M.O. 321. **FOR OFFICIAL USE.** AIR MINISTRY

METEOROLOGICAL OFFICE

THE DINES BALLOON METEOROGRAPH

AND THE METHOD OF USING IT

By

L. H. G. Dines, M.A.

Published by the Authority of the Meteorological Committee.

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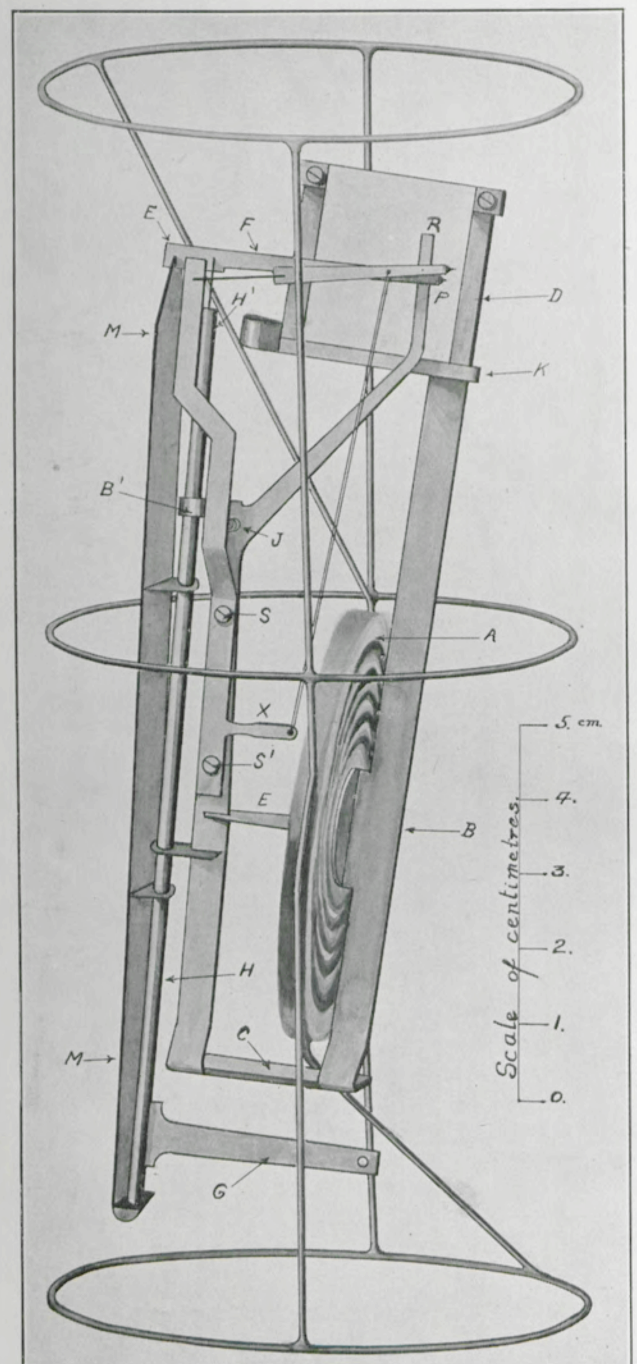

FIG. 1.—General view of the Dines balloon meteorograph for recording pressure, temperature and relative humidity.

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THE DINES BALLOON METEOROGRAPH AND THE METHOD OF USING IT

By L. H. G. Dines, M.A.

INTRODUCTION

The Dines meteorograph for use with registering balloons was designed and perfected by the late Mr. W. H. Dines, F.R.S., during the years 1907 to 1914. The instrument was originally described in "The Free Atmosphere in the region of the British Isles" (M.O. 202), and again in a more modern form in the "Computer's Handbook" (M.O. 223), but both of these publications are now out of print. In its original form only the elements temperature and pressure were recorded, but a device for recording also the relative humidity, originally suggested by Mr. W. H. Dines, has recently been perfected by the author. In the following pages are given descriptions of the instrument thus modified and of the methods employed at Kew Observatory for calibrating it and for tabulating the records.

The construction of the instrument will be apparent from a study of Fig. 1, which shows it with its case removed. It is very light and simple, and is constructed without pin joints of any kind. All relative motion between the moving parts is provided by metal spring joints, so that looseness or backlash of the recording mechanism is impossible. The original barothermograph weighed about 28 gm., but various small modifications have increased the weight so that now the barothermograph alone weighs 36 gm., and when fitted with a hygrograph 40 gm. The aluminium case weighs a further 35 gm.

Owing to the lightness of all the parts the instrument stands shock well and can normally be used many times in succession without needing more than trifling repairs. The record, made by the scratching of two steel scribers on a thin piece of silver-plated metal about 2·5 cm. square, is very durable. It can be seen plainly with the unaided eye, but is read under a microscope.

CONSTRUCTIONAL DETAILS

Fig. 1 shows the meteorograph fitted with a hair hygrograph, but it will be convenient first to describe it in its simplest form as a barothermograph. The frame DBCB′ is cut out of a single piece of nickel silver about 0·8 mm. in thickness. The central boss of the aneroid box is rigidly attached to the frame on the right hand side at B, while at the upper end on that side is formed the plate-holder D. At the lower end the frame is brought round the aneroid box and up again on the other side; the horizontal portion at the bottom is turned down at right angles to the plane of the frame to form a spring joint C, so that the two side parts of the frame may open and shut like a pair of spring compasses, under the action of the aneroid box A and the thin spring connecting piece E. Temperature is recorded by a bi-metallic thermometer consisting of an invar rod and a strip of nickel silver. The invar rod HH′ is shown attached to the frame on the left hand side, it is rigidly fixed in the upper part at B′, but is held by a spring joint lower down to allow for relative expansion. To the left of HH′ is shown the thin strip of nickel silver MM, 125 mm. by 10 mm. by 0·15 mm. thick. The parts HH′ and MM are rigidly joined together at their bottom ends, while at the top they are connected to a steel multiplying lever EFP by means of thin flexible springs, soldered at their ends into the parts which they join. The end of the lever is turned down to form a scriber point at P.

As the pressure falls the expansion of the aneroid box causes the frame to open out, and the scriber P describes an arc on the plate, the centre of rotation being near the middle point of the spring C. The invar rod has a very small coefficient of expansion with temperature, hence when the temperature falls the contraction of the nickel silver strip MM causes an upward movement of P in the form of a rotation about O, the middle point of the thin spring FH′. This latter detail can be more clearly seen in Fig. 2, which shows the arrangement of the two scribers of the thermograph and hygrograph on a larger scale.

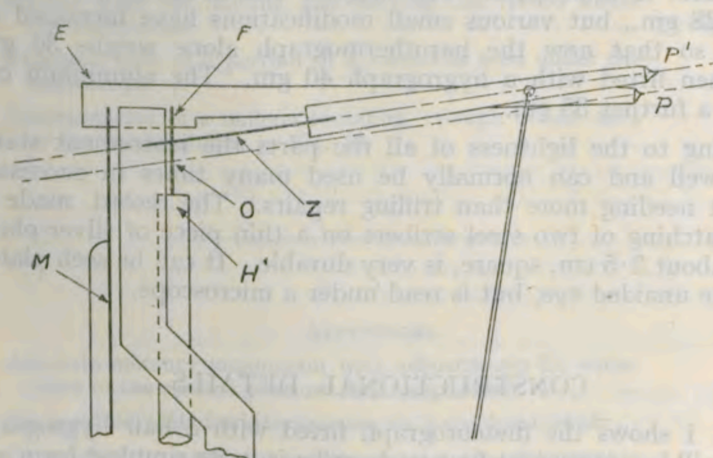

FIG. 2.—Enlarged view of the two recording scribers and levers.

The scale of the record of temperature is about 1 mm. to 65° C., which can easily be read to a fraction of a degree with the aid of a microscope. The scale is usually found to depart a little from perfect linearity, probably owing to a slight variation of the coefficient of expansion of invar with temperature.

When recording, the scriber P is kept in contact with the plate by the natural spring of the lever EFP, which is purposely made thin and flexible. When not in use this lever is held up by the arm R and the spring K so that the scriber P does not bear on the plate. Immediately before a sounding is made a small wooden wedge is inserted behind the frame in such a manner as to depress the spring K and bring the scriber into action. To the wedge is attached a piece of red string about 20 cm. in length having a slip of thin wood fastened at the other end. The string and slip of wood are left hanging out of the case, and the finder is requested in the instructions printed on a label attached, to pull out the string, and thus remove the wedge and lift the scriber off the plate.

The instrument is mounted in a light frame made of nickel-silver wire in the form of a cage, all the points of attachment being on the rim of the aneroid box; in handling it only the wire cage or the edges of the aneroid box should be touched. The silvered plate on which the record is made slides into the holder, in which it must fit tightly; it is clamped in position by means of two small screws shown in Fig. 1. Instructions for preparing and plating the metal on which the record is made are given in Appendix I.

At the bottom of the instrument is seen an arm G, soldered to the invar rod. This arm is used solely for the purpose of calibration and acts thus. When a small force is applied vertically to the end of G the parts of the thermograph are slightly distorted and the scriber P is caused to move slightly in a direction roughly perpendicular to that of the pressure registration. Convenient pressure marks can be made by this means, which is referred to in more detail in the section dealing with calibration.

The aneroid box is made of hard nickel silver about 0·13 mm. in thickness. No control spring is employed but a definite quantity of air is sealed up inside the box; the details are given in the drawings and specification of the instrument held by the Director of the British Meteorological Office, London. By this device the great advantage is gained that the expansion of the box depends mainly on the elasticity of the included air and hence the hysteresis is small. The temperature correction is large, but this is not of great importance because it is impossible to make an aneroid barometer which is perfectly compensated for temperature over the large ranges of temperature and pressure normally encountered by the meteorograph. By the method of calibration described later all difficulties connected with temperature compensation are automatically got over.

A powerful control is exerted by the aneroid box over the motion of the scriber P, the force necessary to displace P against the control being of the order of 100 gm. per mm. The tip of the scribing point P should be in the form of a portion of a sphere of radius about 0·02 mm. The coefficient of friction between such a scriber and the silvered plate is about 0·4, while the average value of the pressure scale is about 1·45 mm. to 100 mb. A convenient value of the force with which the scriber bears on the record plate has been found to be about 1½ gm., whence it follows that the resistance of a pair of well adjusted scribers will not cause a greater lag in the pressure record than about 0·8 mb.

The instrument is protected by a thin cylindrical aluminium case fitted with coned-out ends, and is hung from the balloon with its axis vertical. As the balloon rises its vertical velocity thus forces a stream of air to pass over the instrument, providing the necessary ventilation. The metal parts of the instrument are left with a normal metal finish, as is also the inside of the aluminium case; the outside of the latter is highly polished. The effects of solar radiation are thus minimised, a point which will be referred to again later. The nickel-silver strip which forms the active member of the thermograph is very thin and is freely exposed to the air on both sides, this reduces the lag in response to changes of air temperature.*

THE HAIR HYGROGRAPH

When a hair hygrograph is fitted to the meteorograph it takes the form of the separate attachment, shown in Fig. 3, secured to the

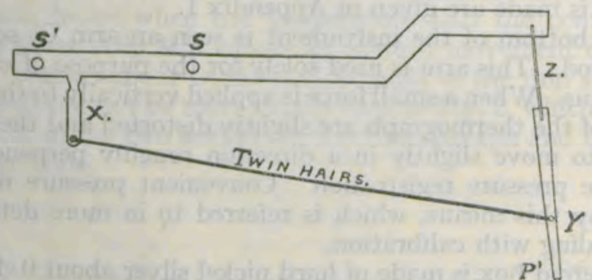

FIG. 3.—Hair hygrograph attachment.

frame by means of two small screws passing through the holes S and S'. The screws may be seen in position in Fig. 1. When a hygrograph is to be fitted the frame of the parent instrument is stiffened by soldering a light strip of nickel silver of L-shaped section to the back from J to S' (see Fig. 1), an adjusting screw is also provided, passing through the frame from the back at J, to regulate the pressure of the scriber P' on the plate.

Turning to the details of the hygrograph, the dimensions of the apparatus are such that a change in the relative humidity from saturation to 50 per cent causes the scriber to move by about

* For an analysis of the temperature lag see :—*Memoirs of the Indian Meteorological Department*, Vol. 24, Part V, by J. H. Field.

0·5 mm. A double length of human hair is employed attached to a flexible steel arm, which is somewhat similar to the lever EFP in the barothermograph and ends in the scriber P'. The latter is rather longer than the corresponding part of the barothermograph, so that the hygrograph arm can ride over the thermograph arm without the two touching each other. The hygrograph arm is supported by means of a thin spring Z made of hard nickel silver, which serves the double purpose of forming a hinge and maintaining the hair under tension. Small holes are bored in the fixed arm X and in the flexible steel arm at Y to provide points of attachment for the hair. A convenient method of mounting is to pass one end of a long hair through the hole in X, then to pass each end through the hole Y but in opposite directions, and finally to tie the two ends together in a knot. Some kind of cement is necessary to secure the hair firmly to the supports, and this must be suitably chosen in reference to the solvent action of the calibrating bath. A celluloid solution known as "Durofix" has been found very suitable for the purpose. Before being finally secured by the cement the hair is adjusted so that as far as possible the two portions are under equal tensions. The hair used should not be too fine, a good working rule being to use none less than about 0·06 mm. in diameter. For such hair the spring Z should be adjusted to give a working load on the double hair of not more than 3 gm. If too great a load be put on the hair it will cause trouble by stretching, while insufficient tension results in a weak control of the scriber. To test the tension of the double hair a weight of 3 gm. is hung on a light hook by a long thread, the hook is placed over the steel arm near the point of attachment of the hair and the weight allowed to hang freely with the thread parallel to the hair; it is then at once apparent whether the tension of the double hair is greater or less than 3 gm. The spring Z is then bent slightly as may be required, an operation which requires a little practice but is not difficult.

Before the hygrograph is put into service it is desirable to season the hair by immersing the whole fitting in warm water at about 318a. for half an hour, with a small additional weight hung on the steel arm in such a manner as to increase the tension of the double hair to about 5 gm. This treatment has the effect of straightening out and slightly stretching the hair, and greatly reduces the likelihood of spontaneous shifts of zero occurring afterwards.

Adjustment of the zero of the hygrograph scriber is effected by bending the arm X. This arm is purposely made flexible and may easily be bent to the required degree by the aid of a small pair of pincers. The best relative positions of the thermograph and hygrograph scribers is a matter of some importance and is discussed below.

The process of fitting the hygrograph to the frame of the parent instrument is one requiring care. It is usually carried out by the maker of the instrument before the hair has been fitted, but as it is desirable for the user to be acquainted with the details of construction a description is given here. Each hygrograph is specially adjusted to fit the individual meteorograph for which it is intended and, to avoid confusion, is stamped with the same serial number. Referring to Fig. 3, the holes for the two screws S and S′ are drilled in standard positions, but the corresponding holes in the frame of the meteorograph are not drilled until the hygrograph has been temporarily clamped in position. In doing this the following points must receive attention : (*a*) the hygrograph scriber P′ must be just so much to the right of the thermograph scriber P that it can cross over the track of the latter without the two arms fouling each other (see Fig. 2) ; (*b*) on placing the hygrograph arm P′Z in the position shown in Fig. 2 (by flexing the spring hinge Z if necessary), the two effective centre lines P′Z and PO must be parallel to each other, and their projections on the plate 1 mm. apart.

These details are exceedingly important. It will be seen from a consideration of the design of the instrument that if the aneroid box were by some means to be rendered insensitive to changes of pressure and temperature, the independent movements of the scribers P and P′ would then be respectively perpendicular to the lines PO and P′Z. If these movements are not parallel to each other under average conditions of humidity and temperature, it is much more difficult subsequently to determine corresponding points on the hygrogram and thermogram ; if also the distance between PO and P′Z be too great it is impossible to bring the two records into the field of view of the microscope at the same time. When the conditions (*a*) and (*b*) have been satisfied the holes for the screws S and S′ are marked off from the existing holes in the frame of the hygrograph, drilled and tapped and the screws fitted.

The next process is to bend the spring Z upwards to a uniform curvature to such a degree that when the hair is fitted and the two arms are in the positions shown in Fig. 2, the total tension on the double hair is 3 gm. The degree of bending required is easily tested by means of the weight, hook and thread previously described, but in this case the hook is inserted in the hole Y in the arm ; it is very much easier to adjust the spring in this manner than to leave it until the hair has been fitted. It is necessary to ensure that the pressure of the scriber P′ on the plate is approximately correct ; coarse adjustment is effected by bending the upper part of the frame of the hygrograph, fine adjustment by means of the screw J. It is best to arrange that with J quite loose the pressure is a little in excess of 2 gm., so that only a small adjustment of J is necessary to obtain the final required pressure of about 1½ gm. The determination of the pressure between the scribers and the plate is greatly facilitated by the use of a special piece of apparatus which is described in Appendix IV.

PREPARATION OF THE METEOROGRAPH FOR CALIBRATION

Before a new meteorograph is taken into use, or after an old one has been subjected to extensive repairs, it is desirable to season the aneroid box by submitting it to a number of slow reductions of pressure covering the whole range of pressure from atmosphere down to as low a pressure as can conveniently be obtained. A new aneroid box is generally in an unstable state, and the more use it has experienced the more constant will be its subsequent behaviour. If the meteorograph has not been adjusted recently it is necessary to examine it before a calibration is commenced to see that the details referred to on page 6, under the headings (*a*) and (*b*) are correct. The two scribers must be examined to see if they are sufficiently sharp, since they frequently become blunted in use. An approximate guide to the form of the scribers has been given on page 4, but individual users are likely to differ in the exact degree of sharpness which they prefer. Too sharp a point increases the resistance and tends to cause a lag in the pressure record, too blunt a point may lead to indistinct records. A convenient method of sharpening the scribers is to use a small very smooth file, or a piece of smooth emery paper pasted on a slip of wood, and then to form the point into the form of a four-sided pyramid having a semi-vertical angle of about 15 degrees ; it is easier to do this than to attempt to form a circular cone and satisfactory results are obtained from points so formed.

Next the pressure of the scribers on the plate must be adjusted. With scribers brought to the degree of sharpness suggested on page 4 a pressure of between 1 and 1½ gm. is sufficient to obtain clear records ; too great a pressure yields distinct traces, but increases the resistance. A common effect of too much pressure is the production of a double trace when the pressure is quickly reduced and increased again at constant temperature. The adjustment of the pressure in the case of the thermograph scriber P is effected by slightly bending the steel arm EFP, for which purpose a small pair of ribbon pliers are a great assistance ; in the case of the hygrograph scriber the adjustment is made as stated before by turning the screw J. A clean record plate is inserted in the holder and securely fixed by means of the screws provided, the wooden wedge is inserted to bring the scribers down on to the record plate and the meteorograph is ready for calibration.

It may be mentioned here that trouble is occasionally experienced with rain or fog droplets accumulating on the record plate as the balloon rises. When a higher level is reached this water freezes into a layer of ice which the scribers cannot penetrate, and therefore slide over it without leaving any record on the plate. The simplest way of dealing with this difficulty is to fit a small roof to the top of the plate-holder made of aluminium sheet about 0·04 mm. thick. The roof is a separate fitting which may be used or not as required ; it is shown in Fig. 4, both separately, and in position on the plate-holder; it is secured in position by the same screws which hold the plate and must be fixed at the same time that the clean plate is put in.

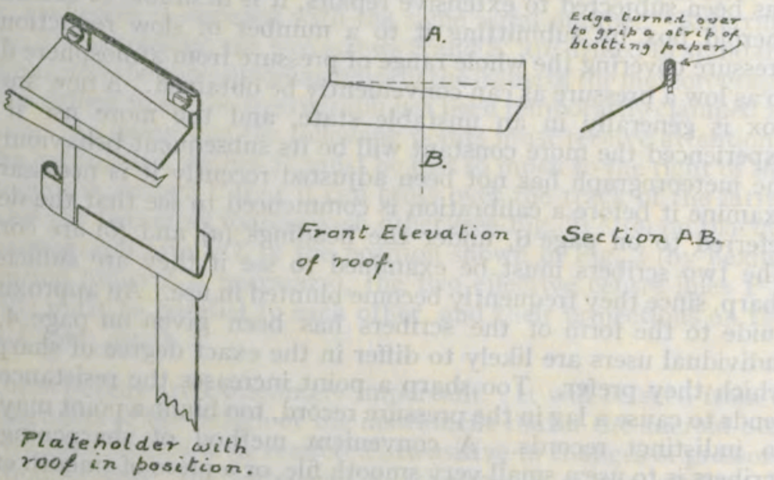

FIG. 4.—Detachable roof to keep rain off the record plate.

METHOD OF CALIBRATION

The process of calibration will be dealt with under three heads:—

(1) Calibration of the barothermograph, to which no hygrograph is intended to be attached.

(2) Determination of the scale value of the hygrograph alone.

(3) Procedure in the case of the meteorograph fitted with a hygrograph.

(1) **Calibration of the barothermograph alone.**—New instruments should be calibrated within a few weeks of the date when they are to be used, but old ones in which the aneroid boxes have become well seasoned by use are not liable to change of zero, and may be kept longer without harm. It is an essential feature in the use of the Dines meteorograph that the calibration marks are in general made without subsequent disturbance on the same record plate as is used in the actual sounding. While this process necessarily involves a large amount of calibrating, it increases the accuracy of the record by eliminating questions of zero or scale error. By the method to be described the further advantage is gained of automatically allowing for the temperature correction of the aneroid box.

Calibration is based on four reductions of pressure made at constant temperatures which approximate to definite selected values. Each reduction covers a somewhat greater range of pressure than is likely to be met with in practice. Thus it is unnecessary to make pressure marks at low pressures with a high temperature, or at high

pressures with a very low temperature, since such conditions can never occur in a sounding. A range of temperature from about 205a. to 300a. must be covered under European conditions. Calibration marks are made at a series of absolute pressures which may be decided by experience, but a great deal of trouble is saved subsequently by adhering in every case to the same series, and by making the marks with an accuracy such that the departures of the actual pressure from the ideal are small enough to be neglected. Intervals of 100 mb. have been found convenient in most cases, ranging from 900 mb. down to 100 mb., with an additional mark at 70 mb.

Fig. 5 shows a section of the vessel used for calibrating meteorographs at Kew Observatory. Full drawings are held by the Director of the British Meteorological Office, a brief description is given here. The vessel consists of a brass chamber with a detachable air-tight lid, placed in a wooden box filled with an insulating lagging material. Around the outside of the chamber is soldered a length of stout copper tube of about 1 cm. internal diameter which is used for cooling purposes and is referred to later. Two smaller pipes are

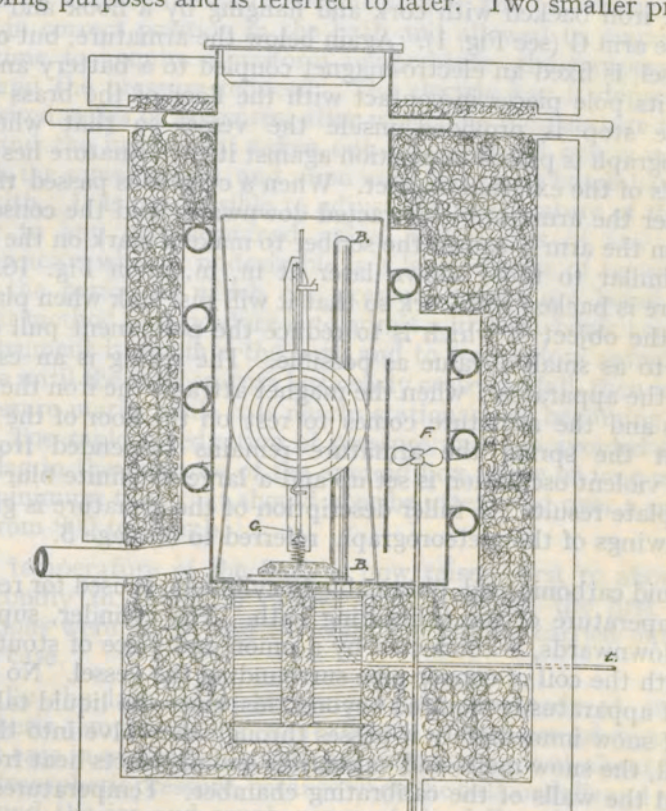

FIG. 5.—Vessel for calibrating the meteorograph.

shown on either side at the top, the one communicates with an air pump, receiver and valve, capable of reducing the pressure to about 30 mb., the other with a mercury manometer.* The meteorograph is shown standing in position; when in use the vessel is partly filled with petrol, or other liquid having a low freezing point, in which the meteorograph is immersed. It is important that the depth of the liquid be maintained constant, and it is to be noted that the fluid pressure on the aneroid box must be allowed for on the pressure scale of the manometer. A spirit thermometer is provided in the form of a long metal bulb BB, communicating by a capillary tube t with an open-ended glass indicating tube. Such a thermometer is not accurate in the absolute sense as its zero varies slowly with time, it is chiefly required for indicating small changes in the temperature of the liquid bath.

The fan F is driven by an external electric motor, and is intended to maintain a constant circulation of the liquid in the calibrating chamber. Below the meteorograph is seen a light armature formed of sheet iron backed with cork and hanging by a hook and spring from the arm G (see Fig. 1). Again below the armature, but outside the vessel, is fixed an electro-magnet coupled to a battery and key, having its pole pieces in contact with the floor of the brass vessel. A guide stop is provided inside the vessel so that when the meteorograph is placed in position against it the armature lies across the poles of the external magnet. When a current is passed through the latter the armature is attracted downwards and the consequent strain on the arm G causes the scriber to make a mark on the record plate similar to those shown later at m, m, m in Fig. 16. The armature is backed with cork so that it will just sink when placed in water, the object of which is to reduce the permanent pull on the arm G to as small a value as possible. The spring is an essential part of the apparatus; when the magnet attracts the iron the spring extends and the armature comes to rest on the floor of the vessel. Without the spring the armature remains suspended from the arm G, violent oscillation is set up and a large indefinite blur on the record plate results. A fuller description of the armature is given in the drawings of the meteorograph, referred to on page 3.

Liquid carbonic acid, obtainable in cylinders, is used for reducing the temperature of the calibrating bath. The cylinder, supported valve downwards, is connected by a union and piece of stout metal pipe with the coil of copper pipe surrounding the vessel. No special piece of apparatus is required beyond this, since the liquid takes the form of snow immediately it passes through the valve into the pipe and coil, the snow melts and vapourises and abstracts heat from the coil and the walls of the calibrating chamber. Temperatures down

* For a description of a convenient type of manometer see Appendix II.

to 200a. can easily be obtained, and the only practical difficulty which arises is to maintain the temperature of the bath at a reasonably constant value. It is not possible to pass a continuous small stream of carbonic acid into the coil because the valve rapidly becomes choked, and the best method is to admit a sufficient quantity at regular intervals; some experience is necessary to obtain the best results. The temperature is determined accurately by means of an independent spirit thermometer placed in the bath, with which the incorporated thermometer is then compared, subsequent small changes in the temperature are then accurately indicated by the changes of the latter. A better arrangement is to fit an electrical thermometer which is capable of indicating the absolute temperature of the bath without correction.

It is usually convenient to calibrate about 10 meteorographs at the same time. When they have been prepared, as explained in the previous section, the temperature of the bath is first reduced to the lowest value at which it is proposed to calibrate. A little time is allowed for the conditions to become steady, the first instrument is placed in correct position in the bath and allowed to remain for a short time to acquire a uniform temperature, the temperature is noted and the pressure reduced. The electric key is depressed at any desired series of pressures, after which the temperature is again noted and the instrument taken out. The second one is now put through the same process, and so on until the whole batch have been dealt with. It is not feasible to adjust the temperature of the bath exactly to any predetermined value, nor is this of any serious consequence; what is undesirable is a large change of temperature during the period in which the pressure marks are being made. The best method of procedure is to admit a little carbonic acid when the instrument is put into the bath and to wait before reducing the pressure until the temperature has nearly ceased to fall, then to make the pressure marks while it is nearly stationary or beginning to rise again. Too rapid a reduction of pressure must be avoided since it causes lag in the response of the aneroid box, three or four minutes is the minimum time that should ever be attempted over a pressure range from 900 to 70 mb.

The temperature of the bath is now raised, first to about 25°, and secondly to about 50° above that at which the first set of calibrations were made, and the complete process carried out again in each case.

Finally the last set of pressure marks are made at ordinary atmospheric temperature or thereabouts. There are advantages in this last case in making an additional pressure mark at about 50 mb. below atmospheric pressure, because when the balloon falls and reaches the ground the jar and rough usage of the fall make a large blur which effaces any mark made near the atmospheric pressure; it is desirable to have a reliable mark as near the bottom as possible because the scale of pressure is not linear and cannot be extrapolated with precision. The wedge is now withdrawn so as to lift the scriber off the plate, and the instrument put aside till required.

Fig. 16 (see page 28) represents on an enlarged scale a record obtained in an actual sounding. To save space it is shown in two parts, the original being in the form of a narrow strip in which the right hand end of the lower panel of the diagram joins on to the left hand end of the upper panel. The lines and marks of calibration are shown, the figures at the right hand side indicating the temperature of the bath, the corresponding line traced out by the scriber in each case appears as a flat arc having small transverse marks at intervals indicating pressures. Corresponding pressure marks at different temperatures are joined by dotted lines, which have been inserted in the figure for the sake of clearness and are not part of the original record. The pressure values are entered along the arc of temperature 285a.

For the most accurate work the pressure during calibration should be decreased slowly, so that the rate of reduction corresponds with that met with in the case of an actual sounding. It has been found, however, that with the form of aneroid box used the difference between pressure readings made during a comparatively fast reduction taking about eight minutes and a slow one taking one hour is too small to be worth troubling about.

A considerable saving of time and labour can be effected when a number of meteorographs have to be calibrated if the calibrating vessel be made large enough to take three at a time. This involves a more expensive apparatus, but is worth while in view of the fact that only one third the number of accurate determinations of pressure and temperature have to be made in dealing with a given number of instruments.

(2) **Determination of the scale value of the hygrograph.**—It is necessary to determine the scale value of each hygrograph, since different hairs do not contract by the same amount for a given reduction of relative humidity. To this end it has been found convenient to employ the auxiliary piece of apparatus which is illustrated in Fig. 6. A frame F has an arm B connected to it by means of the spring hinge H. An aneroid box A is secured to the frame on the upper side and is connected to the arm B by means of a flexible piece K. A plate-holder D forms part of the frame, in which a small piece of silvered plate can be inserted. The hygrograph is attached to the arm B by two screws S and S′. An adjusting screw (not shown) is provided behind the arm B and bears on the frame of the hygrograph itself ; by means of it the pressure of the scriber P′ on the record plate may be regulated. L is a lever intended to lift the scriber off the plate. The aneroid box A is open to the atmosphere through the small tube T, and by blowing or sucking

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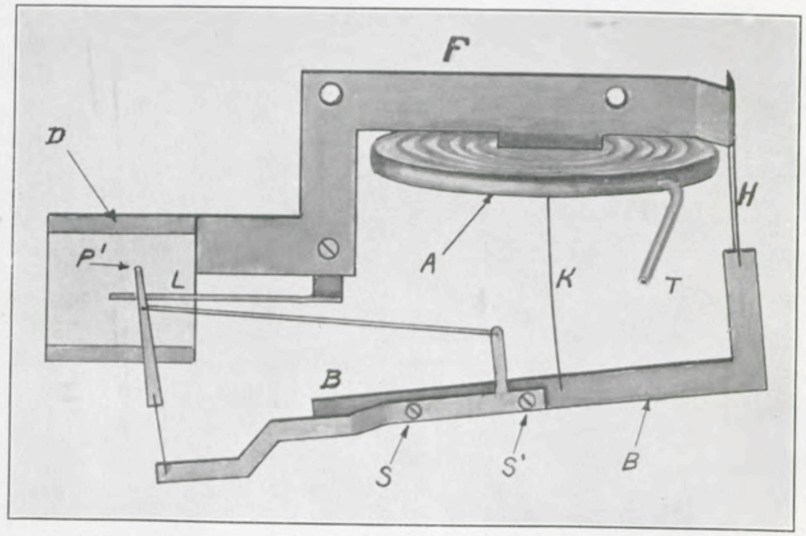

FIG. 6.—Auxiliary apparatus used in the calibration of the hygrograph.

gently through it the box is caused to expand or contract, thereby causing P′ to describe an arc on the record plate.

When a hygrograph is to be calibrated it is first set up on the auxiliary apparatus described above, the whole is then immersed in water with the hygrograph downwards as shown in Fig. 6, or it may equally well be placed in a dense artificial fog; in either case it is left for ten minutes so that the hair may take up its steady saturated length. While still immersed, a mark is made on the plate by blowing into, or sucking from, the aneroid box through a rubber tube connected to the tube T, and the arc so made on the plate represents the 100 per cent or saturation line. The auxiliary apparatus and hygrograph are now transferred undisturbed to a chamber in which the relative humidity can be varied and measured at will, and further arcs are described on the plate as may be thought necessary. The object of the test is to determine the movement of the scriber P′ corresponding with a given change in relative humidity, but since the motion of P′ is not necessarily perpendicular to the arcs drawn on the plate such movement cannot be determined until the direction of motion relative to the arcs is known. To determine this the hairs are disturbed slightly by pressing them sideways in the middle, a line is thus drawn on the plate transverse to the arcs, and the true movement of P′ corresponding to variation of the relative humidity is obtained by measuring the intercepts on this line between the various arcs. The measurement is made by the aid of a microscope fitted with a graticule, the data obtained being the displacements of P′ in millimetres from its position under conditions of saturation and the corresponding values of the relative humidity. The information is plotted on a graph for future use.

An enlarged view of the record made on the plate is shown in Fig. 7. For the sake of clearness the values of the relative humidity corresponding to the various arcs have been entered at the top, the transverse line drawn when the hairs are pressed sideways is indicated by MN.

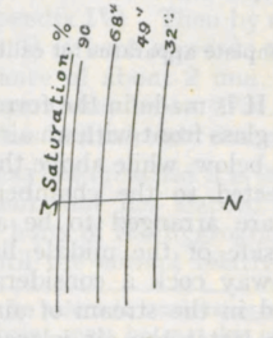

FIG. 7.—Magnified record of a calibration of a hygrograph.

The apparatus shown in Fig. 6 can be modified to take two hygrographs at once, which reduces the time in calibrating a number.

The provision of a suitable humidity control chamber in which to test the hygrograph may be left to the choice of the worker, but a form of apparatus used at Kew Observatory has proved convenient in use and is accordingly described. A diagram of the whole outfit is given in Fig. 8 ; at the bottom on the left is seen a box of ice and on the right a vessel of warm water, pipes from these lead to a two-way cock which allows air to be drawn either through the ice or over the warm water, or in different proportions from both sources at once. Above the cock is placed a heater with an adjustable gas flame, and on passing out from the heater the stream of air enters the control chamber H which is illustrated in more detail in Fig. 9. On leaving H the air passes through an aspiration psychrometer SS′, and thence to an electric fan which maintains a continuous stream of air through the apparatus.

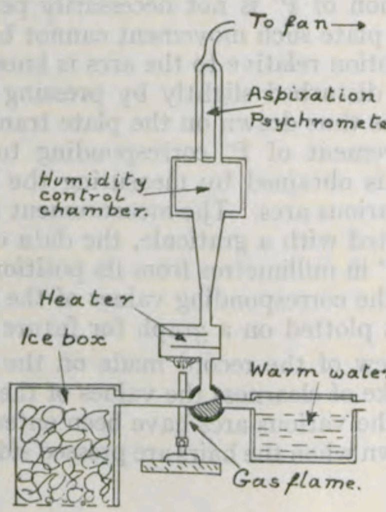

FIG. 8.—Diagram of the complete apparatus for calibrating the hygrograph.

The control chamber H is made in the form of a shallow wooden box having a detachable glass front with an air-tight joint. A coned metal air inlet K is fixed below, while above the two branches of the psychrometer are connected to the chamber by air-tight joints. Internally the fittings are arranged to be as nearly as possible symmetrical on either side of the middle line. By varying the adjustment of the two-way cock a considerable range of vapour pressure can be obtained in the stream of air entering the heater, while by the aid of the latter the air is warmed and its relative humidity therefore reduced to any desired degree. At Kew Observatory the range of relative humidity obtainable in the chamber H

by this means lies between 100 and 20 per cent. Lower values than 20 per cent generally entail the use of a greater difference in temperature than is desirable between the interior of H and the air of the room.

The hygrometer and auxiliary apparatus are fixed in the chamber H in the position shown in Fig. 9, where it will be seen that a separate thermometer is provided having its bulb close to the hairs. The vapour pressure in the air stream is accurately measured by the psychrometer SS′, and thence knowing the temperature of the stream as it flows past the hairs the relative humidity is immediately determined. The aneroid box A can be seen on the right connected up to an external pipe by a piece of rubber tube so that calibration marks can readily be made without disturbing anything inside. Some experience is needed in manipulating the various controls, but when this has been acquired the apparatus serves its purpose very well, and the fact that the air passes through at a considerable speed reduces lag and enables observations to be made quickly.

It is absolutely essential to ensure that the temperature of the air passing through the two branches of the psychrometer is the same. This may be tested by running the two thermometers as dry bulbs and comparing their readings. It may be found that when the heater is in use and the temperature inside H is above that of the surrounding air, one thermometer reads systematically higher than the other, and that the excess increases with the temperature inside H. This is due to a want of symmetry of the stream lines on either side of the middle of H, and adjustment is made by fitting small baffles by the method of trial and error until a balance has been obtained.

(3) **Calibration of the complete meteorograph with hygrograph attached.**—When the meteorograph is fitted with a hygrograph a form of procedure somewhat different from that set out in section (1) on page 8 is required. The hygrograph having been calibrated is attached to the parent instrument again, and the pressure of the two scribers on the plate is tested and adjusted if necessary to about 1½ gm. each (see Appendix IV). Then by means of a pair of pincers the arm X (see Fig. 1) is bent upwards until the two scribers are separated by a distance of about 2 mm. The meteorograph may now, as regards temperatures below 273a., be calibrated in exactly the same manner as has been already described in section (1) above.*

When this stage has been reached it is left standing in air for some hours until a sufficient time has elapsed for the petrol to dry off completely from the hairs of the hygrograph. The arm X is then bent down again until the correct relative adjustment of the two

* An objection may be taken to immersing a hair hygrograph in a liquid such as petrol. The point may be met by employing alcohol instead of petrol, but tests made to that end have shown that immersion in petrol does not seem to affect the hygroscopic properties of the hair to any appreciable extent.

scribers has been obtained, care being taken to avoid straining any part of the instrument during the process. The best adjustment is attained by so setting the scriber P′ that the two centre lines ZP′ and OP shown in Fig. 2 are parallel to each other under conditions of a temperature of 270a. and a relative humidity of about 60 per cent. It is not possible to make this setting with absolute accuracy, but slight errors do not matter so long as an approximately correct result is obtained.

The calibrating vessel is now filled with clean water and the final calibration made in water instead of in petrol. The instrument is placed in the vessel in exactly the same way as before, but is allowed to stand for ten minutes in the water while the hair takes up its steady saturated length. The pressure in the vessel is then reduced and marks are made by means of the electro-magnet in the same manner as has been described before. The fluid pressure of the water is not the same as that of the petrol and must be allowed for. When the calibration is finished the instrument is removed from the water bath and the hairs are disturbed slightly by pressing them sideways in the middle. A short line is thus drawn on the plate transverse to the arcs of constant temperature, which indicates the direction of motion of the scriber P′ when the temperature and pressure are constant. It is very important not to omit this operation, a point which is explained more fully later.

Referring to Fig. 16, the line of saturation drawn by P′ is indicated by MB′, the pair of sinusoidal lines in the upper part of the figure represent the record of humidity, the ascending trace being marked by arrow heads; the pair of sloping lines starting from the lower right hand corner of the upper panel represent the record of temperature. The lines drawn by P′ during the calibration in petrol are outside the limits of the pressure-temperature record and have been omitted from the figure. It will be evident from the geometrical point of view that the corresponding temperatures and pressures indicated by any point of the pressure-temperature record can be readily determined by interpolation between the arcs of constant temperature and the dotted pressure lines. The corresponding relative humidity is a little more difficult to determine because, the two records being independent, a means of synchronisation is essential. It will usually be found that while the pressure marks are distinct on the pressure-temperature lines they do not show up well on the pressure-humidity line, this is immaterial because the point of minimum pressure reached while the meteorograph was in the water bath is quite distinct on both records; these minimum points are denoted in Fig. 16 by B and B′.

From geometrical considerations, starting from the relative positions of B and B′ any other corresponding pair of points on the two records can be determined. The process is quite straightforward provided that the two scriber arms have been adjusted with the centre

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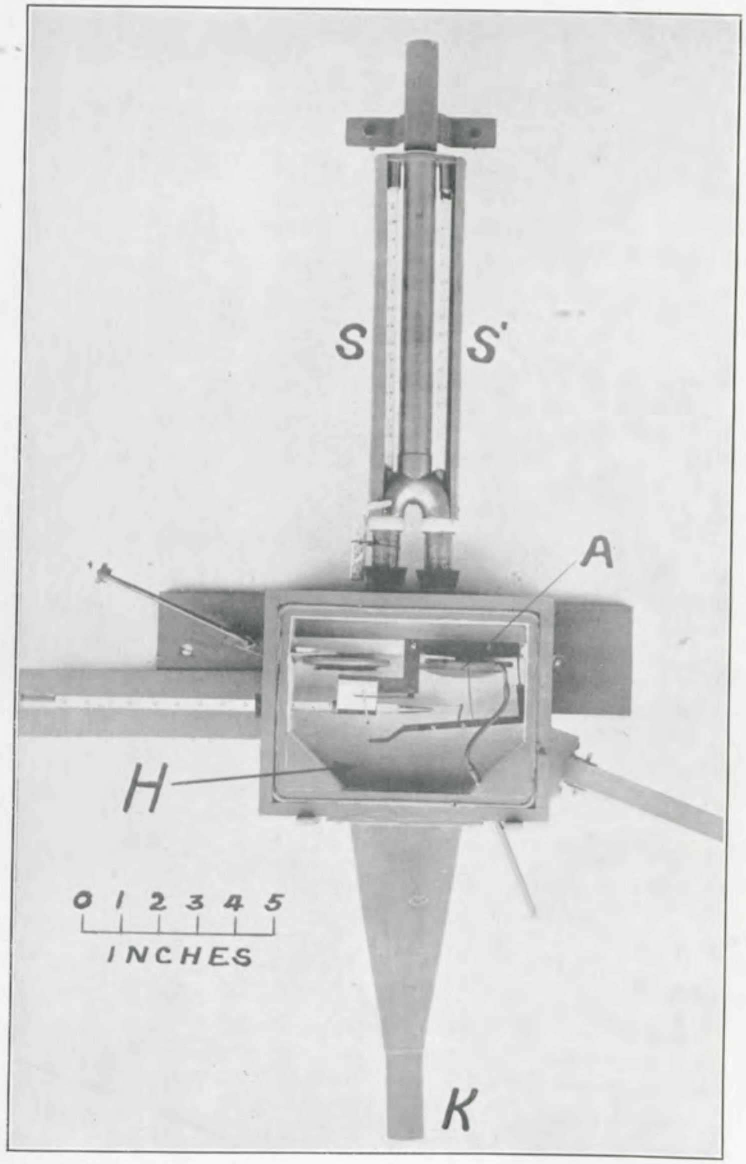

FIG. 9.—Humidity control chamber.

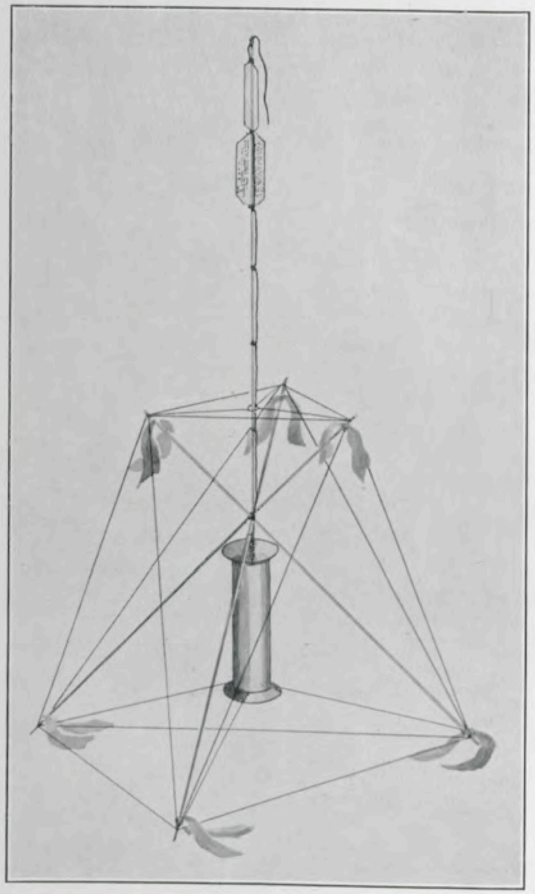

FIG. 10.—Bamboo frame or "spider," inside which the meteorograph is suspended. The label offering a reward is shown incorporated into the arrow.

lines ZP′ and OP parallel to each other in the manner already described. Practical means of tabulation and synchronisation are described in a later section (see page 34).

An alternative method of calibration of the complete meteorograph is available which avoids the necessity of immersing the hairs in petrol and of bending the arm X. The method has certain disadvantages, perhaps more serious than those which it is designed to overcome, but is given briefly here for reference. The barothermograph alone is first calibrated in the petrol bath at all temperatures desired below 273a. Then the hygrograph is attached, the pressure of the scriber P′ on the plate is adjusted and its position relative to P, without disturbing the record plate and the lines and marks of calibration already made upon it. Finally the whole meteorograph is calibrated in the water bath in the manner just described. The disadvantages of the alternative method are: first that there is a likelihood of straining the frame of the parent instrument when screwing on the hygrograph and thereby slightly spoiling the accuracy of the calibration marks already made; secondly that since during the first part of the calibration only one scriber is in operation, the conditions of the instrument as regards strain and resistance to motion of the scribers are definitely different from what they are during the actual sounding, and a small error may on that account exist in that part of the record of pressure which is based on the first part of the calibration.

When, by whatever process of calibration, the pressure-temperature network has been scribed on the plate the meteorograph must be carefully handled in order that no shift of zero may occur before the sounding is made. The instrument may be subjected to comparatively violent treatment without sustaining structural damage, but rough handling may cause shifts of zero which cannot be detected by the unaided eye, and must therefore be avoided after the instrument has been calibrated.

PREPARING FOR A SOUNDING

When a sounding is to be made the meteorograph is mounted in a bamboo frame, known as the "spider," to protect it from damage. The spider is shown in Fig. 10 and is constructed as follows. Take three strips of hard bamboo about one metre in length and about three millimetres in diameter. Tie them together at about 30 cm. from one end in such manner that they are mutually at right angles to each other. By means of thin pieces of cotton tie each end of any one strip to the four ends of the other two strips, requiring twelve pieces of cotton in all. To save trouble the ends of the bamboo strips may be split, when knots can be avoided by twisting the cotton round a few times and then passing it through the split. At each end of each strip tie a small flag consisting of a strip of brightly coloured silk, which renders the whole apparatus conspicuous as it lies on the ground, and attracts the attention of passers by.

The above describes the simplest form of spider. In Fig. 10 is shown a further refinement in the form of an additional vertical bamboo, or arrow, provided with crossed vanes of waxed card. The object of the arrow is to keep the apparatus vertical during the fall after the balloon has burst. The weight of the spider and arrow complete is about 60 gm.

No parachute is employed to break the fall of the meteorograph; the whole apparatus is so light that the resistance of the spider alone is sufficient to keep the velocity of fall within reasonable limits, and the elasticity of the bamboo frame shields the meteorograph from undue shock when it falls to the ground. The rate of fall is about 700 m. per min. on the average, being more in the stratosphere and less near the ground.

When the spider has been prepared the meteorograph is placed in its own numbered case with its upper end against the cross wires of the case, and is wired in by passing a piece of thin aluminium wire through the holes provided at the other end and turning over the ends; the finder seldom meddles with wire but will untie string. Force must not be used in inserting the instrument in the case, and therefore care must be taken that the wire cage slides in easily; on the other hand, it must not rattle when finally in position.

The meteorograph is securely tied just below the point where the three bamboos cross, by means of a piece of string attached to and coaxial with the case. A short spiral spring is usually inserted in the length of this string to prevent the case rattling in the spider, since any looseness causes indistinct records. At the bottom end of the case three more lengths of cotton are tied to the three bottom ends of the bamboos.

If the meteorograph is not provided with the roof over the record plate shown in Fig. 4, another method of guarding against trouble due to water freezing on the plate is to place a small drop of mineral oil or clock oil on the plate before the sounding is made. This tends to prevent ice sticking to the plate to some extent and is sometimes worth adopting in an emergency; the oil is apt to spread over adjacent parts of the instrument if too much is applied, and in any case instruments so treated require to be washed by pouring a little petrol over the oily parts before they are put into the calibrating bath again, or the latter will become contaminated.

A label is attached to some conspicuous part of the spider offering a reward to the finder. The label used in England is illustrated below, it is soaked in melted parafin wax to protect it against wet. In

Fig. 10 the label will be seen forming one of the cross vanes of the arrow.*

Form 4710.

O.H.M.S.

5 SHILLINGS REWARD.

INTERNATIONAL INVESTIGATION OF THE UPPER AIR.

Delicate Meteorological Apparatus.

This instrument is the property of the Air Ministry, London. The above reward will be paid for the instrument if it is not tampered with. The finder is requested carefully to pull out the piece of red string (with the match end attached), to put the instrument away in a safe place and to write to THE SUPERINTENDENT, KEW OBSERVATORY (UPPER AIR SECTION), RICHMOND, SURREY, stating where it was found. Instructions, and if desired, information will then be sent.

The balloon need not be returned.

The next operation is the filling of the balloon. Rubber balloons weighing 350 gm. are large enough for many purposes; if balloons of this size be filled with hydrogen till they have a free lift of 450 gm. they will, when carrying the meteorograph and spider, ascend with a vertical velocity of about 200 m. per min.; heights up to from 13 to 17 km. can be reached with them, but not usually much more. A vertical velocity of 200 m. per min. is sufficient to ensure adequate ventilation of the meteorograph when the sun is below the horizon or only a few degrees above it. During the daytime, and especially so in summer, records obtained with a vertical velocity as low as 200 m. per min. show signs of insufficient ventilation on the ascent, particularly at great heights. Larger balloons weighing 800 gm., filled to give a free lift of 700 gr. or over, will raise the meteorograph at 300 m. per min. or more and yield much more satisfactory records in the daytime. Heights up to 21 km., or sometimes a little more, can be reached by their use.

It is better if possible to avoid making soundings to great heights when the sun has an elevation of more than 57°, because the standard case of the meteorograph does not afford sufficient protection under

* It is sometimes convenient to make soundings from stations other than that at which the meteorographs have been calibrated. It has been found by experience that calibrated instruments should not be sent through the ordinary parcels post, as the violent shocks sometimes experienced are apt to cause disturbances to the zero readings, sometimes of a serious nature. The best method of transport has been found to be to wrap the case in a loose roll of cotton wool till the covering is about 15 cm. in diameter, and then to pack a number of the instruments thus wrapped up into a wooden case provided with separate partitions, and send by passenger train. Meteorographs returned by the finders may be sent through the post similarly surrounded by cotton wool, since in that case disturbances to the zero readings, if such occur, are comparatively unimportant.

such circumstances, even with a vertical velocity of 300 m. per min. After the balloon has burst the increased velocity of the fall reduces the disturbing effect of insolation considerably, and in the case of soundings made in the daytime it is certain that at great heights the descending record represents the true temperature of the air more accurately than the ascending one.

While being filled, rubber balloons sometimes develop pinholes which may best be repaired by means of thin rubber patches cemented on with thick rubber solution. If a thin rubber solution be applied to a hole in a stretched balloon it will almost certainly burst at once.

When filled to the required free lift the balloon is attached to the spider by means of strong cotton, which is tied either to the upper end of the arrow if that be employed, or if not, then to such a part of the spider that the meteorograph hangs vertically during the ascent. It is better to use a long piece of cotton than a short one, because a balloon on which the sun is shining may reach a temperature many degrees above that of the surrounding air and may, therefore, leave a wake of warm air behind it as it rises. A distance of 40 m. between balloon and meteorograph is ample to prevent any trouble from this cause.

In windy weather it is difficult to launch a balloon at the end of so long a piece of comparatively weak thread, and to meet the difficulty the device shown in Fig. 11 is employed. It consists of two pieces of wood, a longer and a shorter ; the longer one is 65 cm. long by 12 mm. square, the shorter 7 cm. long by 12 mm. by 3 mm. The shorter piece, which is to be seen at the top of the figure, has a hole bored through it near the upper end through which a short piece of string from the neck of the balloon passes and is tied. To the same piece of wood is tied also the end of the cotton thread at A, which is then wound evenly round the two pieces of wood after the manner of a splice. The winding is continued evenly down the length of the long piece of wood and is finally wound evenly back again over itself in the opposite direction from B till it ends up at C. The free end at C is unwound a metre or so when required, and tied to the spider. The action is as follows. As soon as the balloon is released the cotton unwinds slowly from the part C to B, allowing the balloon to get clear of the surface with the meteorograph hanging comparatively close to it. As soon as the winding reaches the bottom and the thread begins to unwind upwards it runs off at a rapid rate, until finally the long piece of wood is unsupported and falls away, leaving the short piece behind as a link in the suspension. The essential points to attend to if the device is to function properly are, that both pieces of wood must be smoothed down free from rough corners in which the thread might catch, that the winding must be smooth and even throughout, and lastly that the winding back from B to C must start from well above the middle of the longer piece of wood.

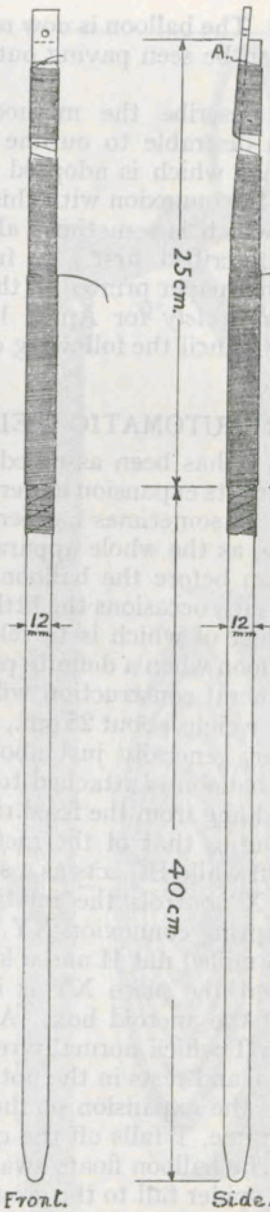

FIG. 11.—Device used for launching the balloon and meteorograph.

Last of all the wedge is inserted behind the spring K (Fig. 1), and the scribers brought into action on the plate. As the meteorograph is inside the case this operation needs a little care to carry out and is facilitated by the use of a pair of long-nosed pliers. Care must also be taken to see that the red string attached to the wedge hangs freely outside the case with a slip of wood attached to the free end, and is arranged inside in such a manner that on being pulled the wedge will slide out easily.* The balloon is now released on its flight and the launching device can be seen paying out the cotton thread as it rises.

Before passing on to describe the method of reading and tabulating the record it is desirable to outline briefly a modified method of making soundings which is adopted when observations are required over the sea. In connexion with this an auxiliary piece of apparatus is employed which is sometimes also found useful on land and is accordingly described first. A full account of the instrument is to be found in a paper printed in the *Quarterly Journal of the Royal Meteorological Society* for April, 1929, and with the permission of the Society's Council the following description is taken primarily from that paper.

THE BAKER AUTOMATIC RELEASE

In the preceding pages it has been assumed that the sounding balloon is allowed to rise until its expansion under decreasing pressure finally causes it to burst. It sometimes happens that this method of procedure is not feasible, as the whole apparatus may be carried by the wind over the ocean before the balloon has ascended high enough to burst. To meet such occasions the little instrument shown in Fig. 12 is used, the object of which is to release the spider and meteorograph from the balloon when a definite predetermined height has been reached; the general construction will be apparent from the figure. The instrument weighs about 25 gm., and is hung between the balloon and the spider, generally just above the latter. The cord from the neck of the balloon is attached to the loose ring R at the top, while the spider is hung from the fixed ring F at the bottom. The frame ABCD is similar to that of the meteorograph, the two parts AB and CD being stiff while BC acts as a spring hinge between them. The aneroid box X controls the relative positions of AB and CD by means of the spring connexion XY, the latter ends in a threaded rod on which is a milled nut H and a lock nut. The spring hinge BC is so formed that the piece XY is in tension under all conditions of expansion of the aneroid box. Across the top of the frame is hinged the trigger T which normally rests on a catch at D, the ring R is slipped over T and rests in the notch as shown. When the external pressure falls the expansion of the aneroid box opens out the two sides of the frame, T falls off the catch and the ring R slips off and is released. The balloon floats away while the releasing device, meteorograph and spider fall to the ground. A small label is attached to the release requesting the finder to return it with the meteorograph.

The aneroid box X is made of rather thin metal and is sealed up with air inside, so that at atmospheric pressure and temperature the two diaphragms are parallel and unstressed, and the air pressure

* It is advantageous to soak the wedge in melted paraffin wax beforehand, as this greatly facilitates insertion and subsequent withdrawal.

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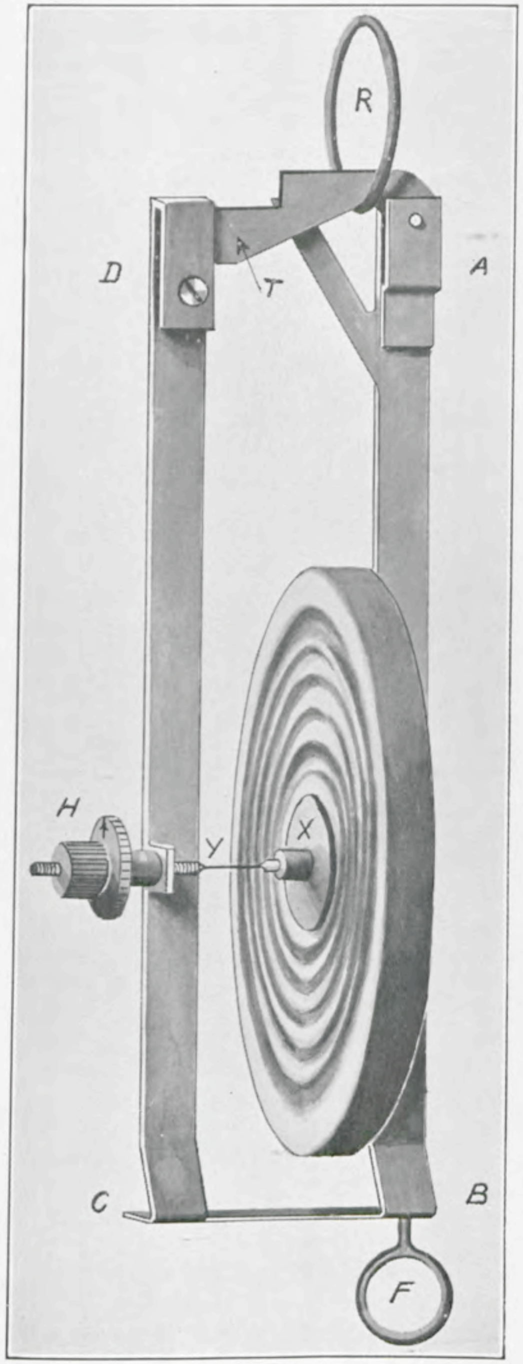

FIG. 12.—Baker automatic release for releasing the meteorograph from the balloon at a predetermined height.

is the same inside and out. This of course entails a very large temperature correction but provides a powerful control and enables the weight to be kept low. It will be seen that the further to the left the nut H is screwed the higher will be the pressure at which the ring R will be released, and it is necessary to calibrate the instrument once for all in order to determine the relation between the position of H and the pressure of release. If, for example, it is desired to release the meteorograph at a height of 9 km., it is first necessary to form an estimate of the temperature and pressure at that height on the day in question, and then the requisite setting of H is determined from the results of the calibration test. Since a high degree of accuracy is not needed it is sufficient to estimate the temperature and pressure by the aid of mean tables and a knowledge of the existing surface conditions.

The method of calibration is as follows. The instrument is turned upside down and a weight is hung on the ring R equal to that which it will be called on to sustain in an actual flight, that is about 160 gm. The working parts are oiled and the nut H is adjusted so that the ring is about to drop ; the position of H so found is marked and is henceforth regarded as the datum. The external pressure P_0 and the temperature T_0 at which the test is made are noted. The nut H is then screwed inwards by exactly one turn, the external pressure is reduced slowly and its value noted at the instant when the ring drops off, the process being repeated one turn at a time until the working range of the instrument has been covered.

The data thus obtained are plotted on a diagram similar to that shown in Fig. 13, where the points A_0, A_1, A_2, A_3, A_4, etc., indicate the pressure at which the ring falls off for each complete turn of the nut H at the definite temperature T_0. The diagram has been drawn for the conditions given by $P_0 = 1{,}000$ mb. and $T_0 = 292$a. From the plotted points it is at once possible by interpolation to set the nut H so that the ring will be released at any desired pressure, provided that the temperature remains at 292a. As, however, variations of temperature have to be allowed for it is necessary to determine the effect of temperature change on the expansion of the aneroid box, and a similar observation must be made at a lower temperature. It is convenient for this purpose to use the same vessel which is used in the calibration of the meteorographs ; the temperature of the bath is reduced to about 223a., and the nut H is screwed inwards from the datum position by such a whole number of turns as would be expected to cause the ring to fall at a pressure of about 200 mb. Suppose that it is screwed in by eight turns, the exact pressure at which the ring falls off and the temperature of the bath at the time are noted and plotted on the diagram in the point B_8. If great accuracy is required a series of observations must be made at the lower temperature similar to that already made at normal temperature, but for ordinary purposes sufficient accuracy is obtained by plotting one point only, as B_8.

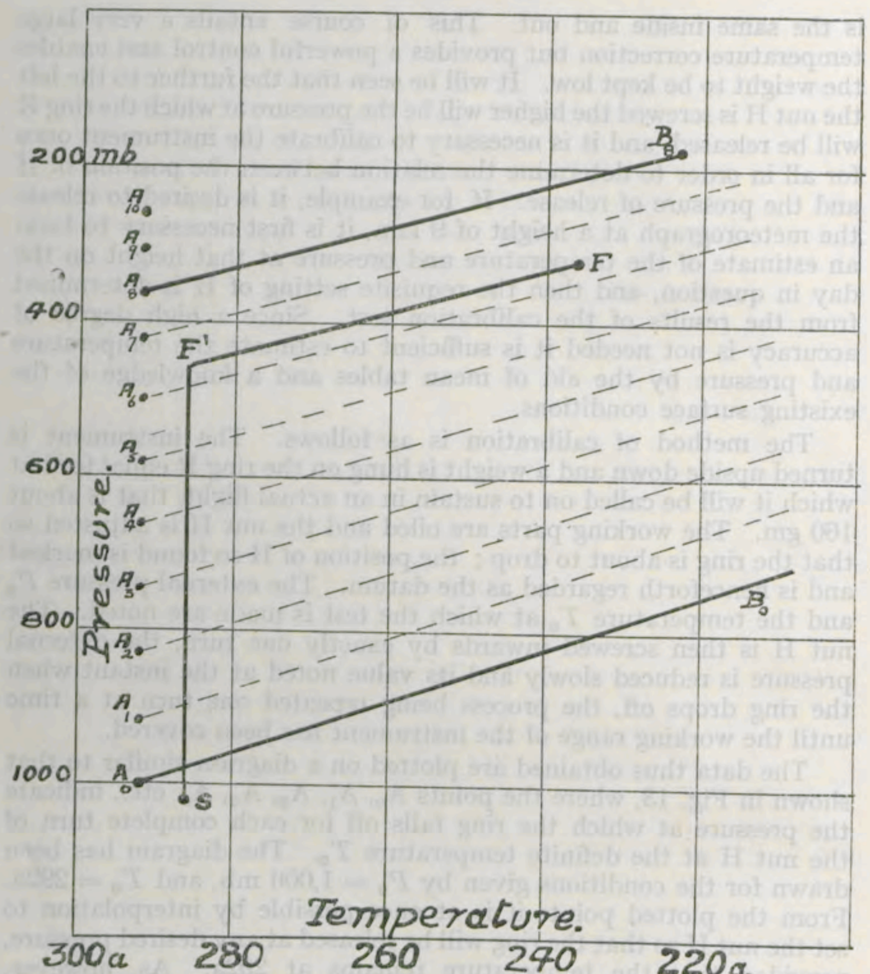

FIG. 13.—Baker automatic release.—Relation between the pressure and temperature at the instant of release of the ring and the number of turns of the nut from the datum.

From the construction of the instrument it is evident that with any definite number of turns r of the nut H from the datum position there is associated a definite internal volume of the aneroid box at the instant of release. If, therefore, isopleths of volume can be drawn passing through the plotted points A_0, A_1, A_2, A_3, the number of turns which must be given to H to ensure release of the ring under any given conditions of both temperature and pressure can be determined. It is clear that one such isopleth is a curve passing through A_8 and B_8, and more detailed experiments have shown that it is very nearly a straight line ; the next step is to determine the isopleth passing through A_0, this can be done at once because at atmospheric pressure the aneroid box is nearly unstressed and, therefore, the pressure inside is very nearly the same as that outside, hence the isopleth of constant volume is determined by the condition

that P/T is constant, where P and T refer to the external conditions. This relation gives a straight line which is indicated by A_0B_0. To the degree of accuracy required it may be assumed that all the other isopleths are also straight lines and they may be drawn in through A_1, A_2, A_3, etc., on the principle of continually decreasing slope between A_0B_0 and A_8B_8.

Suppose that it is desired to release the ring at a height of 9 km., it is first necessary to plot on the diagram the expected value of the pressure and temperature there, shown by the point F say, then to draw through F the isopleth of constant volume FF′ by interpolation between the neighbouring lines. Next plot the surface pressure and temperature at the time of the sounding in the point S, and draw through it the ordinate SF′ to meet the other line in F′. By interpolation determine the values of r corresponding with S and F′ and call their algebraic difference N. In Fig. 13 the point F′ corresponds with a value of r of 6·3, and S with one of −0·4, so that N = 6·7. The weight must now be hung on the ring again and the position of H found at which the weight drops off under the surface conditions, and then H is screwed inwards by 6·7 turns from that. Ideally it should be possible to set the nut without any reference to the surface conditions, using only the point F and the original datum, but this would presuppose that no shift of zero had taken place since the original calibration, which is not likely to be the case in practice.

THE MEASUREMENT OF UPPER AIR TEMPERATURES OVER THE SEA*

If soundings with free balloons are made over the sea it is essential to provide means to prevent the meteorograph from sinking, and at the same time to render its presence conspicuous to passing boats.

Two balloons are required for each sounding, in general larger than balloons required for soundings on land. They are sent up in tandem carrying a standard Dines meteorograph. A sea anchor float is also attached. The balloons are observed through a theodolite on the ship from which they are released as long as they are in sight, and an estimate of where they are likely to fall is made.

On attaining a height of say 10 or 12 km. one of the balloons will burst, and the remaining one, being unable to support the instrument and float, descends until the latter reaches the water. The balloon is now able to support the instrument some feet above the surface of the water and is prevented from drifting by the sea anchor float until recovered by the ship which has followed it. The balloons take about an hour to go up and an hour to come down.

* The method described here is adapted with slight modifications from that first used by Professor H. Hergesell in 1904 and described by him in a paper published in *Beiträge zur Physik der freien Atmosphëre*, **1**, p. 200. A brief account of the method was contributed by Professor Hergesell as Appendix I to "The free atmosphere in the region of the British Isles" M.O. 202.

In order to minimize the chance of losing the apparatus, and in cases where the sea room is limited the automatic release which has been described above can be employed to release the upper balloon at a predetermined height. The apparatus is illustrated in Fig. 14 and is described below.

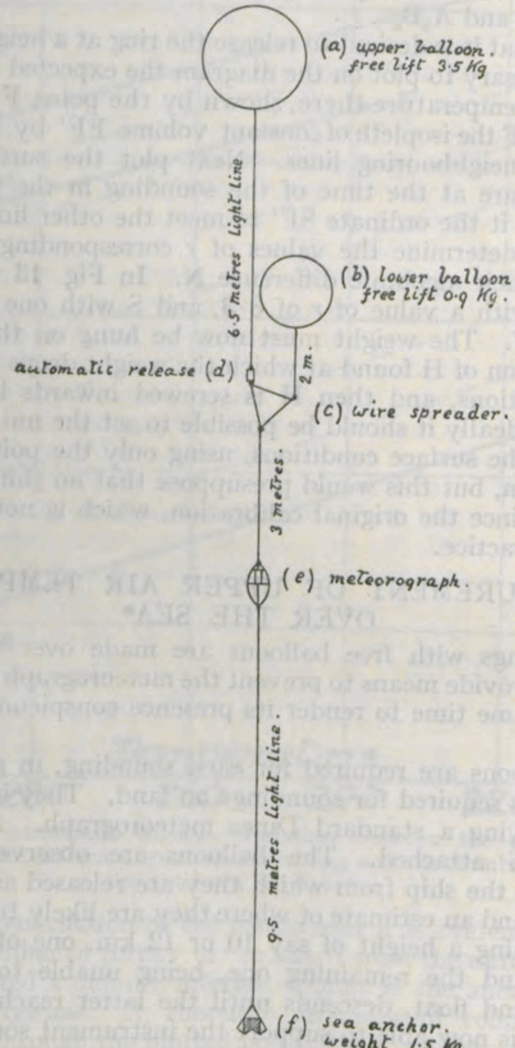

FIG. 14.—Arrangement of the apparatus when soundings are made at sea.

The upper balloon (*a*) is inflated with hydrogen to give a free lift of about $3\frac{1}{2}$ kg., its diameter would then be about 2·1 m. The lower balloon (*b*) is inflated to give a free lift of 0·9 kg. The balloons are attached to a wire spreader (*c*), a triangle made of wire with sides about 15 cm. in length, and to one corner of which the automatic

release is rigidly attached. This detail is shown in the figure much exaggerated for the sake of clearness. The sea anchor float (*f*) consists of a cylinder-shaped wicker frame covered with canvas, 60 cm. high by 30 cm. in diameter, which is secured to a base of canvas one metre in diameter. The latter is perforated with holes and is attached to the line from the balloon by three lines passing through beckets on the upper part of the cylinder, thus making it collapsible during ascent. When in the water the base fills with water and acts as a sea anchor, the cylinder preventing it from sinking. The weight of the float is $1\frac{1}{2}$ kg. A label offering a suitable reward on lines similar to that previously described is attached to some conspicuous part of the apparatus.

The Dines meteorograph (*e*) is attached to a point on the line between the spreader and the float. The method of attachment under such circumstances is of considerable importance, because any arrangement which permits of vibration causes a serious lack of sharpness of the record. The method adopted is illustrated in Fig. 15. Three strips of split bamboo of about 5 mm. in section and 75 cm. long are tied together at each end, they are then opened out till each is in the form of a bow and a hoop formed of another piece of similar bamboo is placed inside and tied to each. The result is a stiff frame into which the meteorograph is tied in the same manner as in the case of the spider. Cords are tied to the top and bottom of the frame, the one leading up to the spreader and the other down to the float.

READING THE RECORD

When the meteorograph has been returned by the finder it is convenient to calibrate it again in the water bath before the record plate has been disturbed, in the same manner as has been already described. This provides a rough check on the validity of the original calibration, but in view of the violent shocks which the instrument may receive in the fall and subsequently in the hands of unskilled persons a perfect agreement between the two is not to be expected. It may be put on record that at Kew Observatory it is found that in only about 20 per cent of the total number of cases does the discrepancy between the original and subsequent calibrations exceed 2° in temperature or 9 mb. in pressure.

The record plate when received back is sometimes very dirty, it may then often be improved by pouring a little strong ammonium hydrate over it, and in any case this process cannot do any harm. Another method, which is useful if the first fails, is to prepare a hot 10 per cent solution of potassium cyanide, dip the plate quickly into it and instantly transfer to boiling water. The latter process must be very carefully done, for if the plate is left in the cyanide solution for more than a fraction of a second the record may be partially dissolved away; it is a very efficacious method if skilfully employed.

Fig. 16 represents on an enlarged scale a record obtained in an actual sounding. The record is read under a microscope having a

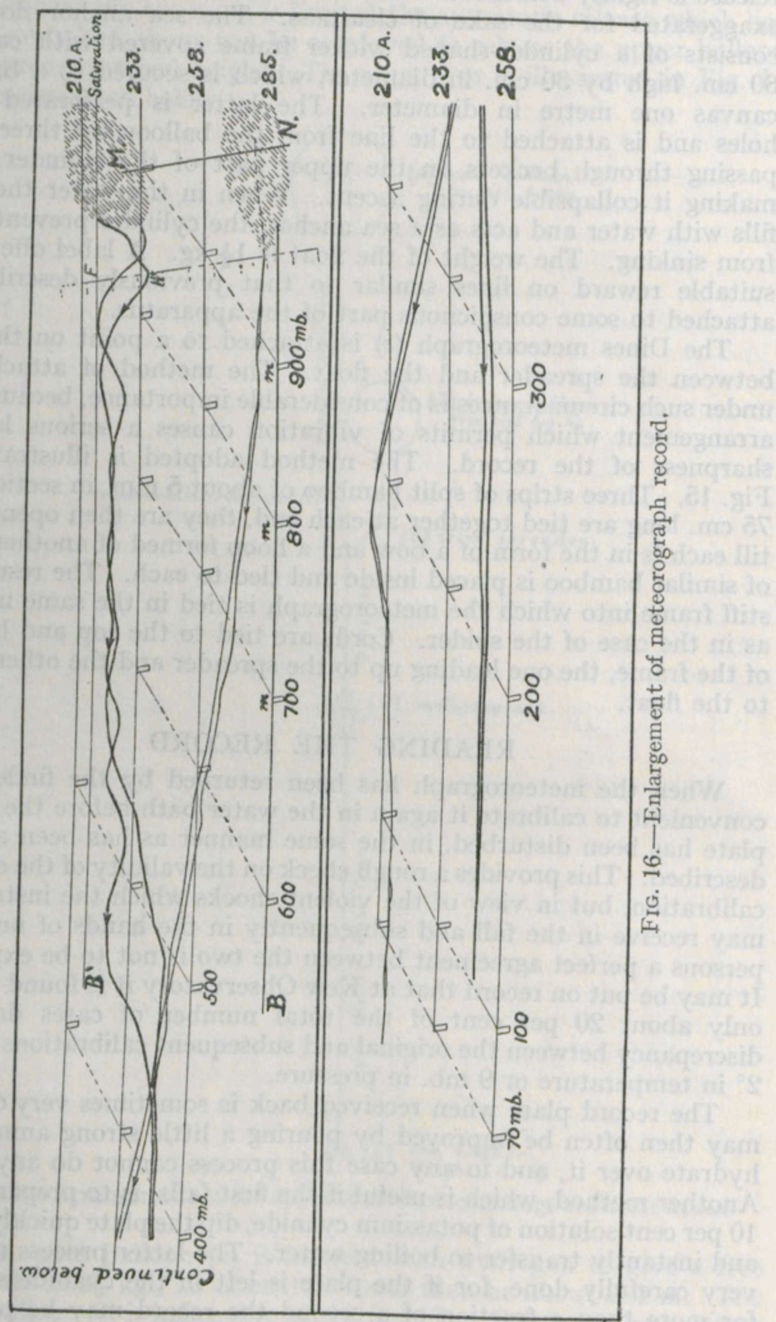

FIG. 16.—Enlargement of meteorograph record.

[*To face page* 28.

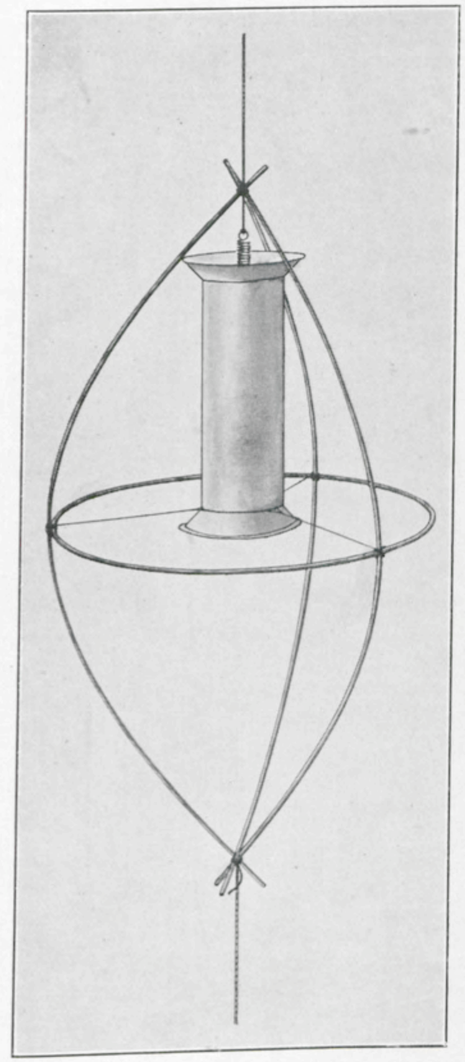

FIG. 15.—Bamboo cage supporting the meteorograph when suspended in the middle of a long line.

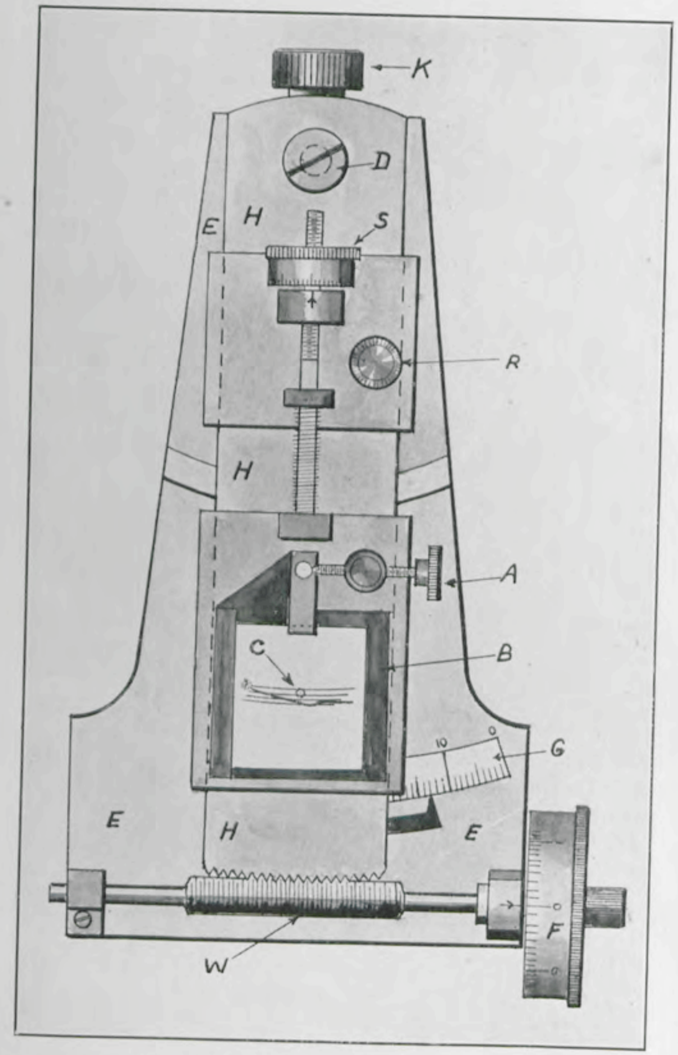

FIG. 17.—Stage for holding and moving the record under the microscope.

magnification of about 80, and for the purpose it is mounted on the special stage depicted in Fig. 17. The plate is there seen with temperature calibration arcs and a record sketched in for the sake of illustration ; it is held in a holder B (the details of which are not shown), which is pivoted at C on to the piece HHH and can be rotated about C by turning the screw-head A. The holder can also be moved up and down on the piece HHH so as to bring the record into the field of view, rough adjustment is provided by the clamp R and fine adjustment by the screw S. The piece HHH is pivoted on to the plate EEE and the bottom end of it is formed into a toothed arc centred about D, engaging with a worm W and divided head F, which rotates in bearings fixed to EEE. By turning the head F the piece HHH is caused to move about D as a centre of rotation, and a measure of such rotation is provided by the scale G (indicating whole turns of the worm), and the head F which is divided into hundredths. The dimensions of the apparatus are such that one turn of the worm causes the record to move under the microscope by about 1 mm. The whole stage can be moved so that the distance between the optical axis of the microscope and the pivot D can be varied to suit the requirements of different meteorographs ; this is effected by means of an under-carriage, and the adjustment is made by means of the screw-head K seen at the top of the figure. The distance between the optical axis and the pivot D should be capable of variation between 10 and 13 cm.

When the record plate has been fixed in the holder the first process is to adjust the latter by means of the screw-heads A, S and K so that the arcs of constant temperature are centred at D when the record is in the field of view. This is easily effected by trial and error under the microscope, and when done the arcs will maintain constant positions in the field of view as the divided head F is rotated. In the focal plane of the eyepiece of the microscope is placed a graticule, the edge of which lies diametrically across the field of view and which can be rotated in its own plane so that its edge can be set at any desired angle. For the present in order to simplify the explanation the graticule will be supposed to be set so that its edge lies along a radius drawn from D. The divisions of the graticule are numbered from 0 to 100 and cover a distance somewhat less than the diameter of the field of view. Fig. 18 shows the appearance as seen under the microscope of a portion of the same record which is represented in Fig. 16.

A reference to Fig. 16 shows that the record takes the form of a long narrow strip, and when the correct setting of the record plate has been obtained the field of view may be made to cover any part of the strip solely by rotating the screw-head F. The angular rotation of the record plate about the point D may be conveniently determined by a co-ordinate which represents angular displacement from some arbitrary zero, and it is evident that this hypothetical co-ordinate is measured to some definite scale by the reading of the scale G and the divided screw-head F. If this reading be denoted by the symbol ψ any point on the original record may be tabulated in terms of the two co-ordinates ψ, and the reading of the graticule.

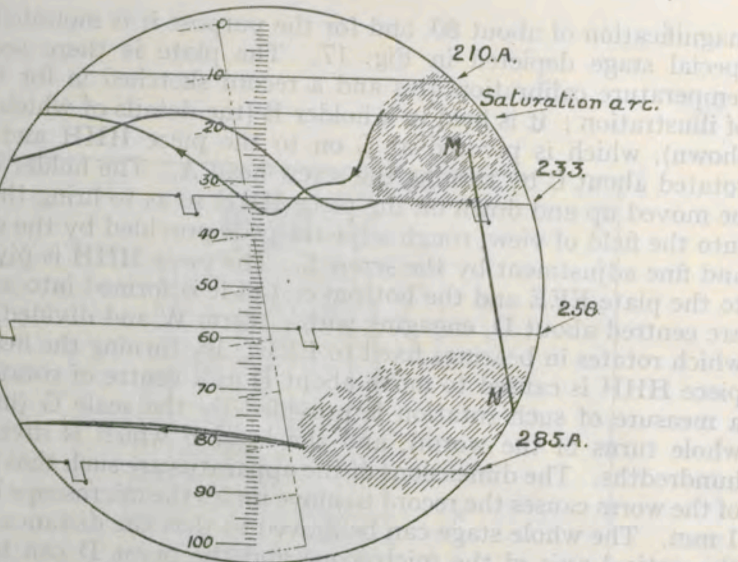

FIG. 18.—Enlarged view of a record as seen under the microscope.

As has been explained above all points on an arc of constant temperature will show the same reading on the graticule, so that the divisions of the latter may be employed to provide a measure of the temperature indicated by any point of the record. The most accurate method of determining the temperature is to note the reading on the graticule of each of the temperature calibration arcs, and to plot them on a graph against the known temperatures to which those arcs refer, thence the value of any particular reading of the graticule may be determined. The graph so formed may not be quite linear, but if, as is usually the case, the departure therefrom is small, it is possible to simplify the process and to obtain direct readings of temperature in degrees from the reading of the graticule. To this end the microscope is provided with a draw tube by means of which the magnification may be varied, and by suitable adjustment it is possible over large parts of the scale to make one division of the graticule correspond to one degree of temperature to a sufficient degree of accuracy. In Fig. 18 it has been assumed for the sake of simplicity that the scale of temperature is linear, and the magnification of the microscope has been adjusted so that ten divisions of the graticule correspond with 10° C. on the record. The record has also been set so that a temperature of 273 on it agrees with 73 on the graticule, so that temperatures can be read off at once in degrees absolute.

Fig. 18 shows the part of the record near the start ; the large hatched areas represent confused blurs on the plate which are caused mainly by the vibration incidental to the launching operation, the subsequent fall and possible rough handling which the instrument

may subsequently receive ; the record relating to the region between the surface and a height of about half a kilometre is generally lost in this way. The upper pair of traces represent the humidity, the lower pair the temperature ; the sloping line MN on the right hand side is the same as that shown in Fig. 16, it is the mark made by the hygrograph scriber when the hair is pressed sideways in the manner described on page 16. The small arrow heads on the traces have been inserted to distinguish between the ascending and descending records, and it may be stated in passing that when the worker has acquired a little experience it is nearly always easy to distinguish between them. It is, for example, often possible to see plainly under the microscope which of two lines crossing each other was drawn first and therefore to identify that as the record of the ascent ; sometimes also peculiarities on the thermogram can be correlated with corresponding features on the hygrogram, so that if the identification of the one has been effected that of the other follows. The hygrograph record of the descent has peculiar features due to the increased sluggishness of the hair when it has lately been subjected to very low temperatures, this provides a useful means of distinguishing between ascent and descent.

Consideration of the hygrogram can conveniently be deferred for the moment. Dealing then solely with pressure and temperature, the whole record, both calibration marks and the record obtained in the actual sounding, must be tabulated in terms of the co-ordinates, temperature and ψ. The tabulated figures are then plotted on a graph on squared paper which is reproduced in Fig. 19. The particular sounding on which it is based is the same as that illustrated in Fig. 16. The small circles indicate the pressure-temperature marks made during calibration and the record itself appears as a pair of sloping lines. By joining the pressure-temperature marks isopleths of pressure are obtained for each 100 mb., and by interpolation between them the whole diagram may be covered with pressure isopleths at any desired interval. It will be noticed that the intervals between successive isopleths vary in size throughout the range of pressure, so that interpolation must be made on a non-linear scale ; it is desirable to have some quick way of doing this, and it has been found convenient to use for the purpose a transparent scale engraved with a set of radial lines. A description is given in Appendix 3, with an explanation of the method of its use.

The graph shown in Fig. 19 incorporates all the information as regards pressure and temperature which it is possible to extract from the original record, and is used as the basis of all subsequent determinations of height or geopotential. It is a simple matter to express any point on the graph in terms of pressure and temperature, and further it is easy to estimate the mean temperature over any desired range of pressure ; the latter process is accomplished by means of the principle of equal areas and is illustrated in Fig. 19 for the ascending record over the range of pressure 500 mb. to 600 mb.

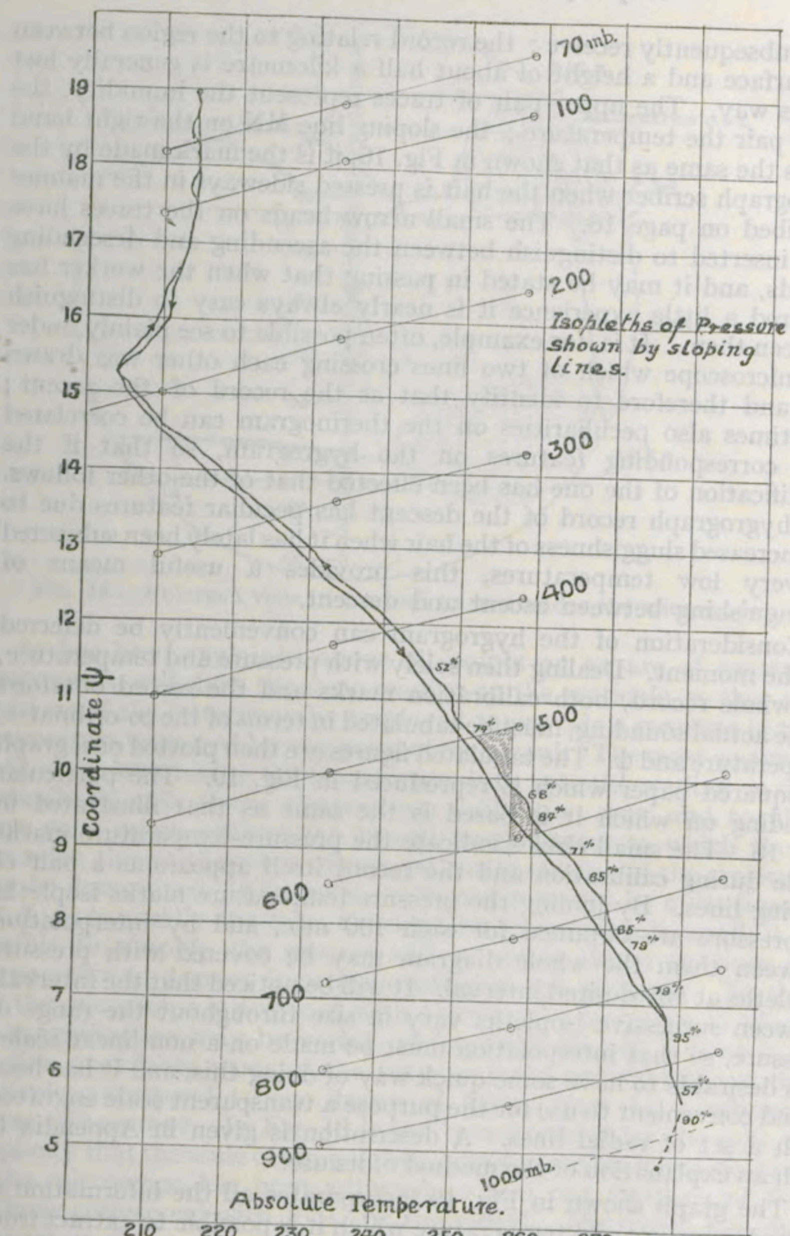

FIG. 19.—Interpretation of a balloon sounding. Graph of the data obtained from the record shown in Fig. 16.

It will be noticed on Fig. 16 that pressure marks have not been made at any pressure higher than 900 mb., and, therefore, there are not strictly any data available for drawing the isopleth of 1,000 mb. on the graph on Fig. 19. It has been found, however, by experience that in such cases it is possible to extrapolate the isopleth of 1000 mb. to a degree of accuracy quite sufficient for practical purposes. Put into mathematical notation the principle on which this is done is, that for any definite temperature if p denote the pressure, then over the range of pressure from 700 to 1000 mb. the quantity $\frac{d^2\psi}{dp^2}$ may be treated as constant. To take a practical example from Fig. 19, consider the temperature 285a. and let ψ_{700} denote the ordinate corresponding with the pressure 700 mb.

By scaling from the diagram,

$$\psi_{700}-\psi_{800} = 1{\cdot}21$$
$$\psi_{800}-\psi_{900} = 1{\cdot}08$$
$$\psi_{900}-\psi_{1000} = x, \text{ suppose.}$$

The right hand column denotes average values of $\frac{d\psi}{dp}$ over successive intervals of 100 mb. We have to make the differences between adjacent entries equal to each other, and therefore $(1{\cdot}08-x) = (1{\cdot}21-1{\cdot}08)$, or $x = 0{\cdot}95$. This enables us to plot on the diagram the point given by 1000 mb. and a temperature of 285a. Another point can be determined for some other temperature in a similar manner and the estimated position of the isopleth of 1000 mb. drawn in as shown.

RECORD OF RELATIVE HUMIDITY

Lastly it remains to determine the relative humidity corresponding with any particular value of the pressure. The principle difficulty lies in the synchronisation of records made by two independent scribers. As has been stated previously on p. 6, the work is simplified if the two scribers have been correctly adjusted in relation to each other, and in what follows it is assumed that this has been done.

In the account of the tabulation of the pressure-temperature record which has been given above it has been assumed that the edge of the graticule was set approximately perpendicular to the arcs of constant temperature as seen under the microscope; the graticule is shown in Fig. 18 in full lines in this position. The process of tabulation is, however, equally valid at whatever inclination the graticule be set, provided that it be not disturbed at any stage of the proceedings. When the record of the meteorograph includes relative humidity it saves a great deal of trouble to set the edge of the graticule parallel to the line MN in Fig. 18 from the start, and to tabulate the pressure-temperature record with it in this position. The graph of temperature and ψ in Fig. 19 is then drawn as before; it is similar to but slightly distorted from its original form, and, of course, yields identical results in terms of pressure and temperature. It will be seen that in order to make the divisions of the graticule fit the temperature scale as before, it is necessary to adjust the optical magnification of the microscope slightly differently from what is required with the graticule in the perpendicular position. The dotted lines in Figs. 16 and 18 show the general appearance of the graticule when set parallel to MN.

With this adjustment the geometrical conditions are such that associated with any definite configuration of the aneroid box the independent movements of either scriber will leave records on the plate very nearly parallel to the edge of the graticule as seen in the microscope. The hygrogram is now to be tabulated in the same manner as the thermogram, the data obtained being readings of the screw-head F (see Fig. 17) and divisions of the graticule. Suppose that for points on the hygrogram the reading of the screw-head F be denoted by the symbol ψ', while ψ retains its old meaning; it then follows from geometrical considerations that if P and P′ be any pair of corresponding points on the thermogram and hygrogram respectively, the quantity $(\psi_P - \psi'_{P'})$ is constant for all parts of the records, the suffixes indicating the points to which the co-ordinates refer.

Turning again to Fig. 16 and considering the known synchronous points B and B′, the readings ψ_B and $\psi'_{B'}$ are first determined; denote the difference $(\psi_B - \psi'_{B'})$ by the symbol p. Now select any salient point on the hygrogram, as H′; the problem is to find the corresponding point H on the thermogram, and to identify it on the graph shown in Fig. 19. We have in the notation employed above $(\psi_H - \psi'_{H'}) = p$. Of these quantities $\psi'_{H'}$ is read off from the screw-head F when the edge of the graticule has been made to pass through the point H′, and p has been already determined. Hence ψ_H is known and the corresponding point on the graph in Fig. 19 is found by reading off the ordinate on the scale on the left hand side; the point so found is then marked by a dot or short stroke. To find the relative humidity at that point the number of divisions of the graticule is read between H′ and the point where the edge of the graticule cuts the saturation line, shown in Fig. 16 by the letter F. Denote the number by n. Reference is now made to the constants of the microscope to determine for the particular setting employed the number of divisions of the graticule corresponding with 1 mm. in the field of view; thence the quantity n is expressible in millimetres, and by further reference to the calibration of the hygrograph (p. 13), the relative humidity indicated by the point H′ is determined.* The value is entered beside the mark already made on the graph in Fig. 19. For the sake of clearness only a few entries are shown and they have been taken from the record of the ascent only; by interpolation between them the relative humidity at intermediate points may be determined.

TABULATION SHEETS.

Examples are given on the following pages of two forms used in working up the records.

* The readings of the hygrograph are not quite independent of temperature at temperatures below 0° C. For a discussion of the whole question see Kleinschmidt, *Beitr. Physik. Atmosph., Leipzig*, **2**, 1906–8, p. 99.

TABLE I.—WORKING SHEET OF PRESSURE AND TEMPERATURE DATA

Sounding No.—725. **Station.**—Kew Observatory. **Date.**—16.4.29. **Time.**—07.15 G.M.T. Balloon fell at Hawtridge, Ashampstead, Berks.

Surface Conditions.—Pressure at M.S.L. 1016·2 mb. Temp. at surface 278a.

Meteorograph No.—C.8926. Microscope:—Position of focussing tube .. 2·1 cm. Length of radius .. .. 11·2 cm.

Temperature. Ascent.	Temperature. Descent.	Co-ordinate ψ Ascent.	Co-ordinate ψ Descent.
200+75	200+75½	6·39	6·48
74	76	6·54	
74	77	6·60	
75	78½	6·69	
76½	78½	6·77	
77½	78	6·88	
77½		6·96	
77	76½	7·13	
76	74½	7·33	
75	74	7·43	
73	72	7·64	
72		7·73	
70	69	8·00	
69	67	8·15	
66½	65½	8·38	
65	64	8·74	
60	58½	9·54	
55	54	10·36	
53½		10·44	
53½	52½	10·65	
52		10·91	
51	49	11·22	
47½		11·58	
45	44	12·18	
45	43½	12·44	
50	45	12·65	
54	50	12·88	
56	54	13·00	
56		13·04	

Tables derived from computations of height.

Pr. mb.	Ht. km.	Temp. a.	R.H. %	Pr. mb.	Ht. km.	Temp. a.	R.H. %
1016	·007	278	88	1000	·13	—	—
956	·5	275	100	950	—	276	100
898	1·0	276	62	900	·98	277	62
844	1·5	272	71	850	—	273	70
792	2·0	268	62	800	1·92	269	64
743	2·5	265	58	750	—	265	64
697	3·0	263	34	700	2·96	263	34
611	4·0	257	42	650	3·53	259	31
534	5·0	251	40	600	4·13	255	44
465	6·0	245	25	550	4·78	252	43
450	6·23	245	25	500	5·47	247	32
				450	6·23	245	25

Remarks.—Mean of both traces used in determining the temperature throughout. R.H. from ascent only. The balloon did not burst, and floated for a time at the top. The temperature shows a rise of 12 at the top due to isolation, the sounding has been taken as terminating below this level.

Meteorograph calibrated on January 28–29, 1929.

Temp. of calibration.	200+78·9	200+58·5	200+31·0	200+12·2	200+84·6
Graticule as set.	78·9	58·6	30·9	12·3	84·6
Pressures at which calibration marks were made.	Co-ordinate ψ.				
900 mb.	7·28	6·65	5·86		7·47
800	8·41	7·73	6·91		8·60
700	9·67	8·97	8·11		
600	11·11	10·37	9·46		
500		11·95	11·01	10·34	Calibration made after return of meteorograph.
400		13·72	12·73	12·08	
300		15·63	14·68	14·00	
200		17·64	16·71	16·08	
100		19·70	18·81	18·23	
71		20·29	19·45	18·86	

Inversion:—

Pr. mb.	Ht. km.	Temp. a.	R.H. %
965	·43	275	100
930	·72	277	70

TABLE II.—WORKING SHEET OF HUMIDITY DATA

Station.—Kew Observatory.
Date.—16.4.29.
Time.—07.15 G.M.T.

Number of Meteorograph.—C.8926.
Number of Sounding.—725.

Microscope.—Setting of focussing tube—2·1 cm.
Setting of graticule—Parallel to line MN.
Number of divisions of graticule per millimetre of the object—60.

Corresponding values of co-ordinates ψ_B and $\psi'_{B'}$.	Thermogram.	Hygrogram.	Conditions.
	12·01	11·71	Points of lowest pressure reached in calibration.
	9·29	9·00	

Mean value of $(\psi_B - \psi'_{B'})$:—+·295, denoted by (p).
Reading of saturation line on graticule :—4 divisions, denoted by (w).
Remarks on saturation line :—No shift of zero of hygrograph.
Relative extension of hair at 25 per cent. as found by calibration :—·0088.
Equivalent length of hair :—92 mm.
Divisions of graticule measured from the saturation line corresponding to different relative humidities, derived from the calibration of the hair and the constants of the microscope.

R.H. per cent.	100	96	90	80	70	60	50	40	30	25
Divs. ..		0	4	10	16	22	29	35	43	47

ASCENT.

Graticule reading of hygrogram less (w) n.	Relative Humidity per cent.	Co-ordinate ψ'	Co-ordinate ψ $\{\psi = (\psi' + p)\}$
— 4½ Divs.	100	6·20	6·50
— 4	100	6·33	6·63
— 1½	98	6·43	6·73
14	73	6·55	6·85
18	67	6·67	6·97
22	60	7·00	7·30
16	70	7·32	7·62
15	72	7·55	7·85
22	60	7·93	8·23
11½	77	8·12	8·42
30	48	8·45	8·75
40	34	8·82	9·12
43	30	9·35	9·65
37	38	9·70	10·00
31	47	10·15	10·45
33	43	10·60	10·90
37	38	11·04	11·34
36	39	11·12	11·42
46	26	12·00	12·30
47	25	12·53	12·83
50	23	12·72	13·02

In Tables I and II working sheets are shown covering the whole process which has been described above. Table I deals with the temperature-pressure calibration and the reading of the temperature-pressure record in terms of the co-ordinates temperature and ψ, and carries the work to the stage of incorporation of the data into Fig. 19. Tables of data in terms of height are included also, but this is a subsequent process for details of which the reader is referred to the "Computers Handbook." Table II deals with the record of the hygrograph, and also carries it to the stage of incorporation into Fig. 19.

Fig. 19 contains in a permanent form all the information which is deducible from the original record. If it be carefully drawn the smallest details of the pressure-temperature record may be incorporated into it. The scale to which it is drawn should be at least 2 cm. to 10° C. on the temperature scale, and 2 cm. to 1 mm. of movement of the scriber on the pressure scale. A smaller graph involves errors in reading greater than those involved in the original tabulation of the record under the microscope, and is undesirable.

ABRIDGED ROUTINE FOR USE WITH WELL SEASONED METEOROGRAPHS

The routine which has been here described provides for a much more frequent calibration of the meteorograph than is usually considered necessary in the case of instruments which employ a clock and drum for recording; the question remains whether it is possible to abridge the process without undue loss of accuracy. Some form of datum line must of necessity be made on the record plate previous to any sounding, and this conveniently takes the form of a pressure calibration at one constant temperature. Since that temperature may be near the normal air temperature the meteorograph may be calibrated in water and the hygrograph may be set to its final adjustment beforehand. It is manifest that if such a process can be made to give sufficiently accurate results a very great saving of time and labour will be effected. The routine which should be followed is summarised below, together with certain precautions which it is essential to observe.

Assuming the meteorograph to have been thoroughly seasoned, on the first occasion of its use a pressure-temperature calibration graph similar to that shown in Fig. 19 must be prepared, covering the whole range of both temperature and pressure, more particularly as regards the higher temperatures.

The next time the meteorograph is prepared for a sounding a pressure calibration covering the whole range must be made at a definite temperature, as nearly as possible identical with the highest temperature employed on the first occasion. When the subsequent record is worked up under the microscope it is absolutely essential that the setting of the stage should be the same as before, both as regards the length of the radius employed and the optical magnification of the microscope. The graticule must also be inclined at the same angle, and the temperature arc must cut it at the same point as an arc of like temperature on the first occasion would have done. The temperature and co-ordinates indicated by different points on the record can now be read off from the graticule and the screw-head F in exactly the same manner as on the first occasion, and the series of isopleths of pressure shown in Fig. 19 can be built up from the definite known points at their right hand ends, which the calibration at one temperature has supplied ; the basis on which such building up is done is that the shape and slope of each isopleth may be taken as unaltered, each is identical with its predecessor save that it has been shifted parallel to itself upwards or downwards on the diagram.

Whether the shortened process will give a sufficient degree of accuracy is a question which individual workers must decide for themselves. A good deal depends on the quality of the instruments used, but with good instruments which have not suffered damage between successive soundings the additional errors which to some extent must be introduced are not likely to exceed a few millibars of pressure and one or two degrees of temperature. If, as a result of a violent shock or ill-treatment, a particular instrument needs repairs before it can be used again, it is undesirable to rely on a previous calibration ; even under the best of conditions it is much better to keep a check on the behaviour of every instrument by periodically submitting it to a complete calibration.

APPENDIX I

Instructions for preparing the plated metal on which the record of the Dines balloon meteorograph is made

Hard nickel silver is used, 0·15 mm. in thickness. On this is first deposited a coating of copper in order to give a smooth structureless surface for the final coating of silver.

For convenience the metal may be cut into pieces 10 cm. square, choosing only such pieces as are free from scratches etc. Metal which has been rolled by a high-class firm has a good surface for this purpose as it leaves the rolls, and needs no further treatment, but if it has been allowed to become scratched it is necessary before plating to rub it down with successive grades of emery paper, finishing with a very fine grade.

For the first plating with copper a saturated solution of pure copper sulphate is used, to which has been added about 5 per cent. of sulphuric acid. With a copper anode, and a current of 0·8 amp. per 100 sq. cm. of the metal, the plating is completed in from 10 to 15 minutes. The exact time can hardly be specified, but if any tendency to roughness appears on the surface of the deposited copper the time in the bath must be reduced. The plate is then washed thoroughly and while still wet is placed in the silvering bath. In this case, using a silver anode, the current must not exceed 0·15 amp. per 100 sq. cm. ; sufficient silver is deposited in 10 minutes. The plate is again washed thoroughly and dried on clean blotting paper. In the process just described the anode is supposed to take the form of a flat plate about 10 cm. square, placed parallel to the metal under treatment and at about 10 cm. distance from it.

The silvering solution is most conveniently made from salts which can be bought ready mixed for the purpose. If desired, however, it can readily be made by dissolving pure potassium cyanide in distilled water in the proportion of 50 gm. per litre. With a silver anode, and a copper kathode in a porous pot, a current of ⅓ amp. per litre is passed through the solution for half an hour. At the end of this time sufficient silver will have been absorbed, and the solution is ready for use.

When completed the silvered surface should have no polish, but be smooth, white, and free from marks of any description. Trouble may arise by the appearance of dark stains and discolorations ; these are sometimes caused by too heavy a flow of current, but are usually due to a shortage of free potassium cyanide in the solution. The remedy in the latter case is to add a little of a 10 per cent. potassium-cyanide solution from time to time as required. It is advisable to test the working of the plating bath on an odd piece of coppered plate before starting on larger pieces. If, when examined under the microscope, the silvered surface appears rough and pitted the cause is that too much copper has been deposited. It is important that all electrical connexions be made before the plate is dipped into either of the plating solutions ; if this is not done the deposted metal may fail to adhere properly. It is best not to keep the plated metal in a room where gas is burnt, not only is the surface discoloured but a hard skin may be formed on which the scribers make very faint marks.

APPENDIX II

A mercury manometer for measuring absolute pressures between one atmosphere and zero, under any conditions of surface pressure and temperature

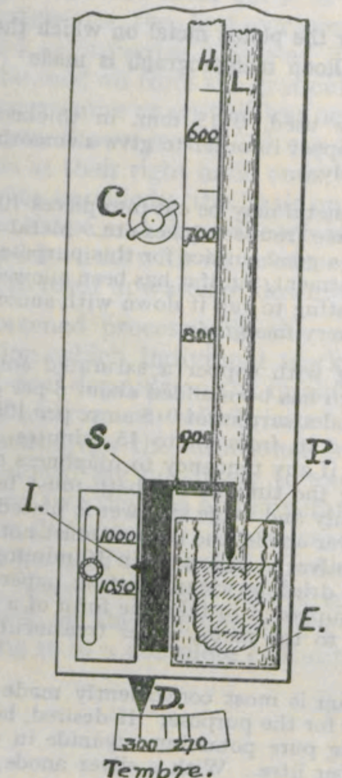

FIG. 20.—Absolute mercury manometer with adjustments for variations in the surface pressure and temperature.

It is evident that a liquid pressure guage may be graduated to suit when vertical a liquid of any density, and that when the glass tube of the gauge is tilted out of the vertical its graduations will be correct for a liquid of greater density. If therefore a mercury gauge be arranged to suit mercury at 300a., it will suit mercury at any lower temperature provided that it is inclined to the vertical at the correct angle.

The proper angle is readily calculated, for if the vertical position is correct for a temperature T_0, and θ is the inclination to the vertical for temperature T, then it follows that

$$\cos\theta = 1 - \cdot 00018\,(T_0 - T).$$

From a table of cosines, if T_0 be 300a., and θ be the circular measure of the inclination to the vertical, the following table may be deduced.

T	300	295	290	285	280	275	270
θ	00	·042	·060	·074	·085	·095	·104

If T_0 have any other value under ordinary atmospheric conditions, the same table may be used by adding or subtracting the corresponding quantity to the temperatures in the top row.

The gauge, of which a diagrammatic illustration is given, is mounted on a board pivoted near the centre and provided with a clamp C, and a pointer D moving over the temperature scale. The mercury cistern E is coaxial with the tube and is capable of being moved up and down with respect to it. The pressure scale H is fixed with respect to the tube L, and is continued downwards to a point on the scale somewhat greater than the highest atmospheric pressure likely to be experienced. An adjustable pointer P, similar to that used in a Fortin barometer, is arranged in the cistern directly in front of the tube, and is fixed to a slide S capable of moving parallel to the tube and having an index or vernier I reading against that part of the pressure scale representing the range of variation of atmospheric pressure.

If the index I be provided with a means of vertical adjustment on the slide S relative to P, then all constant corrections which have to be applied to the gauge can be allowed for once for all; they include such items as the effect of capillarity on the mercury column, and that of the pressure head of the liquid bath on the meteorograph. Variable corrections due to change of atmospheric pressure and temperature are allowed for, first by setting I to the atmospheric pressure on the scale H and then adjusting the level of the mercury in the cistern to the pointer P, second by setting D to the appropriate point on the temperature scale.

In a modified form of the gauge which is somewhat simpler to construct the indices I and P are permanently fixed in relation to each other, and the adjustment for constant corrections is made by another means; the lower part of the pressure scale from about 950 to 1050 mb. is mounted on a separate slide which can be moved up and down in respect to the upper part and clamped as required. The illustration shows the gauge in the modified form.

APPENDIX III

A transparent scale for interpolation on a non-linear scale

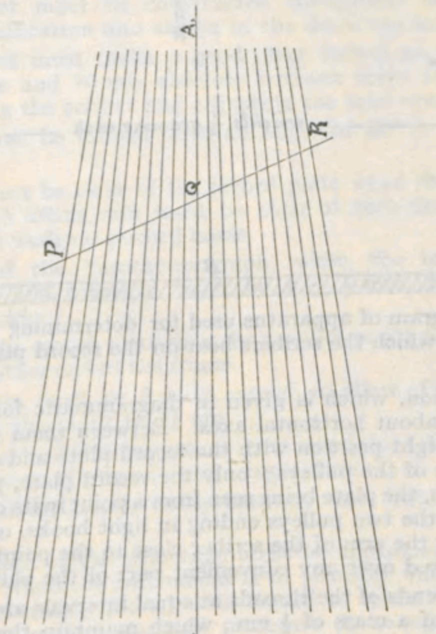

FIG. 21.—Transparent scale used for interpolation on a non-linear scale.

The scale is illustrated in the figure. The 21 converging lines all meet in one point and are drawn so that any cross line perpendicular to AB, the middle one, will meet them at equal intervals along its length.

As an illustration of the use of the scale suppose that it is desired in Fig. 19 to interpolate pressures between 600 mb. and 800 mb. on some particular ordinate of temperature. Let this ordinate cut the isopleths of 600, 700 and 800 mb. in the points P, Q and R respectively. The scale is now moved about until the outer pair of the 21 converging lines pass through P and R, while the middle one AB passes through Q. On the ordinate chosen the converging lines will now provide a varying scale of pressure in tens of millibars which fits the plotted isopleths in the three points P, Q and R and may be used to give a good estimate of intermediate pressures.

APPENDIX IV

An apparatus for determining quickly the pressure with which the scribers of the meteorograph bear on the record plate.

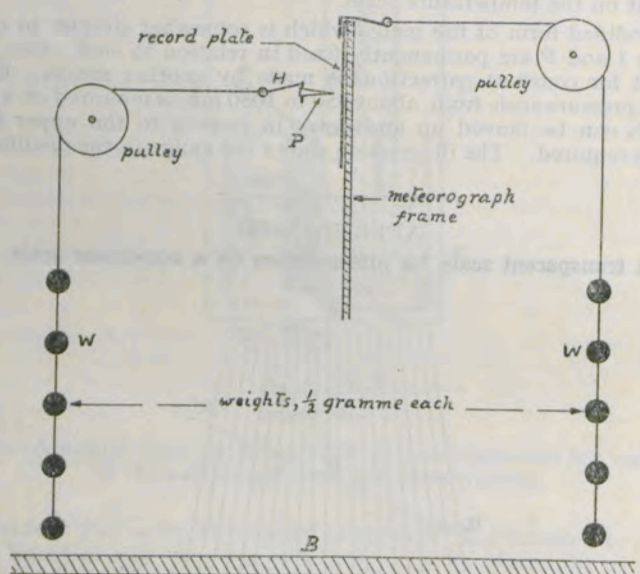

FIG. 22.—Diagram of apparatus used for determining the pressure with which the scribers bear on the record plate.

The illustration, which is given in diagrammatic form only, shows two pulleys turning about horizontal axes. Between them the meteorograph is placed in an upright position with the record plate and scribers at the same level as the tops of the pulleys; only the record plate, plate-holder and one scriber are shown, the plate being seen from a point in its own plane. Threads are passed over the two pulleys ending in light hooks, one of which marked H is placed over the arm of the scriber close to the point, while the other on the right is hooked over any convenient part of the plate-holder.

At the other ends of the threads at equal intervals are fixed small weights W W W, each of a mass of ½ gm., which maintain the threads in tension. At the base of the apparatus is shown a horizontal platform B, capable of being raised or lowered by hand; as it is raised the weights rest upon it one by one and the tensions of the two threads are continually reduced, but remain equal to each other.

In using the apparatus the platform B is first raised until all the weights rest upon it, it is then gradually lowered and the scriber examined meanwhile with a magnifying glass. When the tension of the thread exceeds the pressure with which the scriber normally bears on the plate the point P will be seen lifting off the plate, and by counting the number of weights still hanging in the air that pressure can be at once written down in the form—pressure lies between 1½ and 2 gm. say. The object of the second thread and hook on the right is for purposes of symmetry in the strains set up in the meteorograph.

APPENDIX V.

Schedule of tests applied at Kew Observatory to Dines balloon meteorographs submitted by manufacturers.

Certain British instrument makers are in a position to supply Dines meteorographs made in accordance with the official specification. To ensure that purchasers may obtain approved instruments arrangements have been made for verification at Kew Observatory. The following schedule summarises the requirements for certification of the barothermograph alone. Approved instruments will be marked with the symbol Ⓚ followed by a serial number, and a certificate will be issued indicating that the instrument complies with official requirements.

It must be clearly understood that such certification does not obviate the need for subsequent calibration by the methods described in this pamphlet.

MECHANICAL CONSTRUCTION.

1. The instrument must be constructed throughout of the materials described in the specification and shown in the drawings associated with it.

2. The instrument must make a good clear record as between normal atmospheric pressure and 70 mb. absolute without more attention than is implied in sharpening the scriber and adjusting the load upon it.

3. The scriber must be formed with an angle of 30° ± 4°, as stated in drawing K.O.40 B

4. The scriber must be clear of the record plate when the wooden wedge is pulled out, and the lifting arm must be clear of both the frame and the scriber arm when the wedge is pushed home.

5. The scriber of the barothermograph, when the instrument is at normal temperature and pressure, must be 4 ± ½ mm. from the nearest point of the plate-holder.

6. The plane of the record plate must be parallel to the axis of symmetry of the spring at the other end of the frame.

7. The scriber arm must be flexible enough to allow of the easy adjustment of the load on the point to 1½ gm.

8. The working parts of the instrument must stand clear of the aluminium case under all conditions of pressure and temperature.

9. The instrument must slide easily into the case, but without rattling when in position.

10. The bottom end of the wire cage must be approximately normal to the axis of the case when the instrument is in position, and the calibrating tailpiece must be accurately placed with regard to it, so that the normal process of calibration with a standard armature (Drawing No. K.O. 60A) can be carried through without further adjustment of the instrument.

PERFORMANCE.

The instrument will be submitted to a pressure calibration at normal temperature between atmospheric pressure and 70 mb. absolute, and a similar one at a temperature about 30° C. less than the first.

11. The scale of the pressure registration must be such that the scriber does not move more than 14 mm.* nor less than 10 mm.* between the absolute pressures 900 mb. and 100 mb. The pressure scale is not intended to be uniform, but sudden discontinuities in scale value must not occur in any part of the range tested.

12. The scale of the temperature registration must lie between 55° and 75° C. per mm.

13. At constant temperature the record made with a falling pressure must not differ from that made with a rising pressure by more that the equivalent of 0·75° C. with a load of 1½ gm. on the scriber.

14. The record of pressure at constant temperature must follow a circular arc whose radius lies between 10 and 12 cm.

15. A test for lag will be applied by reducing the pressure from one atmosphere to 70 mb. absolute and increasing it again to one atmosphere in a total time of from 8 to 10 minutes. The total lag is defined as the difference between the readings of the scriber (in terms of pressure) at one and the same pressure as between falling and rising pressure conditions. The total lag will be determined at pressures of approximately 800, 500 and 200 mb. absolute with a load on the scriber of about 1½ gm. The maximum value must not exceed 4·5 mb. nor the mean of the three 3·5 mb.

* These figures apply specifically to instruments fitted with aneroid boxes of type D as shown in Drawing No. K.O.59A.

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