ACCOUNT OF THE CONSTRUCTION OF A STANDARD BAROMETER, AND DESCRIPTION OF THE APPARATUS AND PROCESSES EMPLOYED IN THE VERIFICATION OF BAROMETERS AT THE KEW OBSERVATORY.

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I.—Standard Barometer.

In the course of the years 1853–'54 several attempts were made, under the superintendence of the Kew committee, to prepare, by the usual method of boiling, a barometer tube of large dimensions. Mr. Negretti, to whom was entrusted the preparation of the tube, succeeded repeatedly in boiling, apparently satisfactorily, tubes of fully one inch internal diameter. Many of these, however, broke spontaneously before they could be mounted, some of them within a few hours and others after an interval of several days. Two or three tubes were ultimately erected, but their condition was not satisfactory. The adhesion of the mercury to the glass was so great, that in a falling barometer the convexity of the top of the column was destroyed, and the surface of the mercury assumed even a concave form. After a few days rings of dirt or other impurity were formed on the glass near the top of the column, which soon increased to such a degree as entirely to interfere with the observation. The mercury employed in filling the tubes had been previously treated for some weeks with dilute nitric acid, and afterwards kept in bottles under strong sulphuric acid, being well washed with water and dried by repeated filtering before use. Dr. W. A. Miller examined specimens of the mercury, and could detect no impurity in it.

Suspecting that some injurious effect might have been produced upon the mercury or upon the glass by the great heat to which the tube was necessarily exposed in boiling so large a mass of mercury, it occurred to me that the difficulty might be removed by another method of filling the tube, which I shall now describe:

The tube was, in the first place, prepared as follows: To its upper end was attached a capillary tube bent thrice at right angles, having its bore much contracted at the middle point of its length, with a small bulb blown at another part of its length, being finally drawn out to a fine point and there hermetically sealed. To the lower end of the large tube was attached ten inches of a smaller tube, having a bore of three-tenths of an inch, and to that again was added about six inches of capillary tube. A bulb of three-fourths of an inch was blown at the end of the smaller tube, which, at its junction with the larger tube, was finally bent into a syphon. The end of the lower capillary tube was now connected with a good air pump, and the air very slowly extracted at the same time that the whole tube was strongly heated by passing a large spirit lamp along it. When the air had been as well as possible extracted, and whilst the air pump was still in action and the heat still applied, the lower capillary tube was sealed by a blow-pipe flame. When the tube had cooled, it was placed at a small inclination with the end of the upper capillary tube in a vessel containing mercury which had been previously boiled. The point of this tube was broken off under the mercury, which then rose in the tube by atmospheric pressure. The mercury continued to rise until the bulb at the other end was more than half filled, the remaining space being occupied by the air which the pump had failed to extract. It was estimated from the amount of space thus left unoccupied by the mercury that the pressure of the residual air in the tube when cold must have been less than five hundredths of an inch. The basin of mercury was then withdrawn from beneath, leaving the point of the capillary tube exposed, the bore of which remaining quite filled with mercury. The blow-pipe was then applied to the point, and the opening sealed. When the glass had cooled, the large tube was placed erect, the mercury separating at the contracted part of the capillary tube, leaving the remainder filled, or very nearly so, and the part between the point of contraction and the large tube a vacuum. The upper capillary tube was now sealed at about the middle of the vacuum, and the remaining portion removed. Finally the syphon tube at the lower end of the large tube was broken under mercury, leaving about an inch of the syphon remaining.

The earlier tubes filled by this process were not satisfactory, there being, as in those previously prepared by boiling, a considerable adhesion of the mercury to the glass, with the formation, after a few days, of rings of dirt; so similar, indeed, was the appearance of these tubes to that of the boiled tubes, that I was led to believe that the evil in both cases was due to the same cause. Being satisfied that there was no impurity in the mercury, which, besides having been cleaned with nitric acid, had before these last experiments been redistilled, and suspecting that the evil might have been owing to imperfect cleaning of the tubes, which had only been *wiped* out by the glassblower in the usual way, I had fresh tubes made under my own inspection, and sealed at the glass-works immediately after being drawn. Great care was also taken by the glass-blower to prevent the entrance of moisture during the subsequent operations with the blow-pipe. These tubes, however, still showed the same imperfection, though in a less degree. About this time I had the advantage of consulting Mr. John Adie, of Edinburg, who informed me that he had also experienced the same inconvenience, and that he had removed it by thoroughly cleaning the tubes by sponging with whiting and spirits of wine. Following his directions, I had the satisfaction of finding the tubes when filled almost wholly free from the imperfections mentioned. A tube of 1.1 inch internal diameter, prepared in July, 1855, by the process above described, is at this time in as good condition as when first erected. The top of the column presents a good convexity in all states of the barometer, with only a very slight trace of dirt. No appearance of air-specks can be detected, except a few very minute ones near the lower end of the tube, which have existed since the commencement, and were produced by the temporary entanglement of a small air-bubble at the shoulder-bent part of the syphon tube in the operation of filling. These specks have not increased in number nor shown any tendency to rise. A portion of the syphon being retained at the lower end of the tube, it is highly improbable that any air can now enter, the mouth of the syphon being cut off from communication with the external air by the mercury in the cistern. The tube extends to about nine inches above the mean height of the mercury.

The tube is supported over a glass cistern in a strong brass frame secured by brackets to the wall of the old mural quadrant of the observatory, the height of the mercury being measured by a cathetometer* fixed to the same wall at a distance of five feet. A conical point, at the lower end of a short rod of steel, is adjusted by a screw to the surface of the mercury in the cistern. At the upper end of the steel rod, and above the level of the glass cistern, is a fine mark, whose distance from the conical point has been found by comparison with the Kew standard scale to be 3.515 inches. When an observation is made, the lower point is adjusted to exact contact with the mercury in the cistern; the telescope of the cathetometer is then levelled, and its horizontal wire made to bisect the mark on the upper end of the steel rod, the scale reading of the cathetometer being noted. The telescope is then raised, again levelled, and the wire made a tangent to the surface of the mercury in the tube, the cathetometer scale reading being again observed. The difference between the two readings of the cathetometer scale added to the length of the steel rod is the height of the column of mercury. Besides the rod terminating in the conical point, a second adjusting rod is provided, whose lower extremity is a straight edge. No difference could be detected between the results from the two methods of adjustment. In order to avoid the inconvenience of light being reflected into the telescope from the surface of the mercury in the tube, a movable screen is provided, the upper part of which is black and the lower part oiled paper. which is so adjusted as to shut off all light which comes from a higher level than the top of the mercurial column. The surface of the mercury thus presents in the telescope a well-defined dark outline. A window behind the barometer gives a good illumination to the paper screen; a lamp being required at night. A thermometer whose bulb is within the mercury of the cistern gives its temperature, and the scale of the cathetometer being of brass, the usual tables can be employed for the temperature correction, the difference in the expansion of steel and brass being insignificant for the length of the short adjusting rod. The variations of the temperature of the room

* A small telescope, with a horizontal wire in the focus of the eye-piece, sliding on a vertical graduated measuring rod.

are not rapid, so that no sensible error arises from assuming the temperature of the cathetometer to be the same as that of the mercury. The cistern of the standard barometer is 33.9 feet above the mean level of the sea, being 9.1 feet above the ordnance bench-mark on the northeast corner of the observatory, whose elevation is stated by Lieutenant Colonel James to be 24.83 feet.

Observations of this barometer being too troublesome when an extensive series is required, a standard by Newman, (No. 34,) having a tube of 0.55 inch, which has been recently compared with the great Kew standard, is employed for ordinary use, its index correction (which, inclusive of capillary action, is $= + 0.003$ inch) being first applied to the observed readings.

Comparisons, by means of two portable barometers by Adie, London, were made during last summer between the Kew standard and that of the observatory at Paris. The result of these comparisons was, that the Kew standard reads higher than the Paris standard by 0.001 inch, no correction being applied to either instrument on account of capillary action.

II.—Verification of Barometers.

In the best barometers of the present day a provision is made for adjusting the surface of the mercury in the cistern to the zero of the scale at each observation. Supposing the tube to be in good order, which is easily ascertained by mere inspection, the only source of error in such instruments is to be looked for in the scale. The graduation of the scales of all carefully made barometers is performed by means of a dividing engine, and it is not likely to be inaccurate to any sensible extent within the ordinary range of the mercury. If, however, the barometer is intended to be used at considerable elevations, or if it should otherwise be considered desirable to examine the graduation, the error of the divisions can be readily obtained by measurement with the cathetometer. It frequently happens, however, that the point to which the level of the mercury is adjusted is not the true zero of the scale. The error arising from this source is, of course, constant for all heights of the barometer. As the capillary action of the tube is also supposed to be constant for the same barometer, and as it is seldom possible to determine its true amount, it is better to consider it in connexion with the zero error. This is the more advisable, since a reference to the zero point in a completed barometer to any point of the scale is rendered difficult and uncertain by the circumstance that it can only be viewed through the glass of the cistern, which, from its irregularity, may considerably affect its apparent position. It is therefore the practice to suspend the barometer to be examined beside the standard, to make a sufficient number of simultaneous observations of the two instruments, and to adopt the mean difference of their indications as a single constant correction for the combined effects of zero error and capillary action.

In many portable barometers, and in nearly all marine barometers, there is no means of adjusting the mercury to a constant level. It becomes therefore necessary to determine the correction for "capacity," or the variation in the zero point corresponding to different heights of the column of mercury. The amount of this correction may be determined during the construction of the instrument; or, by reducing in the required proportion the lengths of the divisions, it may be allowed for in graduating the scale, as has been done in the marine barometers made under the supervision of the Kew committee by Mr. P. Adie, of London. In order to test the accuracy of this correction, it is necessary to compare the barometer at two considerable different pressures with a standard instrument, that is, with one in which the mercury is adjustable at each observation to a constant zero point. This is done by placing the barometer and a standard within a receiver provided with the means of altering at pleasure the pressure of the inclosed air.

The receiver is of cast iron, its horizontal section being rectangular. It is 39 inches high, 12 inches by 6½ at its lower end, and tapering to 10 inches by 4½ at the upper end; there being room for three marine barometers besides the standard. Windows of strong plate glass, each 11½ inches high and 9½ inches wide, let into both sides of the receiver, admit of the barometers being observed by a cathetometer. Smaller windows below, each three inches square, show the cistern of the standard barometer, the mercury in which is adjusted to a constant level by a screw passing through a stuffing-box in the base of the receiver. The barometers to be verified are suspended by a gimbal arrangement from the upper end of the receiver, a massive lid closing the opening at the top, by which they are introduced. An opening in the base, furnished with a stop-cock, is connected by a flexible tube with a pump which regulates the pressure of the inclosed air. The pump consists of a single barrel and piston. There being openings at both ends of the barrel, the valves are so arranged that when the flexible tube is attached to the lower opening, air is extracted from the receiver, and when with the upper air is forced in. The receiver is supported by an iron bracket, securely fixed to the quadrant wall, about 10 feet from the standard barometer. The cathetometer being between the receiver and standard barometer, can be used at pleasure for either. The adjustable barometer used in the receiver for comparison with the marine barometers has a tube 0.35 in diameter; there being a contraction in the tube of the same kind and to about the same degree as in the ordinary marine barometers made by Mr. Adie. This apparatus for the verification of marine barometers has (with the exception of the adjustable barometer, which is by Mr. Adie) been entirely constructed in the observatory by Mr. Robert Beckley, the mechanical assistant, who has executed the work in a most satisfactory manner, and who has shown much ingenuity in arranging the mechanical details so as to afford the utmost exactness in observation and convenience in manipulation.

The mode of observation is the following: supposing air to have been extracted from the receiver until the barometers stand at about 27 inches, sufficient time having elapsed to allow the mercury to come to a state of rest, and the zero of the standard having been adjusted, the height of the mercury in each of the barometers is observed by the cathetometer. Air is then admitted till the mercury stands at about 31 inches, when the same operation is repeated. The length of the graduated scale of the barometer under comparison is then measured by the cathetometer. If A a be the cathetometer readings at the higher pressure of the standard and marine barometers, respectively, B b those for the higher pressure, and if L be the measured length of one inch of the scale of the marine barometer, then the correction for capacity for one inch $= L - \frac{a - b}{A - B}$. In order to avoid the error which might otherwise arise from the different capillary actions of the standard tube and that of the marine barometer, it is the practice to make these comparisons only in the forenoon, when the temperature of the room, and consequently the pressure of the air within the receiver, is slowly increasing.

Besides the determination of the capacity correction, a series of simultaneous observations are made of the marine barometer and the standard, "Newman 34," for the purpose of obtaining the zero error. From twenty to thirty comparisons are usually made, care being taken that there shall be, as nearly as possible, an equal number of observations with the barometer rising and falling; this being necessary in order to eliminate the retardation produced in the movements of the mercury by the contraction of the tube combined with the capillary action. The final corrections at different heights of the mercury are thus deduced from the data now obtained. Let H be the height (corrected for zero error) of Newman 34; h the corresponding height of the marine barometer; T the temperature of Newman 34; and t that of the marine barometer; K being the "capacity" correction; the correction corresponding to any height h_0 of the marine barometer is—

$$H - h + K(h_0 - h) + (t - T) \times 0.0027.$$

Each barometer, when it leaves the observatory, is accompanied by a statement of its corrections, of which the following is a specimen:

Corrections to the scale readings of marine barometer, B. T., No. 231, by Adie, London.

Inches. At 27.5	*Inches.* At 28.0	*Inches.* At 28.5	*Inches.* At 29.0	*Inches.* At 29.5	*Inches.* At 30.0	*Inches.* At 30.5	*Inches.* At 31.0
+ 0.001	0.000	— 0.001	— 0.001	— 0.002	— 0.003	— 0.004	— 0.005

When the sign of correction is +, the quantity is to be added to the observed reading; and when —, to be subtracted from it. The corrections given above include those for index error, capacity, and capillarity.

III.—Cathetometer.

The cathetometer hitherto employed was made by Mr. Oertling, of London, on the plan of that used in the experiments of M. Regnault.

It was originally mounted on an independent support; but this was found to be too unsteady for exact observation. It was accordingly removed from its support and mounted between brackets attached to the quadrant wall. The scale of this instrument has been compared with the Kew standard scale, both in the horizontal and vertical positions; in the former by observation of both scales by fixed micrometer microscopes. and in the latter position in measuring by the cathetometer the divisions of the standard scale, placed vertically at a distance of five feet. In the horizontal position there appeared to be no appreciable error in the graduation of the cathetometer; but when vertical, its scale was found to be somewhat too long, the measurement of a length of 30 inches requiring a correction of + 0.003 inch. Besides this discrepancy, which is probably due to irregular flexure of the bar and to imperfect fitting of the sliding frame which carries the telescope and level, the manipulation of the instrument is exceedingly inconvenient and troublesome, and requires much care and patience. It is believed, however, that when the requisite care and time are bestowed, the measurements, after allowing for the correction mentioned, are accurate.

A new cathetometer is at present being constructed by Mr. Beckley, at the observatory, which promises greater accuracy and convenience. This instrument is very nearly completed, and will be described in a subsequent communication.