

bulb, E, above which rises a graduated tube, F. The two other bulbs, G G', are placed upon the extremities of the U-shaped tube, and are provided with branch tubes, gg', into which the mercury is poured until its level reaches to about the middle of the three bulbs. Then on top of the mercury are poured several drops of glycerine into the bulbs, GG', and a few drops of water or alcohol into the tube, F.

In order to preserve the mercury and other liquid from contact with the air, the U-shaped tube is prolonged above the two bulbs to unite again with the central tube at the top of the apparatus, as shown in Fig. 1. In this way the liquids are inclosed in an atmosphere of their own, having no communication with the external air.

In order to measure the intensity of the magnetic field by this apparatus, metal rods, H H', are introduced through the tubular branches, gg', into the bulbs, G G', so that their ends are immersed in the mercury. The rods, H H', are then connected with the poles of a generator, and the part, B, of the tube is placed in the magnetic field to be examined, and with the tubes, B and D, at right angles to the line of magnetic force. The mercury will immediately rise in the bulb, E, and force up the liquid therein, which may be colored, into the tube, F. The diameter of the latter being much smaller than that of the bulb, the movements of the liquid therein are correspondingly amplified.

Referring to Fig. 4, if it is desired to measure at the point, a, the intensity of the field of a magnet pole, Z, it suffices to place at a the part of the apparatus representing the intersection of the horizontal tube, B, with the middle tube, D, to pass through the tube, B, a known current of, say, from 1 to 10 amperes, and to read the change of level produced in the column of colored liquid in the tube, F. If d represents this height read on the scale, F, and C be the current traversing the apparatus at a, then the magnetic force, H,

at that point will be represented by $\frac{d}{KC}$, K being the constant of the instrument.

The rise of the mercury is due to the reaction between the electric current traversing the tube, B, and the magnetic field. For the examination of a vertical field it suffices to curve the lower part of the tube at right angles.—*The Electrician*.

A NEW AIR PYROMETER.*

By Professor J. WIBORGH, School of Mines, Stockholm.

GAY-LUSSAC, Dulong, Rudberg, and Regnault, having by their famous experiments decided the coefficient of the dilatation of the air, instruments similar to those which they had employed for this purpose were used as measurers of temperature, and were called air thermometers, or, if they were specially designed for ascertaining greater degrees of heat, air pyrometers.

In consequence, however, of the construction of these instruments, and the care and practice necessary for their proper use, they have only been employed as measurers of temperature in the cause of science, or, at most, for grading other pyrometers designed for the needs of industrial pursuits.

Though the coefficient of the expansion of the air, even at a very high degree of heat, is constant, still the expansion of the air ought to be the surest base for the construction of a reliable pyrometer, and, therefore, it seemed to me of great importance that these air pyrometers should be brought to a simpler and a more practical form.

Before proceeding to a more particular description of my contribution to the solution of this important question, I will first say a few words concerning the two principles which have hitherto been followed when constructing pyrometers. These are, first, that a certain given amount of air, even when heated, is kept at the same volume, when the requisite pressure gives a measurement of the increase of temperature; and the second, that the air is kept under unvaried pressure, when the degree of heat is determined by the change of volume.

These two systems are seen in Fig. 1 annexed, where V represents a thermometer bulb filled with air, which, by means of the capillary tube, A, is connected with an open manometer, the one part of which, V', is graduated in cubic centimeters, and the other, B, consists of a longer vertical tube. The manometer tubes, V' and B, are connected in their lower part, and, furthermore, communicate with a caoutchouc ball, K, containing mercury, which is driven up into the manometer when the vessel is compressed. By another capillary tube, C, provided with a tap, D, the thermometer bulb, V, can be put in communication with the outer air.

The volume of the capillary tube is supposed to be so slight that it need not enter into the calculation.

Should this instrument, according to the principle first mentioned, be used as a thermometer, the tap, D, is opened, and the mercury is driven up to the mark, m, close to the capillary tube. The surface of the mercury will then be equally high in both the manometer tubes, since the same pressure—that of the atmosphere—acts on both of them. Afterward, when the tap, D, has been shut, the bulb, V, is exposed to the temperature sought, when the inclosed air dilates and forces up the mercury, so that in the manometer tube, B, it rises above the mark, m. On forcing into the manometer so much quicksilver that its surface rises in the tube, V, to the mark, m, so as to reduce the volume of the air to its original volume, the quicksilver in the tube, B, rises still further, say to h; this height, h, then gives a measurement of the temperature, according to the following simple formula:

$$h = H \cdot a \cdot t.$$

In this, h signifies the higher pressure which is requisite for the air being kept at an unvaried volume; H the prevailing barometrical pressure for the time being; a the coefficient of the dilatation of the air; and t the increase of temperature of the air in the bulb, V. By giving this form to the air pyrometer, as seen by the formula, we are independent of the size of the thermometer bulb, and the excess pressure, h, is pro-

portional to the increase of temperature. But this excess pressure, on the other hand, is so important that, for an increase of temperature of the air in the thermometer bulb of 270 deg., h increases a whole atmosphere, or 760 mm.; and this circumstance, as can easily be understood, renders it impossible to use this thermometer for ascertaining high degrees of temperature, so that it never can be a pyrometer in the real sense of the word.

If the same instrument is to be used as a thermometer, according to the second principle, the mercury is adjusted as before to the mark, m, but while the thermometer bulb is warmed t' , by which the air is dilated, part of the air is allowed to escape freely into the graduated tube, V', and causes the mercury in the manometer to sink, so that it is constantly at the same level in both the tubes, and the inclosed air is thus kept at the same pressure. For a given increase of temperature, t, the air dilates with a certain volume, V', which may be read on the graduated tube, and thus becomes a measurement of the temperature according to the formula

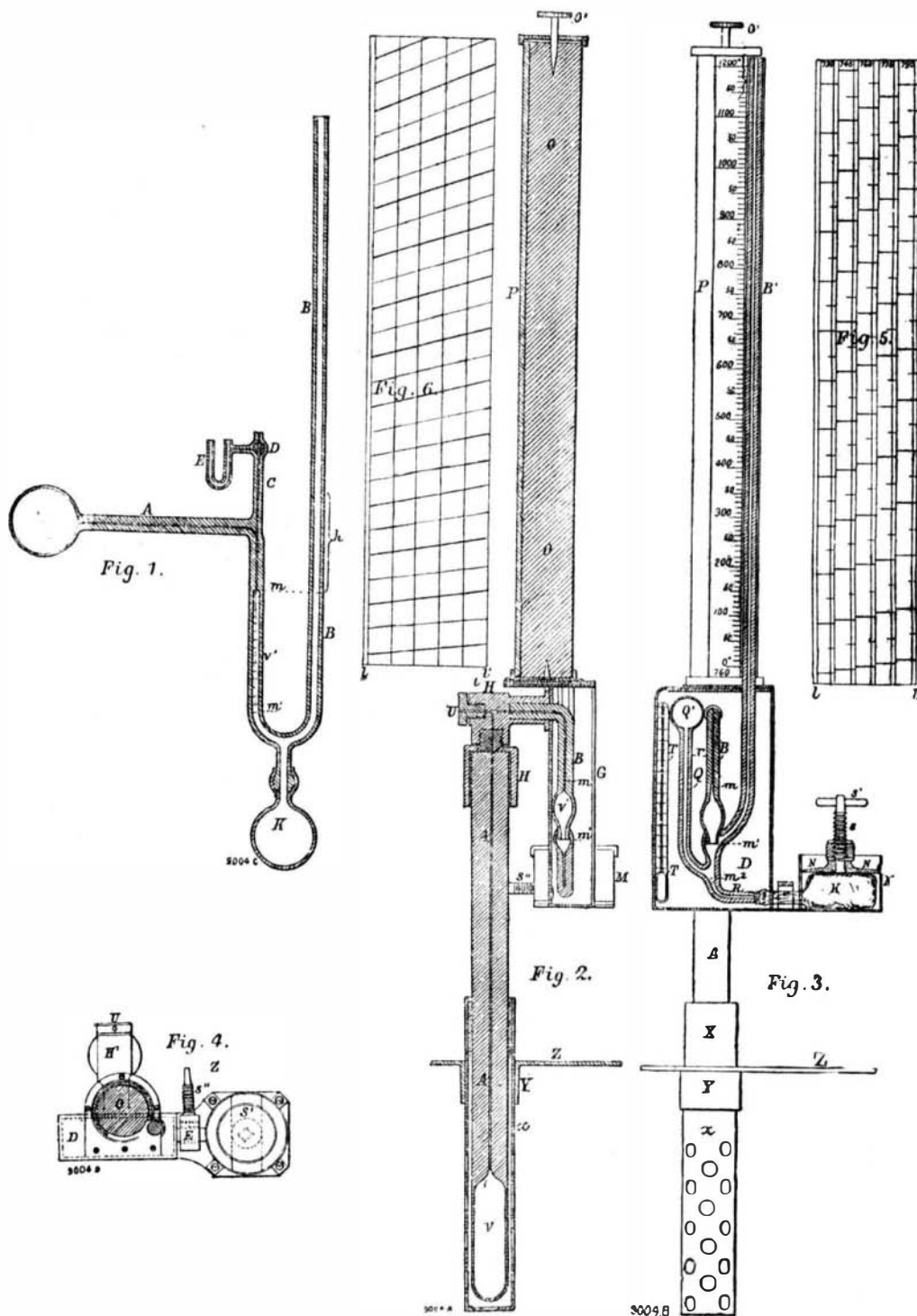
$$V' = V \frac{at}{1 + at}$$

supposing that the volume of air, V, at the reading has the same temperature that it originally had, and that

manometer, E, which contains a light fluid, and is therefore very sensitive. When the surfaces of the mercury in the manometer tubes are almost on the same level, communication is opened to this manometer by means of the tap, D, by the help of which the mercury can afterward be regulated to a nicety, so that the inclosed gas obtains atmospheric pressure. This, however, is not enough; the temperature of the volume of air, V, ought also to be ascertained with the same accuracy if any useful results are to be obtained, and this part of the manometer must therefore be surrounded by water of a known temperature, which makes the handling of the instrument extremely inconvenient. From the above it will be seen that air pyrometers founded on the principles hitherto used cannot possibly be of practical use for measuring temperature in the service of industry.

On looking at Fig. 1 a little more closely, it will easily be seen that there is another mode of constructing air pyrometers. The mercury can be adjusted to the mark, m', and the tap, D, be left open, so that the volume of air, V, is in communication with the outer air. As the thermometer bulb is heated or cooled, a certain quantity of air flows out or in, as a matter of course, so that the air remaining in the thermometer bulb is always under atmospheric pressure.

When the temperature is to be ascertained, the tap,



A NEW AIR PYROMETER.

the barometric pressure has not changed during the experiment.

In this case we are independent of the barometric pressure, but the increase of volume is not proportional to the increase of temperature, and the influence that this latter circumstance may exercise on the possibility of making nice calculations of temperature may be seen from what follows. Suppose the thermometer bulb that is heated contains 10 cubic centimeters. When the temperature rises from 100 deg. to 200 deg., it corresponds to a difference of volume of 1.55 cubic centimeter; but between 900 deg. and 1,000 deg. the difference of volume is only 0.19 cubic centimeter. From this it is plain that the sensibility of this thermometer decreases as the temperature increases.

If the bulb of the thermometer be made larger, an increased volume, V', can certainly be read, as shown by the formula, but in these cases practical inconvenience is occasioned by being obliged to use a large thermometer bulb, and the readings must therefore be made with this pyrometer with the greatest nicety. In order to make this possible, Professor O. Pettersson, of the high school of Stockholm, has made a very ingenious improvement, the principle of which is shown in Fig. 1. He has combined the capillary tube, C, with a small

D, is shut, and the mercury is driven into the manometer as high as the mark, m, when a certain given volume of air, V', is forced into the bulb of the thermometer. If the air, when forced into the bulb, is t' warm, and the temperature of the bulb is T' , the former is heated $T' - t'$, and being retained in the bulb, requires a certain pressure, h, over and above the atmospheric pressure, which excess pressure, h, becomes a measurement of the temperature sought, T.

It is this principle, which has never before been employed for air pyrometers, which forms the fundamental basis of my new air pyrometer, the theory and construction of which I will now explain.

The Theory of the Pyrometer.—Into the thermometer bulb, V, which contains air of atmospheric pressure of the warmth of T' , a certain volume of air, V', at the temperature of t' and atmospheric pressure, is to be forced and heated to T' .

If the pressure was unvaried, the entire volume of air after heating would be

$$V + V' \{ 1 + a(T - t) \}$$

but as the volume of air, V', must be contained in the thermometer bulb, V, the pressure must also be altered

* Paper read before the Iron and Steel Institute at Edinburgh.—*Engineering*.

† V. Meyer and Langer have proved that the dilatation coefficient of oxygen and nitrogen is constant up to 1,700 deg. Cent. (*Wagner's Jahresbericht*, 1885, page 395).

with a certain magnitude, h , from which the following equation is obtained:

$$\left[\frac{V + V' \{ 1 + \alpha(T-t) \}}{H + h} \right] \cdot H = V \quad (1)$$

or

$$h = \frac{V'}{V} \cdot H + \frac{V'}{V} \cdot H \cdot \alpha(T-t) \quad (2)$$

or

$$T-t = \frac{V \cdot h - V' \cdot H}{\alpha \cdot V' \cdot H} \quad (3)$$

In these formulæ the volume of the capillary tube is not taken into account, since, in relation to the volumes, V and V' , it must be small enough not to influence the determinations of temperature to any considerable degree. For the same reason no account is taken of the dilatation of the bulb of the thermometer; but should there be a wish to allow the latter to enter into the calculation, then, instead of formula (2), we have

$$h = \frac{V' \cdot H}{V \cdot (1 + K \cdot T)} \{ 1 + \alpha(T-t) \} \quad (4)$$

where K is the coefficient of cubical expansion of the material of which the bulb of the thermometer is made. From the formula (3) it is seen that the thermometer only gives the difference of temperature between the volumes, V and V' , and from (2) that for $T=t$, i. e., when both the volumes of air are at the same temperature, h is equal to the first term of the equation $\frac{V'}{V} H$, which thus represents the position of the point of zero of the instrument.

The second term in the formula (2), on the contrary, shows the excess in the height of pressure above the point of zero, which is furthermore necessary for pressing the one volume of air, V' , into the other, V , as they are at different temperatures. These excesses, as is seen from the formula (2), are proportional to the differences of temperature; from which it again follows that the thermometer for a certain increase of heat must give as great a result, whether the temperature be high or low. From what has just been stated it follows, moreover, that the temperature sought, T (the temperature of the thermometer bulb), can only be obtained after adding the degree of heat of the volume of air, V' , before it is forced in, to the temperature, or, more properly speaking, the difference of temperature, which is shown by the instrument.

From the formula (2) it also follows that the position of the point of zero and the excess pressure occasioned by the differences of temperature are both dependent on the barometric pressure, which must therefore be known, as also the ratio of $\frac{V'}{V}$. The larger the bulb of the pyrometer is made in relation to the volume of air, V' , which is to be pressed in, the smaller must the excess of temperature be which shows a certain effect on the manometer, and these air barometers can therefore be made to meet different requirements, so that they give greater or less results for a certain degree of heat, in full accordance with the case of the common mercury thermometer, where the same thing is arrived at by varying the volume of the bulb of the thermometer and the diameter of the tube of the thermometer.

It is plain that this air pyrometer can be used just as well for measuring cold as heat, for if the bulb of the thermometer is colder than the volume of air, V' , the second term in the formula (2) becomes negative, which means that the pressure h sinks below the point of zero, but at a distance from it which answers to the difference of temperature in question.

The Construction of the Pyrometer.—Figs. 2, 3, and 4 show the construction of the pyrometer in question, where it is chiefly designed for determining the temperature of the blast of a furnace. The bulb of the thermometer, V , which holds about 12 cubic centimeters, forms the one end of the porcelain tube, A , the outer diameter of which is 20 mm., while the inner is but $\frac{1}{2}$ mm., so that it can be regarded as a capillary tube. This tube, which is to sustain the other parts of the instrument, must be of great strength, and for this reason the thickness of the material is so great. The tube is cemented into a metal casing, H , which is screwed firmly to a metal cylinder, H' , through which the capillary tube is connected with the manometer, B or B' . The glass tube forming the manometer is at first capillary, but at m it is for a length of about 10 mm. made somewhat wider, $1\frac{1}{2}$ mm. to 2 mm., after which a further enlargement commences for holding the volume of air, V' . When determining the temperature, this volume, V' , is to be led into the bulb of the thermometer, V , which should be made about ten times greater than V' . At m' , where the longer manometer tube, B' , is extended, the inner diameter is about 2 mm., the outer about 8 mm., and below the glass tube is bent and connected with a caoutchouc ball, K , which contains mercury. The ball K is placed in a metal box M , with a movable lid, N , which, by means of a screw, S , can be pressed down into the box. Thus the ball is squeezed, and the mercury driven into the manometer tubes.

The screw, S , is turned by a metal plate, S' , which is loosely fixed on the tap-like end of the screw, so that this plate may be easily taken away, and meddling and careless driving up of the mercury through the manometer tube, B , into the bulb of the thermometer, thus injuring the instrument, is prevented.

To protect the tubes of the manometer, they are inclosed in a small rectangular box, D , made of metal, the front being formed of a glass plate, G . The longer tube of the manometer, B' , proceeds through this box, and runs along the folded edge of a metal tube, P , which surrounds a wooden cylinder, O . On this cylinder, which can be turned by the knob, O' , the scales are fixed, a segment of the metal tube being cut away nearest to the manometer, so that the scale may be visible. By turning the scale cylinder, the proper scale, or that answering to the barometrical pressure, may be brought to the tube of the manometer.

In order to prevent dust from penetrating into the open tube of the manometer, B , and destroying the mercury, a little cotton wool is placed in the upper end of the tube, on which a glass cap may afterward be hung.

If the volume of air, V' , be as warm as the bulb

of the thermometer, and the mercury is forced up to the mark, m , as has before been stated, it rises in the manometer tube, B' , to a certain height, which forms the point of zero of the thermometer corresponding to the prevailing barometrical pressure.

In order to ascertain which is the correct scale, it is thus only necessary to turn the scale cylinder, so that the scale whose point of zero coincides with the height of the mercury reaches the manometer tube; but on the other hand, when the instrument is so placed that V is warmer than V' , it is, of course, impossible to decide the correct scale in this manner. To avoid the consequent use of a separate barometer, a third tube, Q , ending in a ball, Q' , is applied to the tube of the manometer, which, below the manometer tube, B' , opens into the common tube, R . When the mercury is forced into the manometer, it of course rises in the tube just mentioned, and for the point of zero of the instrument attains a certain height, where a mark (r) is notched. Thus the same principle is applied as for the pyrometer, viz., that a certain given volume of air is forced into another. But as the tube, Q , and the ball, Q' , are of the same temperature, the pyrometer's point of zero may be determined by the aid of this mark (r), even should V be warmer than V' .

As the pyrometer shown in Figs. 2 to 4 is chiefly intended for determining the temperature of the blast of a furnace, the instrument should be of solid construction and easily applicable. For the protection of the lower part of the china tube, A , which contains the thermometer bulb, and is therefore more fragile, it is at that part surrounded by a perforated metal covering, x , but the upper part of the same tube is not covered with metal, partly because, in consequence of its construction, it is sufficiently durable, and partly because, on account of the small power which porcelain possesses of conducting heat, it is intended to serve to isolate the other parts of the instrument from the hot gas main. At the upper part the metal covering is provided with a somewhat conical ring, y , which rests on a suitable opening in the gas main when the pyrometer is put in it. As a protection against the radiating heat of the gas main, a plate of metal, Z , is applied to the metal ring just mentioned.

It often depends on local conditions whether the pyrometer can be conveniently placed above the gas main or on one side of it, and the instrument should therefore be constructed so that it may be used in either case. For this purpose the metal cylinder, H' , which connects the capillary tube of the porcelain tube with the manometer, is arranged so that the pyrometer tube, A , can be moved and replaced by the screw plug, U , which in this case must be fixed in the place formerly occupied by the tube of the pyrometer, so as to shut off all communication with the outer air at this point.

For cementing both the tube of the pyrometer and also that of the manometer in their respective metal sockets, a cement is used made of finely ground protoxide of lead (litharge), which is well mixed with so much glycerine that the mass becomes pretty thick. This cement hardens quickly (within a few hours), tightens extremely well, and can be heated to about 250 deg. C. before it splits.

In order to avoid stopping the capillary tubes when cementing, the two tubes are connected by a metal wire carried through them, when the end of the tube is held slightly outside the metal socket, and is covered with a layer of cement. The tube is afterward pushed gently into the metal socket, and the interstice is again well filled with cement. After an interval of about half an hour the superfluous cement outside the socket is removed, and the metal wire is drawn out.

When transporting the pyrometer the mercury must be shut off, so that it cannot escape into the tubes of the manometer. For this purpose, between the caoutchouc ball and the manometer tube there is a clamp, E , which consists of a couple of metal plates connected by a screw, S' . This squeezes the neck of the caoutchouc ball when, by tilting the instrument, the mercury has run into the ball. The screw, S' , is turned by the same metal plate, S' , which is used for the screw, S . The temperature of the volume of air, V' , before being forced in, is the same as the temperature of the surrounding air, which is determined by a thermometer, T , placed close to the manometer tube.

Calculation and Drawing of the Scale of the Pyrometer.—Before the scale can be calculated and drawn, the position of the point of zero must first be determined. For this purpose a fine but plainly visible scratch, m , is made on the tube of the manometer, just below that place where the capillary tube ends. This being done, the bolt, U , is unscrewed, and the mercury in both the tubes of the manometer is then under atmospheric pressure. The mercury having been raised to the mark, m , the height to which it then rises in the other tube is ascertained by means of a cathetometer, or is marked for the occasion on this tube. The mercury is then again sunk so that it only mounts to m' —i. e., below the tubes, Q and B' . The screw bolt is then again adjusted, and in order that it may completely close the capillary tube, a thin piece of caoutchouc, of at most a half millimeter in thickness, and of somewhat smaller diameter than the screw, U , is placed before the opening.

A similar packing must also be employed when screwing the pyrometer tube into the socket, H , although with this difference, that a small hole is then made in the middle of the thin piece of caoutchouc, so that the capillary tubes are in communication, the one with the other.

If the mercury be now again forced to the mark, m , in the other manometer tube, it rises to a certain height, which is also measured or marked with a mark on the tube. Should these two observations have been taken during a known atmospheric pressure, H , and while the volume of air, V , as also V' , are of the same temperature, the difference in the height of pressure, h , which is a function of these two measurements, is just the point of zero of the thermometer at the atmospheric pressure in question, according to the formula already mentioned,

$$h = \frac{V'}{V} \cdot H,$$

and since both h and H can easily be determined, the ratio $\frac{V'}{V}$ is thus arrived at for this instrument; and from this formula, moreover, the position of the point

of zero of any atmospheric pressure can easily be determined.

From the second term of the formula (2)

$$\frac{V'}{V} \cdot H \cdot \alpha \cdot (T-t)$$

it can also be calculated how far, or to what height above the point of zero, the height of pressure must be increased for an atmospheric pressure, H , and a certain difference of temperature between the two volumes of air, V and V' , of, for instance, 1,000 deg. Celsius. The position of the point of zero, as also the length of the scale for a certain atmospheric pressure and a difference of temperature of, let us say, 1,000 deg., having thus been determined, it is easy to draw this scale as may seem most suitable for the readings; for since the excesses in the height of pressure are proportional to the differences of temperature, it is only necessary to divide the length of the scale found by, for instance, 100, in order to ascertain how large that part of the scale is which answers to an increase of temperature of 10 deg.

In this manner the scales of temperature can be calculated for a few certain atmospheric pressures, as, e. g., 730, 745, 760, 775, and 790 mm., and be drawn and fastened to the wooden cylinder, O . When drawing the scale, two parallel lines l and l' , Figs. 5 and 6, are drawn at a distance from each other, like that of the periphery of the wooden cylinder. The area between these lines is then divided into five fields of the same width, and in these scales are drawn answering to the atmospheric pressures just mentioned. The point of zero for a scale of 730 mm. of atmospheric pressure is chosen arbitrarily, and the situation of the other points of zero is calculated in proportion to this.

The scales having been drawn, the complete scale is cut out, rolled together, and pasted in such a manner that the lines l and l' coincide, after which it is threaded on to the cylinder, and fastened with a few small pins, care being taken that the point of zero for a certain atmospheric pressure is at a proper height. The scale should then be varnished, so that dust and soot cannot so easily adhere to it.

Instead of drawing the scales in the manner just described for several different atmospheric pressures, as shown on Fig. 5, it is also possible to limit the operation, simply calculating the scales for the highest and lowest probable atmospheric pressures, viz., for 730 mm. and 790 mm., and after grading them on the lines l and l' , connect the respective parts of the scale, when sloping lines are obtained, which represent the temperature of every intervening atmospheric pressure.

Management of the Instrument.—When unscrewing or removing the manometer tube, A , care must be taken that the instrument be not leaky. In order to ascertain this, the mercury is screwed up to the mark, m , when it should remain at an unvaried height in the other manometer tube for a period of at least two minutes. Should there be any leakage, the mercury sinks in the tube last mentioned, but rises in the other, and mounts into the capillary tube.

It must be remembered when making such an observation, as also when determining temperatures in general, that in consequence of compression a slight increase of temperature occurs when forcing in the volume, V' . If V and V' are equally warm, the above mentioned increase of temperature of the air causes the height of the mercury, h , to fall slightly immediately after the air has been forced in, and only after the lapse of half a minute or thereabout does it again become constant; but should V be colder than V' , forcing in the colder air causes a decrease of temperature, and in this case the compression acts favorably, since it contributes toward making the air in the bulb of the thermometer assume more quickly the required temperature, T , or that which the bulb of the thermometer was at before the volume, V' , was forced in.

When a determination of temperature is made, it often happens that if the mercury has been driven up to the mark, m , on afterward loosening the screw, S , the mercury sinks rapidly, not only in the manometer tube, B , but in both the tubes at the same time. This circumstance does not depend either on there being a leakage in the instrument or on the compression, but on the elasticity of the caoutchouc ball.

The following rules ought to be observed when handling the instrument:

1. The mercury should never be forced higher than the mark, m .
2. After every observation the mercury should at once be brought down, so that its surface is below the inlet to the tubes, B and Q .
3. Observations should not be attempted when the bulb of the thermometer is in a state of rapid increase of temperature or of cooling.
4. Should the prevailing atmospheric pressure not be known, the quicksilver must first be driven up to the mark, r , of the tube, Q , the scale cylinder being then turned until its point of zero is at the same height as the mercury in the tube of the manometer. This is the correct scale from which the readings of temperature should be taken, after having again forced up the quicksilver to the mark, m .

5. When making very accurate determinations of temperature, 15 to 30 seconds should be allowed to elapse before taking the readings, during which time the height of the quicksilver is constantly regulated so that the surface is at the mark, m .

Against the construction of the pyrometer the objection can be made that the air, the dilatation of which is here employed for determining the temperature, has not previously been freed from moisture. In a case like this, however, the usual amount of moisture of the air cannot cause any remarkable effect, more especially as the aqueous gas present in the air is more like the permanent gases in respect to the effects of compression and expansion when the temperature rises.

For determinations of temperature only designed for practical purposes, it can therefore be of little importance whether perfectly dry air be used or no; but if, as in the case of strictly scientific examinations, this source of error is to be avoided, it is easily done by lengthening the manometer tube, B' , with a tube which contains either pieces of chloride of calcium or pieces of pumice stone moistened with sulphuric acid, when, of course, only dry air can enter the tubes of the manometer and the bulb of the thermometer.

Compared with measures of temperature of the same sort that have previously been used, this new air pyro-

meter has several important advantages, as it is of a simpler construction, and can be handled by a common workman; it gives as great a result for a certain difference of temperature, whether the temperature itself be high or low; the determinations of temperature can be made very rapidly, but yet with great nicety; the bulb of the thermometer is not exposed to any difference of pressure outwardly or inwardly, other than during those moments when the observations of temperature are made; lastly, the pyrometer, without further seeing to, is ready at any moment for readings of temperature; all these being qualities which should contribute toward fulfilling that purpose for which it has been constructed, viz., of being a practical and reliable pyrometer in the service of industry.

INTRODUCTORY ADDRESS ON THE ELECTRO-MOTIVE PROPERTIES OF THE HUMAN HEART.*

Delivered at St. Mary's Hospital Medical School, at the Opening of the Session, 1888-89.

By AUGUSTUS D. WALLER, M.D., Lecturer on Physiology.

THERE is a growing disposition to regard introductory lectures as a survival—a survival unfit for the times. But, like all other customs, this custom, having had its particular reason of being in the past, lives on with altered ends and in changing shape. In its primitive shape, as a general guidance addressed to those who have just enlisted, it may be no longer necessary nor acceptable, but it certainly cannot be unfitting in any time that each member of a teaching body should in turn be called upon to say, in the presence of his fellow-workers, that which he thinks to be the best worth saying. My particular task on this occasion has been made easy by my colleagues; it was suggested to me that I should speak about physiology, and I am very willing to do so. Let me at once explain why.

The St. Mary's Hospital Medical School is at present rapidly growing, not merely in size, but in complexity; and it has within the last few years developed two entirely new organs, a physiological and a pathological laboratory. It is not unnatural that those who are most responsible for the development should be glad to hear something about the functions of these organs, and should expect from me, as the person responsible for the physiological laboratory, some report of progress during the last four years. I am, on my side, very willing that my duty as your introductory lecturer should take this form, which will allow me, not, indeed, to report progress in its full and formal sense, but to report on an item of progress; and I shall, therefore, occupy the greater part of the thirty or forty minutes allowed me in describing a new bit of knowledge, and how it has been obtained. Our new bit of knowledge is about the human heart, not in a metaphysical or figurative sense, not its motives, but only its action; not its power, but its electrical potential. Put into a single sentence, I am going to describe how the heart of man can be shown to act as an electrical organ, and what we learn from such action.

It is a well known fact that every beat of the heart is accompanied by an electrical disturbance. The nature of this disturbance has, moreover, been studied and understood with the assistance of cold-blooded animals, and in this laboratory, in particular, an investigation was carried out to learn whether or no warm-blooded animals manifest similar electrical disturbances. These I will not now enter upon, and will only make the passing remark that, while to all appearance the electrical disturbances are similar in the two classes of animals, they are not identically so. These seem to indicate that the contraction which at each beat of the cold-blooded heart runs down from the base to the apex, runs in the opposite direction in the warm-blooded heart. But this is only by the way, and I make no attempt to explain. It is to the next step that I invite your attention to-day, namely, to the human heart.

Led on from thought to thought, it occurred to me that it should be possible to get evidence of electrical action on man by connecting not the heart itself, which is obviously impossible, but parts of the surface of the body near the heart with a suitable instrument. Having verified this supposition, the next step was to see whether or no the same evidence can be obtained by connecting the instrument with parts of the body at a distance from the heart with the hands or feet. The answer was, as you can well see, satisfactory. Finally, I tried whether two people holding hands and connected with the instrument gave evidence of electrical shocks through each other, and I found they did.

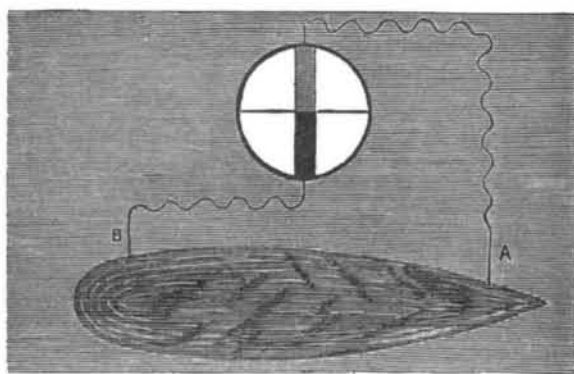
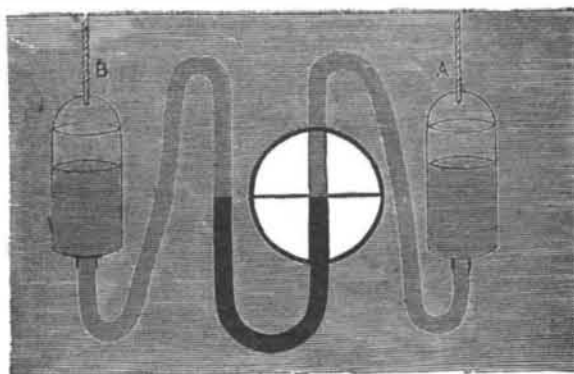
The only portion which I wish to explain in any detail is the second step in these experiments, namely, the analysis of the results which are obtained when a single individual, whether man, horse, or dog, is connected with the electrical indicator.

Let me briefly explain the principle of action of an electrical indicator by referring to this diagram, in which the effects of water pressure are compared with those of what I may call electrical pressure (potential is the correct term, but I take it to be part of my task to-day to avoid technical terms).

A and B are two bottles of water, each connected by flexible pipes with a bent tube half full of mercury. If the two bottles are at the same level, the mercury in the bent tube remains at zero, and it is evident that this is still the case if both bottles be raised together or lowered together. But if the bottles be moved unequally, either up or down, the level of the mercury will alter. It is obvious that if A is lower than B, the mercury in this limb of the tube will move upward, whereas if B is lower than A it will move downward. And if we imagine everything hidden from us by a screen with the exception of this portion of the tube which we can view through a circular opening, while the two bottles are being moved by unseen hands, it is obvious that we shall be able to tell by the movements of the index whether A is below B or B below A. If the mercury goes up, A is below B; if it goes down, B is below A.

Now this is what happens when the two ends of an electrical indicator are in connection with any two

points, A and B, of a living body. If A and B are at the same level the index stands at zero, and it does not move if the two points are raised or lowered together to an equal amount. If the index moves up, we know that A is lower than B; if down, that B is lower than A.



Let us now apply our instrument to the heart. This, which seems rather a bold proposition, is really a very simple and easy matter. We need simply dip the two hands into two basins of water which are in connection with our indicator, when we shall see that the mercury beats up and down with the pulse. These movements of the mercury are due to the electrical changes which occur with every beat of the heart. Or we may dip a hand and a foot each into a basin of water with a similar result, only it must be the right hand. The left will not do. This difference, apparently so curious and puzzling at first sight, which seemed unsymmetrical and irrational, is in reality most reasonable, and proved to be the master key which threw open the meaning of every subsequent experiment. The difference depends upon the unsymmetrical position of the human heart, which is tilted to the left side, somewhat as shown in this diagram.

Allow me to return for one moment to the physical A B C of the subject. The points, A and B, are respectively applied to the apex and base of the heart; and if with the contraction of the organ these two portions undergo any electrical change, the change will spread over the whole body, in accordance with known laws. I will say no more than that. The form of the change is represented by these oval lines. If the electrical level falls at A, it falls over the red area (see note and fifth diagram), which, as you see, includes the left hand and foot and the right foot. If the electrical level falls at B, it falls over this blue area, which includes the right arm and the head.

Now, it is obvious that the two ends of the indicator must be connected with A and with B before it will indicate any difference between A and B. If both ends are connected with A, or both ends with B, nothing will be seen. This was precisely what we got when the left hand and a foot were connected with the instrument, which begins to pulsate as soon as the right is substituted for the left hand. I might multiply instances, but will only just mention one. If the mouth and right hand are connected with the instrument, its index does not move, but it does so as soon as the left hand is put in the place of the right one. You must connect up a blue and a red point; two blue points or two red points are ineffectual.



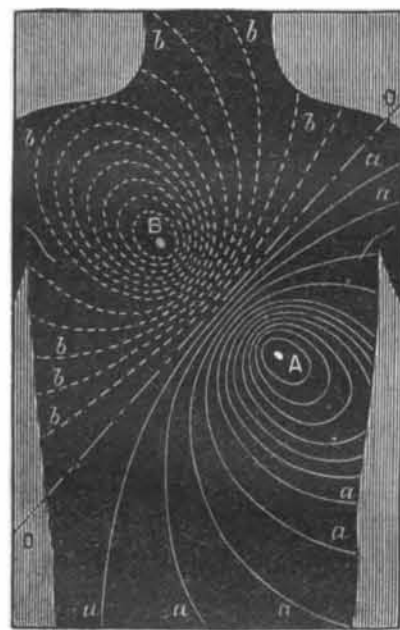
But this evidence does not stand alone. Cases every now and then present themselves with a transposition of the viscera, which are in such people situated just like those of a normal person as they would be viewed in a mirror. The heart, among other organs, is reversed, and, instead of pointing to the left, points to the right. As regards the electrical relations which I was follow-

ing out, they were precisely as expected. The left arm was in this case the exceptional limb, and formed an effectual couple with any one of the other three limbs, but was ineffective in combination with the mouth. To make a long story short, the results were throughout as indicated in the diagram; any two blue points or any two red points in connection with the indicator were silent, but as soon as connection was made with a red point and a blue point, then the index moved with each pulsation of the heart.

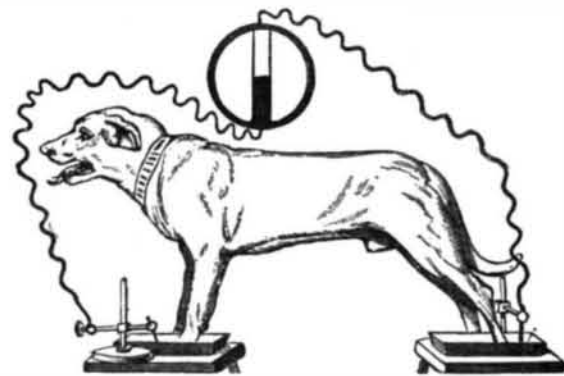
Let us hear one more witness. The heart of a quadruped (dog, or cat, or rabbit, or horse) is placed far more symmetrically than in man; it is very nearly in the middle line, so that the changes of electrical level, whose foci are at A and B, spread straight up and down the body, not obliquely, as in man. The upper half of the body is under the influence emanating from B; the lower half under that emanating from A. Unlike what occurs in man, the two front paws coupled with an indicator are silent, while either front paw taken with either hind foot gives us the now familiar answer.

These are the principal facts. What can we learn from them with regard to the normal action of the heart? I must be content with simply stating the answers.

The fact that each beat of the heart gives an electrical change beginning at one end of the organ and ending at the other proves that the contraction does not occur throughout the mass of the heart at one and the same instant of time. If the two points, A and B, rose and fell together, there would be no alteration of the index. The movements of the index show that there is a fall of A at the beginning of the contraction and a fall of B at the end of the contraction.



One of the most fundamental and certain facts in physiology is that the active state of a living tissue is marked by a fall of electrical level; in other words, an electrical depression is the best, most certain, and most delicate physical sign of physiological action; it proves the fact that living tissue is in excitement just as certainly as a dog's bark proves that a living dog is in excitement; A barks first, B barks last. In the contraction of the human heart, the beat begins at the apex and ends at the base.



We have here the answer, and more than the answer, to a question which has often been asked but never settled—namely, does the heart (that is, the ventricles) beat simultaneously in every portion, or does the contraction take place progressively, as a state of action traversing the whole mass from a beginning to an end? The answer is a distinct affirmation of the second alternative to the exclusion of the first, with the additional and unexpected rider that the contraction begins at the apex and terminates at the base.

I have tried to sketch out in language as little technical as might be the scope and outcome of a physiological research. I fear—nay, I am sure—that to many of my audience it has been dry and tedious, yet I cannot but hope that some of you have been interested to hear by an actual example what kind of work goes on inside a physiological laboratory. That has been on the learning side. I should like to touch upon the teaching side.

We may take for granted the importance of physiology in medical education; you have, apart from all higher considerations, a very prominent and tangible sign in the still growing requirements of every examining board, on the Embankment as well as at Burlington House.

Your chief stumbling block is in the indefiniteness of the subject. You are expected to show that you understand certain sequences and relations between the chief functions of the human body, and that you remember a list of facts, laws, numbers, formulae, and germane opinions. Now it generally happens when a man sends in his schedules that he distrusts his memory rather than his understanding; but I am well assured

*Dr. Waller, who has kindly given us permission to republish his address in full from the columns of the *British Medical Journal*, wishes it to be known that the electrical indicator referred to is Lippmann's capillary electrometer.—EDS. ELK. REV.