## ON THE SCIENCE OF WEIGHING AND MEASURING, AND THE STANDARDS OF WEIGHT AND MEASURE *

IX.

IN the comparison of standard weights, the difficulty and risk of error in determining the weight of air displaced by them is to be avoided by weighing them not in air, but in a vacuum. Two methods are employed for this kind of weighing.

In the first and simplest method, when an ordinary balance of precision is used, each standard weight is placed in an exhausted receiver just large enough to hold it, and is weighed separately against a counterpoise by Borda's method. Sensible discordances have, however, been found in the results of this method of weighing in exhausted receivers, which render its use inexpedient when scientific accuracy is required. These discordances are perhaps attributable to a small quantity of air being present in the receiver during the weighings, the amount of which cannot be accurately determined. Another probable cause is a change in the temperature and atmospheric pressure affecting the balance itself and the weights in the pans during the long time necessarily occupied in the whole process of this method of weighing. Indeed it may be generally stated as a rule that the risk of discordances in the results of weighings is in proportion

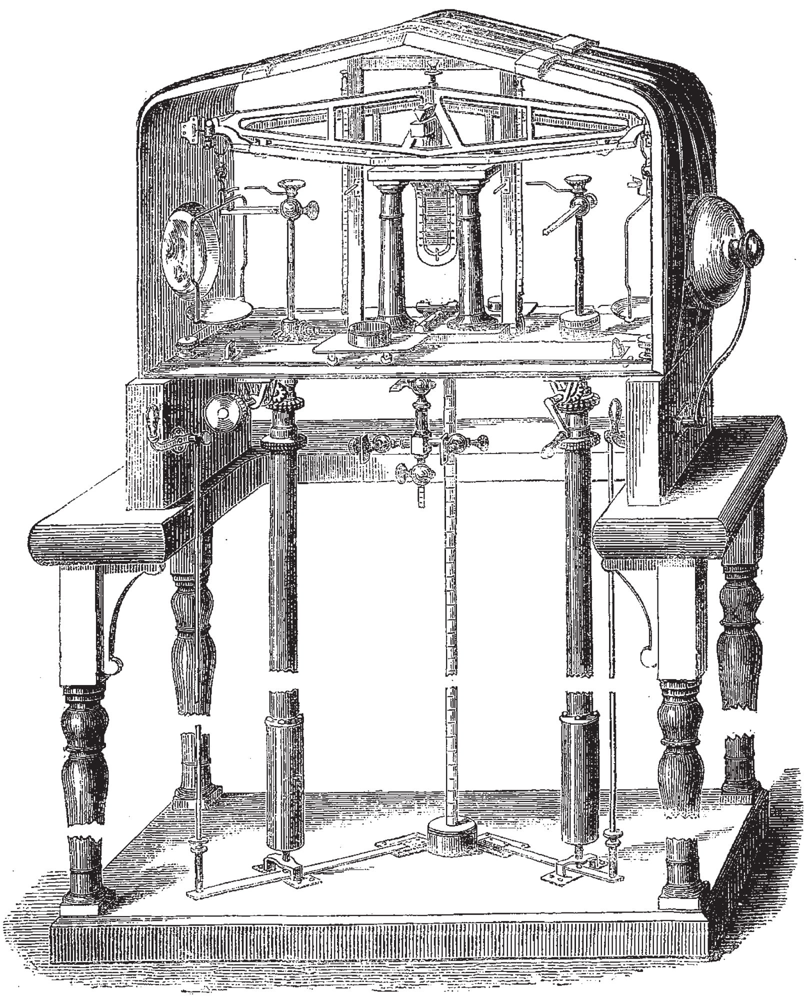

FIG. 19.—New Vacuum Balance of the Standards Department.

to the time occupied in the operation. Such discordances are not found when the weighings are made by the second method, when a vacuum balance is used, that is to say, when the balance case itself is made an exhausted receiver.

A vacuum balance has been constructed at Paris by M. Deleuil, and is now used at the Conservatoire des Arts et Métiers, consisting of a balance of the best construction placed in a very strong cast-iron case that can be made perfectly air-tight. This case has four circular openings for giving admittance and light to the inside, which are closed with strong glass covers. It has a stuffing box for the handle of the lever by which the balance is put in action and arrested. This balance has been found to give very accurate results of weighing in a vacuum. But the comparison of standard weights in this vacuum balance takes a considerable time from the necessity of opening the case and re-establishing a vacuum at least a second time in order to change the weights in the pans even when Borda's method is used; and occasionally this must be done again if a small additional balance weight is required to be placed in either pan, in order to obtain a sufficiently approximate equilibrium, so that the pointer may not exceed the limits of the index scale.

* Continued from p. 49.

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Some improvements on Deleuil's vacuum balance have been designed by Prof. W. H. Miller, and have been practically carried out in a vacuum balance constructed by Mr. Oertling for the Standards Department. The balance case consists of a strong brass frame cast in one piece, with a rectangular base, two sides, and an arched top. Two solid glass plates, each 1¾ in. thick, form the front and back of the case, being clamped to plane surfaces of the brass frame, and made air-tight by interposing thin india-rubber. They are thus removable when required, for instance, when any alteration is needed in the balance. There is a circular opening 4⅝ in. in diameter, on each side of the brass frame, similar to those on Deleuil's balance, to which glass covers are fitted. There is no stuffing-box, but when the Standard weights to be compared are placed in the pans, and the balance case exhausted, contrivances are arranged for putting the balance in action and arresting it, for adding any balance weights to either pan and removing them, and for interchanging the pans and weights by transferring them to the other end of the beam, without any disturbance of the vacuum, or necessity of opening the case.

These arrangements enable the weighings to be made by Gauss's method of alternation. The balance case is firmly placed upon a strong mahogany stand. Two iron tubes are fixed underneath and opening into the balance case. They rest in iron cups containing a sufficient quantity of mercury. Within each tube is a steel rod rising to the required height inside the balance case, and having at the top an arm of convenient form. By means of a simple lever handle outside the tube, either rod can be lifted about an inch, and it can also be turned round. By this rotary motion, when the left-hand rod is in its normal position, it acts upon two bevelled wheels, and thus lowers the supporting frame of the beam and puts the balance in action; and by reversing the motion, the action is stopped. By raising either rod to nearly its full height, it can be made to take up one of several small balance weights riding on a little rail fixed to the pillar of the balance, and transfer it to a similar rail at the top of the pan, or to transfer it back again. Again by raising either steel rod to an intermediate height, and turning its arm under the arched rods of one of the pans, and then raising it a little, the pan and weight can be lifted off the hook of the beam and transposed to a small carriage standing upon a railroad near and parallel to the front of the balance-case. In a similar way the other pan and weight can be transferred to a second carriage at the back of the case. By means of a cord and pulleys, one of which is upon the right-hand steel rod and can thus be turned round with the hand, the two carriages can be moved to the other ends of the case, and then each pan with its weight can be attached to the hook at the other end of the beam. The desired results are all thus attained, and the whole action of the balance is open to view.

The construction of this new vacuum balance may be seen from Fig. 19.

The balance itself is similar in construction to the other Standard balances made by Mr. Oertling. It is constructed to weigh a kilogram in each pan. There are two Standard thermometers inside the case, one fixed to each pillar, and adjustible as to height, so that its bulb may be on the same level as the centre of gravity of the weight. A mercurial gauge is fixed between the pillars, and there is the same arrangement of three tubes and stopcocks communicating with air-pumps and with a mano-barometer, as in Deleuil's vacuum balance. Two glass vessels containing chloride of calcium, are also introduced for absorbing any moisture in the balance case.

There are two ways of comparing and verifying standard measures of capacity. The first and most accurate, as well as scientific method, is by weighing their contents of distilled water; the second method, which is simpler and more ordinarily used, consists in comparing the measure of water contained in them, with the contents of a verified standard measure.

In weighing the contents of distilled water contained in a standard measure, when quite full to the brim, and with the surface of the water made accurately level by a disc of plate glass slid over it, Borda's method of weighing is employed. The measure with its disc is placed empty in one of the pans of the balance, and is accurately counterpoised. A verified standard weight equal to the legal weight of water contained in the measure is then added to the pan containing the measure and disc, and is accurately counterpoised, and a sufficient number of weighings is taken until the mean resting-point of the balance is determined and noted. The standard weight is then removed. The measure is exactly filled with distilled water, and its temperature, together with the reading of the barometer noted. Any difference in the actual temperature and barometric pressure from the normal temperature and pressure is to be compensated by equivalent weights placed either in the measure pan or weight pan as required. If an equipoise is not now obtained, additional weights are placed in the pan until an equilibrium is produced, and any difference from the normal correcting weight for temperature and barometric pressure

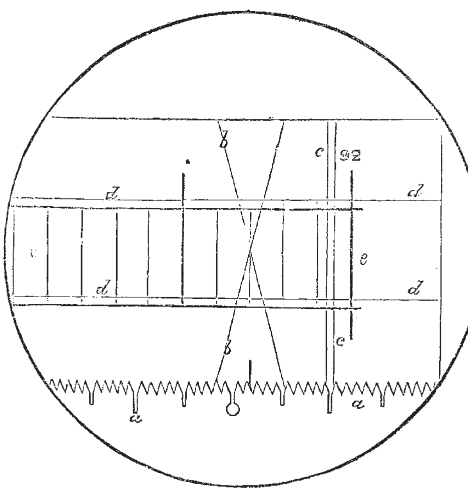


FIG. 20.—Field of Micrometer of Microscope.

either plus or minus, shows the error of the measure in relation to its legal weight of water at the standard temperature and barometric pressure.

For ascertaining the exact amount of the proper corrections for temperature and barometric pressure, authoritative tables are computed both for Imperial and for Metric Measures. Such tables will be found in the Papers appended to the Fifth Report of the Standards Commission, published in 1871 (pp. 81, 193, and 196), and to the Sixth Annual Report of the Warden of the Standards, published in 1872 (pp. 49 and 51).

With regard to comparing instruments for standard measures of length, their construction has necessarily varied according to the form of the standard measure. As has been already stated, the earlier scientific standards of length were defined by two points, and all comparisons were made by means of a beam compass.

The introduction by Mr. Troughton of the use of the micrometer microscope was a great step in advance towards the attainment of scientific accuracy in the comparison of our standard measures of length. It enabled optical observations to be made without injurious contact to the defining points or lines, and thus without interference with the permanence of the

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measures. Several descriptions of comparing apparatus with micrometer microscopes have been constructed at various times, but all are made upon the same principle. The microscope is fixed in a vertical position, and is provided with a spirit level and with screws for accurate levelling and focal adjustment. The defining marks of the two standard measures to be compared are brought successively under it, their height being adjusted to the focal distance of the microscope. Any difference of length between the defining marks of the two measures is read off from the graduated head of the micrometer. This part of the apparatus consists of an endless screw with the very finest threads, having a large head divided into 100 parts. The screw is placed in a horizontal position, and when turned carries with it a nut moving in horizontal guides, together with an open frame, which has cobweb lines stretched across it. Two of these lines (*b b* Fig. 20) cross each other at equal angles to the axis of the screw, and so that a line bisecting them is normal to its axis. Two other lines (*c c*) are placed nearly close, and parallel to each other and normal to the axis of the screw; and there are two longitudinal lines (*d d*) parallel to the axis of the screw, by means of which this axis is made parallel to the axis of the measure under observation. When turning the screw, the number of revolutions is read off by the aid of a pointer from a rack (*a*) placed at the edge of the open frame and parallel to the screw, whilst the number of divisions in one revolution is read off on the graduated head of the screw, from a fixed line marked on the upper surface of the microscope. Looking through the eye-piece of the microscope at the magnified first ten hundredths of the inch 36—37 marked on the subdivided standard yard of the Standards' Department (here inverted), the field of the microscope is seen as represented in Fig. 20.

In this figure the cross lines are used for observation, and are seen adjusted to the 0·03 in. line. The pointer at the rack shows the screw to be turned between one and two revolutions from the middle of the field.

All micrometer microscopes used for the comparison of standard measures of length are constructed upon the principle thus described. But there are various kinds of arrangements for supporting the standard measures in a proper position, and for more conveniently bringing their defining marks under the microscopes. Under one of the arrangements, a single micrometer microscope is used, and fixed over the supporting apparatus, which, for the purpose of comparison, has both a transversal and a longitudinal displacement.

The two standard measures (denoted as A and B) being placed with their axes exactly parallel, and their defining marks as nearly as possible in the same line normal to the axes, the left-hand defining mark of A is brought under the microscope, and the position of the micrometer read off on the index scale and noted. By the transversal displacement, the left-hand defining mark of B is next brought under the microscope, and the reading of the index scale noted. The two measuring bars are then moved their whole length by longitudinal displacement, and the right-hand defining marks of A and B successively read off and noted, thus affording the means of ascertaining the difference of length of the two standard measures. The temperature of the bars at the beginning and end of the observations must be determined by thermometers, and the mean temperature noted, and allowance must be made by computation for any difference of length arising from unequal expansion or contraction of the two bars, when this temperature differs from the standard temperature. For this purpose it is absolutely necessary that the coefficient of expansion of each standard bar must be previously determined.

This method of comparing with a single microscope is used in France, but not in England, where the risk of error arising from the longitudinal movement of the bars is avoided by using two microscopes, and only a transversal displacement of the bars during the observations, although there are also means of longitudinal displacement for the purposes of adjustment. The objection raised against the use of two microscopes, that the distance between them may vary during the period of observation by the expansion or contraction from alteration of temperature of the material which unites them, is obviated by fixing them firmly and independently upon a solid stone support.

Placing measuring bars directly upon a plane support is objectionable. It has been proved that there is a risk of discordances in comparisons being caused by almost undiscoverable inequalities in planed surfaces, as well as by a difference of temperature in the plane surface and the under surface of the measuring bar, when thus placed. To guard against this risk, the bars are supported upon rollers, and the measuring bars ought to be stiff enough to bear to be supported upon a few points at which rollers can be conveniently applied. For a short bar two rollers are sufficient; for a longer bar more supports are required. The standard yard bars are supported upon eight rollers, and it is always requisite that each support should exert the same vertical pressure upwards, in order that the interval between two points upon the surface of the bar may not be altered by the flexure. This object is attained by a proper arrangement of levers; and it is easily seen that an arrangement of levers by which equal pressure upwards may be exerted at four or eight points is very simple. Each bar rests upon two brass lever-frames.

It has been shown by the Astronomer Royal, in his paper printed in the Royal Astronomical Society's Memoirs, vol. xv., that the value of the intervals (supposed equal) which ought to exist between different supports of a bar, each support exerting the same vertical pressure upwards, is as follows: $n$ being the number of supports, the resulting intervals of supports is:—

$$\frac{\text{length of bar}}{\sqrt{(n^2-1)}}.$$

In order to ascertain with scientific precision how far the results of comparisons of standards obtained by the use of weighing and measuring instruments are to be depended upon for their accuracy, a calculation is to be made of the probable error of every such result, whether it be the result of a single comparison, or the mean result of any number of comparisons. And when other elements are to be taken into account, it is necessary that the probable error of each computation should be determined and allowed for before the final results of comparison can be determined and allowed for.

The mode generally adopted for calculating the probable error is based upon the method of least squares, and is fully stated by the Astronomer Royal, in his "Theory of Errors of Observation," pp. 44-7.

H. W. CHISHOLM

## *EARTH-SCULPTURE* *

## II.

YOU are aware that the revival of the half-forgotten doctrines of the early Scottish School of Geology has not been without vehement protest on the part of the older geologists, who have been inclined to treat them rather as novelties and departures from the older and purer faith. No one resisted them more determinedly than my much-missed friend and benefactor, the late Sir Roderick Murchison. He looked with regret, and even, perhaps, sometimes with a little alarm, upon their advance, and to the last he battled against them. He was, indeed, in this country the leader of his party, which has been called the "Convulsionist School," and his death

* Opening Address to the Edinburgh Geological Society, by Prof. Geikie F.R.S. (continued from p. 52).

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