XXV. *On determining the Depth of the Sea without the use of the Sounding-line.*

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Received January 20,—Read February 24, 1876.

INTRODUCTION.

IT occurred to me some years ago that the inferior density of sea-water as compared with solid rock, such as that composing the crust of our earth, might be taken advantage of to devise a method of determining the depth of sea below a vessel. If an instrument could be constructed which, when suspended on board ship, would indicate extremely slight variations in the total attraction of the earth, those indications might be referable to the depth of sea, and a scale be obtained whose divisions would give the depth in fathoms, or other units, without having recourse to the laborious process of sounding by means of the sounding-line.

Terrestrial Attraction: NEWTON.—Our knowledge regarding terrestrial attraction dates from NEWTON, who proved that "the attraction of a spherical shell on an external particle is the same as if the mass of the shell were collected at the centre," and that the earth might be considered as consisting of an aggregate of such shells. Bearing in view, however, the fact of the earth's rotation he proved its ellipticity, and that partly in consequence of that form, and partly on account of the centrifugal force engendered by its rotation, the total attraction of the earth in reference to a point on its surface must vary with latitude[*]. He determined the ratio of increase on the supposition that the earth is homogeneous, and showed that it varies as the square of the sine of the latitude. It is actually represented by the formula

$$g=g'(1+\cdot005133\sin^2\lambda),$$

in which g signifies gravitation at a place in latitude λ, and $g'=32\cdot088$ gravitation at the Equator.

Recent Researches: STOKES *and* AIRY.—The recent researches by STOKES and others have shown that these determinations are correct only approximately, and that the actual total attraction of the earth at any one point, even if taken upon the sea-shore, is influenced by the rising land of continents, or by cavities in the interior of the earth. He also established a reason for an observation made previously by AIRY, that total gravitation is greater on an island than it is near the sea-shore of a continent, and greater on the sea-shore than on an estuary inland[†].

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[*] NEWTON'S 'Principia,' Book iii. proposition xx. problem iv.

[†] Cambridge Philosophical Transactions, vol. viii. pp. 672–695.

Employment of Seconds' Pendulum.—The seconds' pendulum has been the instrument employed in all cases to determine variations in the total attraction of the earth upon its surface, this being the method first proposed and adopted by NEWTON.

Spiral Spring proposed by HERSCHEL.—Sir JOHN HERSCHEL has proposed to use instead of the pendulum a weight attached to a spiral spring, and he has shown that with increase of the force of gravitation, the spring must be proportionately elongated. Sir JOHN HERSCHEL writes, that "the great advantages which such an apparatus and mode of observation would possess, in point of convenience, cheapness, portability, and expedition, over the present laborious, tedious, and expensive process, render the attempt to perfect such an instrument well worth making"*. It appears, however, that this proposal by Sir JOHN HERSCHEL has never been practically realized, and that, indeed, no serious attempt has been made to construct an instrument of such delicacy as to show statically minute variations in total gravitation, notwithstanding the great oscillations to which a weight so suspended would be liable, and notwithstanding the influence of changes of temperature and atmospheric density.

General Conditions.—Neither the pendulum nor the apparatus suggested by Sir JOHN HERSCHEL would be applicable to the measurement of the height of a mountain or plateau above the sea-level, owing to the considerable error which would be caused by changes in gravitation, through the local attraction of the mass of the mountain itself above the horizon, nor would either instrument be serviceable on board ship for obvious reasons. But if an instrument could be devised which would be capable of indicating extremely slight variations in the total gravitation of the earth, subject only to comparatively slight causes of error, it would be found, I contend, that these indications would vary with the varying depth of water below the instrument, in such a definite ratio as would render it possible to construct a working scale, the divisions of which would represent depth of water.

Attraction influenced by Depth of Water: General Statement.—The reason why the total attraction upon the surface of the ocean must be less than on the shore, is evident from the fact that the density of sea-water is nearly three times less than that of such calcareous, siliceous, and aluminous rocks as constitute the principal portion of the crust of the earth; and it is also evident that, although the total mass of the earth and the distance of the instrument from its centre remains the same in gliding along the liquid surface of the sea, the total gravitation must be influenced in a greater measure by the mass near at hand, and that in proportion to the thickness of the layer of the substance of inferior density the total gravitation must be affected.

Ratio of decrease of Gravitation with Depth.—The ratio of decrease depends, in the first place, upon the ratio of the density of sea-water to that of solid rock. The mean density of sea-water may be taken at 1·026, and the density of the rock composing the crust of the earth may be taken to be the mean of the following densities:—

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* HERSCHEL'S 'Astronomy,' Cabinet Cyclopædia, footnote p. 125.

Mountain Limestone	2·86
Granite	2·63 to 2·76
Basalt	3·0
Red Sandstone	2·3 to 2·52
Slate	2·8 to 2·9

Average density of above 2·763 nearly.

It is dependent, in the second place, upon the total gravitation of the earth in reference to a point on its surface, and upon the influence exercised in that general result by the strata of matter in the immediate vicinity of that point.

Mathematical Investigation.—In Plate 63. fig. 1 the circle represents the circumference of the earth, which I propose to consider for the present irrespectively of its rotation, and as being spherical and of uniform density.

Let P be the point upon the surface of the globe where the attraction is to be measured; then, in order to calculate the amount of variation that will be produced in the total attraction of the earth, supposing it to be of uniform density, by a given depth of water below the attracted point P, a line is drawn from that point to the centre of the earth, and the same is divided into an unlimited number of indefinitely thin slices, by planes perpendicular to that line.

In taking one of these slices at the distance h from the attracted point, an expression is obtained representing its aggregate attraction, thus—

The slice is composed of concentric rings of sectional area

$$dh\,.\,dx=dh\,.\,z\,.\,d\alpha : \cos\alpha,$$

and of the capacity

$$2\pi\,.\,z\,.\,\sin\alpha\,.\,dh\,.\,z\,.\,d\alpha : \cos\alpha,$$

which gives

$$\frac{2\pi\,.\,z\,.\,\sin\alpha\,.\,dh\,.\,z\,.\,d\alpha}{z^2}$$

as the differential of the attraction, where z and z in the numerator and z^2 in the denominator, although variable quantities, always vary together, or

$$ddA_1=2\pi\,.\,dh\,.\,\sin\alpha\,.\,d\alpha.$$

This expression has to be integrated between the limits of h and 0, and α and 0; thus

$$\int_0^h\int_0^\alpha 2\pi\,.\,dh\,.\,\sin\alpha\,.\,d\alpha=\int_0^h 2\pi dh\int_0^\alpha \sin\alpha\,.\,d\alpha=2\pi\int_0^h dh\,(1-\cos\alpha).$$

Since

$$\int_0^\alpha \sin\alpha\,.\,d\alpha=1-\cos\alpha,$$

also

$$\cos\alpha=\frac{h}{z}=\frac{h}{(x^2+h^2)^{\frac{1}{2}}}=\frac{h}{\{(2R-h)h+h^2\}^{\frac{1}{2}}}=\frac{h}{\sqrt{2Rh}}=\frac{h^{\frac{1}{2}}}{2R^{\frac{1}{2}}},$$

$$\therefore 2\pi\int_0^h dh\,(1-\cos\alpha)=2\pi\int_0^h\left(1-\frac{\sqrt{h}}{\sqrt{2R}}\right)dh=2\pi h-2\pi\int_0^h\frac{\sqrt{h}}{\sqrt{2R}}\,dh$$

$$=2\pi h-2\pi\frac{1}{\sqrt{2R}}\,.\,\tfrac{2}{3}\,.\,h^{\frac{3}{2}}=2\pi h\left(1-\tfrac{2}{3}\sqrt{\frac{h}{2R}}\right)=A_1\;.\;.\;.\;.\;.\;\;(1)$$

is the total attractive force exercised by the uppermost portion of the globe to the depth h.

For small values of h, the expression $\sqrt{\frac{h}{2R}}$ may be neglected, and the formula may be written

$$A_1=2\pi h.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\;\;(2)$$

In substituting 2R for h in formula (1) we obtain

$$A=\tfrac{4}{3}\,R\,.\,\pi,$$

the expression for the total attraction of the earth, which was determined by NEWTON; a verification is thus furnished of the correctness of the above calculation.

The proportion between the attraction exercised by the upper segment and the whole earth, supposing them to be composed of uniform material, is therefore as

$$A_1 : A=2\pi h : \tfrac{4}{3}R\pi$$

or as

$$h : \tfrac{2}{3}R.$$

Ratio of variation of Attraction, as the depth to the Earth's radius.—If sea-water had no weight, the total force of gravitation at the point P would be diminished in the ratio

$$\frac{\text{depth of sea}}{\frac{2}{3}\text{ radius}};$$

but, inasmuch as the ratio of the difference of mean rock and sea-water to mean rock is

$$\frac{2{\cdot}763-1{\cdot}026}{2{\cdot}763}=\frac{1{\cdot}737}{2{\cdot}763},$$

it follows that the real influence of depth, on the supposition of the earth's density being throughout that of mean rock, would be represented by the expression

$$\frac{\frac{1{\cdot}737}{2{\cdot}763}h}{\frac{2}{3}R}=\frac{h}{\frac{614}{579}R}=\frac{h}{1{\cdot}06\,R},$$

or approximately as the depth to R.

Thus, for a depth of one thousand fathoms, gravitation diminishes by $\frac{1}{3691}$ of itself.

Necessity for modifying result, neither compression great enough to be sensible in its *effect, but the two not equal.*—The rock composing the crust of the earth will be under compression, and therefore denser at the depth corresponding to the depth of sea; but sea-water itself will increase in density with depth in a somewhat similar ratio, so that the comparison between sea-water and solid rock remains virtually the same for all depths. The greater density of the earth towards its centre will, however, greatly influence the measure of this dependence as established by the foregoing calculation; but in constructing a measuring instrument it will be safer to rely upon the result of actual measurement, in the absence of reliable information regarding the increase of density towards the centre, by comparing its indications with those obtained by means of the sounding-line. It may here be remarked, however, that the indications of variation of gravitation with variation in the depth of water, which have been obtained by the use of the instrument, show in excess of what the above calculation gives with the mean density of the rock composing the crust of the earth as a factor, and agree more nearly with what would result if the upper strata of the earth were of a density equal to the mean density of the whole earth. Actual observations, as given in the Table further on, confirm, in a remarkable degree, the arithmetical ratio of decrease of gravitation by depth which results from the foregoing calculation.

First attempt to construct a Bathometer.—Several years ago I constructed an instrument in which the gravitation of the earth was represented by a column of mercury in a glass tube closed at its upper end, and resting upon a cushion of air enclosed in a large bulb, which air, when kept at a perfectly uniform temperature, represented uniform elastic force unaffected by gravity or atmospheric density. The principal difficulty that presented itself in designing a workable instrument on this principle, consisted in obtaining a scale sufficiently large to show such extremely slight variations in the total gravitation of the earth as would result from ordinary variation in the depth of water. From the calculation given under the previous head, assuming the mercury column to have a height of 760 millims., each fathom of depth of water would represent a variation of potential force in that column equal to a height of ·0002059 millim., a quantity which it would be impossible to show on any scale. A scale would in reality not even realize this quantity of decrease in the upper surface of the column, because a portion of the adjustment of height would take place in the air-bulb below, partly from the rise of mercury into the bulb, and partly through increase of pressure of the imprisoned air due to its compression. I succeeded, however, by means of an arrangement of the instrument with three liquids of different densities, in increasing the effect of a change of gravitation upon the mercury column three hundredfold, whereby a change of 10 fathoms depth would be represented by a movement of ·6177 millim. of the boundary between the two liquids in the vertical tube, a quantity sufficiently large to be appreciated in the divisions of a scale. This instrument is shown in Plate 63. fig. 2.

Tests of Instrument.—This instrument was tested by me in 1859 on board H.M.S. ‘Firebrand,’ commanded by Capt. Dayman, during a trip undertaken for the Admiralty for the purpose of determining a line of soundings across the Bay of Biscay, with a view to the establishment of a submarine cable: it proved successful to the extent that I was able to predict, approximately, the depth that would be found on the use of the sounding-line. The difficulty, however, of observing the instrument was great, owing to the excessive pumping-action, the consequence of the oscillations of the ship, as well as to the difficulty of obtaining perfect uniformity of temperature. The method of observation pursued was to take series of ten observations of alternate maxima and minima positions of the film, or boundary line between the liquids, of which the mean was taken to be its true position upon the instrument; but occasionally oscillations of extraordinary amount occurred, tending to vitiate the value of even these means. The instrument was both bulky and delicate, and it was found impracticable at the time to provide the ship with a sufficient store of ice (to be used in maintaining the instrument at a uniform temperature) to last during a lengthy voyage. In consequence of these drawbacks, I relinquished for a time the idea of constructing a reliable bathometer.

Present construction of Bathometer.—Last year the practical difficulties encountered in laying submarine cables in water the depth of which had not been accurately ascertained beforehand, revived in me the conviction that an accurate instrument would be of considerable value, not only to the cable-layer but to the navigator generally, when unable to determine his position astronomically. In the instrument about to be described, the mercury column is retained as the representative of the force of gravitation, but the balancing force is obtained through two spiral steel springs, which are so adjusted to the force of the mercury column that changes of temperature are entirely eliminated from the result.

The instrument, which is represented on Plate 64, consists of a tube of steel, with cup-like extensions at the two extremities, which is suspended in a vertical position from a universal joint, at some little distance above the centre of gravity of the system, with a view of preventing pendulous action.

The upper cup-like extension of the tube is closed with a lid, provided with a closed stopper, which is screwed down when the instrument is not in use, and released for the access of atmospheric pressure shortly before observations are about to be taken. The lower portion is closed by means of a thin diaphragm of corrugated plate of steel, similar to the corrugated plates used in the construction of aneroid barometers. The centre of the diaphragm rests upon a crosshead, to which two carefully tempered steel springs are attached, which pass upwards on opposite sides of the mercury column, and are held at their upper extremities by adjusting-screws in the sides of the upper cup. The neck of the vertical pipe where it opens out into the upper cup is nearly closed by means of a disk or stopper of steel, perforated by a hole of only ·2 millim. diameter, the object being to reduce the pumping-action on board ship to a minimum. Before screwing-in this stopper the tube is filled with boiled mercury up to about the middle of the upper cup.

Available Force.—The mercury column represents the potential of force resulting from the area of the lower cup, multiplied into the height of column and the density of mercury.

The instrument of which the results have been chiefly recorded in the Table given further on has cups of 90 millims. in diameter and a height of mercury of 600 millims., representing an available force of 51·9 kilogrammes susceptible to variation in gravitation; whilst the instrument of which the drawing is given has cups of 50 millims. diameter and a mercury column of 500 millims., representing an available force of 13·35 kilogrammes. These amounts are amply sufficient to overcome by their variations any slight frictional resistance in the liquid column or in the diaphragm. But this frictional resistance is really eliminated from consideration by oscillations of the vessel, which cause certain pumping-action (kept within narrow limits by the contracted orifice), and bring the diaphragm into the true mean position, notwithstanding slight frictional resistances.

Range of Scale.—Under this head we have to consider what will be the effect on the instrument by a given change in the total attraction. Assuming a diminution of gravitation equal to say $\frac{1}{370,000}$, representing about 10 fathoms of depth, this would be equalized by a reduction in the height of column of $\frac{600}{370,000}$ millim. $=\cdot00162$ millim. The column of mercury in rising under this changed condition of equilibrium will, however, not become shortened, as in the case of the barometer when affected by a diminution of atmospheric pressure, or as was the case in the instrument before described, but for every fraction of a millimetre which the top level rises the centre of the diaphragm will rise also, and in an increased ratio, depending upon the proportion of the diameter of the solid central portion of the diaphragm to the diameter of the cup. If the central solid part of the diaphragm was only a point, it is easy to see that for every fractional rise of the mercury in the upper cup the centre of the diaphragm would rise three similar fractions, and the real height of the mercury column would diminish two fractions instead of increasing one. But in reality the central portion of the diaphragm is so proportioned to the cup, that for a rise of one increment of height of mercury the centre of the diaphragm would rise to about double that amount, and the effectual height of the mercury column would decrease instead of increasing to the amount of readjustment required. If the elastic range of the springs balancing the pressure of the mercury were equal to the height of the mercury column, the increase of height on the one hand would be exactly balanced by the increase of elastic force on the other, and the instrument would be in a condition of unstable equilibrium, similar to that of a balance-lever suspended at its centre of gravity. If, on the other hand, the elastic range of the springs were equal to one half the height of column, the increase of elastic force would proceed at double the rate of the increase of potential of the column, and the result would be a scale proportionate to the simple height of column.

It follows from this that the elastic range of the springs must be less than the length of the mercury column. In the actual instrument the elastic range of the spring exceeds to some extent half the length of the column, so that one division of the instrument represents less than its seeming proportion of the total gravitation. It would be difficult to determine the actual scale of the instrument *à priori*; and I therefore adopted the easier and safer method of relying for its final adjustment upon the result of actual working. The limits to the sensitiveness of action of the instrument are chiefly imposed by the diaphragm itself, which must be maintained near its neutral position, because its elastic range is limited and discordant with the range of the spiral springs. It is desirable on this account to make the diaphragm of as thin and flexible metal as possible, and to make the annular indentations as deep as they can be made. This consideration led me to try a diaphragm of silk impregnated with solution of india-rubber, which diaphragm has the advantage of being more flexible than one made of metal, but is liable, on the other hand, to stretching under the constant pressure of the mercury. A diaphragm of thin steel plate has been found to be sufficiently flexible for the purposes of the instrument.

It was desirable to avoid levers, pulleys, and other such working parts in the instrument, which parts are liable to derangement from stretching, bending, and abnormal expansion, which would make the instrument liable to change its zero position. I have therefore had recourse to a micrometer-screw with electrical contact, which, with great solidity and simplicity of parts, affords the advantage of a long and accurately divided scale.

Reading of Bathometer.—The micrometer-screw passes vertically through a boss below the centre of the diaphragm, which is attached to the tube by means of two insulating supports of ebonite. A galvanic battery is connected through one pole to the body of the tube, and by the other to the boss through which passes the micrometer-screw. An alarum or galvanometer is comprised in the electrical circuit, which is closed whenever the end of the micrometer-screw touches the extreme point of the crosshead supporting the centre of the diaphragm, and therefore the weight of the mercury column. The galvanometer and alarum are so constructed that one element is sufficient to produce the signal, as, if a number of elements were employed, discharges of currents would ensue and affect the surfaces of electrical contact. It is important to clean these surfaces from time to time, by passing a sheet of stout paper or of fine emery-paper between them. A graduated circle is provided to indicate the precise angle through which the micrometer-screw is moved from its zero position when its point touches the end of the crosshead, an event marked by the sounding of the alarum or motion of the galvanometer-needle. The points of contact on the crosshead and on the micrometer-screw are made of platinum in the usual way; but the contact-piece carried by the screw is attached to the same through the medium of a strong and short horseshoe spring, the object of which is to soften the contact between the two points, and thus allow of the natural oscillations of the weighty column as influenced by the motion of the vessel. The pitch of the micrometer-screw being 5 millims. nearly, and the graduated circle being divided into 1000 equal parts, it follows that each division of the scale through which the screw is turned raises the contact-point ·005 millim., a quantity which is intended to represent the depth of a fathom. The micrometer-screw is turned by a wheel geared into a pinion, which is brought up to a place near the point of suspension of the instrument, where it can be turned by means of a milled-head, without the observer being inconvenienced by the oscillations of the instrument relatively to the vessel. Instead of two spiral springs three might be applied, dividing the circle equally, probably with some advantage, viz. that of imparting additional steadiness to the crosshead in its horizontal position. The letters of reference on the drawing, with the references given below, sufficiently describe the mechanical details of the instrument. It remains to be shown how an instrument answering to this description can be depended upon for giving true indications of the varying depths of water below the same, notwithstanding changes of temperature, of atmospheric pressure, and of geological formation and condition of the bottom of the sea.

Influence of Temperature.—In considering the influence of temperature upon the instrument, it was necessary to investigate its action upon the component parts separately. The effect of temperature upon the linear dimensions of mild steel, of which the instrument is mainly composed, is sufficiently well known. Steel expands, according to the experiments of DULONG and PETIT, ·000012 of its length for every degree Cent. rise of temperature between 0° and 100° C.; and this number agrees closely with experiments by REGNAULT, who found the cubic expansion of mercury to be ·00018153 per degree C., between 0° and 100° C.; in both these metals the ratio of expansion by heat may be considered as strictly arithmetical between ordinary limits of temperature.

Influence of Temperature on Steel Springs.—Regarding the influence of temperature upon the elasticity of springs, we have investigations by M. G. WERTHEIM[*], which show a diminution of elasticity with rise of temperature in all metals except iron. This latter metal attains its maximum elasticity (according to this author) at 100° C.; but annealed cast steel agrees with gold and silver and other metals in showing a diminution of elasticity with rise of temperature. The results given in the table prepared by M. WERTHEIM show a coefficient of diminution of elasticity for cast steel of ·00033768 per degree Centigrade, the modulus of elasticity at 0° C. being 19561, and at 80° C. 19014. Before the bathometer was set up, I had experiments made on the variation of the elasticity of its spiral steel springs in the range of ordinary temperature, which proved this important result,—that the elastic force of well-tempered steel springs diminishes with increase of temperature, within the limits of ordinary temperature, in an arithmetical ratio. The coefficient which I obtained from these experiments was ·000258 of diminution of elasticity per degree Centigrade rise of temperature; and the small difference between this and the coefficient deduced from WERTHEIM'S table will be due most likely to a difference of temper in the steel.

In the bathometer the linear expansion of the springs is compensated by the linear expansion of the tube to which they are attached; and we have therefore only to deal with the variation of elastic force which has to be compensated for, in order to make the indications of the instrument independent of temperature.

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[*] Annales de Chimie et de Physique, sér. 3, 1845, xv. 119. "Sur l'influence des basses températures sur l'élasticité des métaux."

Compensation for Temperature-effects.—The means of such compensation is provided in the mercury column. If this column were to consist of a plain cylindrical vessel, not subject to change in diameter by temperature, it is evident that its pressure upon the diaphragm would be the same whatever the temperature of the mercury might be; for with increase of temperature the height of the column would increase, and the density of the mercury decrease in precisely the same degree: such a column might be called one of *uniform potential*, and would not afford the means of compensation here desired. If, on the other hand, the column were made to consist of two shallow cups at top and bottom, connected by a tube of such diameter that its area, compared with that of the cups, might be neglected in calculation, it is evident that the potential of such a column would vary with the temperature in the ratio of the dilatation of mercury; in other words, the absolute height of the column would remain practically the same at all temperatures, whereas the density of the mercury would vary in the well-known ratio of ·00018153 per degree C. If a spring could be found whose ratio of variation was less than that required for the mercury, it is evident that between these extreme forms one might be found in which the two ratios of variation would be exactly alike. The ratio of variation of the steel springs depends upon their degree of hardness; and in the case of the instrument here referred to it amounted to ·000258, or was in excess of the compensating power furnished by the mercury. Complete compensation could therefore in this case not be obtained, although the remaining error is extremely small, and was rendered practically inappreciable by allowing the comparatively inelastic diaphragm to take a portion of the mercurial pressure.

The proportion, as resulting from calculation, would at any rate have to be modified in order to allow for the linear expansion of the steel composing the tube as affecting its capacity; but this expansion proceeding also in an arithmetical ratio will only affect to a small extent the precise relative diameter to be given to the tube, without in any way disturbing the ratios of arithmetical increase upon which the compensation of the instrument is based. An easy verification of this arrangement, which may be called a *parathermal system of adjustment* between gravitation and elastic force, is furnished in suspending the complete instrument in the hot-air chamber in which the experiments for variation of elasticity were made, when the variations of temperature gradually and artificially produced within the chamber should remain without effect upon its reading.

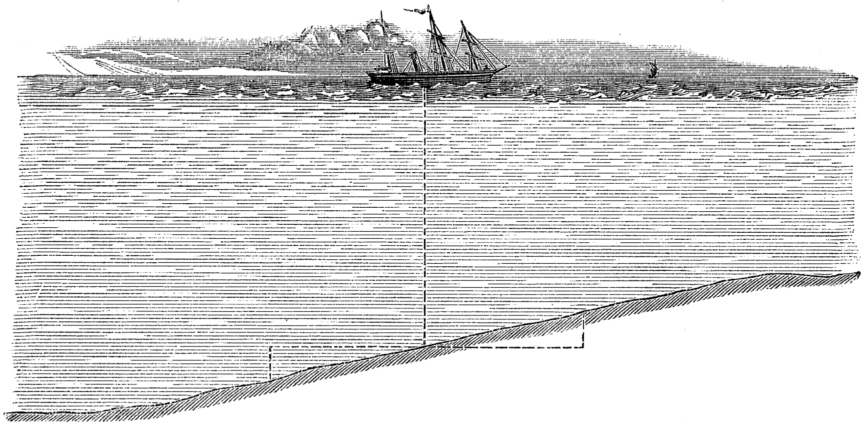
On subjecting the first instrument constructed on this principle to this test, a variation was discovered amounting to ·00000125 per degree C., which was not corrected, however, in trying the instrument on board the steam-ship 'Faraday;' and the results then obtained, and given below, have had to be adjusted to this extent for variation in temperature.

Influence of variation in Atmospheric Density.—The atmosphere presses equally upon the surface of the mercury in the upper cup of the bathometer and upon the diaphragm below, and variations in the height of the barometer, therefore, exercise, *per se*, no influence upon the instrument; but inasmuch as the mercury column exercises a preponderating gravitating influence only in the measure of its superior density to the atmosphere which the mercury replaces in the tube, it follows that changes in atmospheric density must exercise an influence upon the readings of the instrument. The atmospheric density depends upon barometric pressure, temperature, and admixture of aqueous vapour, the amount of which can be easily ascertained by readings of the dry- and wet-bulb thermometers and the barometer at the time of taking the bathometrical observations. These corrections have been made and applied to the observations taken on board the steam-ship 'Faraday;' the readings, however, having been taken at sea, the air was regarded as saturated with vapour, and the tension of the vapour at the temperatures has been employed. In ordinary usage of the instrument these corrections might be neglected without serious error, or a table might be constructed giving the amount of these corrections for observed changes of the barometer and thermometer.

Geological Influences.—The readings of the bathometer depend upon the inferior density of sea-water as compared with the solid constituents composing the earth's crust, which have been taken, in the calculation at page 673, as 2·763. No account was taken, in assuming the above average density of the earth's crust, of the presence of denser materials, such as metallic ores, heavy spar, &c., on the one hand, or of subterranean cavities on the other. But these abnormal occurrences are not frequent on dry land, being chiefly confined to mountainous districts, and may be assumed to be of less frequent occurrence in the great depressions constituting the sea-basins. Their relative effect upon total gravitation, as measured upon the surface of the water, is less, moreover, than it would be if measured upon the solid surface, on account of their greater distance from the instrument. The uniform density of the sea is an element eminently favourable to the attainment of uniform indications on its surface.

Geographical Influences.—The configuration of the bottom of the sea below the instrument must also exercise a sensible influence upon its readings. The instrument would not indicate, for instance, the existence of a local depression surrounded by elevated ridges or plateaux, nor would it indicate the existence of a peak. Considerable variations must therefore be occasionally expected between the readings of this instrument, however correctly adjusted, and the results of actual soundings; but it may be observed that broken ground, such as would cause these differences, is comparatively rare below the sea, which deepens gradually from the land in such a way that the contour lines of uniform depth can generally be distinctly traced; and the principal value of the instrument would consist in its indicating its passage above varying depths. The indications of the instrument must coincide very nearly with those of a sounding-line upon an even slope, because the comparative proximity of the ground towards the rise of the slope will be balanced by the absence of solid matter towards its descent, as will be apparent from the accompanying sketch (p. 682).

Attention has already been called to Sir GEORGE AIRY'S observation of the greater apparent gravitation on islands than on the sea-shore, and there than inland, and also to Professor STOKES's explanation of the matter. The working zero of the bathometer may be taken as a maximum or island indication; and the diminution due to the depth of water is therefore not influenced by the irregularities met with on solid land, in consequence of the matter raised above the natural surface of the sea. It has, however, been shown by Archdeacon PRATT and others that continents exercise an influence upon the level of the sea, that level being raised up towards the masses piled above the surface; and such disturbance of the natural water-level must necessarily exercise an influence upon the readings of the instrument. But this influence would be perceptible only in estuaries or upon the sea-shore of a mountainous continent, and may be neglected in dealing with the surface of the sea under all ordinary circumstances.



The more important disturbing cause affecting the instrument under this head is that of the ellipsoidal form of the earth and the varying centrifugal tendency on its surface, to which reference has already been made.

Effects of Latitude.—The determinations of the effect of latitude upon gravitation as made by NEWTON, CLAIRAUT, M'LAURIN, and others have already been alluded to, and it is important that the influence of this disturbing cause upon the instrument should be accurately ascertained in order that allowance may be made for latitude in its ordinary use. In order to test separately the effect of latitude upon the instrument, its indications were taken on the 8th of December at Westminster, lat. 51° 31′ N., long. 0° 7′ W., and afterwards at Brighton, lat. 50° 50′ N., long. 0° 10′ W., which is nearly due south of Westminster 41 nautical miles. At Westminster the indications were

Bathometer.	Barometer.	Thermometer. ° Fahr.
2 turns 432	30·425	43·4
431	30·425	43·6
430	30·425	43·4

These readings were taken at intervals of 5 minutes. The instrument was then carefully packed and removed to Brighton, where it was again set up. The first reading was taken an hour after arrival, and the readings taken during the afternoon are noted below.

		Bathometer.	Barometer.	Thermometer. ° Fahr.
From	2 turns	449·5	30·315	40·5
12.55 to		449	30·315	40·5
1.10 P.M.		451·5	30·32	41
From	2 turns	449·5	30·31	42·8
1.44 to		448·8	30·31	42·8
2 P.M.		449·5	30·31	42·8
From	2 turns	449·7	30·3	43·4
4.13 to		449	30·29	44
4.30 P.M.		449·5	30·29	44

The readings of the instrument taken the next morning at Westminster were—

2 turns	440	30·42	43
	439·5	30·42	43·25
	440	30·42	43·2

It will be found that, on correction being made for variation of temperature and atmospheric density, and taking the mean of the several readings (the first observed Westminster indications being taken as the standard), the above indications may be reduced to the following:—

	Bathometer.
Before leaving Westminster	431
At Brighton	452
On return to Westminster	439·25

Taking the mean of the Westminster readings, there would be a difference on the scale of 17 divisions, equivalent to a diminution in attraction of ·0000046, whereas calculation gives a difference of ·000066.

I have not succeeded in finding a satisfactory explanation of this apparent anomaly, which can hardly be attributable to defects of the instrument or to errors in observation, because on taking the instrument on board the steam-ship 'Faraday' from the Thames down the Channel, the variations observed (as recorded in the Table, page 684) accord very fairly with the increasing depth of water, but give no evidence of the great variations in total gravitation due to differences in latitude. In order to test the influence of latitude further, I caused the instrument to be taken to Scarborough, which is 207 miles north of Westminster; and the observations there taken confirmed generally those of Brighton, in showing insufficient variation, although their absolute value was rendered unreliable by an accidental disturbance of the instrument in transit.

It must be borne in mind that both Brighton and Scarborough are on the sea-shore, and that Westminster is upon an inland estuary, which circumstance would exercise an influence in the direction of equalizing the total gravitation at Brighton and Westminster.

Actual trial of the Instrument on board ship.—The foregoing may suffice to show what are the disturbing influences to be met with in the use of the instrument which forms the subject of this paper; but it was important to ascertain what would be the actual indications of the instrument in taking it on board ship over seas of varying and known depth, in order to compare the indications of the instrument with those of the sounding-line. For this purpose two instruments, the smaller of which is represented in Plate 64, were placed on board the steam-ship 'Faraday.' They were suspended in a closet adjoining the electrician's room, near the centre of motion of the vessel, and were observed carefully in Victoria Docks before starting, continuously during the voyage, and on the return of the vessel from Nova Scotia, where it had been sent for the purpose of reuniting the Direct United States Submarine Cable, which had been fractured, where it crossed the Newfoundland Bank, by the dragging of an anchor. The observations during this first trial of the instrument were made by Dr. HIGGS, the chief of the Electric Staff accompanying the expedition. The following Table gives the results of these observations.

TABLE I.—Bathometer Record: Steam-ship 'Faraday,' October 1875.

Date.	Hour.	Position.	Thermometer.	Barometer.	Bathometer Divisions.	Depth.
			° F.			fathoms.
Oct. 15.	Noon.	Victoria Docks	64·5	29·7	Zero.	2
18.	Noon.	Tidal Basin	65	29·95	3·5	
19.	8 A.M.	Lower Fort, Tilbury ...	60	30·00	9·0	
19.	10.35 A.M.	Off Southend	59	29·7	11·5	
21.	11.45 A.M.	Off Lizard	60	29·6	47·5	
22.	9 A.M.	....	56·3	29·5	92·5	
23.	Noon.	51° 0′ N.; 14° 37′ W. ...	Bad	weather.		By Chart.
25.	Noon.	51° 25′ N.; 26° 25′ W. ...	56	29·15	2130	1900
26.	Noon.	51° 7′ N.; 31° 14′ W. ...	56	29·75	2600	2000
27.	Noon.	Dead Reckoning	56	29·15	2870	2100
28.			Bad	weather.		

In this Table no correction for latitude has been made; and although the differences of latitude are not very great, they would nevertheless be more than sufficient to swamp the results of such minute differences of depth as are met with, for instance, in passing from the Thames down through the Channel. The concordant results shown in the Table seem to prove either that the correction for latitude is (for some reason, which, as already stated, I am not able to explain) much less in this instrument than it would be in the case of pendulum indications, or that the reading of the instrument had not been taken with a proper degree of care. It might be assumed that the known depths of the channel might have betrayed the observer involuntarily into a mistake when observing only small divisions on the instrument, although I must personally dissent from such a supposition, because I entertain the highest opinion of the conscientious

TABLE II.—Record of Bathometer readings compared with soundings taken on board the steam-ship 'Faraday,' October and November 1875.

Date.	Hour. G. M. T.	North Latitude.	West Longitude.	Thermometer.	Barometer.	Bathometer Divisions uncorrected.	Corrections for variations in Temperature and Atmospheric Density.	Bathometer Divisions corrected.	Sounding. Fathoms.	Difference.
	h. m.	° ′ ″	° ′ ″	° F.	″		(−)			
Oct. 29.	3 0 P.M.	47 50	47 0	56	29·5	216	14·55	201·45	197	+ 4·45
29.	8 55	47 34	48 23	57	29·7	113	13·5	99·5	100	− 0·5
30.	1 52 A.M.	....	......	58	29·5	74	10·95	63·05	54	+ 9·05
31.	12 0 P.M.	....	......	57·5	30·05	96	13·7	82·3	82	+ 0·3
31.	1 8	45 5	54 28	58	30·05	231	12·85	218·15	204	+ 14·15
31.	2 20	....	......	60	30·05	87	9·15	77·85	69	+ 8·85
31.	2 59	....	......	59·5	30·05	66	10·2	55·8	54	+ 1·8
31.	3 27	45 9 45	54 14	60·5	30·9	66	11·2	54·8	54	+ 0·8
31.	5 47	45 10 42	54 18 20	57·5	30·7	66	15·9	50·1	56	− 5·9
31.	7 27	45 11 15	54 17 53	56	30·7	66	18·55	47·45	54	− 6·55
Nov. 1.	12 15	45 10 12	54 18 25	55·5	29·5	66	15·7	50·3	58	− 7·7
1.	2 18	45 7 15	54 21 30	55	29·0	82	15·65	66·35	69	− 2·65
1.	3 25	45 6	54 22 48	60·5	28·9	87	4·6	82·4	73	+ 9·4
2.	12 50	....	......	59	28·78	63	6·85	56·15	47	+ 9·15
2.	2 58	....	......	55	28·9	63	14·35	48·65	46	+ 2·65
2.	5 30	....	......	60·5	29·0	85	4·9	80·1	69	+ 11·1
3.	7 57	45 5 48	54 25 42	58·5	29·3	120	9·4	110·6	100	+ 10·6
3.	9 20	45 4 50	54 28 34	58	29·5	226	10·95	215·05	200	+ 15·05
4.	2 10	45 10 36	54 20 6	57·5	29·7	82	12·5	69·5	64	+ 5·5
5.	12 35	....	......	57	30·0	95	14·5	80·5	80	+ 0·5
5.	1 45	....	......	58·5	30·0	98	11·8	86·2	86	+ 0·2
5.	4 16	....	......	58	30·0	90	21·65	68·35	76	− 7·65
7.	5 19	46 45	47 17	58	29·7	400	11·65	388·35	353	+ 35·35
7.	6 35	46 35	46 57	58	29·8	811	11·95	799·05	698	+ 101·05
7.	9 50	46 26	46 20	58·5	29·9	617	9·4	607·6	503	+ 104·6
8.	11 25	46 23	41 11	59	30·05	2800	11·05	2788·95	2516	+ 272·95
10.	2 31	48 12 30	33 12	58·5	29·95	2400	11·6	2388·4	2320	+ 68·4
11.	1 4	48 49	28 55	58	30·05	1920	12·85	1907·15	1861	+ 46·15
11.	6 46	48 56	28 3	57	30·0	1630	14·5	1615·5	1700	− 84·5
24.	1 0	Victoria Docks.	......	57	30·05	11	16·05	5·05		

care peculiar to the observer; but no such cause could possibly have operated regarding the observations of the instrument recorded in the series of observations given in the second Table, when the vessel passed through seas which had not been before sounded, but which were sounded after each observation of the instrument had been made.

In this Table columns 1 and 2 contain the dates and hours observations were made;
3 and 4, the latitude and longitude of the locality when ascertained;
5, the indications of the thermometer;
6, the indications of the barometer;
7, the indications of the bathometer;
8, the corrections for variations in temperature and atmospheric density;
9, the readings of the bathometer so corrected.
10, the soundings taken.
11, the difference of these and the bathometer indications.

The soundings were made by means of Sir WILLIAM THOMSON'S steel-wire sounding-apparatus, by which admirable improvement over the old sounding-line it is now possible to take soundings exceeding 2000 fathoms in an hour, when 5 or 6 hours were formerly required, and by the application of mechanical power to recover the steel wire itself in from 15 to 20 minutes when a detaching-weight is employed.

The reading of the bathometer was in each case reported to Captain TROT, of the steam-ship 'Faraday,' before the sounding-line had reached the bottom; and the fair accordance between the results obtained by sounding and those given by the instrument furnishes ample proof of the reliable nature of the bathometer indications. The series of observations was unfortunately interrupted during the homeward voyage by a heavy gale, whereby the instrument was exposed to splashes of sea-water from the deck; it had to be taken down, and was only remounted when the vessel had arrived at Victoria Docks. It will be observed that the readings taken in the Victoria Docks, before and after the voyage, agree, after allowing for difference of temperature and atmospheric density, within 5 divisions on the scale of the instrument, representing 5 fathoms of depth, an accordance which must be considered highly satisfactory.

Influence of Elevation above the Earth's surface.—The bathometer is applicable also to the measurement of height, for which purpose it possesses the advantage over the aneroid barometer that its indications are not affected by changes of atmospheric pressure, excepting the small correction for change of atmospheric density before referred to, and which could be avoided in excluding the atmosphere from the extremities of the mercury column.

The total attraction of the earth varies in the inverse ratio of the square of the distance from the centre of the earth; and the ratio of the attraction on the surface of the earth, and at a height h above the surface (supposing the earth to be a sphere), will be expressed by

$$\frac{w}{w'}=\frac{(\mathrm{R}+h)^2}{\mathrm{R}^2},$$

which for relatively small values of h may be written

$$\frac{w}{w'}=\frac{R+2h}{R}$$

or

$$\frac{w-w'}{w}=\frac{h}{\frac{1}{2}R},$$

proving that attraction decreases with elevation in the simple ratio of $\frac{1}{2}$R. The decrease on account of depth of sea takes place, as shown on page 674, nearly in the ratio of R, or the readings of fathoms on the bathometer may be taken for yards in raising the instrument above the sea-level.

The corrections for latitude necessary for reading depth of sea are also applicable for height; but in the latter case another correction will have to be made for the attractive force exercised by the mass composing the mountain or elevation above the sea-level supporting the instrument, and this will vary greatly with the breadth, being a maximum in the case of an elevated plateau. The instrument will, in such cases, give indications of height considerably below the real elevation, and it is doubtful on that account whether it can be made available for such a purpose.

Test for Elevation.—Being desirous to test the instrument for height, I decided to take it up a tower; and having obtained the permission of the Board of Works, through my friend Dr. PERCY, to make use of the Clock Tower for the purpose, the instrument was tested on the 18th of December, the readings being as below:—

	Bathometer. (Mean*.)	Thermometer.	Barometer.
At top of tower . . .	1067·75	45°·0	29·64
At foot of tower . .	1022·5	45·63	29·88

being a difference of 45·25 divisions, equivalent to a difference of height of 135 feet, the aneroid indicating a difference of 208 feet. This difference of readings may appear at first sight excessive, but may be accounted for by disturbance of the instrument in taking it by hand up the steep steps of the tower, where little time was allowed to insure the complete readjustment of the column. In this case also the reading of the instrument gives a result inferior to the indications of theory as compared with its indications on board ship, which latter indications I consider are the more reliable, because the instrument, when once suspended, is not disturbed, and its indications are rendered more delicate through the oscillations of the vessel.

Modifications in the Instrument.—The instrument, as constructed at present, leaves room for such improvements as have partly been, and are likely still, to be suggested by experience. It would be possible to eliminate entirely the effect of variation of temperature by more carefully proportioning the diameter of the mercury column to that of the cup. The influence of variation of density of the atmosphere might also be

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* Including correction for variation in atmospheric density.

entirely eliminated if the spaces in the cups above and below the mercury column were closed against the atmosphere, and were brought into communication with each other. The mode of reading the instrument may also be simplified in various manners, or the instrument may be made self-recording by the addition of a chronograph. My present object has been to demonstrate the possibility of constructing a bathometer capable of giving indications of moderate variations in the depth of sea below a vessel, and to describe rather the instrument actually used than such modifications as may prove more advantageous hereafter.

Practical uses of Bathometer.—The useful purposes for which a bathometer, so arranged as to be observable without difficulty by the commander of a ship, may be employed, are, I think, apparent. It often happens at sea that through clouded skies and fogs it is impossible for astronomical observations to be taken, and it is well known that the compass and dead-reckoning are very uncertain guides to the position of a ship; and as the sounding-line can only be of assistance after the ship has arrived at such depths as are positively dangerous, many calamities are on record where, under such circumstances, not only sailing-vessels, but well-equipped steamers have run ashore. The indications of the bathometer would warn the commander of a vessel of the gradual approach of shallow water; and if in possession of accurate charts, he would in many cases be able to determine his actual position by noting in which direction and at what rate the depth varies.

Position obtained by Soundings.—An illustration from actual practice may serve to show how accurate a guide a knowledge of the depth of the sea can be made. In laying the Direct United-States Cable to America, of which operation Mr. CARL SIEMENS took the principal charge, it occurred that, in November 1874, heavy weather had prevented the taking of observations for three days, when an increasing gale, and the suspicion of a slight fault having passed overboard, rendered it necessary to cut the cable and buoy the end. Before cutting the cable a sounding was taken by Sir WILLIAM THOMSON'S wire, and the depth was found to be 800 fathoms. The gale lasted several days; and when the 'Faraday' returned to the spot where the end was supposed to be buoyed, no buoy could be found, and it became evident that it had been torn away from the anchor-chain by the violence of the gale. The sounding taken at the point where dead-reckoning had placed the ship at the time of buoying the cable gave a depth of 521 fathoms, lat. 48° 32′ N., long. 45° 21′ W., and showed at once that the end of the cable must be looked for elsewhere. There exists no chart of the part of the Atlantic in question, giving such soundings as might have assisted in the search; but special soundings were taken in all directions, from which the dip of the Atlantic basin in that locality could be ascertained. The cable was parted over a depth of 800 fathoms; and in constructing the contour-lines of the Atlantic basin in the locality, which was dipping towards the N.E., it became evident that in order to obtain the cable with the grapnel, it must be caught up in a line parallel to the contour-line, but a mile or two to the eastward. The expedient adopted proved successful, and the cable was recovered in lat. 48° 44′ N., long. 44° 44′ W., or at a point 25 nautical miles removed from the place where it was supposed to have been lost (see Plate 63. fig. 3). If complete information regarding the depth of the Atlantic Ocean had been available in laying the cable, and if the steam-ship 'Faraday' had at that time been furnished with a reliable bathometer, the uncertainty regarding the position of the vessel when the cable was buoyed would never have arisen, and much anxiety and time would have been saved in recovering the end. In cable-laying a bathometer is more particularly of use, because the amount to which the retarding-brake has to be weighted bears a definite relation to the depth of sea traversed; and an accurate knowledge of that depth is essential to prevent either loss of cable from excessive slackness, or permanent danger through an insufficiency.

A bathometer of careful construction would be extremely useful in increasing our knowledge of the depth of the ocean, whilst instruments of inferior accuracy would serve the useful purpose of furnishing the navigator with timely warning of approaching shallows.

It is chiefly with a view to this latter result that I venture to place my inquiries into this subject before the Royal Society. In doing so I wish to acknowledge the valuable assistance I have received from Mr. Bamber and Dr. Higgs, the former having conducted the experiments to determine the influence of temperature on the elasticity of springs, and effected the adjustment of the instruments on land, while the observations on board ship were taken by Dr. Higgs.

Addendum.—*On an Attraction-meter.*

Received February 23, 1876.

At the reading of the foregoing paper, I exhibited an instrument for measuring horizontal attractions, which, at the same time, illustrates the action of the bathometer. This instrument (Plate 65) consists of a horizontal tube of wrought iron 400 millims. long, terminating at each end in a horizontal transverse tube of cast iron of 60 millims. diameter and 300 millims. long. The first-named horizontal tube is partially closed at its ends, and communicates with the transverse tubes below their horizontal mid section. The transverse tubes communicate also by means of a horizontal glass tube of 2 millims. diameter at a superior level to the former.

The whole apparatus being mounted upon three set-screws is filled to the level of the half-diameter of the transverse tubes with mercury, which mercury fills also the whole of the longitudinal connecting-tube; the upper halves of the cast-iron transverse tubes and the glass connecting-tube are filled with alcohol tinted with cochineal, comprising, however, a small bubble of air, which can be made to occupy a central position in the glass tube by raising or lowering the set-screws.

If a weighty object is approached to either extremity of the connecting-tube an attractive influence will be exercised upon the mercury, tending to a rise of level in the reservoir near at hand, at the expense of the more distant reservoir; and this disturbance of level between the two reservoirs must exercise a corresponding effect upon the index of air in the horizontal glass tube, moving it away from the source of attraction. The amount of this movement must be proportionate to the attractive force thus exercised, and is considerable, because the transverse cross section of each reservoir-tube is $60 \times 300 = 18,000$ square millims., whereas the section of the glass tube is only about 3 millims.; the motion produced by the effect of gravity is thus increased 3000-fold, and could easily be increased, say 30,000-fold, by simply increasing the horizontal area of the transverse or reservoir-tubes. Variations of temperature have no effect upon this instrument, because the liquids contained on either side of the index of air are precisely the same in amount; and the total expansion of the liquids is compensated for by an open stand-tube rising up from the centre of the connecting-tube, through which the apparatus can be easily filled. By means of this instrument the effect of 1 cwt. approached to one end or the other of the mercury connecting-tube causes a sensible motion of the air index.

It is suggested that an instrument of this description may be employed usefully for measuring and recording the attractive influences of the sun and moon which give rise to the tides. The instrument, which is of simple construction and not liable to derangement from any cause, would have to be placed upon a solid foundation with its connecting-tube pointing east and west, records being taken either by noting the position of the index upon the graduated scale below, or by means of a self-recording arrangement through photography.

This mode of multiplying the effect produced by gravitation is applicable also to the bathometer; and one of these instruments was shown which was fitted with a spiral glass tube laid horizontally upon the upper surface of the bathometer upon a regularly divided scale, which horizontal tube is connected at one end with the uppermost chamber of the bathometer above the mercury, while the other end remains open to the atmosphere. The space above the mercury in the upper chamber is filled by preference with oil, which terminates in the horizontal spiral glass tube at a point which will vary with the total attractive influence of the earth, and thus furnish a means of reading the instrument. The electric contact arrangement described in the paper is thus rendered unnecessary, and the reading of the instrument much simplified.

Received December 19, 1876.

SINCE presenting my Paper on the Bathometer to the Royal Society in February last, I have continued my endeavours to produce an instrument in such a form as to be practically independent of the disturbing influences to which reference is made in my paper, and of a construction so simplified as to render the instrument available for practical uses.

It is my intention to present before long a supplementary paper to the Royal Society describing the improved instrument, and giving an account of the further trials which I have had the opportunity of making, for the purpose of verifying the indications of the instrument by actual sounding.

The first set of observations was made by Mr. ALEXANDER SIEMENS, on board the steam-ship 'Faraday,' in American waters of a depth not exceeding 100 fathoms, when the readings were found to accord closely with the results of sounding. Besides this, several trials of the instrument have been made: one under my immediate superintendence in crossing lately from New York to Liverpool, on board the steam-ship 'Bothnia,' Capt. M'MICKAN (who rendered me every facility); another on board H.M. steam-ship 'Fawn,' between Southampton and Gibraltar; while another has been made, at the instance of Dr. HIGGS, with a modified form of apparatus, on board a sailing-ship in its passage from Southampton to Rio Janeiro. The results of the observations on board the 'Fawn' were unsatisfactory, owing to a mechanical defect in the apparatus, whereas the others confirmed generally the results given in my paper, confirming also the observation there referred to, that differences of latitude do not seem to exercise the full amount of effect upon the instrument which might be expected, in consequence of the combined influence of centrifugal force and ellipticity of the earth.

Criticisms have appeared in several papers questioning the applicability of the bathometer for determining the depth of the sea, owing to the disturbance of the sea-level by continental attraction. This cause of disturbance had not escaped my attention in writing my paper[*]; and it should be borne in mind that the instrument cannot do more than indicate comparatively small variations in total terrestrial attraction, which the hydrographer or navigator using the bathometer will have to interpret according to the circumstances of the case. The zero-point of the instrument must vary no doubt with latitude, continental attraction, and also in consequence of special geological causes; but it is important to observe that these causes are of a permanent character, and that if an ocean has been once surveyed with the aid of the bathometer, such special local conditions would become observed facts, and so far from hindering the

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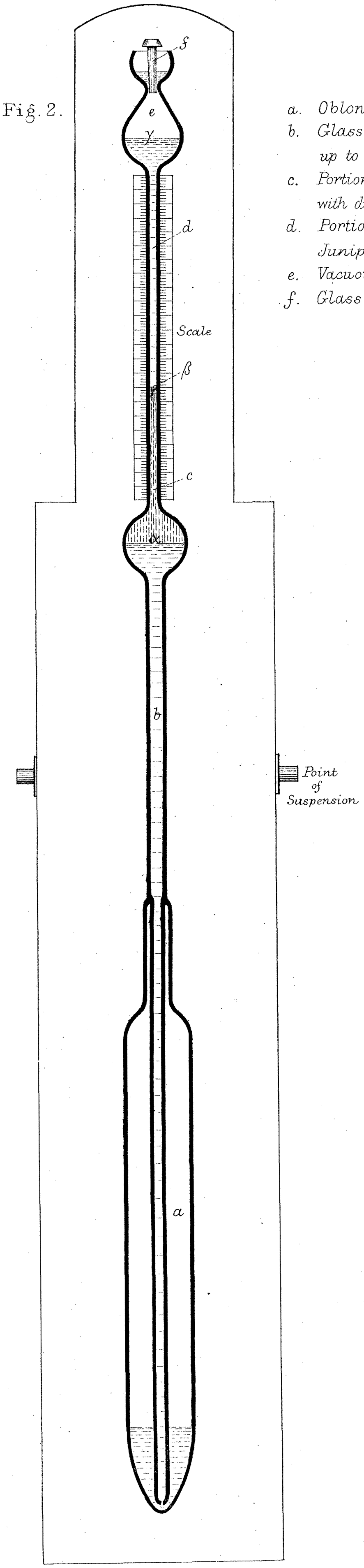
[*] See page 682.

advantageous use of the instrument, would serve, on the contrary, to increase its measure of usefulness in the hands of the navigator.

In the Addendum to my paper of the 23rd February, I described a modification of the principle of the bathometer, designed for the purpose of measuring horizontal attraction; and I take this opportunity of stating that I have constructed an instrument of this description, which has been erected upon a solid foundation at the Loan Exhibition, South Kensington. The measure of sensitiveness of this instrument is given by the fact, that the weight of a person stepping from one side of it to the other causes the indicating bubble to travel through one division (of 1 millim.) of the scale. It would not be difficult to construct such an instrument of still greater sensitiveness; and I believe that it could be made a useful adjunct at physical observatories, for the observation of diurnal changes in the horizontal attraction produced by the sun and moon as well as of terrestrial causes of disturbance of the superficial equilibrium of the earth.

First attempt to construct a Bathometer.

Fig. 2.



a. Oblong Air-bulb of glass.
b. Glass-tube filled with mercury up to Level α.
c. Portion of Glass-tube filled with diluted alcohol to Level β.
d. Portion of tube filled with Juniper-Oil to Level γ.
e. Vacuous space above Oil.
f. Glass stopper.

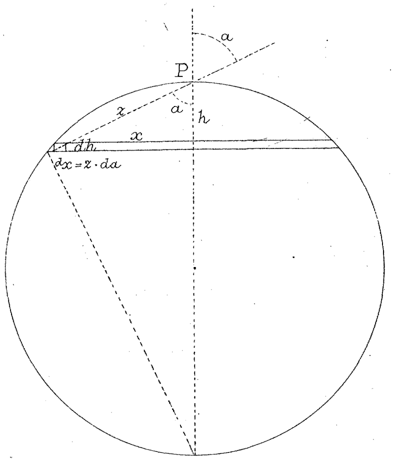
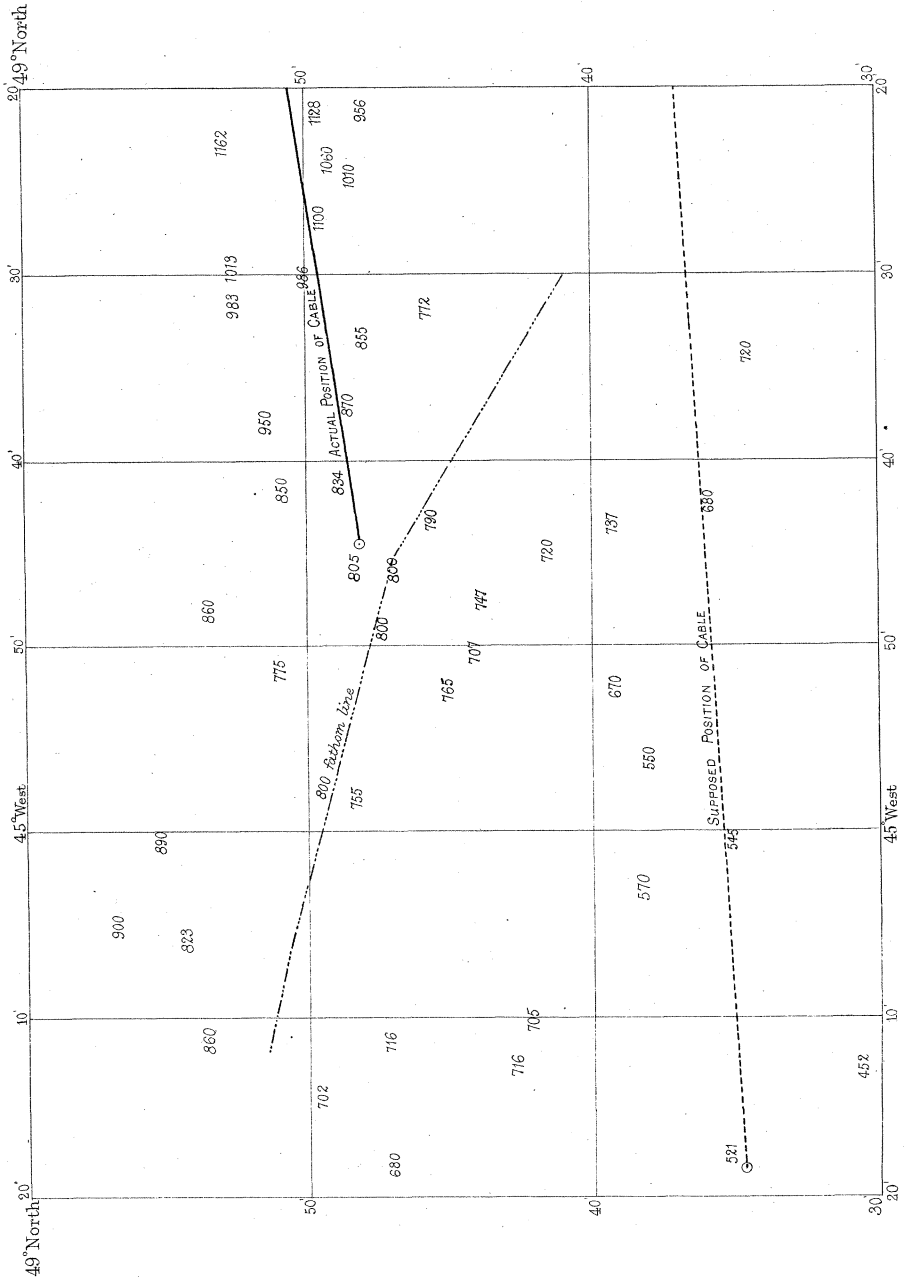
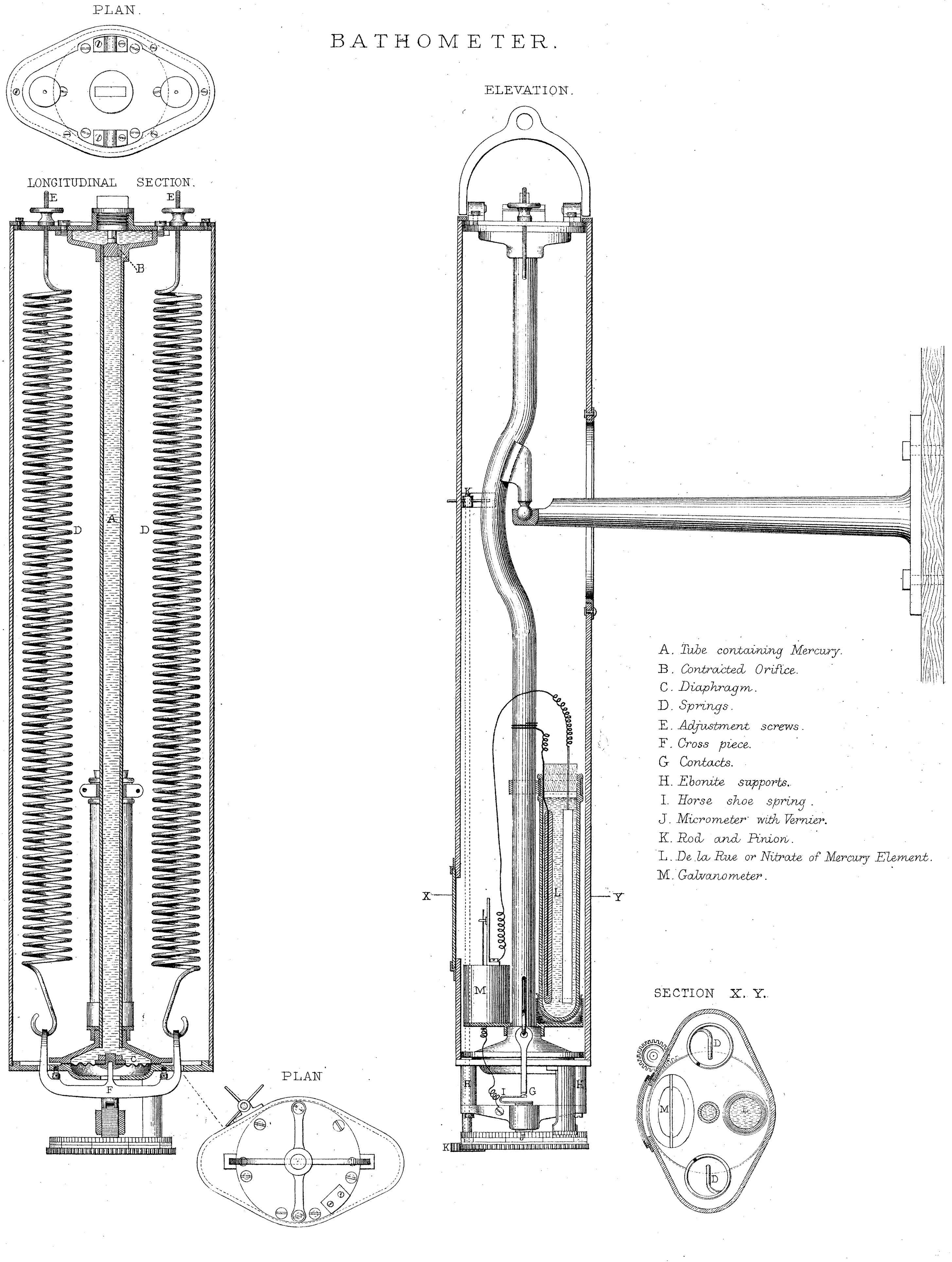


Fig. 1.

Fig. 3.



BATHOMETER.

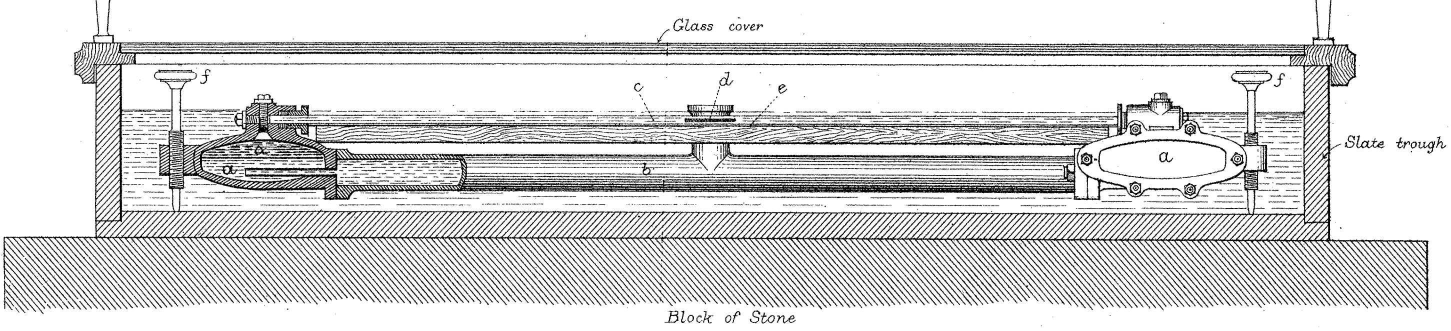


A. Tube containing Mercury.
B. Contracted Orifice.
C. Diaphragm.
D. Springs.
E. Adjustment screws.
F. Cross piece.
G. Contacts.
H. Ebonite supports.
I. Horse shoe spring.
J. Micrometer with Vernier.
K. Rod and Pinion.
L. De la Rue or Nitrate of Mercury Element.
M. Galvanometer.

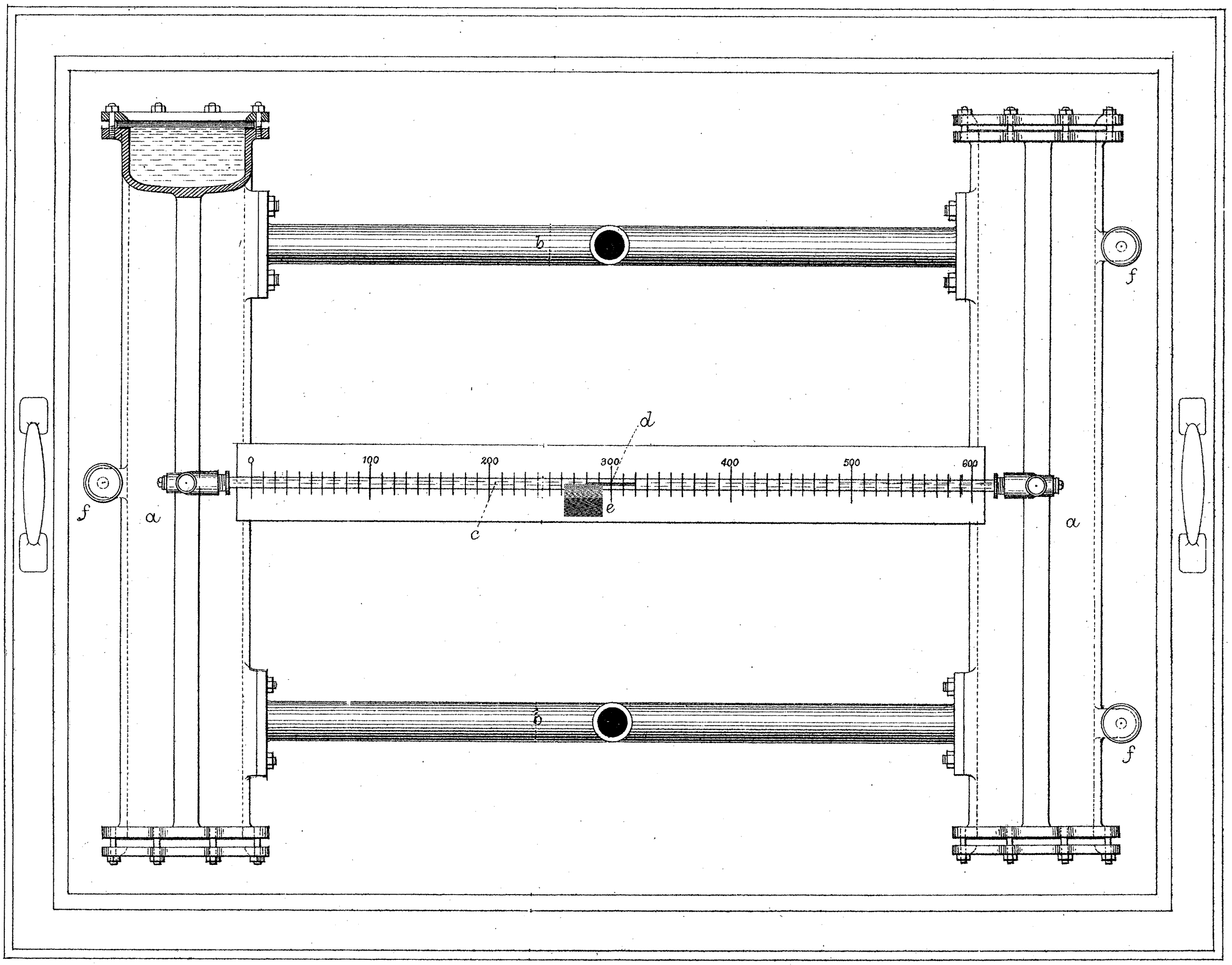
W. West & Co. lith.

HORIZONTAL ATTRACTION METER

ELEVATION & SECTION



PLAN & SECTION.



a. Reservoirs filled with mercury to Level α, and alcohol above that Level.
b. Cross tubes connecting reservoirs below.
c. Glass tube connecting reservoirs above.
d. Index Air bubble.
e. Scale.
f. Levelling screws.

W. West & Co. lith.