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(THIRD REPORT).

THE CALIBRATION OF THE BALLOON METEOROGRAPHS AND THE READING OF THE TRACES.

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PARTICULARS FOR CALIBRATING AND READING THE TRACES OF THE BALLOON METEOROGRAPHS.

PROCESS ADOPTED AT PYRTON HILL.

[*Note.*—In this paper the scale of pressure in millimetres of mercury is used, whereas the use of millibars is now becoming customary at the office. The changes necessary to adapt the instructions for use with a millibar scale can easily be made, but the references in this paper turn upon the diagram facing p. 150, and the millimetric scale has been retained.—W. N. S.]

In a previous publication, M.O. 202, an account is given of the method of calibrating the balloon meteorographs used in England; but since that date various alterations, that are found by experience to be improvements, in the instruments and methods have been made and it seems desirable, since several institutions in the colonies and elsewhere are now using this particular form of meteorograph, to print instructions for their guidance.

It is not, of course, claimed that no further improvement is possible. These instructions are only published as hints whereby those who have to do the work may save themselves time and trouble, and also that anyone interested may judge for himself as to the accuracy of the results and form an opinion as to the chance of there being some undiscovered systematic error. This latter point seems to me of especial importance, for, if for any reason published figures seem doubtful, it is natural first of all to ascertain how they were obtained, and if no information is available the doubt is pretty certain to remain, even though it be unjust. In this case, however, it may be stated that the figures published by the Meteorological Office relating to the upper air, and the corresponding figures for Western Europe, published by Prof. Hergesell at Strassburg, agree even down to the smallest details.

No important change has been made in the meteorograph, but the knife edges have been entirely given up and springs substituted; also it has been found that the temperature scale is not quite linear but shows a slight contraction at the lower temperatures.

As a general rule, the meteorographs are calibrated some time in the week before the date on which they are sent up, and the calibration is done on the same piece of plated metal on which the trace is subsequently made.

The calibration consists of three marks made over the range of pressure from 700 to 50 or 100 mm. at temperatures* of about 280° A., 250° A., and 220° A., and cross marks, consisting in reality of a small blur, made on each of the three marks, at the pressures of 700, 600 . . . etc., mm.

The calibrating vessel is designed for making these marks. It is a cylindrical brass vessel 3 inches diameter and 12 inches high, fitted with an air-tight cover and well lagged with felt. It is used in connection with an air pump and a mercury gauge which

* The absolute temperature on the centigrade scale is used, where 273° is the freezing point. This greatly facilitates reading the micrometer scale in the microscope.

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should be corrected for temperature, so that any desired pressure below the atmospheric may be obtained inside it. It is filled with petrol, the temperature of which can be reduced by means of liquid carbonic acid, which is allowed to run into a copper coil of tube surrounding the vessel and there takes the form of carbonic acid snow.

The pressures are marked by striking the strip of the thermograph by a small electric striker. This striker and its armature are inside the vessel, and the electro magnet is outside. A vertical brass tube inside the vessel forms the bulb of an air thermometer, which may be fitted up and used for determining the temperature of the petrol; it also serves as a guide for placing the thermograph in position. A thermometer graduated to 210° A. is used for taking the temperature. The electro striker is arranged to work with 4 volts, though sometimes 2 volts may be sufficient.

Instructions for Calibrating.

Prepare the instrument for calibration by placing a clean piece of plated metal in position. The metal must fit tightly, so that there is no risk of its shifting in the slightest degree until it is withdrawn after the ascent.

Insert a small wedge to bring down the spring that holds the writing points off the plate.

Place the instrument in the calibrating vessel, by means of a wire hook, with the plate end upwards and the sloping wire in contact with the air-thermometer bulb, and see that the instrument is entirely covered by petrol. The pressure of this petrol, about 5 mm. of mercury, must be allowed for on the pressure scale. The instrument should now be in such a position that the electric striker will hit the metal strip of the thermograph when contact with the battery is made.

Take the temperature of the petrol, place the cover to the calibrating vessel in position and fasten it down.

Use the air pump to reduce the air pressure inside to exactly 700 mm. Make a momentary contact.

Reduce to 600 mm., and again make contact; and so on down to 100 mm.

(If the temperature be high the petrol vapour may prevent so low a pressure as 100 mm. being reached; if so, be content with 200 mm.)

Remove the instrument from the vessel and examine it with a magnifying glass to see that it is properly marked. Take and note down the temperature of the petrol.

Place the instrument carefully on one side, and if a batch of instruments is being calibrated, proceed similarly with the next.

Now reduce the temperature in the calibrating vessel to about 250° A. (245° to 255° A.). This is done by making a pressure tight connection (rubber tube will not serve) with a cylinder of liquid CO_2. A metal union is provided for the purpose. (Note that the valve of the CO_2 cylinder must be downwards when it is opened and only a small quantity of CO_2 is required.)

Take the temperature of the petrol after stirring well and seeing that it has become nearly stationary, and then insert meteorograph as before.

Use the air pump and electric striker as before, but make contacts at 700 . . . . . . 100, and 50 mm., and then carefully decrease the pressure to exactly 40 mm. but no further. (The reason will be subsequently given.)

Remove the instrument, examine it to see that the marks are clear, take the temperature again, and proceed with the next instrument.

Reduce the temperature to about 220° A. and go through the same process with each instrument again.

Remove the wedges, place each instrument in its own numbered case, and take care that they experience no rough usage before the ascent.

The reason for reducing to a pressure of exactly 40 mm. is this: The pressure marks (see fig. 2) consist of small blurs upon the temperature lines, and these blurs cover a range of 3 or 4 mm. of pressure. The top of the mark at 40 mm. is perfectly definite, and from it and the blur at 100 mm. a fairly exact position for the 50 mm. mark can be assigned. Comparing this assigned position with the centre of the blur, it can be seen whether the centre of a blur denoting a pressure of 50 mm. or whether a little above or below it should be taken as the proper position for the corresponding pressure. Since all the blurs on the same plate are much alike, the proper part of each one that should be used is found.

For the most accurate work the pressure should be decreased slowly, so that the decrease in time should correspond with that which occurs on the actual ascent. Careful experiments at Pyrton Hill have shown that with the form of aneroid box there used, the result of a rapid decrease of pressure is that the box does not open out quite as much as it would with a slow decrease, the error being about 2 mm. at the top on a decrease from 750 to 100 mm. At Pyrton Hill the instruments are calibrated rapidly, but allowance is made for this error on the pressure scale.

It is convenient to avoid the trouble of the temperature correction caused by the expansion of mercury by heat in the following way:—It is obvious that if a pressure gauge be constructed to suit a vertical glass tube containing mercury at a fairly high temperature T_0, it may be made to fit any lower temperature by inclining the tube by a suitable angle to the vertical. These angles are readily calculated, since if θ be the angle for temperature T, $1 - \cos\theta$ must be the contraction of mercury in glass per unit length for a fall of temperature of $T_0 - T$ degrees. Hence the gauge is mounted on a piece of wood pivoted at one point, and carries a pointer working over a temperature scale made once for all. The capacity of the cistern is allowed for on the scale. All connections may be made with thick-walled rubber tube.

Also the pressure scale slides by the side of the glass tube and can be clamped in any position to suit the atmospheric pressure prevailing at the time. Allowance for the depth of petrol over the centre of the box is made when the scale is clamped in position.

The chief difficulty of the calibration lies in a correct determination of the low temperatures of the petrol. It is very hard to keep this constant, as even inserting the comparatively warm instrument alters it. The air bulb inside is very useful in this connection; at Pyrton Hill it is used as a constant volume gas thermometer, but if it is simply connected with a small-pressure gauge, it shows if serious changes of temperature are occurring in the petrol, and indicates their magnitude.

Preparing the Instrument for the Ascent.

Place the instrument in its cylindrical metal case with the writing end against the cross wires of the case, and wire it in by putting a piece of aluminium wire through the holes provided at the other end, and then turning over the ends. The finder, at least in England, seldom meddles with the wire, but will untie string; probably he does not possess the necessary pair of small pliers.

Prepare a small wooden wedge and tie to it some six inches of fine red string with half a match tied to the other end. Insert the wedge by means of a small pair of pliers in its place so as to bring the pens down on the plate. Take great care not to shift the plate in the process.

Next prepare the "spider." Take three strips of split bamboo of about $\frac{1}{8}$th inch section and 3 feet 6 inches long. Fix them together at the centre and place them so that each one is perpendicular to the cross formed by the other two. Fix them in this position by ties of fine cotton running from the extreme ends of each to the ends of the cross formed by the other two. Then tie a small red silk flag on each of the six ends. The result is that this "spider" when lying on the ground must have three red flags well above the ground, and is therefore readily visible. Its weight should not exceed an ounce (fig. 1).

Tie the instrument to the "spider" by string from the cross wires of the case to the centre of the "spider." Tie tightly so that the case is jammed against the three bamboo strips. Neglect of this precaution will make a blurred trace. Do not forget to attach the label offering the reward. (A copy of that used in England is given in fig. 3. It is soaked in melted paraffin wax to protect it against wet.) Secure to the balloon by about 40 feet of fine string, so arranged that the axis of the case of the instrument must be vertical during the ascent. In England the distance between the case of the instrument and the centre of the balloon at starting have been made equal to 44 feet but is now to be increased. The angle which this distance subtends is measured on a micrometer scale at the focus of the theodolite telescope, and by this means a fairly accurate calculation of the distance of the balloon, and therefore of the rate of ascent and of the velocity of the wind, can be made.

Working up the Traces.

This consists in transferring the calibration marks and the marks made on the ascent and descent accurately to squared paper. Fig. 2 is from a photograph of an actual trace magnified between four and five times. The left-hand parallel lines with the small blurs at unequal distances on them are the three calibration marks; the left-hand line running from 800 mm. to 90 mm. pressure at the ordinary temperature, the right-hand line from 800 to 40 mm. at about 220° A. The coarse line on the right hand is made by the fixed pen; it is not used in the working up in the general way, but the fact that it is not duplicated proves conclusively that the plate has not shifted between the calibration and the ascent. The sloping line beginning on the left hand at the bottom and running up to just beyond the 100 mm. mark on the right-hand low-temperature line is the actual trace. Seen through the microscope, this line is a duplicated one, plainly crossing here and there, but the two parts never differing by more than 2° C. Both the ascent and the descent provide a trace, hence the duplication. This trace was obtained after sunset; had it been in full sunshine, the up-and-down traces would almost certainly have differed far more, since the instrument ascends in air that has been heated by contact with the hot balloon. Assume that the calibration marks were made at 280° A., 250° A., and 220° A. All three marks are arcs of a circle, and the microscope stage is made so that the point on the stage just under the object-glass shall move in the same circle. (For description of the stage, see M.O. 202, page 34). Mount the plate on the carrier and turn the carrier about its pivot until it is found that on moving the stage by turning the micrometer screw the temperature lines retain exactly their relative position in

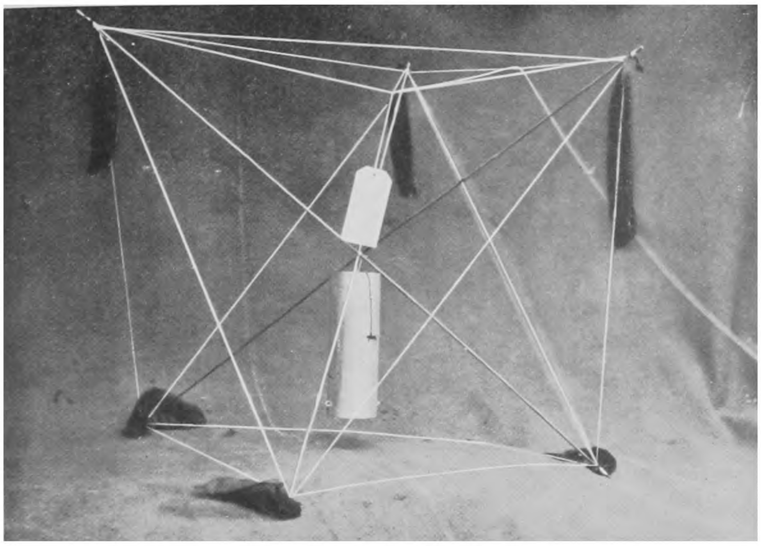

FIG. 1.—Bamboo frame or "spider" inside which the meteorograph is suspended during an ascent. The cotton was unduly coarse so that it might show in the photograph.

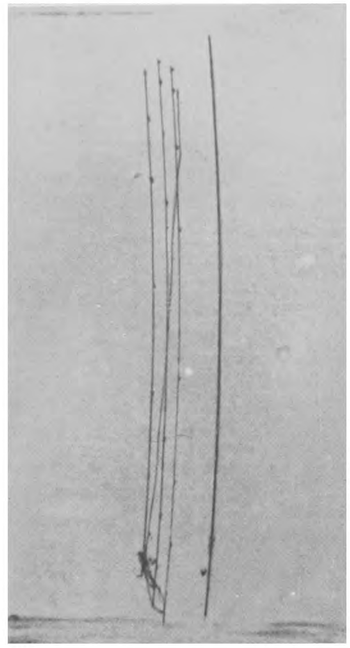

FIG. 2.—Enlarged copy of record from the balloon meteorograph.

M.O. 074.

O. H. M. S.

INTERNATIONAL INVESTIGATION OF THE UPPER AIR.

5 SHILLINGS REWARD.

DELICATE METEOROLOGICAL APPARATUS.

This instrument is the property of the Meteorological Office, London. The above reward will be paid for the instrument if it is not tampered with. The finder is requested 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 Director, Meteorological Office, London, S.W., when instructions, and if desired, information, will be sent.

The balloon need not be returned.

FIG. 3.—Copy of label attached to the meteorograph before the ascent.

Absolute Temperature (first figure, 2, omitted).

Reading on micrometer screw.

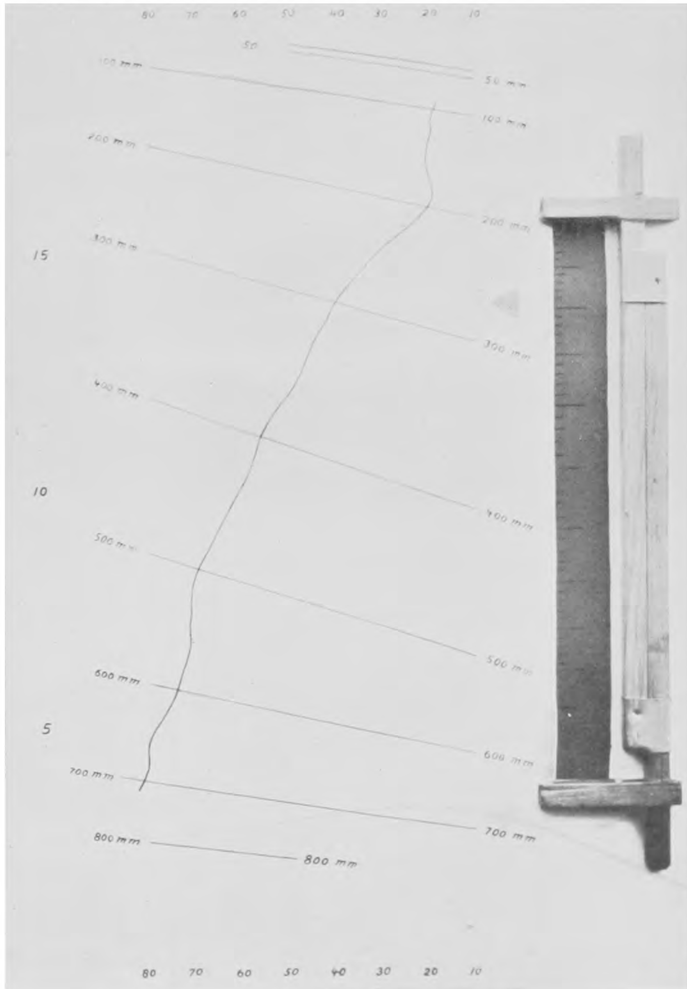

FIG. 4.—Working up the traces. Obtaining simultaneous values of pressure and temperature for any part of the record. The instrument shown is an elastic scale for interpolating for pressure between the sloping lines of the diagram.

the field of view. Adjust the micrometer at the focus by turning the eye-piece round so that the micrometer division marks are parallel to the calibration marks. Now shift the stage till the calibration mark agrees with the micrometer division, numbered 80 (*i.e.* 280° A.). The 220° A. mark will now be somewhere in the neighbourhood of the 20 division of the micrometer scale. The magnification of the microscope can be altered to make them fit by pulling out or putting in the tube that carries the eye-piece. Make them so fit, and then the temperature indicated by any part of the trace can be read off at once in absolute measure by means of the micrometer scale.

It may happen that the scale is not quite linear, and that when the temperatures of 280° and 220° fit on the micrometer, the temperature of 250° may not quite fall on the 50 line as it should do. In this case make the 280° and 250° lines fit for temperatures above 250°, and the 250° and 220° lines for temperatures below 250°.

The trace is now transferred to squared paper (fig. 4). Take vertical lines on the paper to denote absolute temperatures. Plot on the temperature lines of 280°, 250°, and 220° the position of the small blurs on those lines which indicate the pressures of 700, 600, 500 mm., etc., using the micrometer screw and scale of the microscope stage for the purpose. The divided screw-head gives the movement of the writing point to ·01 mm., and the usual range is about 2·00 mm. per 100 mm. pressure. It will be plainly seen from fig. 2 that the scale is not linear. This is because the movement of the aneroid box is naturally greater when the faces of the box are flat than when they are extended or compressed. Now join the dots showing the same pressures and we have a series of sloping lines on the chart marking the pressures of 700, 600, . . . etc. The slope of the lines is more apparent on the actual plate, see fig. 2, than on the chart reproduced in fig. 4, because in the chart the horizontal distances are multiplied up more than the vertical. This large slope is due to the temperature correction required when air is left in the aneroid box. Exhausted boxes have been used, but those containing air give the most accurate result, because that result is less dependent on the fatigue of the metal and also the scale is larger. It is not possible to avoid the temperature correction entirely, and that being so, its magnitude within wide limits is immaterial, and hence it is better to use a box containing air. Next plot the actual trace on the chart, using the micrometer screw and scale for aneroid box extension and the micrometer divisions at the focus for temperatures.

The remainder of the process is tedious, but presents no special difficulty. Interpolation between the lines of equal pressure gives the pressure corresponding to each temperature. When the pressure scale departs widely from linearity—and this is especially the case in the trace shown—some trouble is required for correct interpolation. The following plan is adopted :—The actual extensions of a large number of aneroid boxes over the scale 800 to 50 mm. have been plotted, and a mean curve drawn from them. From this curve a scale has been prepared marked to each 10 mm. of pressure. On this scale each division is of rather different length to its immediate neighbours, the divisions being widest at pressures of about 300 mm. and decreasing on both sides.* This scale is drawn on a uniform strip of thin sheet rubber, about 8 inches long, held in a frame so that it may be stretched (shown on the right of fig. 4). Since it is

* In the illustration, fig. 4, it has not been found possible to get a clear reproduction of the scale, or of the faint lines on the squared paper.

stretched uniformly the proportionality of the divisions is maintained, the scale only being altered. By suitably stretching and selecting the right part of the scale, it is always possible to make a fairly good fit over any consecutive 200 mm. of pressure and thus perform the interpolation to an accuracy of half a mm. at least. Where the slope of the trace is uniform it suffices to find the pressure for each even 5° of temperature, but all inversions and irregularities should be specially noted. In general the two traces, viz. that made during the ascent, and that made during the descent, do not differ by more than 2°C.; this is almost invariably the case in an ascent made at night. They may be treated as a single trace and the mean given. Sometimes in the daytime the difference may reach 4° C. or even more, and in such cases the two values should be given.

A table giving simultaneous pressures and temperatures having thus been prepared, the heights are obtained by means of Laplace's formula. At Pyrton Hill a graphical method using squared semi-logarithmic paper is used (see M.O. Publication 202, page 35).

The following particulars may be of interest:—The balloons mostly used in England weigh from 8 to 9 oz. (300 grammes). Thus the gross weight to be lifted is about 12 oz. (400 grammes). No parachute is necessary. A free lift of from 8 to 13 oz. according to the weather conditions is given, that is, according to the chance of the balloon reaching the sea, since a large lift reduces the distance run, and at starting the diameter of the balloon is about 40 inches (1 metre). Hydrogen compressed in steel cylinders is mostly used, but sometimes it is made from calcium hydride, which may be obtained from a firm in Germany. The usual height reached is between 13 and 18 km., the average 15·5. 95 per cent. of the balloons recovered give a readable trace up to the isothermal.

There is good reason to suppose that the probable error of the recorded temperatures does not exceed 1° C., and that the error in the height of the isothermal (M.O. Publication 210b, page 36) does not exceed 200 metres. Also it has been found that two persons working up the same trace quite independently will obtain results that seldom differ by more than 1° C.

Instructions for making the Plated Metal for Balloon Meteorographs.

Use thin brass or German silver about gauge 35, S.W.G. Clean first with petrol. Plate thickly with copper so as to obtain a surface entirely free from stratches, then with silver.

For the copper, plate about 16 square inches at once in a solution of sulphate of copper with a small quantity, 2 or 3 per cent., of sulphuric acid added, using a copper anode and a 2-volt accumulator cell. About ten minutes is required.

Wash thoroughly, but without rubbing, in clean rain water.

Plate with silver, using a solution of 1 oz. potassium cyanide to 40 ozs. distilled water, with a pure silver anode and a 2-volt cell. About five minutes is required.

Wash at once in hot clean rain water and dry with cotton wool.

The object is to obtain a smooth, non-corrodible surface fairly soft and entirely free from polish or scratches.

Note that the plates are spoilt by being kept in a room where gas is burnt.

An indistinct trace may sometimes be improved by the use of salts of lemon applied with water and a fine soft artist's brush.