it through a narrow slit in a large shield, the slit extending in a direction perpendicular to the direction of movement in the paper. The whole is represented in Fig. 114, where *A B* is the belt and *S* the shield. The shield is intended to be large enough so that the observer sees nothing of the belt beyond it. The shield thus prevents the reactor from seeing the line on the rotating belt, but gives him the opportunity of seeing the single part of the line which lies directly under the opening in the shield. As the belt moves forward, the part of the line which the reactor can thus see will gradually move upward or downward

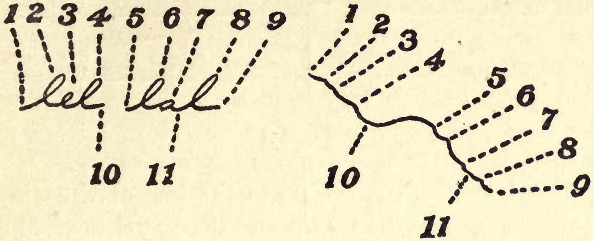


FIG. 112

along the line of the opening in the shield. If the oblique line drawn across the belt is a regular line, and the drum moves at a uniform rate, the point seen by the reactor will travel up and down the slit at a uniform rate in a given direction. Irregularities in the line will result in irregular movements of the points seen through the slit. If, therefore,

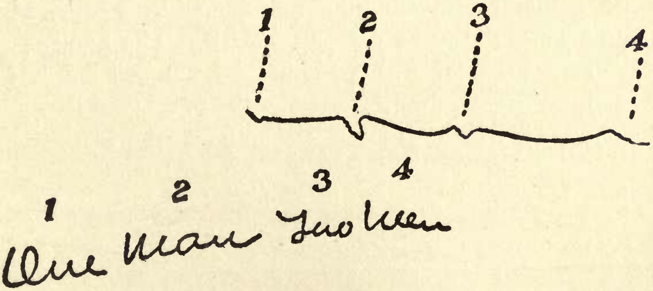


FIG. 113

it is desired that the reactor strike at a point which is moving uniformly, a single line is drawn across the moving belt. If it is desired that a certain change in the rate of movement of the point shall be introduced, irregularities of the type indicated in Fig. 115 may be drawn in the long line on the belt of paper. In order that the effort to react may be

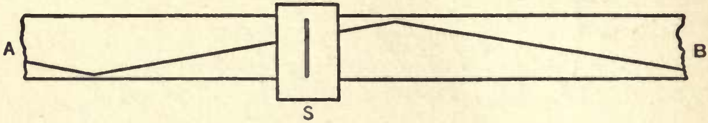


Fig. 114

properly timed with reference to the irregularities in the line, a sounder may be set up and the signal to react may be given by the experimenter by means of this sounder.

The movement of the hand in aiming to strike this moving point can be studied in several ways. First, the shield

Fig. 115

which covers the traveling line may be made of paper and a carbon sheet may be placed under it. The hand may move across the sheet of paper, tracing a pencil line from the point of starting until it reaches the point seen through the slit. All irregularities in the movement will thus be

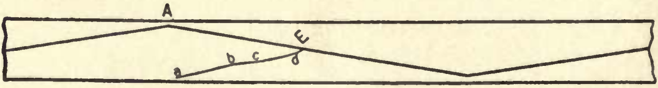


Fig. 116

recorded on the same paper as the line which supplied the point. Such a record is shown in Fig. 116 in the line *abcdE*. The reactor in this case was directed to move his pencil from the position *a* where it was held just at the bottom of the slit until he could strike the point traveling downward. It will be noticed that he moves rapidly upward at first, then pauses and finally makes his last movement with increasing rapidity to the end.

Second, a string may be connected with the hand in such a way that all forward movements of the hand shall draw out the string and indirectly make a record. This method does not permit movements in different planes to be recorded without complicating the apparatus indefinitely. Movement in one plane can, however, be conveniently recorded by such a string. The string should be wound around a cylinder. This cylinder is supplied with an inner coil spring which keeps the string wound up under small tension. It is also fitted into a system of cogs so that any turning of the cylinder as a result of pulling the string results in the movement of a system of wheels and ultimately of a pointer. This pointer may be allowed to trace upon a smoked paper, thus giving a record of the amount of the hand movement. Since such an arrangement as this records the hand movement only in one direction, the conditions of the experiment should be so arranged that the reactor will move his hand chiefly in one plane. One of the best directions in which to allow the string to unwind is downward from directly above the slot in which the moving point appears.

C—SUPPLEMENTARY EXPERIMENTS

A device similar to that described above for recording the movement of the hand may be attached to any part of the arm during writing, in order to record the behavior of this part of the arm while the fingers are forming the letters.

A method which has been employed for the determination of the pressure of the different fingers during writing consists in mounting on the pen a number of small tambours. One is placed under the thumb, one under the first finger, and one under the middle finger. From these various tambours connections are made with recording tambours and a triple record is taken on a smoked surface showing the various changes in the pressure of each of the fingers against the writing pen.

The pressure exerted by a person writing on a sheet of paper can be readily measured by means of the apparatus described on pages 179–180.

EXERCISE XVIII

No special apparatus is required for Exercise XVIII. It is desirable that the figures to be used in this exercise should have a sufficient degree of uniformity to make comparison between the different figures possible. To this end, the figures should all be made up of the same constituent

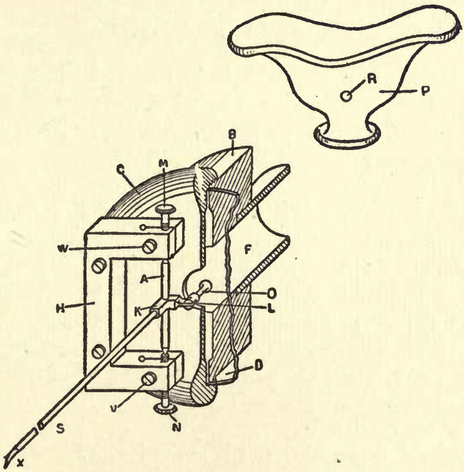


Fig. 117

lines, these being combined in various different arrangements but having the same absolute dimensions and positions in space.

A series of tests of this type is fully reported and discussed in the *Yale Psychological Studies*, New Series, Vol. I, No. 2, pages 349–369.

C—SUPPLEMENTARY EXPERIMENTS

There are a number of methods of recording the rate of vibration of sung or spoken tones. The most familiar methods are those of the phonograph. In this apparatus a voice vibration is delivered against the mica or glass diaphragm. The diaphragm by means of a sharp stylus cuts into a wax cylinder, recording the rate of the vibration which is imposed upon the diaphragm by the voice. The difficulty of reading such a record as this prevents the use of the phonograph for ordinary experiments in the psychological laboratory. The principle of the phonograph may, however, by a slight modification be employed for the purpose of making records of voice reactions.

Fig. 117 represents the apparatus employed by Dr. Cameron in recording the rate of voice vibrations and described by him in the *Yale Psychological Studies*, Vol. 1, No. 2, page 230, as follows:

"The recording apparatus used in the present investigation consisted of a round rubber telephone receiver, a vertical cross section of which is represented in Fig. 117. The box (*B*) is provided with a cover (*C*) of the same material which may be screwed tightly to the face of the box. Between the front edge of the box and the cover is a diaphragm (*D*) of thin mica, which is held firmly in position by the cover, when screwed down. The diaphragm is 5.3 cm. in diameter. Glass diaphragms have also been used, but with less satisfactory results.

"The cylindrical chamber (*F*) communicates directly with the air chamber back of the diaphragm. An aluminum mouthpiece (*P*) is attached to the outer edge of (*F*) by a small piece of rubber tubing. In the latter experiments a long flexible tube was substituted for this form of connection between (*F*) and the mouthpiece (*P*). A small hole (*R*), 3 mm. in diameter, is bored in the mouthpiece to allow the escape of the air forced into the chamber at the moment the tone is sung.

"There is screwed to the front of the box a piece of brass (*H*), shaped as shown in the figure, and used for the purpose of holding the adjustable screws *M* and *N*.

"*M* and *N* are held securely in position by the set screws, *V* and *W*. *M* and *N* are fitted with jewel bearings in which play the tapering ends of the steel axle *A*.

"To the axle is attached the aluminum right-angle piece *KL*. *K* carries a straw (*S*) to the end of which is fastened the recording point *X*. This point is made of hammered brass, carefully cut to a point and polished. Such a point is fine enough to make a sharply defined line on smoked paper, and the lampblack does not adhere to it.

"The other arm *L* is attached by a joint to a smaller link (*O*) of aluminum, which passes through an opening in the middle of the box cover and is fastened to the center of the diaphragm by a drop of glue.

"There is thus provided a system of continuous levers from the outer surface of the diaphragm to the recording point, so that movements of the diaphragm caused by the singing of tones into the mouthpiece or by any other means are magnified and may be recorded on a belt of smoked paper. Since it is desirable to obtain very long series of records, a long belt of smoked paper is used. The belt passes between two drums placed fifteen feet apart. It is smoked at one of the drums and after the record is made is shellaced from behind."

Such a record is reliable for determinations of pitch. It is not useful in determining the form of sound vibrations.

A target can be very easily made of a drawing-board over which has been pasted a sheet of paper with concentric circles. A dart may be made up of a wooden shaft in the end of which has been inserted a sharp needle. The dart should be supplied with guides at the end opposite that carrying the needle. These can be made by cutting slots in the wooden shaft and inserting cardboard strips. The record may be taken by counting the score as in ordinary target practice. It is desirable also to record not only the distance from the center but also the quadrant in which the dart strikes the paper.

The experiment which requires a stylus from which the reactor shall receive no sensation of pressure during writing may be carried on by means of the following device. A pencil or small wooden rod the size of a pencil, is supplied at the end with a tube either of metal or glass, and through this tube is allowed to pass a writing stylus of the form described in Exercise XIII. The reactor will receive no pressure sensations from this pen, as the writing stylus is free to move upward and downward in the tube. The downward movement of the wooden rod will simply result in the sliding of the tube down the writing stylus. Experiments tried with such a stylus by a reactor who tries to write with his eyes closed indicate very clearly the results of withdrawing both visual and tactual sensations in writing activities and in the activities of drawing.

EXERCISE XIX

A—APPARATUS AND PROCEDURE

The apparatus necessary for the first part of this experiment has been fully described in connection with Exercise XIV (see page 175).

The second experiment requires no equipment other than a mirror and some patterns. It should be noted, perhaps, that simple geometrical patterns such as stars and rhomboids are better for the purposes of this exercise than more complex forms.

A convenient method of preparing cards for the third part of this exercise is to secure plain cards and mark them with numerals, or paste on them kindergarten pictures or small pieces of colored paper which will be sufficient to distinguish them.

B—RESULTS

The following table shows the changes in the length of contacts and intervals between contacts during practice with the unnatural or reverse order of finger movements. The first horizontal column shows the rate before practice. The second horizontal column shows the averages of ten cases after 200 trials. The third shows the average of ten cases after 400 trials, and the last shows the average of ten cases after 600 trials.

	Finger I Index		Pause after I		Finger II (Middle)		Pause after II	
	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.
At first...	93	2.1	127	7.7	89	2.4	102	5.7
After 200.	90	3.1	100	8.6	92	2.7	95	5.2
After 400.	87	3.4	92	8.3	84	1.6	90	5.5
After 600.	91	2.8	99	8.1	87	1.9	91	6.1

	Finger III		Pause after III		Finger IV	
	Avg.	M. V.	Avg.	M. V.	Avg.	M. V.
At first............	124	7.1	72	3.1	101	4.4
After 200...........	111	7.7	71	2.7	97	4.7
After 400...........	114	6.4	64	2.2	96	3.5
After 600...........	109	5.1	60	3.0	93	3.1

The following table shows improvement both in time and accuracy in following in five successive trials the same four-line pattern when the pattern was seen in a mirror.

		Corrective Movements				
		Line				
		1	2	3	4	
Trial	Time in seconds					Totals
1	97	4	7	3	4	18
2	46	6	2	5	1	14
3	31	3	3	2	3	11
4	20	0	4	1	3	8
5	22	1	2	1	1	5

The following table shows the time for 10 successive distributions of eighty cards which were marked with the numerals from 1 to 8. The spatial order of these cards in the first series of distributions was: 5–3–6–1–8–4–7–2.

Distribution..........	1	2	3	4	5	6	7	8	9	10
Time in seconds......	84	71	67	54	50	52	57	60	51	57

When the order was changed to 6–4–3–7–5–2–1–8, the time of distribution for the first trial was 92 seconds with many tendencies to return to the first order.

C—SUPPLEMENTARY EXPERIMENTS

Experiments with writing seem to show that the time of writing for a given subject suffers little change from trial to trial.

The simplest method of studying the control of the winking reflex is to hold before the eye a piece of glass and allow the experimenter to strike the glass directly in front of the eye. The degree of control will be shown by recording the number of times during which the observer is capable of resisting the reflex tendency to wink when the glass is struck, the glass being held in the successive trials at various distances.

Methods of working with the typewriter will suggest themselves to any one who is unfamiliar with the manipulation of this machine. Simple copying of prose passages and a measurement of the time required for a given number of letters, together with the errors in these letters, serve very well to indicate the progress of the reactor who begins without previous training. The machine may be utilized for experiments even by experts if, instead of using the regular letters on the keyboard, certain colors or outline forms are substituted for the familiar keys. Each reaction will in this case be recorded as a letter, while the stimulus received by the reactor will not be a letter but the color or outline figure with which the key is covered.

EXERCISE XX

A—APPARATUS AND PROCEDURE

The apparatus required for recording taps has been described in connection with Exercise XIV, page 175.

A metronome can be purchased at any establishment which sells musical instruments or from C. H. Stoelting Co.

B—RESULTS

Table I shows some effects of distraction. The averages are in sigmas.

Reactor	Average normal time for taps without distraction, measured by taking time of five successive taps		Fast metronome		Slow metronome		Movement of other hand		Reading	
	Avg.	M.V.	Avg.	M.V.	Avg.	M.V.	Avg.	M.V.	Avg.	M.V.
A	183	6.3	211	9.3	218	7.5	238	11.4	193	7.7
B	197	4.4	209	8.3	207	13.2	254	10.1	215	6.5

The following results show the effects of fatigue. The first five taps in every 50 were counted and the total time was found as follows:

910 sigmas, 920, 940, 900, 900, 880, 740, 970, 1,000, 1,240, 1,050, 1,070, 1,080, 1,080, 1,300, 1,100, 1,095.

C—SUPPLEMENTARY EXPERIMENTS

Apparatus and methods for the first supplementary experiment are described, and reference to a complete experiment of this type is given under Exercise XVIII (see pages 214 and 215).

The apparatus necessary for the exercise on muscular fatigue consists of a dynamometer such as already described under Exercise XIII. Such a dynamometer may be used continuously for a longer period of time, and a record taken of the amount of work done by the reactor. If the work is continued until the reactor is no longer able to move the dynamometer, the records will show the total amount of work necessary to produce complete fatigue. If

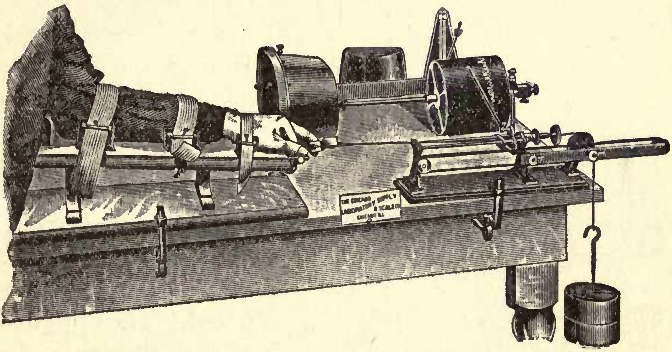


Fig. 118
From the catalogue of C. H. Stoelting Co., Chicago

the work is not continued for a sufficient period of time to produce complete fatigue, the falling off in the records of the movements will show the increasing tendency towards fatigue. The disadvantages of using a dynamometer for such experiments is that it is extremely difficult to secure a record of the total amount of work done. Other forms of instruments have accordingly been devised for recording and automatically measuring the amount of work a reactor can do. Mosso's Ergograph, which is one of the best known instruments, is represented in Fig. 118.

This consists of a sliding bar connected with a weight at one end and a finger holder at the other end. The sliding bar is attached to a pointer which can trace upon a kymograph surface. The experiment consists in allowing the reactor to move his finger so as to lift the weight as long as it is possible for him to make any movement against the weight. The pointer records the form and extent of this movement upon the drum. An addition for the purpose of measuring the amount of movement can be made in the form of an automatic tape take-up which will draw up a tape each time the weight is lifted. During the test the hand and arm of the reactor are held rigidly in position, so as to eliminate as far as possible the movements of all muscles except those which are being tested. The objection to such a weight ergograph is that at the end of a given experiment the finger can undoubtedly do some work, even though it can not do what it is required to do when the demand is made that it lift the large weight which is connected with the apparatus. The finger is in a condition in which it seems to be unable to do further work, not because it is completely exhausted but because it is too exhausted to do the large amount of work demanded. The remedy for this defect of the weight ergograph is to be found in substituting for the weight a spring. If now the reactor is allowed to pull against the spring instead of

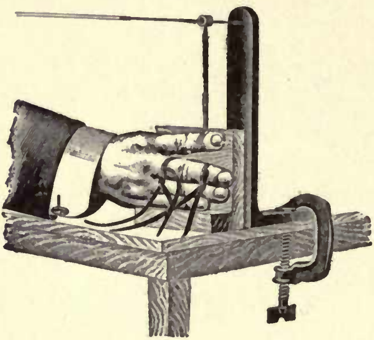


Fig. 119
From the catalogue of C. H. Stoelting Co., Chicago

against a fixed weight, his early movements will indicate the absence of fatigue in the length of the movement. Later, the movements will grow smaller and smaller, and the amount of work demanded for each one of these small movements will, because the reactor is working against a spring, be reduced in quantity. The rate at which the reactor makes the movements should in all cases be a uniform rate determined by a metronome which gives the signals for reaction.

A simple ergograph supplied with the Harvard physiological apparatus and shown in Fig. 119 can be used in securing fatigue records from the index finger.

More elaborate forms of ergographs have been devised. These elaborate forms are designed to secure greater isolation of the muscles exercised. It is possible in most of the simple ergographs for the finger which is called upon to do the work to receive much assistance from the other parts of the hand and arm which it is not intended to test. An elaborate device is described by Professor Bergströme in the *American Journal of Psychology,* Vol. XIV, 1903, pp. 510–540.

EXERCISE XXI

A—APPARATUS AND PROCEDURE

The best method of making up series of nonsense syllables consists in preparing a large number of such syllables on separate slips of paper. These syllables should be made up as follows: Start with the first consonant in the alphabet and the first vowel. Set down as the third letter of the syllable each of the succeeding consonants of the alphabet. Thus, we have bac, bad, baf, bag, etc. A second series should be prepared beginning with the second consonant of the alphabet as the first letter of the syllable. Add the first vowel, and in succession each of the remaining consonants of the alphabet. Thus we should have cab, cad, caf, cag, etc. Another series of variations can be produced by changing the vowel. Thus, the first combinations in the series would be bec, bic, boc, buc. In like fashion we should proceed with ceb, cib, cob, cub. After this series has been prepared, such combinations as "bad" and "bag" should be thrown out because they represent words. Such combinations as "caf" should also be stricken out because they resemble too closely common words of the language. After a series of combinations has been prepared by selecting non-significant forms, the whole collection should be placed in a box and thoroughly mixed. Any desired number may now be drawn from this thoroughly mixed collection and the character of the material will be sufficiently uniform for experimental purposes. The following list presents a few such syllables which may be used in some of the simpler exercises without the more elaborate preparation described above:

Dap, Vac, Jaf, Lar, Bex, Bup, Nat, Hif, Lis, Mor, Cul, Zuc, Jut, Puj, Riv, Sal, Mik, Tex, Pij, Hoj, Dac, Cib, Rev, Bir, Huv, Vog, Gir, Jal, Kod, Dak, Pon, Sab, Def, Dor, Miv, Mel, Jub, Lig, Biz, Gar, Cem, Vub, Har, Dik, Rej, Ber, Lun, Hak, Jec, Fij, Ked, Tol, Soc, Gec.

If experiments are to be performed with these syllables,

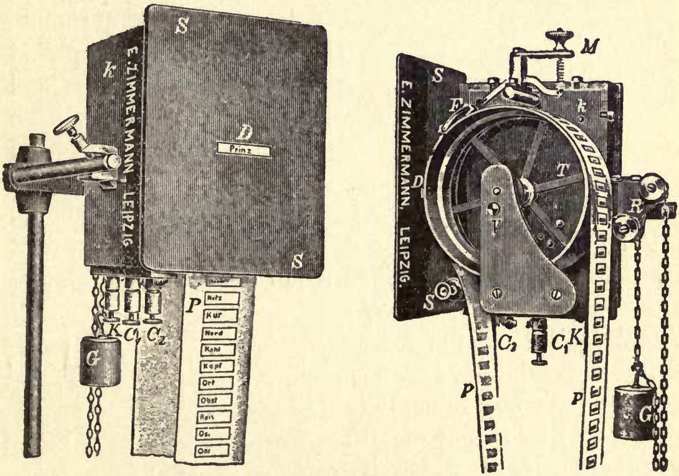


Fig. 120

From the catalogue of Zimmermann, Leipzig, Germany

it is desirable that they should be quite legible. To this end they should be printed or copied on a typewriter or made up of gummed letters which have been pasted on cards. The cards may now be read off in series, each one being exposed to view by drawing off the one above it in a pack held in the hand.

The rate at which the syllables are exposed is a matter of some importance. A device for securing greater uniformity of exposure than can be attained by simply handling the cards, is to paste the syllables on a kymograph and allow them to be seen through an opening in a screen as the kymograph is rotated with a slow, steady motion. This method has the disadvantage of keeping the letters in constant motion during the whole period of exposure. A second device consists of a drum which is moved forward by means of a weight and a pendulum escapement.

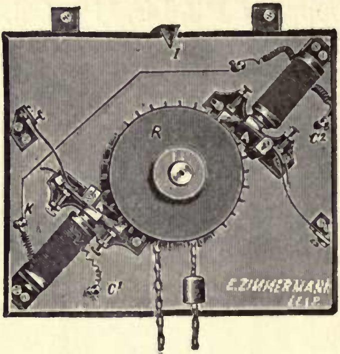


Fig. 121
From the catalogue of Zimmermann, Leipzig, Germany

An electrical device for moving the drum forward at regular intervals is described by Professor Bergströme in the *American Journal of Psychology*, 1907, pp. 206–238. A pendulum, instead of acting directly upon the drum, acts by means of an electric circuit which it makes with each oscillation. The apparatus may be complicated by the addition of a second pendulum so connected with the first that the intervals of movement in the drum shall be regulated differently during the exposure of the syllables and during the intervals between exposures.

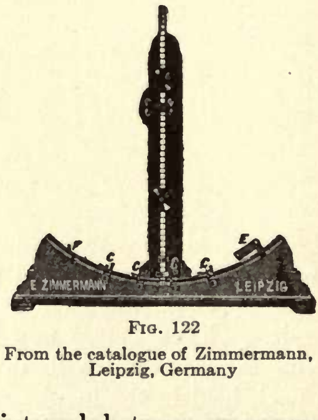


Fig. 122
From the catalogue of Zimmermann, Leipzig, Germany

A very elaborate mechanism has been devised by

Professor Wirth, of Leipzig. It is shown in Figs. 120–121. In Fig. 120 *A* the apparatus is cased in and a single word appears as seen by the observer. In Fig. 120 *B*, the tape with syllables and the wheel on which this tape moves is shown. In Fig. 121 the weights and electrically controlled escapement for the apparatus are shown. When a current is passed through the electromagnets the syllables move forward. The rate of this movement is determined by the apparatus which sends the electric current into the magnets. This controlling apparatus is the pendulum shown in Fig. 122. By means of adjustable bobs the rate of this pendulum can be varied within wide limits. By means of contacts placed along the scale shown at *C*, *C*, *C*, *C*, in the figure the current can be sent as desired to the escapement apparatus.

B—RESULTS

Table showing individual differences and differences in the same individual under varying conditions.

Readings required to learn ten syllables.

Observers	Read silently	Read aloud	Hear read	Heard and seen
A	15	8	18	17
B	6	5	5	5
C	6	7	6	8
D	11	10	14	9

Table showing readings on first learning and after one hour.

Observer	Readings (silently) first time	After one hour
A	15	3
B	6	2
C	6	3

Table showing difficulty of learning series of different lengths, all read silently.

Observer			
No. of syllables	10	15	25
A	15	27	not learned at 50
B	6	12	48

C—SUPPLEMENTARY EXPERIMENTS

The monochord required for memory of tones is described on page 111.

For the other supplementary experiments, no special apparatus is required.

EXERCISE XXII

A—APPARATUS AND PROCEDURE

Equivocal figures such as are required for the first part of the exercise are shown in Fig. 123, *A* and *B*. The record of the rate of fluctuation in these figures can be taken by means of a key such as that described on page 175 and an electric marker such as that described on page 155. The observer is required to press down upon

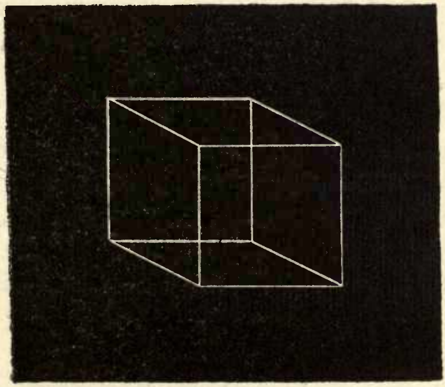


FIG. 123*a*

the key when the figure appears in its first position and to lift the finger when the figure reverses. In some cases it may be necessary to record more than two types of experience. In this case either two markers and two keys can be employed, or a code of signals can be worked out to be operated by the single key and marker.

For the experiments on retinal rivalry a lens stereoscope can be used. (See pages 93 and 94.)

A Masson disk is represented in Fig. 124. It consists of a white disk marked at intervals with black lines which

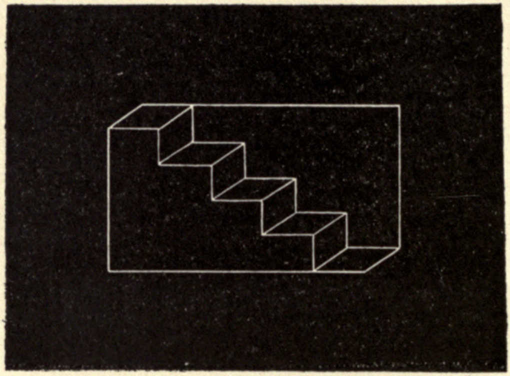


FIG. 123*b*

have all the same absolute width. The relative width of the successive lines as compared with the white area which is mixed with the black when the disk is rotated, grows constantly less from the center outward. The result is that the gray rings which appear when the disk is rotated,

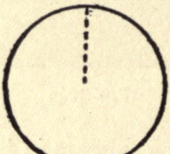


FIG. 124

grow lighter and lighter from center to circumference of the disk. One ring will be found that is only intermittently visible. This is the ring for which a record should be taken.

EXERCISE XXIII

A—APPARATUS AND PROCEDURE

The apparatus necessary for this exercise can be described best by exhibiting at the outset a complete form of the complication pendulum. Substitute devices of a simpler character can be made on the same general principle. Fig. 125 shows the complex form of complication pendulum described by Wundt. It consists in a pendulum PL the upper end of which is coupled by means of a cogwheel with the pointer Z. Whenever the pendulum oscillates, the pointer Z moves in front of a scale S. When the pendulum is in use, all of the mechanism behind the dial is hidden so that the observer can see nothing but the scale and pointer Z as it moves backward and forward across the scale. By means of an adjustable connection, a bell can be sounded or an electric circuit closed when the pointer is at any desired point on the scale. The experiment consists in setting the bell so that it sounds when the lever is at a given point on the dial, and requiring the observer to determine the position of the pointer on the scale at the instant when the bell sounds. The rate of the pointer's movement can be modified by shortening or lengthening the pendulum P.

Simpler forms of apparatus can be devised. For example, an ordinary metronome can be employed, the pointer passing behind an opening in a shield, the opening having graduations so that the position of the pointer behind the shield can be easily read. The sounder, which is always a part of the metronome, can be related to differ-

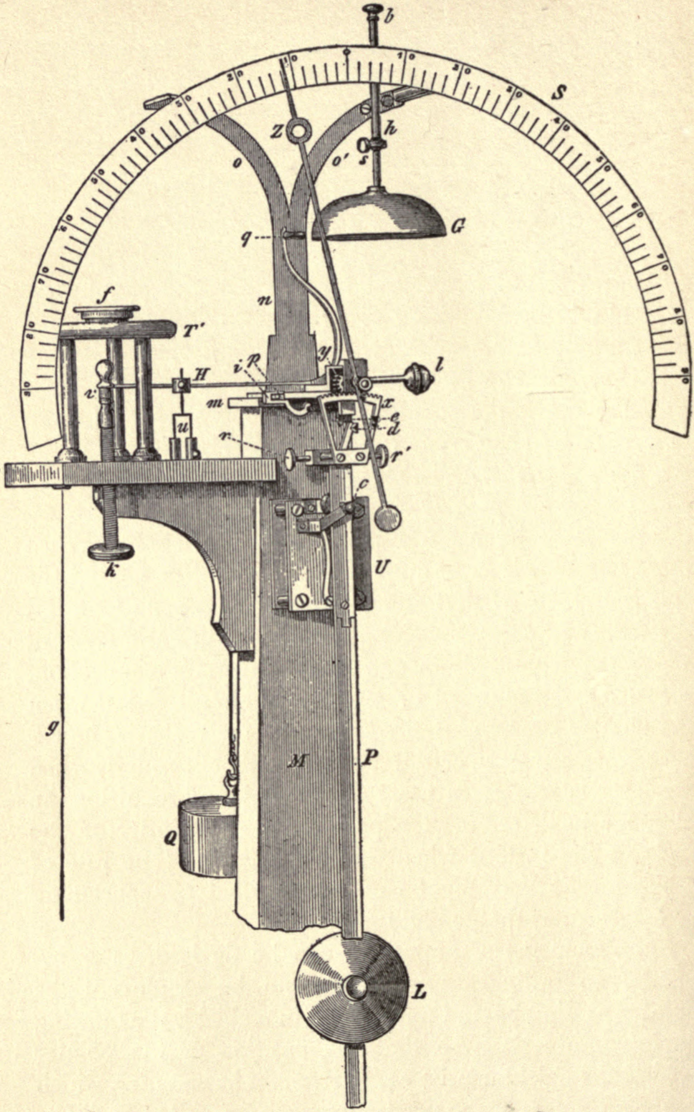


Fig. 125

From Wundt's "Grundzüge der physiologischen Psychologie" 5th Ed., Vol. III, p. 82

ent points on the scale by tipping the metronome into various positions so as to give the sound at various parts of the scale. The experiment consists in requiring the observer to determine, as before, at what point on the scale the sound is produced.

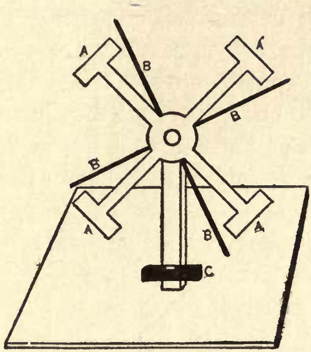


Fig. 126

A complication instrument designed by Prof. A. H. Pierce and described by him as follows. serves the purposes of this experiment very well: "In Fig. 126 *AAAA* are card-holders at the ends of rigid arms, 90° apart, attached to the main axis of rotation. *BBBB* are light steel rods, tipped with platinum wire, attached to a collar which rotates on the main axis behind the card-carrying arms, and which can be set at any point by a screw. The platinum tips pass through a meniscus of mercury, the latter being contained in a well in the wooden block *C*. Thus a sounder, or telephone, is electrically actuated. In practice, the *B*'s are somewhere behind the *A*'s. The cards to be placed in the holders are graduated as desired."

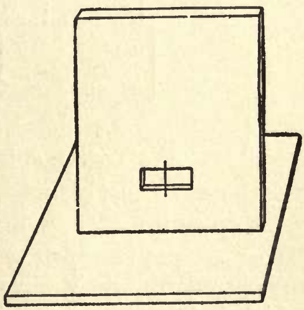


Fig. 127

"Fig. 127 shows the front screen in place. This is all that is seen by the observer. A vertical thread is placed in the window at the exact point where the sound comes. The subject notes the mark on the card which seems to be immediately behind this thread at the instant of hearing the sound. The actual objective simultaneity is determined empirically."

Certain simple forms of exposure apparatus are described on page 197. These can be converted into devices which first expose and then cover up what they have exposed, by placing the figures or light so that they will be uncovered, not at the end of the movement, but in the

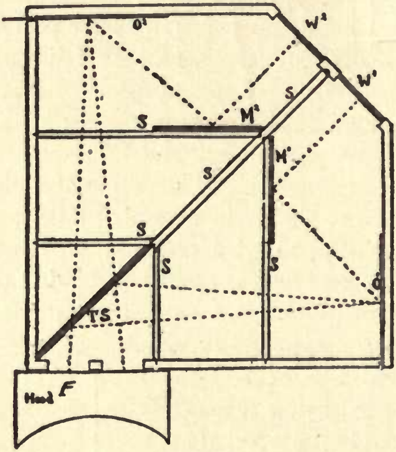


Fig. 128

middle of the movement. Other forms which may be mentioned consist of long pendulums which carry screens with openings of any desired length. Such pendulum tachistoscopes are open to the objection that they distract the observer by their movement. A form of tachistoscope which is free from the objection of a moving surface has been described by Professor Dodge. It consists in a box represented in Fig. 128. This box has two openings at W^1 and W^2 through which light from a convenient source may be allowed to pass. The light from W^2 strikes a mirror M^2 and is reflected to a surface O^2, which is one field upon which letters or numbers or other desired objects may be exposed. The light from O^2 passes along the line O^2F to the opening in front of which the observer's eye has been placed. In the course of the line FO^2 is placed a piece of dark glass TS. This dark glass is not as transparent as ordinary glass and reduces somewhat the light from O^2. Nevertheless, it is sufficiently transparent to give an adequate light from the field O^2 and its chief purpose is served, not in connection with the light that comes through the opening W^2, but in connection with the light which comes through the opening W^1. If now the light is allowed to enter the box through the opening W^1 rather than through the opening W^2, it will be reflected from the mirror M^1 to the field O^1, and from O^1 the light passes to the dark glass TS. From the surface of the dark glass, the light is reflected into the eye of the observer. A certain amount of light also passes through this dark glass to the back surface from which it is in turn reflected into the eye of the observer, but it loses so much intensity in its double passage through the dark glass that the image from the back surface is practically lost and does not attract the attention of the observer. The field O^1 is by this means directly superimposed upon the field O^2. By an adjustment of the openings W^1 and W^2 the intensity of the two fields may be made equal to each other. A suitable device may be provided for changing the illumination from W^1 to W^2, or in the converse direction. For example, a pendulum may be allowed to swing in such a way that an upper shield will cover the opening W^1 for a time, and a lower shield which is allowed to pass by W^2 will allow the light to enter through W^2 for any desired length of time. As the pendulum swings further, the lower shield may be made to cover the opening W^2; while the upper shield is opened so as to allow the light to enter through W^1. While the light is coming only through the opening W^1, the field O^1 will be in clear view and the field O^2 will be invisible. As soon as the entrance of the light is changed by the movement of the pendulum, the fields are reversed and O^2 comes into view to the exclusion of O^1. The appearance of the fields in this case is without visible movement at any point, and the chief objection to the various forms of fall-tachistoscopes is entirely obviated.

Experiments which require series of sounds given with regularity at short intervals can be set up with a metronome. They can, however, be properly carried out only with the aid of complex apparatus. Fig. 72 (page 145) showed an attachment for the Ludwig Kymograph for the purpose of utilizing that apparatus to make and break electric circuits which in turn operate sound hammers or spark devices. The wheel shown at the left of the figure is connected with the shaft of the clock-work. Contacts may be distributed along the graduated scale at known intervals, and from these contacts electric currents may be carried at desired intervals to properly arranged stimulating devices.

A simple form of apparatus which serves many purposes in giving successive stimulations is a heavy pendulum swinging past a long graduated scale such as that shown in Fig. 122 (page 226). The scale should be graduated into time units.

An elaborate apparatus for working with time intervals was designed by Schumann. This apparatus is driven by means of the Helmholtz rotation apparatus described on page 146. It consists of a graduated disk upon which are fastened a number of contacts, one or more of which can be easily moved so as to regulate in the course of the experiment the interval between contacts. A central arm connected with the rotation apparatus moves over these contacts at a regular rate, and the current thus made and broken is conducted to a sound hammer or other suitable device, where it is transformed into a stimulus for one or the other of the senses.

The apparatus for recording the efforts of the subject to reproduce such a series of stimuli is the same as that required for the record in connection with the equivocal figures in the last exercise. If it is desired that the reproduction of the series of stimulations shall be complete, not only a key and marker should be used, but provision should be made for the reactor to hear a series of sounds which correspond to his own movements. This series of sounds can be secured by connecting a sound hammer with the circuit between the reaction key and the marker.

B—RESULTS

In general it will be found that the sound produced in a complication series is always referred to a wrong point in the visual series. Indeed, the experiment was suggested by the fact that the older astronomical observations in which the observer was required to compare a visual and auditory series, always showed more or less error, so that sound and light were never reported in their true objective relation. No general statement can be made with regard to the type of error which will be committed in the experiments, as the direction and extent of the error depend very largely upon individual tendencies.

The other experiments show the increase in scope of consciousness through grouping of experiences, and the impossibility of recognizing correctly a large series of impressions either when given simultaneously or successively. In broad general terms it will be found that the range of accurate recognition is limited to from six to ten impressions, if these are given in such a way as to render rhythmical grouping impossible.

C—SUPPLEMENTARY EXPERIMENTS

The simplest experiment in time perception which can be performed is to give the observer a succession of three stimulations, the first two of which shall be separated by a standard interval, the second and the third by a variable interval. If this variable interval is successively increased and decreased, a determination can be made of the limits of accurate recognition of intervals. It will also be found by a similar experiment that the accentuation of any one of the stimuli in the series modifies the estimation of the interval preceding and succeeding the accentuated stimulus.

If it is desired to use a continuous sound it will be found possible to produce such a sound by shunting an electric tuning-fork into a telephone circuit. The result will not be a musical tone in the telephone, but rather a burr which results from a rapid succession of makes and breaks in the electromagnet in the telephone. It is extremely difficult to control a continuous sound of any ordinary type. The sound of a tuning-fork is not loud enough to act upon a telephone in a remote room and be transmitted as a musical note to the telephone near the observer. Any other form of transmission than the electric suffers from the impossibility of instantly shunting off the sound. There must be some continuous medium between the source of the sound and the observer in such a case, and this continuous medium almost invariably conducts enough of the vibration so that the observer is more or less distracted before and after the strong stimulus which is the subject of the investigation.

EXERCISE XXIV

A—APPARATUS AND PROCEDURE

The apparatus for this experiment can be made very simply. A strip of black cardboard may be passed through two openings lying in the same horizontal line in a white cardboard. Instead of a strip of black cardboard some flexible material, such as a coarse thread, may very easily be employed; or a narrow, firmly woven braid will serve the purpose very well. Extending vertically across the portion of the black strip or thread which is visible to the observer, should be the short cross-line described in the text. The observer can now, by reaching behind the white cardboard, draw the black strip with its vertical cross-line either to the right or to the left, and in this way adjust the cross-line at any desired distance from the points where the line is cut off by the cardboard.

A second method of setting up this experiment is to use the apparatus described under Exercise I for the measurement of illusions. A horizontal line is drawn on the fixed card and a short black line is exposed from behind a white screen, the cross-line and the screen being attached to the movable board in the apparatus. The short cross-line is now adjusted to the desired position along the long horizontal line. The cross-line may be drawn on the back of a glass, in which case there will be no lines in the field of vision except those which are to be compared.

For the second part of this experiment, the simplest method consists in laying before the observer a strip of black paper upon a white background. A second strip of similar paper is provided, and the observer is required by means of a white screen to cover up such a portion of this second strip as he may desire, and to place the visible portion of the second strip across the first piece that was provided. Here again lines on the back of glass may be used.

For the third part of the experiment a series of figures cut from black cardboard or from colored paper may be used to counterbalance the vertical line which is drawn upon the paper at the outset of the experiment. These can be readily adjusted by the observer until he is satisfied. Measurements should be made in this case to the edge of the figure which is nearest to the central point in the field of vision. A very good series of figures for this purpose can be made up by drawing rectangles; first, five which are 20 mm. wide and successively 1, 2, 4, 8 cm. long; and, second, five which are each 4 cm. long and successively 1, 2, 3, 4 cm. in width. Circles of various sizes are also easily produced.

B—RESULTS

The formula which is most common for unequal divisions is that which has commonly been called the golden section and is as follows: The long part is to the sum of the two parts as the short part is to the long part. This principle holds also for the division of crosses and for the relation between their two legs.

The results of symmetrical arrangement of figures is a matter which depends on the size of the figures. Generally speaking a large figure near the center balances a small figure far away.

C—SUPPLEMENTARY EXPERIMENTS

The supplementary experiments require no comment, except possibly the last, which refers to the method of selection. This method consists in presenting to an observer two colors or forms, and asking him to select the one which is more agreeable. Other combinations are now presented, including the selected color or form, until, finally, by a succession of choices the observer has arrived at a final selection of that one which seems to him to be most agreeable. This method was suggested by Fechner in "*Vorschule der Aesthetik.*"

EXERCISE XXV

For the experiments with these higher mental processes the physical conditions are not elaborate. The apparatus may be of the simplest sort. In the two experiments described, the apparatus consisted of a projection lantern which would throw images upon the wall in front of the observer, and of a simple light which could be turned on the wall in very faint intensities.

GENERAL EQUIPMENT

REQUIRED	DESIRABLE
Charts.	
Models.	
	Projection lantern with slides.
	Photographic equipment for making slides.
Drawing material: Drawing board. Drawing paper. Thumb-tacks. T-square. Triangles. Ruling pens. Compasses. India ink.	Supply of millimeter paper.
Carpenter's tools.	Metal and wood-working machine shop.
Electric current.	Lamp batteries.
	Plugs and sockets for connections.
Table clamps.	
S-clamps.	
Rods.	
Meter rods, tapes and rulers.	

EXERCISE I

REQUIRED	DESIRABLE
Sets of cards, five pairs in each set.	
Paper on which to mark lengths of lines as set.	Apparatus for holding cards with recording attachment and roll of paper on which to make records.
Holder for cards during adjustment.	
Millimeter measure.	Thumb-tacks to fasten cards to boards.

EXERCISE II

REQUIRED	DESIRABLE
Head-rest (table clamps, S-clamps, rods.)	Head-rest (independent).
Sealing-wax.	
Shield for eye.	
Colored papers.	
Perimeter or campimeter of simple construction.	Perimeter of more elaborate type with light box for exposure of colors. Electric connections.

EXERCISE III

REQUIRED	DESIRABLE
Colored papers.	
Colored disks.	
Simple color disk rotator.	Electric motor with arbor for holding disks. (Current connections, wires.)
Protractor.	

EXERCISE IV

REQUIRED	DESIRABLE
Head-rest (table clamps, S-clamps, rods).	Head-rest (independent).
Sealing-wax.	
Eye-shield.	
Meter rod.	
Table clamps, S-clamps and rods to hold measuring rod.	
Paper ruled in large squares.	
After-image card.	Box with lamp and Aubert's diaphragm. Dark room. Electric connections. If these are not at hand the third part of the exercise must be omitted.

EXERCISE V

REQUIRED	DESIRABLE
Model of truncated pyramid.	
Drawing material: Paper, ruler, etc.	

REQUIRED	DESIRABLE
Mirror stereoscope of simple construction. (Lens stereoscope may be used.)	Adjustable mirror stereoscope.

EXERCISE VI

REQUIRED	DESIRABLE
Head-rest (clamps on chair).	Head-rest (independent).
Sealing-wax.	
Two sounders.	Two telephones, mercury key, electric connections, battery, wires.
	Interrupter.
Auditory cage, simple construction.	Auditory cage, adjustable.

EXERCISE VII

REQUIRED	DESIRABLE
Quincke's tubes.	
Mouthpiece for blowing same in combinations.	
Two chromatic pitch-pipes with scale.	Set of tuning-forks.
	Resonators (one adjustable).
	Conducting tubes leading from resonators.

EXERCISE VIII

REQUIRED	DESIRABLE
Stamp.	
Ink pad.	
Metallic points in cork.	Holder for various kinds of points.
Wooden rods, sealing-wax, bristles of various sizes.	Metallic points.
	Bristles and grips to fit holder.

EXERCISE IX

REQUIRED	DESIRABLE
Wooden stylus.	
Aniline ink.	
Compass with hard rubber or bone points.	Aesthesiometer with scales.

REQUIRED	DESIRABLE
Millimeter measure.	
Pasteboards cut into various lengths.	Hard rubber strips with edges of various lengths.

EXERCISE X

REQUIRED	DESIRABLE
Weights.	Rotating table for presentation of weights to observer.
Pith-ball sounder (simple construction).	Sounder with accurate holder for balls.
Photometer (shadow).	

EXERCISE XI

REQUIRED	DESIRABLE
Tambour.	
Rubber dam, thread, beeswax, rubber tubing, straws, material for points.	Air valve.
Kymograph. (If no motor is provided in equipment, clockwork kymograph).	Two drums. Pulleys for connection with motor. Motor and connections.
Kymograph paper, paste.	
Flame for smoking paper.	
Shellac tray or table.	Marker for use with fork.
Electric fork with connections.	Interrupter for longer intervals. Pendulum with contacts for long intervals. Coarse marker recording with ink or pencil. Jacquet chronometer.

EXERCISE XII

REQUIRED	DESIRABLE
Thistle tube.	Sphygmograph.
Clamps for above.	Arm-rest.
Rubber tubing.	
Recording tambour.	
Kymograph and accessories.	
Time marker.	
Sugar solution, quinine solution.	

EXERCISE XIII

REQUIRED	DESIRABLE
Tambours (receiving and recording).	
Kymograph and accessories.	
Planchette with recording pen.	

EXERCISE XIV

REQUIRED	DESIRABLE
Spring key with electric connections.	
Marker.	
Kymograph and accessories.	
Time marker.	
Hand-rest to bring the reactor's hand over a moving paper on which he may draw the straight lines required.	Apparatus for holding paper over traveling paper. Typewriter ribbon or carbon paper underneath.

EXERCISE XV

REQUIRED	DESIRABLE
Two keys (experimenter's and reactor's).	
Electric tuning-fork and connections.	
	Ewald chronoscope and wires for connections, or Hipp chronoscope.
Electric markers.	
Tambours (one of these may be substituted for the reactor's key).	Lever key for reaction forms. Sounder to give signal. Shutter to expose colors.
Kymograph and accessories.	

EXERCISE XVI

REQUIRED	DESIRABLE
Three keys (experimenter's, two for reactor).	
Electric fork and connections.	
Markers.	Chronoscope and connections.

REQUIRED	DESIRABLE
Tambours. (One may be substituted for the reactor's key.)	Lever key for recording form of reaction.
Kymographs and accessories.	
	Sounders.
Color exposure apparatus connected with experimenter's key.	Exposure shutter.
	Articulation key.

EXERCISE XVII

REQUIRED	DESIRABLE
Attachment for kymograph to take record of writing.	Apparatus, as described by Mr. Freeman, for writing record.
Recorder to attach to hand.	
Figure for moving point on kymograph.	
Carbon paper to record hand movements.	Cylinder for recording hand movements.

EXERCISE XVIII

REQUIRED	DESIRABLE
Series of patterns.	
Paper for drawing.	
Carbon paper.	
Soft paper.	
Metal stylus.	
Millimeter ruler.	
Protractor to measure angles.	

EXERCISE XIX

REQUIRED	DESIRABLE
Spring key with connections.	
Marker.	
Time marker connected with fork or interrupter.	
Kymograph and accessories.	
Figures.	
Watch.	Stop watch.
Cards marked with numerals or figures.	

EXERCISE XX

REQUIRED	DESIRABLE
Spring key with connections.	
Marker.	
Time-marker.	
Kymograph and accessories.	Porter's ergograph.
Metronome.	

EXERCISE XXI

REQUIRED	DESIRABLE
Cards with nonsense syllables.	
	Kymograph and shield for exposure of syllables.
	Ratchet for intermittent movement of kymograph.
	Wirth's special apparatus.

EXERCISE XXII

REQUIRED	DESIRABLE
Equivocal figures.	
Key, marker, kymograph and accessories, time-marker.	
Stereoscope, colored papers.	
(Masson disk, color mixer).	

EXERCISE XXIII

REQUIRED	DESIRABLE
Metronome and shield.	Complication pendulum.
Exposure apparatus and letters and figures for same.	Dodge's exposure apparatus.
Metronome for series of sounds.	Pendulum with contacts and sounder, or
Spring key, marker, kymograph and accessories.	Attachment for Ludwig Kymograph with contacts and hammer.

EXERCISE XXIV

REQUIRED	DESIRABLE
Cards.	
Adjustable lines.	Illusion apparatus, adjustable cross-line on glass.
Millimeter ruler.	
Strips of black paper.	
Black card figures for symmetry.	

LIST OF DEMONSTRATIONS

TO BE USED WITH THE AUTHOR'S PSYCHOLOGY, GENERAL INTRODUCTION. THE PAGE REFERENCES AT THE LEFT ARE TO THAT VOLUME. THE PAGE REFERENCES AT THE RIGHT ARE TO PAGES IN THIS VOLUME.

PAGE		PAGE
2.	Analyze white light into components with the aid of a prism or spectroscope. Or mix colors and produce gray	47
6.	Memory experiments as illustrating method	222
11.	Plotting of blind-spot	42
15.	Chart or lantern slide of amoeba or other cells.	
17.	Other charts from Jennings.	
23.	Models, or charts, or lantern slides of nervous system of various invertebrate forms.	
27.	Preparation or model of frog's nervous system. To make the preparation, fine, sharp-pointed scissors, a scalpel, and forceps are required. The frog should be chloroformed and dissected.	
30.	Models or preparations of vertebrate brains higher than frog.	
36.	Model of human head showing brain in situ.	
36.	Model of brain showing sections. (Azoux brain model is the best.)	
36.	Charts or slides showing various types of cells and various parts of the nervous system in fine anatomy.	
36.	Charts by Strümpell and Jakob, published by J. F. Lehmann, Munich, Germany.	
75.	Spectrum (if not shown in connection with page 2).	
75.	Gray and colored papers	36
77.	Chart of color circle.	
81.	Model of eye, showing parts.	
84.	Kühne's eye, or other means of demonstrating properties of lenses (camera obscura).	
84.	Show properties of monocular image	64
84.	Thread model showing paths of rays of light entering the eye.	
84.	Model showing muscles of eye.	

INDEX