CHAPTER III.

Oceanic Temperatures—Modes of Determination—Self-Registering Thermometers of Six, Aimé, Negretti & Zambra, and others—Electrical Thermometer—Sources of Error—Professor Tait's Experiments—Piezometers—Compressibility of Water—Specific Gravity Determinations—Collection of Samples of Water—Slip Water-Bottle—Buchanan's Water-Bottle—Combined Water-Bottle and Sounding Rod—Method of taking Temperatures.

ONE of the chief objects of the Expedition was to collect information as to the distribution of temperature in the waters of the ocean. It was therefore important to observe the temperature, not only at the surface, but at the bottom, and at intermediate depths. The determination of the temperature of surface water is simple. It suffices to collect a sample in a bucket, taking care that it is not contaminated with water, either from the scuppers, or from the discharge pipes of the engine, to plunge a good thermometer into it, and observe it carefully. The thermometers[1] supplied for this purpose were very sensitive, and divided into single degrees of Fahrenheit's scale.

For the purpose of observing the temperature of the waters below the surface in lakes and seas, three classes of thermometers have been used—namely, ordinary thermometers, self-registering thermometers, and electrical thermometers.

Ordinary Thermometers.—The earliest observations were made with the ordinary thermometer, and it was used in one of two ways—either it was sunk itself to the desired depth, and was so enveloped and protected by badly conducting material, that in bringing it up again through the layers of water of different temperature it had not time to alter its own temperature, or a quantity of the water at the desired depth was enclosed in a bucket of suitable construction and brought to the surface, and then immediately tested with the thermometer. Many very excellent and trustworthy observations exist which were made in one or other of these ways. Our first knowledge of the temperature of the deep water of freshwater lakes was obtained from the observations of Saussure on the lakes of Switzerland, made with a thermometer so padded and protected that it could be drawn up through 1000 feet of water of any temperature likely to be found in nature without sensibly altering its temperature.

At an earlier date, observations had been made at sea on the temperature of the water below the surface. Captain Ellis[2] was the first to attempt this line of investigation. In 1749, in lat. 25° 13′ N., he fetched samples of water from 3900 and 5346 feet in an apparatus devised by Dr. Hales,[3] and took their temperature when brought to the surface. The method of bringing a sample of the water to the surface, and then testing its

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[1] For list of Thermometers, see Appendix C to Chapter I., p. 42.

[2] *Phil. Trans.*, vol. xlvii. p. 214, 1752.

[3] *Ibid.*, p. 213.

temperature, instead of sending a thermometer to the required depth, was that followed by all navigators up to the beginning of this century, and many valuable observations were made by its means, more especially in the colder waters of the Arctic seas. Various forms of special apparatus were designed and made for the purpose of securing the sample of water, and bringing it to the surface with as little change of temperature as possible, but they all consisted essentially of a vessel, as large as could conveniently be made, furnished at top and bottom with valves opening upwards. While descending these valves were kept open by the rush of water through the apparatus, and while ascending, they were kept shut by the resistance of the water. In many cases where no special apparatus was at hand, one was improvised out of a cask, and its use for this purpose demonstrated to many of these experimenters the enormous effect of the pressure of the water, especially on structured substances like wood. There being very little difference in the temperature of the water at different depths in the Arctic Seas, the results thus obtained were very accurate and valuable.

Whether the water is brought from the required depth and then tested according to the original method of Ellis and Hales, or the thermometer suitably protected is sent down to the water, then brought up and observed according to the method of Saussure, the accuracy of the results depends largely on the skill of the observers and on the approach to uniformity of temperature in the columns of water traversed. In the case of Saussure's observations on the temperatures of lakes in Switzerland and of Fischer and Brunner's on the Lake of Thun, there can be no doubt as to the trustworthiness of the results, as the experiments were made with very great care and attention to every particular; but the method besides occupying much time could not be recommended to any but skilled and careful observers. The same applies, but in a much less degree, to the use of the "sea gauge."

A method of determining the temperature at the bottom, analogous to the use of the sea gauge, consists in bringing up in a dredge or other apparatus as large a sample of the bottom as possible and plunging a thermometer into it. As a mass of mud conducts heat very slowly and is not affected by convection currents, the temperature of its interior is but very slowly affected by variations in that of the surrounding medium.

Self-Registering Thermometers.—By far the greatest number of observations has been made with self-registering thermometers of one form or another.

The first self-registering thermometer was made by Cavendish.[1] He constructed both a maximum and a minimum thermometer, and they were of the kind called by the French *à deversement*, *out-flow* thermometers. In fact, his maximum thermometer is in every particular identical with that known in France as Walferdin's; his minimum is on the same principle, but has a U-formed stem instead of a straight one. There are two

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[1] *Phil. Trans.*, vol. l. p. 300, 1758.

disadvantages in this form, namely, the indications are not continuous, but by jerks, depending on the size of the mercury drops, and they require to be constantly set, the maximum at a higher and the minimum at a lower temperature than the one to be observed; and they also require constant comparison with a standard. They are, therefore, not suitable for use where many observations have to be made expeditiously.

In the year 1782, Six[1] published a description of the combined maximum and minimum thermometer which bears his name, and which has since continued to assert its place among meteorological instruments as, perhaps, the best self-registering thermometer for sea temperature observations. The instrument is too well known to require particular description. It may, however, be noted that Six himself did not use a hair for a spring to keep his indices from falling down, but a fine glass thread soldered to the top of the index, and sticking up in a direction very slightly inclined to that of the length of the index, so that it pressed gently against the sides of the tube. The advantage of the glass over the hair is that it does not lose its elasticity; but, on the other hand, the index takes up more room, and requires a thermometer with a longer stem.

Maximum and minimum thermometers such as Cavendish's and Six's, when used for deep-sea exploration, show only the maximum and minimum temperatures to which they have been exposed in any one excursion, and a single observation with such a thermometer does not give with certainty the temperature of the water at the depth to which it has been sunk. Hence, if it were possible for the temperature of a sea or lake to vary in any conceivable way with the depth, these instruments would be valueless. There is, however, no justification for this assumption; it is known, on the contrary, that in all seas where the surface is not exposed to a freezing temperature, the temperature of the water, as a rule, diminishes as the depth increases; and therefore that the minimum temperature, as shown by the self-registering thermometer, is, in fact, the temperature at the greatest depth attained by the instrument. Hence, in such cases, this instrument is to be relied on, and more especially when *series* of temperatures are taken—that is, when the temperatures at different depths in the same locality are taken, so that the evidence of the decrease of temperature with increase of depth is rendered as strong as possible. In order to render an account of the state of the sea as regards temperature, it is absolutely necessary to have such serial observations; hence, for such investigations, the maximum and minimum thermometer is not only perfectly trustworthy, but a most valuable and, indeed, indispensable instrument, for it has the great advantage that, as it is in the strictest sense *self*-registering, any number can be attached to the same line, and so at one haul the temperature can be observed at a number of different depths.

The instrument used for almost all the observations made on board the Challenger, was Six's thermometer with a double bulb, of the pattern made by Mr. Casella for deep-sea

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[1] *Phil. Trans.*, vol. lxxii. p. 72, 1782.

work, and generally known as the Miller-Casella thermometer. It is represented in fig. 27, and the copper case in which it is enclosed when sent down is shown, on a smaller scale, in fig. 28. The instrument is of small size (9 inches in length), to reduce, as far as possible, the friction in passing through the water. The tube is mounted in ebonite, and the scale (Fahrenheit's) is engraved on slips of glass which are fixed to the ebonite alongside the capillary tube of the instrument. The primary bulb of the thermometer is enclosed in a secondary one, and the space between them partially filled with spirit. The thermometer is filled with a solution of creosote in spirit. The capillary portion is bent in the form of a U, and the bend is filled with mercury; the limb furthest from the bulb ends in a cylindrical reservoir, partially filled with the thermometric liquid, but with a large space empty, or rather containing the vapour of the liquid and slightly compressed air. A small piece of steel wire enclosed in a very thin glass tube forms the index; it retains its place in any part of the tube by the spring of a hair tied on one end of it. Each limb carries an index of this kind. When the thermometer is to be used, the indices are drawn down in each limb of the tube by a strong magnet till they rest on the surface of the mercury on each side. When the thermometer is brought up, the height at which the lower end of the index stands in each tube indicates the limit to which the index has been driven by the mercury, the extreme of heat or cold to which the instrument has been exposed.

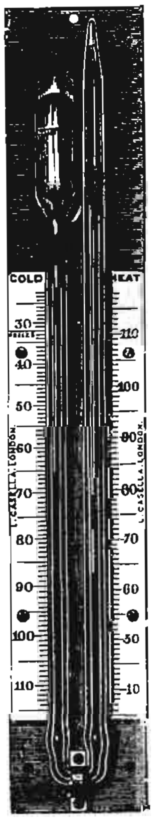

FIG. 27.—Six's Deep-Sea Thermometer.

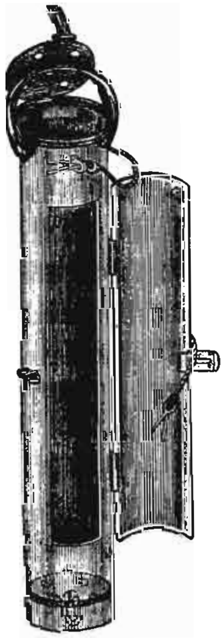

FIG. 28.—Case for enclosing Six's (Miller-Casella) Thermometer.

During the course of the voyage, it became evident that the thermometers as supplied were wanting both in delicacy and in accuracy. It is true that the great source of error had been removed by the application of the secondary bulb, so that the indications were practically unaffected by pressure, but when it had been found that the great bulk of the ocean water is at a low and nearly uniform temperature at great depths, it became of importance to be able to distinguish accurately fractions of a degree. With the thermometers supplied this was impossible, because they were so short for the range of temperature they had to show, that the length occupied by one degree could not easily have been subdivided beyond a quarter, even if the scale had been engraved on the stem, and it was impossible to attain even that degree of accuracy with certainty when the scale was on a slip of glass at the side of the stem, and about a quarter of an inch away from the index, the position of which had to be determined in reference to it. In order to remedy this defect, Professor Wyville Thomson ordered two thermometers to be sent out specially constructed to show low temperatures with accuracy. They were of the ordinary type but longer, and the upper portion of the minimum limb was contracted to a small diameter, so that the degrees between 30° and 40° F. occupied 0·3 inch each, instead of 0·05 inch as in the ordinary ones. Unfortunately these thermometers only reached the ship near the end of the cruise, and in both of them there was a defect about the fitting of the indices in consequence of which they stuck in the tube and allowed the mercury to pass them.

Since the termination of the cruise, Mr. Buchanan has had constructed, and has largely used, an improved form of thermometer of the protected Six type. The size of the instrument is increased so that the degrees are wider apart, a degree Fahrenheit on the minimum leg occupying about three millimetres of its length. Besides the scale of degrees which is attached on enamelled slips to the vulcanite at the sides of the stem, there is an arbitrary (millimetre) scale etched on the stem itself. The values of the divisions of this scale are ascertained by a careful comparison with a standard thermometer. It is thus possible to read with certainty to a quarter of a millimetre or a twelfth of a degree Fahrenheit. The errors due to the scale not being rigidly attached to the thermometer, and to the difficulty of determining the height of the index by reference to a scale at the side of, instead of over, it, are thus eliminated. Finally, by having the ordinary scale at the sides, the instrument can be used independently of the stem-scale, and even where the scale is principally relied on, the scale of degrees at the sides enables the observer to know very approximately the true temperature at the moment of observation without reference to tables; and further, by noting on every occasion the reading on *both* scales, the chance of errors from misreading is greatly reduced.

The maximum leg, which is only rarely used, is of larger bore than the minimum; the degrees, therefore, are closer, and the temperature of the instrument may rise as high as 100° F. without the index entering the terminal bulb. This is a detail of considerable practical importance, for it is impossible always to protect the thermometers when on deck from the direct rays of the sun, which would speedily disable the maximum side of the thermometer if its range were as limited as that of the minimum.

For isolated observations the Six thermometers just described are not so satisfactory, and a very great amount of ingenuity has been displayed in the invention of instruments for registering the actual temperature of the water at any depth independently of that of the water above it. None of the instruments devised for this purpose have been strictly *self*-registering; they have all required some assistance from the observer, who, by various forms of mechanical appliance, brings about a change in the condition of the instrument. It is obvious that any control which an observer may have over an instrument separated from him by, it may be, three or four miles of line, is very limited. By a simple mechanical contrivance vertical motion may be made to produce one of rotation, and, in fact, the assistance thus afforded by the observer to the thermometer to enable it to register its own temperature consists in his turning it either upside down or through a whole circle when it has reached the desired depth. The first observer who made use of such a device was Aimé. By allowing a weight to slip down the line the upper attachment of his thermometer was set free and it fell over. The change thus produced was the means of registering the temperature at the depth.[1] His *thermomètre à bascule*, along with a number of ingenious modifications of existing forms, is described in the same journal.[2] It was unfortunately only after he was obliged to leave the Mediterranean, which had been the scene of his labours, that he invented the very elegant combination of thermometers by which he was enabled to ascertain the temperature at any depth, no matter what the intervening distribution might be. It is described in the memoir just cited. It consists of two outflow thermometers, so constructed that one of them registers the sum of the rises of temperature, and the other the sum of the falls of temperature, to which it is exposed in any excursion. When they have reached the required depth they are inverted, and on their way back to the surface they register, as above described, the rises and falls of temperature to which they are exposed. If r be the sum of the rises of temperature, f the sum of the falls, and s the temperature of the surface, then the temperature at the depth where they were inverted will be $d=s+r-f$. If they are allowed to register on the way down, and then inverted at the greatest depth, so as not to register on the way up, the effect will be precisely the same, though the functions of the thermometers will be reversed. Beautiful and ingenious as Aimé's thermometers are, they have the disadvantages common to all outflow thermometers; they are neither simple enough nor handy enough for work involving many observations.

During the course of the voyage Messrs. Negretti & Zambra patented an instrument which promised to fulfil the conditions required of a thermometer for isolated observations. Staff-Commander Tizard made an extensive series of experiments with it under various conditions, of which he gives the following account:—

"Messrs. Negretti & Zambra's instrument for ascertaining temperatures is a mercurial thermometer (see fig. 29 C), the tube of which is contracted at the point D, so that when the instrument is held upside down the mercurial column separates at that point and falls to the bottom in the enlarged part of the tube E. If a complete revolution of the thermometer be slowly made, the portion of mercury separated falls over into the tube F, which is graduated so as to register the exact amount separated when the instrument is reversed. By attaching this thermometer to machinery which reverses it at a certain time, or at a certain depth, the temperature at that time or depth is registered. To readjust the instrument all that is required

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[1] *Ann. d. Chim.*, sér. 3, t. vii. p. 497, 1843.

[2] *Ibid.*, t. xv. p. 5, 1845.

is to again turn it over slowly, when the mercury in the tube F will fall into the enlarged part E, and from thence into the other tube, rejoining the portion in the bulb, after which it rises or falls in the tube as the temperature increases or decreases. The bulb of the thermometer is protected from pressure by an outer bulb partially filled with mercury.

"From this description it will be seen that the instrument consists of two parts—the thermometer for recording the temperature, and the machine for rotating the thermometer at any required depth. The contrivance for turning the thermometer over may be described as a vertical propeller to which the instrument is pivoted. So long as the instrument is descending the propeller is lifted out of gear and revolves freely; but as soon as the ascent commences the action of the propeller is reversed, and it falls into gear with a pinion connected with the thermometer, and by these means the thermometer is turned over. After one revolution it becomes locked, and remains immovable. The woodcut (fig. 29 A) shows the general arrangement—T being the thermometer, S a metal screw connected with the frame of the thermometer by a wheel and pinion movement at W; S+ is the stop for arresting the movement of the thermometer when it has made one revolution. It was found in practice that the propeller being arrested, after it had turned over the thermometer, brought such a strain on the cogwheel W as to twist it off the spindle and cause its loss.

"This defect was remedied by Mr. Ferguson, the Chief Engineer of the Challenger, who applied an ingenious apparatus by which, when the thermometer has made one complete revolution, the pinion is lifted clear of the cogwheel, and thus the propeller is allowed to revolve as freely in its ascent to the surface as it did in its descent. Fig. 29 B shows Mr. Ferguson's improvement. The pinion Z is lengthened considerably, and is connected to the rod L which turns the thermometer by a key on the rod and a slot in the pinion, allowing it to move up and down the rod. M is a brass nut attached to the rod L, and movable up and down that portion of it which has a screw; from this nut two arms descend, and are attached to a collar round the upper part of the pinion Z. The nut M is kept from revolving by being lengthened sufficiently to clasp one of the supports of the apparatus. As the instrument descends, the wheel W is lifted clear of the pinion as before; directly it is reversed it falls into gear, but, as the pinion and rod revolve, the nut M is raised on the screw part of the rod lifting with it the pinion, and as long as the rod revolves the pinion is rising; the length of the pinion is so arranged that when the thermometer has made a complete revolution the lower part of the pinion is just lifted clear of the upper part of the cogwheel, consequently the screw S and cogwheel W can then revolve freely. The apparatus, as thus improved, has been found to answer admirably.

"Several thermometers for use in the apparatus were forwarded from time to time. A great number were found broken when they reached the ship, owing either to imperfect packing or negligence in the transport, but a sufficient number arrived in safety to admit of their having a fair trial.

"The first time they were used was in the Sulu Sea, where the minimum temperature is reached at a depth of 400 fathoms, and it was thought a good opportunity to try whether the water at greater depths exceeded this temperature. The apparatus was consequently sent to the bottom, the depth being 2225 fathoms, and the thermometer (No. 18) registered 54°, whereas the minimum temperature at 400 fathoms was 50°·5; the temperature of 54° being at the depth of 190 fathoms by the Miller-Casella thermometer. The same thermometer (No. 18) was next sent to 400 fathoms, the depth of minimum

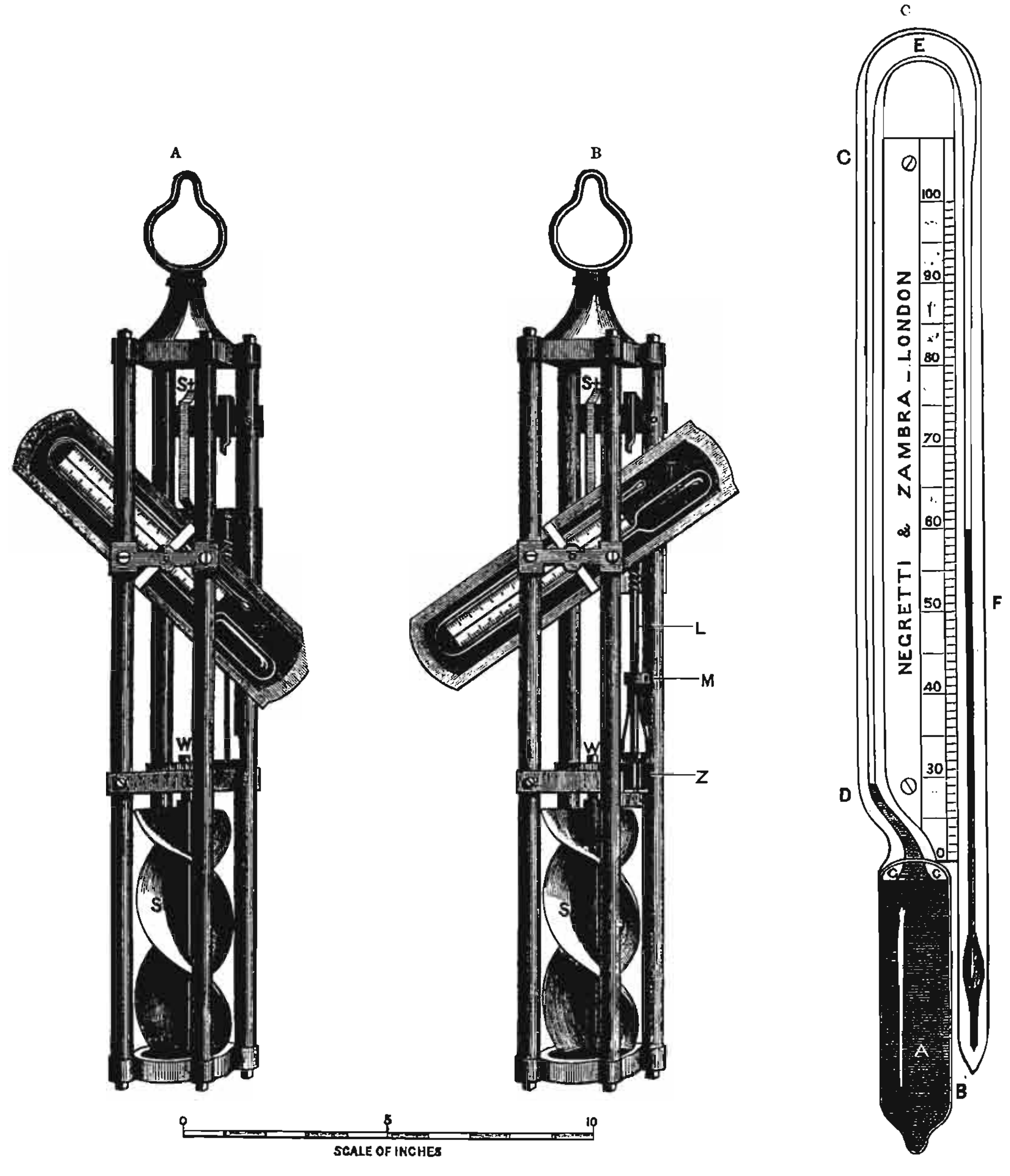

FIG. 29.—A, C, Negretti & Zambra's Deep-Sea Thermometer; B, Ferguson's modification.

temperature, to test its accuracy, for had it given the same result as the Miller-Casella, it would have been a conclusive proof that the water was warmer below the depth of minimum temperature, instead of, as was supposed, remaining at that temperature. This time, however, when hove to the surface, the cogwheel attached to the propeller was missing, and the thermometer was in the same position as it was when sent down, consequently it did not register. On February 12, 1875, the machine being again in working order, the observations were proceeded with. The apparatus was first sent to the bottom in 2550 fathoms, No. 18 thermometer being again used, and it was afterwards sent to less depths with the following results:—

Depth in Fathoms.	Temp. by Miller-Casella.	Temp. by Negretti & Zambra, No. 18.	Depth at which temp. given by Neg. & Zam. was found by Miller-Casella.	Remarks.
50	74°·5	71°·0	80 fathoms	
100	68·0	70·0	85 „	
200	54·0	46·5	290 „	
2550	35·4	43·0	400 „	

"From this date the experiments with this instrument were continued as opportunity offered; the results are embodied in the table on the next page.

"It will be seen from the above and following tables that four thermometers have been under trial on board, Nos. 18, 30, 77, and 152, and that observations with each instrument have been taken at various depths, the results being briefly as follows:—With No. 18 five observations were made, four of which gave a higher reading than the protected Six thermometer, and one a lower reading; with No. 30 twelve observations were taken, ten of the results being higher than those obtained by the protected Six, and two lower; with No. 77 six observations were obtained, all the results being higher than those obtained by the protected Six; and with No. 152 twenty-five observations were obtained, ten of which were higher than the protected Six, fifteen of them agreeing within 1° with the results given by that instrument, and none being lower. Of the fifteen results given by No. 152, which agree so closely with the protected Six observations, it will be noticed that ten of them were taken at depths less than 400 fathoms, whilst the ten results that disagree were, with one exception, taken at depths exceeding 400 fathoms. It will thus be seen that, of forty-eight observations taken with these thermometers thirty were higher, three were lower, and fifteen similar to the observations taken with the protected Six instruments at the same depth.

"That the Negretti & Zambra instrument might occasionally show a lower temperature than the protected Six can easily be understood; for, supposing them both to stand at the same temperature at a given depth, if, in the process of turning, the mercury, instead of separating at the point D as it is intended to do, separates at a point somewhat higher, the amount of mercury which will be deposited in the recording column will be less than it should be, and consequently the instrument will show a lower temperature than really exists, and the three occasions on which the Negretti & Zambra gave a lower reading than the protected Six may be readily accounted for in this manner. That the instrument in the majority of cases gives a higher reading than the protected Six thermometer must be due to one of two causes; either the pressure of the water outside the tube as the thermometer descends is sufficient to close entirely

Date on which experiments were made.	No. of Thermometer used.	Depth to which Therm. was immersed in fathoms.	Temp. by Deep-Sea Therm.	Temp. by Negretti & Zambra's instrument.	Difference.
June 30, 1875	77	175	52°·0	61°·0	9°·0
,,	,,	2775	34·9	55·5	20·6
July 2, 1875	77	200	52·6	56·0	3·4
,,	,,	700	37·3	39·8	2·5
July 3, 1875	77	150	53·4	58·8	5·4
,,	,,	2530	35·2	60·0	24·8
July 5, 1875	30	40	55·5	58 0	2·5
,,	,,	700	36·4	41·0	4·6
July 12, 1875	30	125	50·5	54·2	3·7
,,	,,	500	40·0	34·8	5·2
,,	,,	1500	35·1	53·5	18·4
July 14, 1875	30	800	36·4	52·0	15·6
,,	,,	1500	35·1	54·8	19·7
July 17, 1875	30	225	46·1	29·0	17·1
,,	,,	1500	35·5	49·0	13·5
July 19, 1875	30	700	37·0	45·0	8·0
,,	,,	1500	35·2	56·0	20·8
July 21, 1875	30	1500	35·1	64·0	28·9
Dec. 14, 1875	152	100	49·0	49·0	0·0
,,	,,	300	41·7	42·2	0·5
,,	18	1500	35·2	40·0	4·8
Dec. 17, 1875	152	175	45·5	45·5	0·0
,,	,,	500	39·6	41·0	1·4
,,	,,	1200	35·9	46·0	10·1
Dec. 28, 1875	152	200	42°·5	43°·0	0°·5
,,	,,	600	37·5	40·2	2·7
,,	,,	1000	36·3	38·8	2·5
Dec. 30, 1875	152	1325	36·0	36·8	0·8
Feb. 12, 1876	152	2425	32·7	42·0	9·3
March 2, 1876	152	1000	37·1	38·2	1·1
March 3, 1876	152	1000	36·6	37·7	1·1
March 4, 1876	152	125	62·0	61·8	0·2
,,	,,	400	40·4	41·0	0·6
,,	,,	500	39·2	39·8	0·6
March 8, 1876	152	150	55·4	55·4	0·0
,,	,,	300	44·8	44·6	0·2
,,	,,	700	37·2	55·2	18·0
March 9, 1876	152	50	57·9	57·9	0·0
,,	,,	500	37·5	38·8	1·3
,,	,,	700	37·0	37·7	0·7
March 21, 1876	152	300	42·9	59·8	16·9
,,	,,	800	38·2	45·8	7·6
March 23, 1876	152	100	59·2	59·8	0·6
,,	,,	1000	37·8	40·0	2·2

the contracted point at D, or the outer protecting bulb being filled with mercury instead of spirit does not succeed in preserving the inner bulb from pressure, or both these causes may be combined. That the outer mercurial bulb does not protect the instrument in all cases from pressure appears to be almost certain, as a reference to the table shows that the results given by No. 77 at depths of 2775 and 2530 fathoms are higher than at 700 fathoms, and No. 30 gives higher readings at 1500 fathoms than at less depths. These results could only be obtained if the thermometer bulb were influenced by pressure. Nos. 18 and 152 appear to be affected both from pressure on the bulb and from pressure closing the contracted part of the tube, as at depths less than 400 fathoms they agree fairly well with the protected Six instrument, but at depths over 400 fathoms their indications are very erratic."

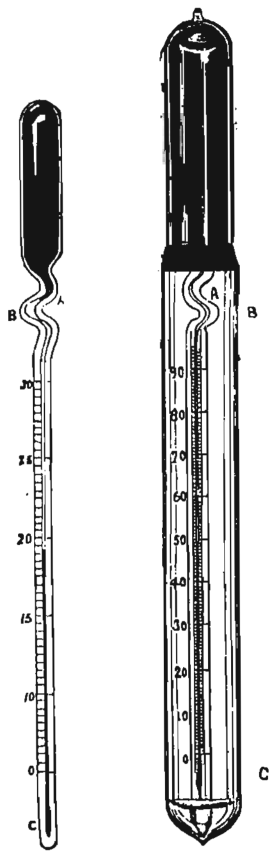

FIG. 30.—Negretti & Zambra's Improved Standard Deep-Sea Thermometer.

Since the return of the Challenger, Messrs. Negretti & Zambra have made an important modification in the form of this thermometer. The new instrument is not double-limbed, and instead of requiring to describe a complete revolution in order to register the temperature, it requires only to describe half a turn. The construction of the thermometer will be understood by reference to fig. 30. The bulb is cylindrical, and mercury is the thermometric fluid. The neck of the bulb is contracted at A, and upon the shape and fineness of this contraction the success of the instrument depends. Beyond A the tube is bent, and a small reservoir is formed at B. At the end of the tube a small receptacle C is provided. When the bulb is downward it contains sufficient mercury to fill the tube, and a part of the reservoir C, if the temperature be high, leaving sufficient space for the expansion of the mercury. In this position no scale would be possible, as the apparent movement of the mercury would be confined to the space C. When the thermometer is held bulb upward, the mercury breaks off at A, and by its own weight flows down the tube, filling C and a portion of the tube above. The scale accordingly is made to read upwards from C. To set the thermometer for observation it is only necessary to place it bulb downward, then the mercury registers the temperature like an ordinary thermometer. Whenever the existing temperature is required, all that has to be done is to turn the thermometer bulb upward, and keep it in this position until read off. The reading may be taken any time after.

The reversing apparatus at first used with this thermometer was somewhat clumsy and unsatisfactory. It has been replaced by a very elegant instrument, designed by Captain

Magnaghi, Hydrographer to the Royal Italian Navy, by means of which the thermometer may be attached to any part of the line during the descent; and after the first regular haul in of from 10 to 80 feet, according to adjustment, any number of stoppages or any amount of line may be afterwards run out without altering the temperature obtained at the commencement of hauling up.

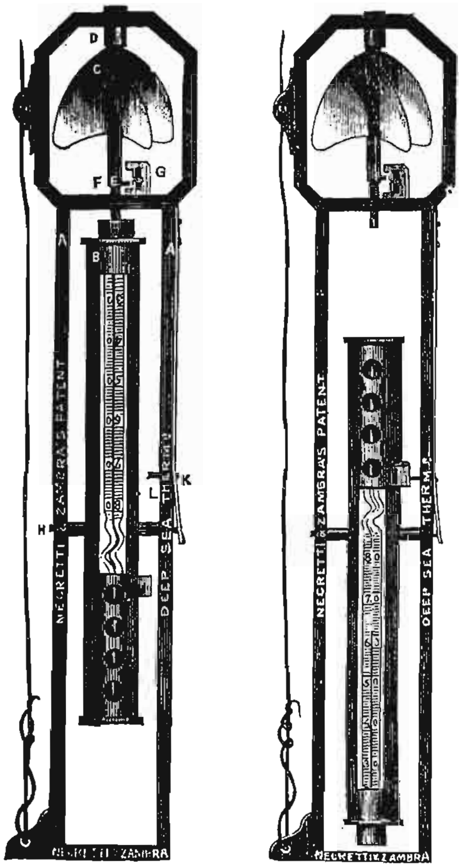

FIG. 31.—Magnaghi's reversing apparatus for Negretti & Zambra's Thermometer.

The apparatus will be best understood by reference to fig. 31. A is a metallic frame in which the case B, containing the thermometer, is pivoted upon an axis H, but not balanced upon it. C is a screw-fan attached to a spindle, one end of which works in a socket D, and on the other end is formed the thread of a screw E, about half an inch long, and just above it is a small pin or stop F on the spindle. G is a sliding stop-piece against which the pin F impinges when the thermometer is adjusted for use. The screw E works into the end of the case B, the length of play being adjusted as necessary. The number of turns of the screw into the case is regulated by means of the pin and stop-piece. The thermometer in its case is held in position by the screw E, and descends into the sea in the position shown in the left hand figure, the fan C not acting during the descent because it is checked by the stop F. When ascent commences the fan revolves, raises the screw E, and releases the thermometer, which then turns over and registers the temperature at that spot, owing to the axis H being below the centre of gravity of the case B as adjusted for the descent. Each revolution of the fan represents about 10 feet of movement through the water upwards, so that the whole play of the screw requires 70 or 80 feet of ascent; therefore the space through which the thermometer should pass before turning over must be regulated at starting. If the instrument ascends a few feet by reason of a stoppage of the line while attaching other thermometers, or through the heave of the sea, or any cause whatever, the subsequent descent will cause the fan to carry back the stop to its initial position, and such stoppages may occur any number of times provided the line is not made to ascend through the space necessary to cause the fan to release the thermometer. When the hauling-in has caused the thermometer to turn over, the lateral spring K forces the pin L into a slot in the case B and clamps it (as seen in the right hand figure) until it is received on board, so that no change of position can occur in the rest of the ascent from any cause. The case B is cut open to expose the scale of the thermometer, and is also perforated to allow the free entry of the water.

The new form of Negretti & Zambra thermometer is completely enclosed in a glass tube, and is therefore not exposed to errors due to pressure. Experiments made with it on board H.M.S "Triton" during the summer of 1882, and by Mr. Buchanan on board the steam yacht "Mallard," showed that, as supplied by the makers at that time, it could not be depended on to turn the moment it was released, but would remain in its original position while being hauled through 10 or 15 fathoms. This defect, however, was very easily rectified by attaching an india-rubber band, so as to press lightly against the upper part of the thermometer when being sent down. As soon as it was released, the india-rubber spring pushed the thermometer out of the vertical, and it at once turned over. With this small but most important addition, the instrument acts satisfactorily, provided that there be no lateral motion of the water relatively to the thermometer. This may occur in one of two ways,—either by the motion of the ship or by currents. In either case the water moving past the instrument turns the screw fan, and sets the thermometer free before it is intended. In the Strait of Gibraltar, for instance, it is impossible to get satisfactory results with these thermometers, except at the periods of slack water.

Quite recently the method, adopted by Aimé, of allowing a weight to slide down the line so as to effect the registration of the thermometer, has been developed by Captain Rung of the Danish Meteorological Institute, by the U.S. Fish Commission, and also at the Scottish Marine Station at Edinburgh. The Danish instrument[1] consists of two pieces, one containing the thermometer which is pivoted to the other and turns over when the weight falls upon a catch, which retains it in position. The "messenger" is very ingeniously made in two pieces, so that it can be put upon the rope at any point. The Scottish instrument[2] is a modification of Captain Magnaghi's: the fan is removed and a pin fits into the slot in the upper part of the thermometer case, this is connected with a horizontal lever, one end of which embraces the sounding line, so that when the weight falls upon it, it lifts the pin out of the slot and the thermometer is released.

Electrical Thermometer.—The Challenger carried a deep-sea electrical thermometer, designed by the late Sir C. W. Siemens, F.R.S.,[3] on the principle of the variation of the electrical resistance of a conductor with its temperature.

The apparatus consists essentially of a coil of wire T, which is lowered by means of a cable to the required depth, and is coupled by connecting wires to form one arm of a Wheatstone's bridge. The connections of the bridge are shown in fig. 32. The arm

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[1] Rung, *Den tekniske Forenings Tidsskrift*, 1883.

[2] Mill, *Proc. Roy. Soc. Edin.*, vol. xii. p. 927, 1884.

[3] *Proc. Roy. Soc. Lond.*, vol. xxxiv. pp. 89–95, 1883.

CD is the comparison coil S, made of the same wire as the resistance coil T, and equal to it in resistance when the temperatures of both are the same. This coil is immersed in a copper vessel with double sides, filled with water, and the temperature of the water is adjusted by adding iced or hot water until the bridge is balanced. The temperature of the water in the vessel is then read by a mercurial thermometer; and this will also be the temperature of the resistance coil T. To avoid the error which would be otherwise introduced by the leads to the resistance coil T, the cable was constructed of a double core of insulated copper wire, protected by twisted galvanised steel wire. One of the copper cores was connected to the arm BC of the bridge, and the other to the arm DC, and the steel wire served as the return (earth) connection for both. The resistance coil and comparison coil were made of silk-covered iron wire 0·15 mm. diameter, and each about 432 ohms resistance at a temperature of 66° F. To allow the resistance coil to be readily affected by changes in the temperature of the water, it was coiled on a brass tube with both ends open, allowing a free passage to the water. Sir William Thomson's marine galvanometer, with a mirror and scale, was employed to determine the balance of the bridge.

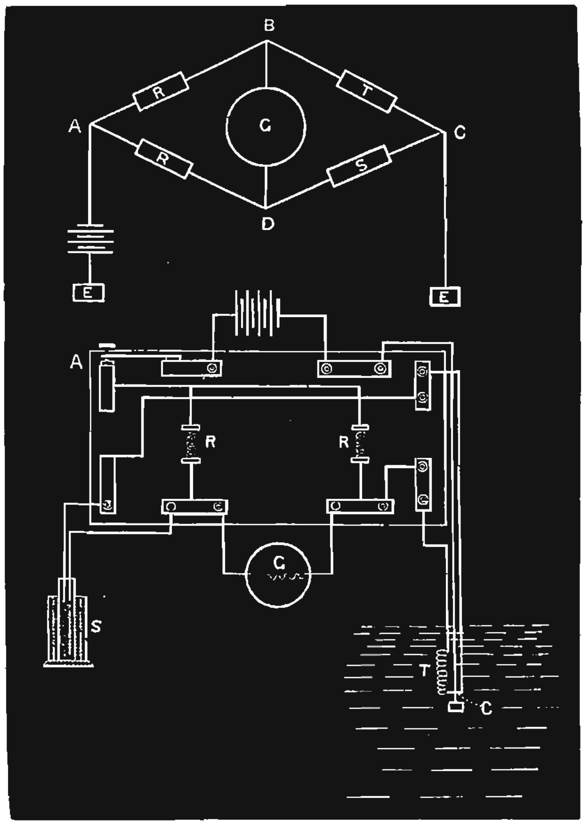

Fig. 32.—Siemens' Electrical Thermometer.

Several more or less successful observations were made with this instrument during the cruise, which agreed fairly well with those made by the protected thermometers. No permanent place was fitted for the galvanometer or apparatus, and in consequence continuous and careful observations were not made.

Dr. Siemens gives, in the paper above cited, an account of some valuable and accurate observations made by one of the instruments on board the U.S.S. "Blake" in 1881. When accurate temperature observations are required from intermediate depths, this instrument is especially valuable, and it will in all probability be extensively used in future deep-sea investigations.

Sources of Error.—In Six's instruments there is a possible error from looseness of the indices, in consequence of which they are apt to be shaken out of their places by the jarring of the line. Errors from this source may be avoided to a great extent by attaching the thermometer to the line by means of an elastic or india-rubber "stop." Where the only scale is on a slip attached to the backing of the instrument, and is not engraved on the stem, there is a great liability to error through shifting of the thermometer relatively to the attached scale. Errors from this source are very liable to occur, and are due solely to defective instrument-making. No instrument of this kind should be sent out of the workshop, to be used on such important work as deep-sea investigation, which has not a scale etched on the stem.

The most serious source of error in the results of observations of the temperature of deep water by means of self-registering thermometers, has been the effect produced on them by the hydraulic pressure to which they are subjected at the moment of recording. This was early recognised.

Cavendish, who invented the self-registering thermometer, foresaw also the most important of the uses to which it could be applied. Thus he suggests that the higher regions of the atmosphere might be investigated by attaching it to a kite—balloons not having been then invented. With regard to deep-sea explorations, he says: "If instruments of the nature above described were to be used for finding the temper of the sea at great depths, some alteration would be necessary in the construction of them, principally on account of the great pressure of the water, the ill effect of which can, I believe, be prevented no other way than by leaving the tube open."[1] This was written in 1757, and it was not till 1762 that Canton proved that liquids are compressible. Cavendish therefore hoped that as the pressure would not produce distortion of the glass when the tube was open, it would have no visible effect on the apparent volume of the liquid. The device of leaving the thermometer open at the end was adopted by Aimé in some of his experiments, the effect of pressure on the apparent volume of the liquid being determined independently, and a correction applied accordingly.

Many attempts were made to use Six's and Walferdin's thermometers at great

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[1] *Phil. Trans.*, vol. l. p. 308, 1758.

depths, protecting them from pressure by enclosing them in strong metal tubes with a top firmly screwed on. This method was extremely uncertain and generally failed. The tube generally came up quite full of water, indicating that it had afforded no protection to the instrument inside it. In some instances Walferdin's thermometer, which is a straight-tubed instrument, and not curved like Six's, was used entirely enclosed in a glass tube hermetically sealed. In this way, of course, complete protection was afforded so long as the glass tube did not collapse.

The method of protection used in the case of the thermometers supplied to the Challenger has been described above. It consists in encasing the true thermometer bulb in another bulb partially filled with liquid to facilitate transmission of heat. The remainder of the space is filled with the vapour of the liquid. Any compression therefore which might be suffered by the outer bulb would produce no rise of pressure in the space between the two bulbs, and would therefore not be transmitted to the inner bulb.

The effect of pressure on a glass vessel is to produce compression and diminution of internal volume while it lasts. When the bulb of a thermometer is compressed and its capacity diminished, the liquid contained in it is squeezed up into the stem, and the top of the column stands higher than it did before, so that the compression of the bulb produces the same effect as a slight rise of temperature.

If now the thermometer be a self-registering one, and it be sunk to a certain depth in a sea of uniform temperature identical with that of the thermometer, the index or recording mechanism will indicate the rise of the thermometric column in the tube due to the compression of the instrument. If the same thermometer, at the same temperature to begin with, be carefully warmed, exactly the same apparent effect will be produced, namely, the thermometric column will rise, and when the temperature has risen to a certain height, it will place the index in exactly the same position as was the case when it was sunk in the sea of uniform temperature. If in the latter case the effect of pressure be neglected, we shall ascribe to the water at the particular depth a temperature higher than the true temperature by the thermometric equivalent of the shift of the index produced by the pressure of the column of water.

It does not require demonstration to show that the apparent effect of pressure on a thermometer will be almost wholly due to its effect on the bulb. The stem suffers compression also, but the apparent effect so produced is negligible compared with that due to the compression of the bulb. Hence when Six's thermometers had to be protected from pressure, it was held sufficient to protect the bulb. There seems to be considerable uncertainty as to who first proposed and carried out the preparation of thermometers with a double bulb, but they were certainly used on board H.M.S. "Cyclops" by Captain Pullen[1] in 1858, and there seems to be good reason for believing that the thermometers used by Sir John Ross in 1818 were protected by the same or some similar device.

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[1] *Phil. Trans.*, vol. clxv. pp. 608, 609, 1875.

Notwithstanding previous experience, when H.M.S. "Lightning" was employed in sounding and dredging in the Færöe Channel in 1868, she was supplied with unprotected thermometers. On her return a number of interesting experiments were made by Professor W. A. Miller and Mr. Casella, to find the "pressure correction" for the instruments used.[1] The corrections so found, though good for the thermometers actually experimented on, are of no use for correcting other instruments, even though they may be of the same pattern. This is due to the fact that the bulbs of even the most carefully made thermometers are never uniform in thickness of glass, and consequently yield differently to pressure. It has been mentioned above that the stem of the thermometer suffers compression though the effect so produced on the reading of the thermometer is insignificant. If the stem be uniform, the effect will be proportional to the length utilised. In the case of the thermometers supplied to the Challenger, the bore of the stem was not uniform. Close to the bulb there was a swelling, and at the bend there were other swellings. As it was the minimum limb that was almost exclusively used, the effect of pressure on the reading was limited to that produced on about 2 inches of tube with a slight swelling near the neck of the bulb. Along with each instrument was supplied, as "pressure correction," the amount to be deducted from the reading according to the depth to which the instrument had been sent. During the first part of the cruise this correction was applied without question, and the results embodied in reports with sections sent home to the Admiralty. As, however, observations multiplied, and side by side with the thermometric observations experiments were made on the effects of pressure on various substances contained in *piezometers*, the readings of which required to be "cleared for temperature" the question of the validity of the "pressure correction" came to be seriously considered, and the conclusion was come to that it had been improperly applied. It was obvious that the correction referred to could have been obtained only in one way, namely, by submitting the thermometer to pressure in a hydraulic machine, and noting the rise of the maximum index. This rise would be caused by the compression of the stem forcing the liquid up the tube, and by the actual rise of temperature produced by the compression of the water of the hydraulic receivers. It was at once evident that the part due to actual rise of temperature caused by compression must be rejected altogether, because in use the thermometer takes the temperature of the water in which it is immersed. Of the residual amount due to actual compression of the stem, only so much ought to be taken as is applicable to the portion of stem between the bulb and the mercury on the minimum leg. This would as a rule be about one-sixth of the length of stem from the bulb to the mercury meniscus in the maximum leg, without adding anything for the swellings at the bend. The errors for a pressure of 3 tons per square inch varied from 1° to $1\frac{1}{2}$° F., and even if nothing be rejected for heat effect, the sixth part would be considerably less than the probable error of observation. The temperature

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[1] Depths of the Sea, p. 295, 1873.

sections sent home in the preliminary reports continued, however, to be constructed with temperatures "corrected for pressure," in order that they might be comparable with those that had gone before, although thus far it had become evident that the thermometers, in so far as they were used as minimum instruments, were sufficiently protected by the outside bulb against the effects of pressure, and that in consequence their readings at great depths were not affected by any sensible error due to this cause.

With a view of finding out the true effect of pressure on the readings of the protected thermometers, Sir Wyville Thomson, on the return of the Expedition, requested Professor Tait to investigate the whole question, and handed over to him about thirty of the thermometers, which had been used during the cruise, and also the hydraulic pressure apparatus constructed in 1872, which had been on board during the voyage. The results of the investigation have been published *in extenso* in Appendix A to Vol. II. of this Narrative.[1]

Professor Tait commenced by remarking that a correction so large as that given by Captain J. E. Davis for the maximum index, if it were to be applied at all, must be applied with but little diminution to the minimum index also. So that the question is a serious one. He then tested the pressure apparatus, but found it to be in many respects unsuitable for the work he contemplated.

1. It was capable of holding only two thermometers at once; and, when two were inserted, there was no room for other necessary apparatus, such as pressure gauges, &c.
2. The Bourdon-gauge attached to it was graduated only to four tons weight per square inch, while it was desirable to carry the pressure to six tons at least.
3. When compared with an air-manometer inserted in the pressure cylinder, this gauge proved to be very inaccurate.
4. Even with the moderate pressures which had been applied to it, the cylinder was not deemed perfectly safe, and had in consequence been strengthened (?) by massive rings of Swedish iron clamped round it.

Professor Tait therefore informed Sir Wyville Thomson, that if the experiments were to be conducted in the Edinburgh University Buildings, it was essential that a stronger and much more capacious pressure cylinder should be procured; and suggested that it should be constructed on the principle of the Fraser gun.

In the spring of 1879 the new instrument[2] (weighing nearly three tons) arrived in Edinburgh from the Royal Gun Factory at Woolwich, and was erected on a mass of concrete embedded in the ground below the floor of one of the basement rooms in the College. As the gas-engine belonging to the Physical Laboratory happened to be fixed in a neighbouring cellar, the requisite shafting was put up to connect it with the pump;

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[1] The Pressure Errors of the Challenger Thermometers, by Professor P. G. Tait, Narr. Chall. Exp., vol. ii., Appendix A.

[2] Described and figured in the above mentioned paper, where will be found a full description of the experiments and their results, also an account of the various new forms of gauges employed for the accurate measurement of pressure.

and, by a simple but effective mechanism, the engine was made after each stroke to open automatically the suction valve of the pump, which was continually liable to become jammed when very high pressures were reached. The only defect of this arrangement was that some minutes elapsed (even when there was no air in the pressure cylinder) before a pressure of three or four tons was reached. Professor Tait therefore procured for his laboratory an additional but very much smaller apparatus, in which a couple of strokes of the pump sufficed to produce the full required pressure. The comparison of the effects produced on the same thermometers, by the same pressure, in these very different instruments was of great value in verifying some of the more important results of the inquiry.

Professor Tait had satisfied himself by calculation from the best data available, that the utmost *direct* effect of pressure on the protected thermometers could be only a small fraction of that assigned by Captain Davis,[1] and he verified this conclusion directly by trials with tubes of varied dimensions.

It only remained to ascertain why the large results of Captain Davis's experiments on the Challenger thermometers, which were closely reproduced by Professor Tait in the new apparatus, were so different from the theoretical amount; and it was found, after several trials with tallow and other plastic materials placed so as to surround the bulbs of the thermometers, that the slabs of vulcanite, on which the thermometers are mounted become heated by compression to an extent hitherto unsuspected, and fully competent to account for the discrepancy. Thus the greater part of the effect obtained by Captain Davis was shown to be due to heating produced by pressure, not to pressure directly.

But when the thermometers are let down into the sea, the circumstances are very different from those in the pressure cylinder, for the constant current of sea water which passes round the bulb of the instrument keeps it and its mounting steadily at the temperature of the sea:—the heat due to compression being (in consequence of the slow rate of increase of pressure) developed much more slowly than in the laboratory experiment, and being besides carried away by convection as fast as it is developed.

He concluded from these experiments, as well as from the experimental verification of his theoretical calculations, that had the tubes of the Challenger thermometers been free from "aneurisms" the utmost pressure correction required in deep-sea observations would have been for the minimum index (which is the important one) about 0°·05 F. only for each mile of depth. The aneurisms above spoken of are small distended parts of the tube. The only serious one, whose object is to prevent the recording index from being drawn into the main bulb if the instrument be exposed to too low a temperature, is close to the protected bulb, and ought itself to have been protected. The pressure effects due to this aneurism are usually greater than those due to the tube of the thermometer. Professor Tait has calculated, for each of the instruments he

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[1] Davis, J. E., On Deep-Sea Thermometers, *Proc. Meteorol. Soc.*, vol. v. pp. 305–342, 1871.

examined, the effect of this aneurism, and his Report concludes with a table of the results. From these it appears that, even with the aneurisms, there is none of the instruments examined in which the requisite correction for pressure amounts to more than 0°·14 F. per mile of depth in the sea, while the average value is considerably lower.

Under the circumstances in which the thermometers are usually hauled on board, and considering also the difficulty of reading to small fractions of a degree, it is clear that it is scarcely necessary to apply any correction for pressure, though it would certainly have been much more satisfactory to have had the aneurisms protected as well as the main bulb.

Professor Tait's experiments with the new apparatus have led to several curious results which, though not directly bearing on the pressure errors of the thermometers, may be found of importance in other departments of the Challenger work. He has, for instance, investigated the compressibility of fresh and salt water at different temperatures under great pressures, and has shown that the maximum density point of fresh water is lowered by pressure. Various additional questions of this kind, directly connected with the great problem of ocean circulation, are now being investigated by means of the new pressure apparatus—and a verification of the unit of his gauge was obtained in the autumn of 1882, by sinking a number of his gauges, whose behaviour in the pressure apparatus had been previously ascertained, to depths of 800 and 1300 fathoms from H.M.S. "Triton," which made a special cruise for this and other connected purposes.

Piezometers.—In the Mediterranean, the Red Sea, and many of the seas of the Eastern Archipelago, besides, possibly, large tracts both of the Atlantic and Pacific Oceans, the temperature decreases regularly down to a certain depth, which varies in different seas, and at all greater depths the protected Six thermometer gives identical readings, indicating that the water is either at the same temperature or some higher one. In the neighbourhood of ice, layers of water are frequently met with at various depths whose temperature, being higher than that of the surface, is indicated by the maximum index of the protected Six thermometer. Besides these layers there may be, and there probably are, others whose temperature is higher than that of the water immediately above them without reaching that of the surface, and their temperature would remain unrecorded.

This fact was brought prominently under the notice of the members of the Expedition during the cruise in Antarctic waters, where a large stratum of water was found at depths exceeding 300 and 500 fathoms from the surface, the temperature of which could not be ascertained by any instrument on board, and had to be reported as uncertain.

In order to prevent the recurrence of such an experience, the matter was carefully investigated by the chemist of the Expedition, who devised and constructed an instrument suitable for determining the temperature of water arranged as it was in the Antarctic Ocean. Before leaving home he had had constructed several piezometers filled with water or saline solutions, with a view of determining the compressibility of these liquids when sunk to different depths (or conversely of determining the depth by the amount of compression). These piezometers are really nothing more than Six's thermometers open at the end. If such an instrument be sunk to any depth in the sea it will register the combined effect of temperature and pressure on its contents and the glass envelope. If the temperature be known the contraction due to pressure can be computed, and conversely, if the depth and so the pressure be known, the temperature to which it has been exposed can be computed. It occurred to Mr. Buchanan at the time to use the piezometers for this purpose, but as they were all filled with either water, sea water, or salt solution, liquids which at such low temperatures show hardly any thermal dilatability, it was felt that no assistance could be got from them. It was not until much later that the idea occurred to open the end of an unprotected Six's thermometer, or to open the end and the secondary bulb of a protected one, and so obtain a record of the combined effect of pressure and temperature on the thermometric liquid usually employed, which could be cleared for effect of pressure by subsequent experiment. Several trials were made with an opened unprotected thermometer in the South Atlantic on the voyage between Sandy Point and Monte Video, and it was found to work well.

As the working of the Negretti & Zambra thermometers which were sent out was not considered satisfactory, a piezometer filled with mercury was constructed. It resembled an inverted Six's thermometer, the bulb filled with mercury and the bend of the tube filled with water, in which the magnetic index had free play. The bulb A (see fig. 33), of about 19 c.c. capacity, held about 250 grammes of mercury. The stem, through a considerable portion of its length BC, was filled with water, in which the index moved. The space between the end of the water column and the end of the stem was filled with mercury, and the end dipped into the bulb D filled with mercury, which communicated with the water or air outside. The instrument was fixed to a backing of vulcanite, principally by wire lashing across the bulb; the small brass clamps on the stem were there solely for steadying and bore no weight. It was fortunate that the possibility of having to do work of this kind was foreseen, and that the laboratory stores included several pieces of ebonite suitable for the purpose, and some graduated capillary tubes of the size used for the piezometers that were taken out. One or two spare indices were also taken, but the supply both of them and of capillary tubes was augmented by preserving the fragments of any thermometers that were broken. In this way an instrument can be constructed filled with a very large quantity of mercury and a very small quantity of water, after whose immersion the position of the index shows the apparent volume assumed by this mixture under the combined influence of temperature and pressure. As far as the effects of temperature are concerned, the amount of water in the instrument is almost wholly negligible; but when the effect of pressure is considered, the apparent compressibility of mercury is so small, being little more than one-fiftieth of that of water, that the presence of even so small a quantity of water as can be contained in the graduated tube increases very materially the amount of contraction produced by pressure. The instrument which was chiefly used contained 256·61 grammes of mercury in the bulb and stem immediately above it; the volume of the part of the stem filled with water was 0·1935 c.c. The apparent contraction of this mass of mercury and water was 0·000581 c.c. per 100 fathoms, and 0·0025 c.c. per degree (C.) respectively. A fall therefore of one degree (C.) in temperature produced the same effect as an increase of pressure equal to 430 fathoms of sea water. Hence (and this forms the important peculiarity of the instrument) as long as the temperature of the sea does not increase with the depth at a greater rate than 1° C. per 430 fathoms, the instrument will record the temperature correctly. The ratio subsisting between the rise or fall of temperature and the column of water, which produced the same effect on the apparent volume, is a constant for each instrument; in this it is $\frac{1}{430}$. By altering only very slightly the amount of water, the sensibility to pressure is greatly increased or diminished, while that to temperature remains practically unchanged. As the instrument described was intended principally for bottom waters, the above ratio ($\frac{1}{430}$) was considered sufficient, and it proved practically useful. It must be remembered that the greater the value of this ratio is made, the greater is the error introduced into the determination of the temperature by any inaccuracy in the measurement of the depth.

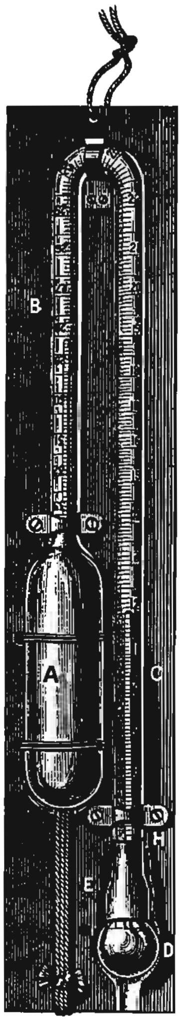

FIG. 33.—Mercury Piezometer.

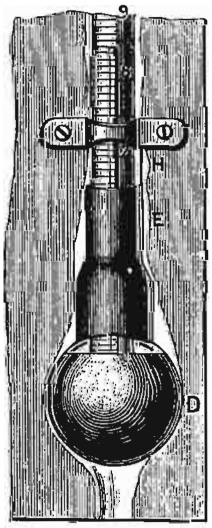

FIG. 34.—Enlarged view, showing attachment of bulb to end of Piezometer.

This instrument was constructed entirely at sea, and though the chemical laboratory was specially lucky in its freedom from breakage, there seemed to be an exception in the case of the mercury piezometer. Four of them had to be made before one stood. The first was broken by accident, the second by a foul on the sounding line, the third in the receiver of the hydraulic apparatus by the collapse of a protected thermometer, which was being exposed to pressure along with it, and the fourth stood, being used as often as possible on the sounding line along with other instruments until the ship returned home, when it was broken in its turn by an over-curious instrument-maker who was employed to copy it. The filling of the instrument with so large a quantity of mercury was effected by means of an improvised

Sprengel pump, which acted quite satisfactorily, even when the ship was rolling steadily through 20° to 30°.

The apparent compressibility of the mixture of mercury and water in glass represented by this instrument was determined in a number of satisfactory soundings between Tahiti and Valparaiso, the temperature being determined by one or more protected thermometers attached to the line close to the piezometer. Of course no "pressure correction" was applied to the readings of these thermometers. The result was, that the apparent compressibility of mercury for 100 fathoms was 0·0000271, being per atmosphere 0·0000015. After the return of the Expedition, the absolute compressibility of glass was directly measured by Mr. Buchanan[1] in a specially designed apparatus, and found to be 0·00000292 per atmosphere up to 240 atmospheres, at a temperature of 12° to 13° C. The absolute compressibility of mercury would therefore be 0·00000442 per atmosphere.

The water piezometer has already been referred to. It is shown in fig. 35. It consists essentially of a thermometer-shaped instrument open at the end. A cylindrical bulb A contained, in the one that was chiefly used, about 9 c.c. The stem, which was rather more than a foot long, had a diameter of almost exactly one millimetre The end of the stem dips into the bulb D, which was filled so far with mercury, and the instrument was set by heating it to such a temperature, that when it cooled down to the atmospheric temperature the mercury would rise to a convenient height so as to be visible and able to be read at any moment at a given temperature by plunging it into water. The arrangement for protecting the open end of the instrument is somewhat peculiar. It is necessary to allow the water on the outside to have access to the mercury in the bulb in order that the pressure may exert itself in the interior of the instrument, in the same way as air must have access to the mercury in the reservoir of the barometer. At the same time it is of importance that the mercury should not be able to come out of the bulb. For this purpose care was taken to have a bulb D blown, into the neck of which the stem of the instrument fitted with some accuracy. This was connected with the stem by means of a piece of india-rubber, which was prevented from fastening hermetically on the stem by having a small piece of glass rod H pushed in between the india-rubber and the stem. In this way communication was constantly kept open between the outer water and the mercury in the bulb.

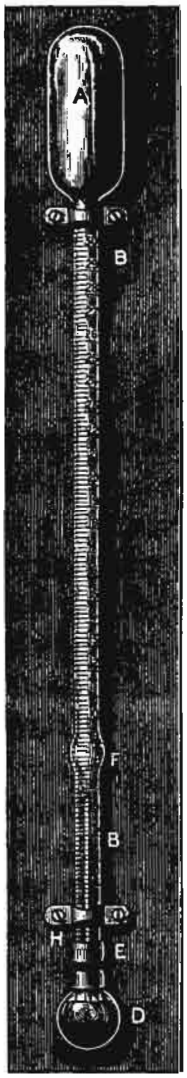

FIG. 35.—Water Piezometer.

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[1] *Trans. Roy. Soc. Edin.*, vol. xxix. p. 589, 1880.

The stem of the instrument was divided into millimetres, and carefully calibrated, the weight of the water filling the instrument, and also the coefficient of expansion of the glass, being at the same time determined.

If the position of the water-mercury meniscus in the stem be noted under observed conditions of temperature and pressure, and the instrument be then observed under different conditions of temperature and pressure, the apparent volume occupied by the water, and therefore the position of the meniscus, will depend on the difference of the combined effects of temperature and pressure on the water and on the glass. This resultant effect is measured by the position of a magnetic index similar to, and in fact exactly the same as, that used in Six's thermometer. The deep-sea thermometer used was after Six's pattern, with a protected bulb. When the instrument is subjected to increased pressure or diminished temperature, or both together, the index is pushed up by the mercury, which enters owing to the decrease of temperature and the increase of pressure, and its position thus gives the sum of the effects of change of pressure and of temperature on the apparent volume of the water.

If now, along with this instrument a sufficiently protected thermometer has been attached to the line, and its readings be taken at the same time, we have a measure of the temperature to which the instrument has been subjected. Knowing the dimensions of the instrument in every particular, and its behaviour under varying conditions of temperature, we can subtract from the whole reading of the instrument that which is due to temperature, and the remainder is that due to pressure. If the coefficient of apparent compressibility of the liquid be known, the depth is given at once.

Attention was principally directed to determining the apparent compressibility of distilled water and some other liquids by means of the sounding line, that is to say, using the sounding line as the gauge of pressure, and taking particular care to observe that these experiments were made when the sounding was not vitiated by perturbing causes. When currents are present, they are always very evident from the behaviour of the sounding line. If the sounding line remain vertical during the whole of the sounding, then it is perfectly certain that there is no disturbance from currents either at the the surface or below. If there be a current of any appreciable force, the sounding line begins to wander about, and has to be followed by the ship. This is an operation of considerable delicacy, even in good weather, and in bad weather, when the winds and currents cross and complicate each other, it is one which calls for the highest skill on the part of the officer in charge. There was, however, no difficulty in determining whether a sounding had been good, and only such soundings, free from vitiation by any of the above-mentioned perturbing causes, were used for this purpose.

In fig. 35 the stem of the water piezometer is represented as being swelled into a small bulb at F. The purpose of this bulb is to enable the instrument to be used at depths so great that with a uniform stem the contraction produced would be equal to the whole volume of the stem. The capacity of F is equal to the contractions due to the fall of temperature and the increase of pressure produced by the first 1000 or 1500 fathoms of depth, so that the instrument would only register depths greater than 1000 or 1500 fathoms, but it would do so with almost as much precision as can be obtained at less depths.

The observations which have been taken as a basis for determinations of depth were made in the latter part of the year 1875, in the South Pacific Ocean. They were twenty in number, and were made at depths varying from 500 to 2300 fathoms, and at temperatures varying from 1°·4 to 4°·03 C. The mean compressibility of water determined from these observations was 0·0008986 per 100 fathoms of sea water, the extreme values being 0·000915 and 0·000882. Observations made at greater depths in the North Pacific, gave as a mean of six observations at depths varying from 2740 to 3125 fathoms the value 0·000878, indicating a slight diminution in the coefficient of compression at very high pressures.

The change of volume of water with change of temperature at the low temperatures found in the deep sea is very slight. The change of volume of mercury, however, for all ordinary temperatures is very considerable. On the other hand, the compressibility of water, or its sensibility to change of volume with change of pressure is very great, whereas that of mercury is very small. Consequently, by sending a pair of these instruments down on the sounding line, and reading them when they come up, two independent values of the sum of the effects of change of temperature and of pressure are obtained. Taking as the first approximation to the depth the length of the sounding line, applying it to the reading of the mercury instrument, and so correcting it for pressure, we have a first approximation to the temperature; applying this temperature to the reading of the water piezometer, we obtain a second approximation to the depth, indeed, practically the true depth. The reading of the mercury piezometer now being corrected for pressure by this value of the true depth, we have a second approximation to the temperature. In fact we have now practically the true depth and the true temperature.

Fig. 36*a* refers to the water piezometer, and fig. 36*b* to the mercury piezometer; the thick lines represent the apparent changes of volume for changes of pressure, and the dotted lines the apparent changes of volume for changes of temperature. Distances measured along the horizontal line of abscissæ represent depths on the scale of 0·01 inch to a fathom, and temperatures on the scale of 0·1 inch to a degree centigrade. Distances measured along the line of ordinates represent scale divisions (millimetres) on the scale of 0·1 inch to a division. For 100 fathoms of depth the apparent contraction of the mercury instrument was 0·7 millimetre on the stem; in the water instrument the apparent contraction for 100 fathoms was somewhat over 7·8 millimetres. Considering that the effect of a change of temperature of 1° C. causes an apparent change of volume in the mercury piezometer represented by about 2·5 millimetres, while in the water piezometer at the low temperature always found in the deep sea the temperature may be anything between 0° and 10° C. without altering the apparent volume of the water by more than 2 millimetres on the stem, we see that an error in determination of the depth of 100 fathoms would only make a difference in the reading of the mercury instrument of about 0·6 millimetre, equivalent to a difference of temperature of about 0°·25 C. Therefore, applying the possibly erroneous depth given by the sounding line to "clear" the reading of the mercury piezometer for effect of pressure, we obtain a first approximation to the temperature which would almost always be within half a degree of the truth, but which might occasionally differ more than a degree from it. Using the temperature thus found to clear the reading of the water piezometer for the effect of temperature, we obtain a second approximation to the depth which cannot differ appreciably from the true depth. Applying the depth so found to clear the reading of the mercury instrument for effect of pressure, we obtain a second approximation to the temperature which cannot differ appreciably from the truth. This process of gradual approximation may of course be carried as much farther as we please, but the results obtained in the second approximation may under all circumstances be taken as representing the truth.

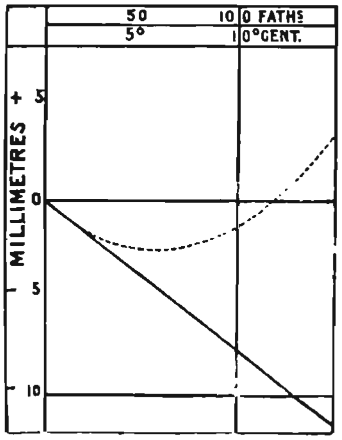

FIG. 36a.—Diagram for Water Piezometer.

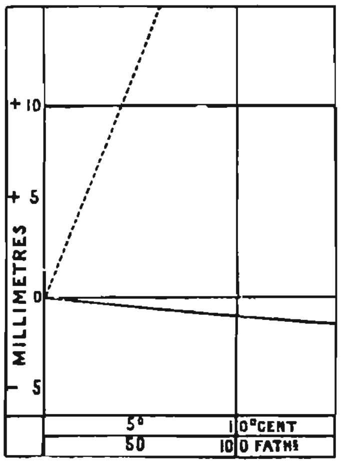

FIG. 36b.—Diagram for Mercury Piezometer.

The use of water for filling piezometers to be used in the determination of great depths is not to be recommended, as its elasticity varies greatly with the temperature, so that a small error in the determination of the temperature has a serious effect on the depth as given by the piezometer.

The piezometer, when filled with sea water, shows directly, when corrected for the contraction of the glass, the density of the water at the depth where it registers. A certain number of observations in this direction was made during the cruise.

Specific Gravity of Ocean Water.—It has been shown above that the density of the water, in so far as it depends on temperature and pressure, can be directly observed with the piezometer. When the salinity of the water varies, and it is required to observe its variations, it is necessary, by one method or another, to measure and weigh a mass of the liquid. This was effected satisfactorily by the use of a hydrometer (fig. 37), specially designed by Mr. Buchanan for the purpose.[1]

The following is a description of the instrument used for the whole of the work done during the cruise. The stem, which carries a millimetre scale 10 centimetres long, has an outside diameter of about 3 millimetres, the external volume of the divided portion being 0·8650 cubic centimetre; the mean volume of the body is 160·277 c.c., and the weight of the glass instrument is 160·2128 grammes. With this volume and weight, it floats in distilled water of 16° C. at about the lowest division (100) of the scale. In order to make it serviceable for denser waters, a small brass table is made to rest on the top of the stem, of such a weight that it depresses the instrument in distilled water of 16° C. to about the topmost division (0) of the scale. By means of a series of six weights, multiples by 1, 2, 3, 4, 5, and 6, of the weight of the table, specific gravities between 1·00000 and 1·03400 can be observed. It is not necessary that these weights should be accurate multiples of the weight of the table; it is sufficient if they approach it within a few milligrammes, and their actual weight be known with accuracy. The weights of the table and of the weights in actual use were :—

Weight of table,		0·8360	grammes.
,, of weight No.	I.	0·8560	,,
,, ,,	II.	1·6010	,,
,, ,,	III.	2·4225	,,
,, ,,	IV.	3·2145	,,
,, ,,	V.	4·0710	,,
,, ,,	VI.	4·8245	,,

For oceanic waters, the hydrometer is always used with the table, and either No. IV. or No. V. weight.

For using this instrument at sea, about 900 c.c. of sea water are taken, and the containing cylinder placed on a swinging table, in a position as near the centre of the ship as possible (fig. 38). The observation with the hydrometer, loaded with the necessary table and weight, is then effected in the ordinary way, the accuracy of the readings being but little affected by rolling; pitching, however, is found to have a distinctly disturbing effect, and when it is in any way violent, it is advisable to store the specimen of water till the weather improves.


FIG. 37.—Hydrometer.

The temperature of the water at the time of observation is determined by one of

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[1] Phys. Chem. Chall. Exp., part ii., 1884.

Geissler's "normal" or standard thermometers, graduated into tenths of a degree centigrade; and it is essential for the accuracy of the results that the water, during the observations of the hydrometer, should be sensibly at the same temperature as the atmosphere, otherwise the changing temperature of the water makes the readings of both the hydrometer and the thermometer uncertain.

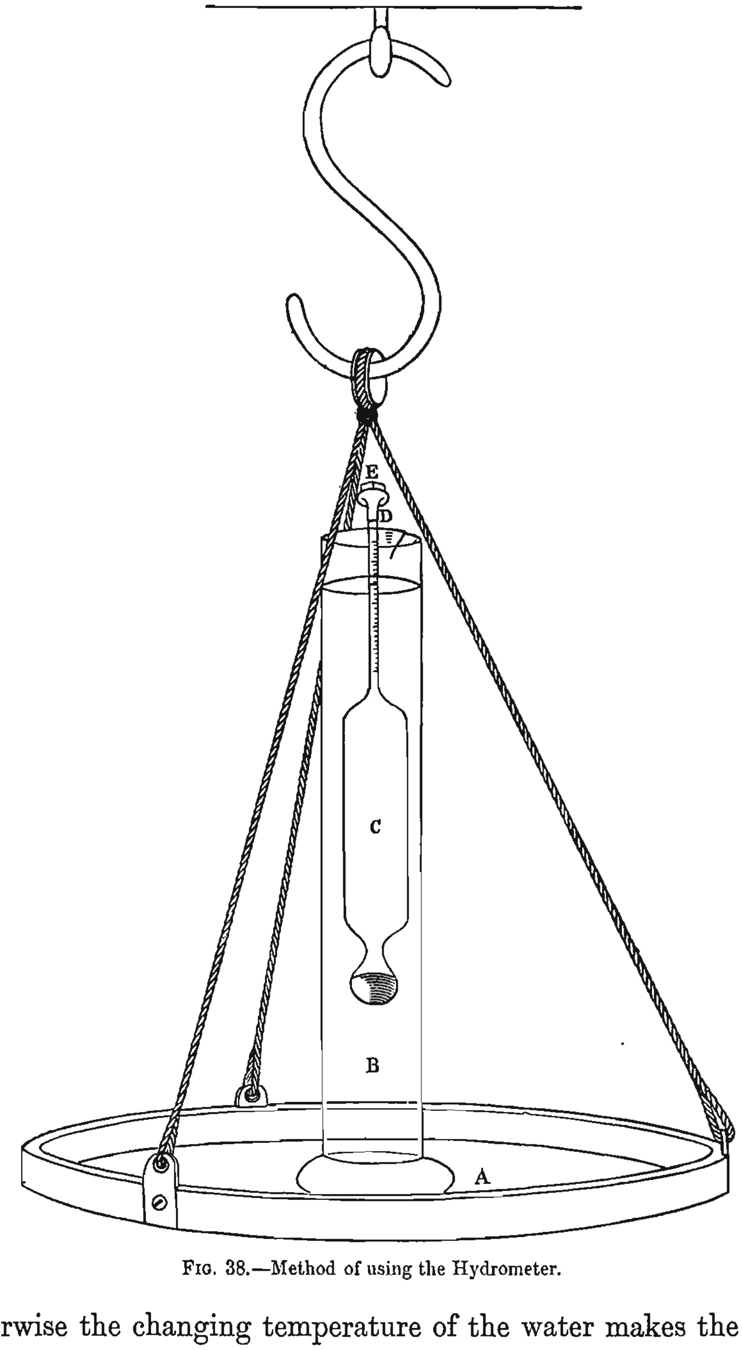

Fig. 38.—Method of using the Hydrometer.

Collection of Samples of Ocean Water.—Water from the *surface* was collected in the ordinary way in a bucket. Water from the *bottom* was collected in an instrument specially constructed for the purpose.

The Slip Water-Bottle consists essentially of a brass cylinder A (fig. 39), which slides up and down a metal shank B, of at least twice its length. When the water-bottle is sent down, the cylinder is fixed in the upper part of the shank; and when it arrives at the bottom it is released and falls down to the lower part, where it rests on the lower of two accurately ground valves C and D, which fit into two conical surfaces on the inside of its upper and under edges. Thus the water which surrounds the shank at the moment of slipping is securely enclosed. The proper working of the instrument is dependent on the shank remaining straight; any bend in it would cause the valves to leak. In the instrument used in the German North Sea Expedition[1] this was provided for by the two valves being connected by a short iron rod, and the upper valve with the slipping arrangement by means of four slighter ones. But for deep soundings, where it is attached to a line along with a weight of three and often four hundredweight, greater strength is necessary to enable it to withstand the knocks to which, even with the utmost care, it is exposed, in being hoisted over the ship's side in a sea-way. Mr. Milne of Edinburgh, into whose hands the construction of the instrument was put, secured this end in a way which adds equally to the elegance and to the strength of the instrument. The shank and valves are one solid brass casting of the shape shown in the figure, the cylinder is another, and the slipping arrangement E, fixed to the end of a rod F of suitable length and great stoutness, is screwed into the top of the shank, the screw being secured by a rivet. The water enclosed is removed by means of a tap G, passing through the lower

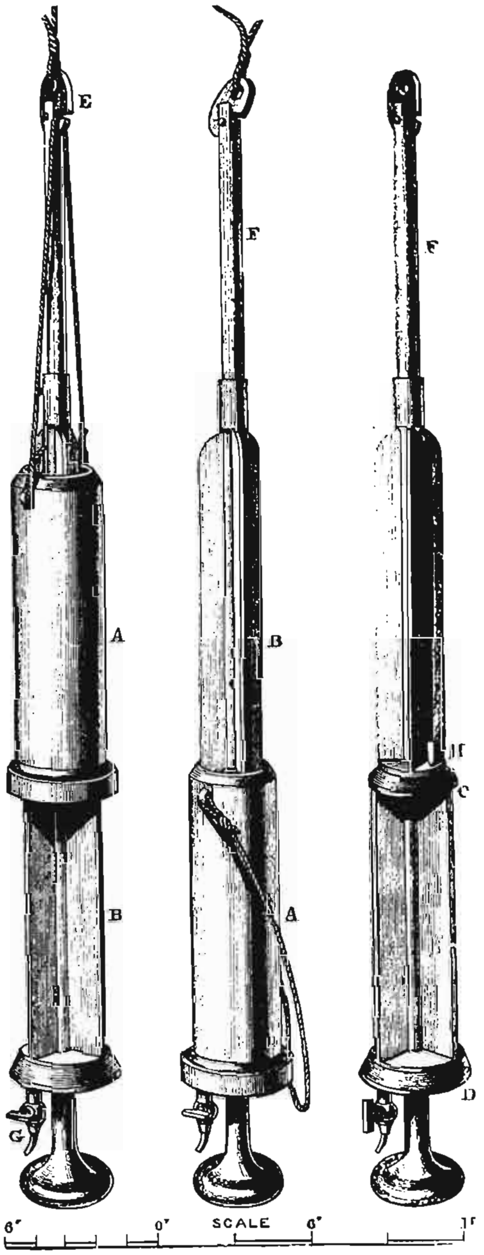

FIG. 39.—The Slip Water-Bottle.

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[1] Die Expedition zur physicalisch-chemischen und biologischen Untersuchung der Nordsee im Sommer 1872, Berlin, 1875.

valve, air being at the same time admitted at the top by the removal of a plug H, from a hole in the upper valve. The lower valve and stop-cock are protected from damage when striking against the ground by the casting extending about six inches below the valve. The arrangement and dimensions of the parts are sufficiently apparent from the woodcut to make further description unnecessary. The slipping arrangement is in principle the same as that used on Brooke's sounding rod.

In order to adapt this water-bottle to collecting water at intermediate depths, it is fitted with a slipping plate (see fig. 40), furnished with a metal flap Q, which depresses it when the motion of the instrument is reversed. It is inserted into a slot S, immediately below the usual slipping plate to which the sounding line is attached, and differs from the latter in having a deeper notch R, and having a slot instead of a hole for the reception of the pin T, round which it turns. The object of this slot is, that after the string has been cast free, the flap may fall down close alongside the rod and afford as little resistance as possible in pulling up. In using the instrument, it must be let go before the flap enters the water, and not checked until the depth desired has been reached. On board the Challenger the slip water-bottle was only used to obtain specimens from the bottom.

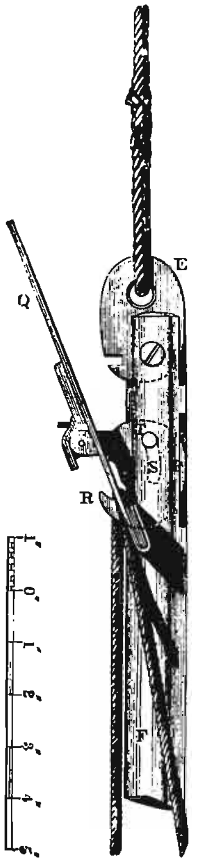

FIG. 40.—Instrument for slipping the Cylinder at intermediate depths.

The Stop-cock Water-Bottle.—Water from *intermediate* depths is obtained in an instrument represented in fig. 41. It is made entirely of brass, which, however, might advantageously be nickel-plated. It consists of a cylinder A, terminated at both ends by similar stop-cocks B, B, which are connected by the rod C. This rod carries, near its upper extremity, a piece of stout sheet brass E, 10 centimetres long by 15 broad, soldered to the casting F, which is movable about an axis. The function of this part of the apparatus will be more easily explained by describing the manipulations necessary when collecting water.

When intermediate water is to be obtained, the water-bottle is firmly attached to the sounding line, which carries at its end usually a 56 lb. or a 1 cwt. lead; the stop-cocks are then opened, giving them, with the rod C, the position represented in the left hand figure. The line is then lowered carefully by hand, until the water-bottle is close to the surface, when it is let go, and the line allowed to run out without a check. During its passage downwards, the water courses freely through it, being considerably assisted by the conical end pieces M, M. When the requisite depth has been reached, the line is checked, hauled in a few fathoms, then let go, checked again at the same mark, and finally hauled in altogether by the donkey-engine. When the line is hauled in at first, the flap E falls down into a horizontal position, when it is caught by the movable piece of brass F, and is supported on the side opposite to E, by the rod G, which rests on the spiral spring H. The water rushing past E when thus in a horizontal position, exercises a sufficient pressure upon the rod to close the stop-cocks B, B. When the speed with which the bottle is hauled through the water is increased, the pressure on E becomes so great that it overcomes the tension of the spring H, and F passes the catch G, and the rest of the journey upwards is performed with the flap E hanging down, thus offering the least possible resistance to the

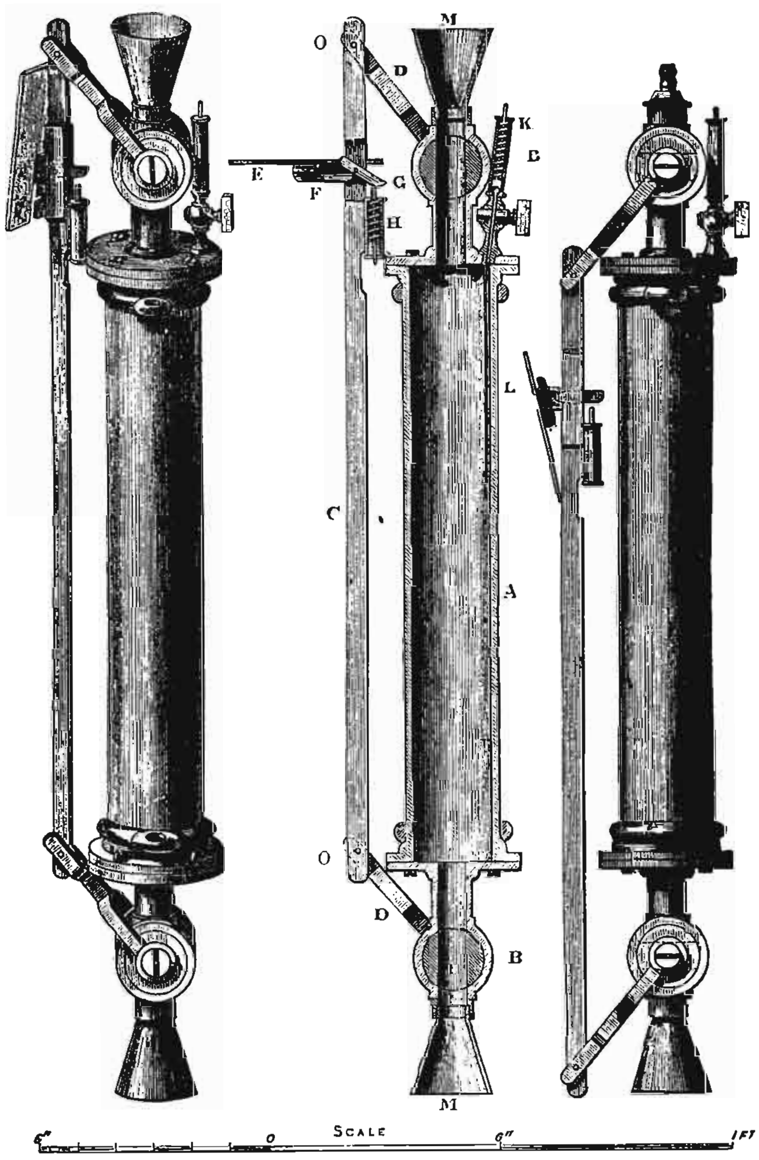

FIG. 41.--Stop-cock Water-Bottle, in section, closed and open.

water. The object of at first hauling in only a couple of fathoms or so, and letting the line go again, is to ensure the cocks being closed; for, supposing after the first hauling in they were not quite closed, by letting the instrument descend through the water, the flap E sets itself again, and, on heaving in, it shuts down the stop-cocks, which were before but partially closed; or, if they were closed before, it shuts them the tighter. When the water-bottle has been brought up, it is only necessary to substitute for the lowermost brass funnel a small nozzle, when the water may be tapped into any vessel destined to receive it. This done, the bottle may be at once lowered to any other required depth, much time being saved by not having to detach it each time. At the upper end of the bottle a small spring safety-valve K is introduced, in order that the considerably denser water from below may be able to make room for itself as the surface is approached. In order that the instrument may do its work properly, it is evident that, firstly, the stop-cocks should be so stiff that the weight attached to their levers be not sufficient to close them, and secondly, the spring H should be so strong as to ensure the shutting of the cocks before it gives way itself. These conditions are secured by the following means of adjustment. The stop-cocks can be made stiffer in the usual way, by tightening the screws which secure the "plugs" in the "barrels"; the tension of the spring H can be increased or diminished by means of a screw at the lower end of the tube containing it; and the mobility of the stop-cocks can be further regulated by means of the screws O, O. Although from this description the operation of adjustment may appear complicated, it is in fact, practically, very simple. After being once used, it is rare that any further adjustment is required than a turn of the screws O, O.

The diameter of the apertures at either end is necessarily smaller than that of the cylinder; it is therefore impossible for the water in it to be entirely changed while it descends through a distance equal to its own length. It became a question, therefore, for experiment to decide what actually was the rate of change of water. To this end, a few experiments were made in a freshwater lake. The bottle being filled with water containing some yellow prussiate of potash, was sunk in the lake, until the surface of the water was on a level with the upper stop-cock, when the stop-cocks were opened and the line let go. On being brought up again, the contents were tested with solution of perchloride of iron. It was found that when the bottle had been sunk to a depth of a fathom and a half the water had been entirely changed, the iron solution being wholly without action on it. It is certain, then, that the water obtained by this means is an average of the last two fathoms through which the bottle has passed.

The weight used as a sinker should be chosen so as to impart sufficient velocity not to lose time unnecessarily over the operation, and at the same time not to give an excessive velocity at the depth where the water is to be collected, because the rate of change of water depends on the friction of the water inside the bottle, and so on the velocity of descent. In practice, for depths over 100 fathoms a weight of 112 lbs. was used, and for depths from 25 to 100 fathoms a weight of 56 lbs. was used, whilst for depths less than 25 fathoms the weight of the bottle itself was sufficient. The velocity of descent at the depth where the water is to be collected should not exceed 12 feet per second. The mean velocity of descent for the interval between 75 and 100 fathoms from the surface was, with 56 lbs. 9 feet, and with 112 lbs. 11½ feet per second.

When once let go, it is essential that the line should run out to the required depth without a check; then, however, it is immaterial, as far as the water-bottle is concerned, what interruptions occur in heaving in. The fulfilment of the condition of running out without a check never presented any difficulty on board the Challenger, depending as it does on the care of those who tend the line. When, however, by accident a check does occur, the line is stopped, and the water-bottle brought up, reset and sent down again. In order to utilise any such accidents, it is usual to take the water from the greatest depth first, then if a check should occur, it may do so at one of the desired intermediate depths, and so no time would be lost.

Buchanan's Improved Stop-cock Water-Bottle with Depth Gauge.—During the whole of the cruise, when it was in daily use, Mr. Buchanan felt that the mechanism for relieving the pressure in the instrument as it came towards the surface ought to be made to register the depth at which it closed. It was at once obvious that if the volume of the instrument could be allowed to increase, and its increase could be measured, while no water was allowed to escape, a method would be found. If instead of the safety valve K, a calibrated plunger penetrated through a water-tight joint into the body of the instrument, then after closing at a certain depth, the plunger would be thrust out as the instrument rose. At the first glance this seems a simple and effective method, but when the actual dimensions, which the plunger must have, come to be considered, it is evident that the method is impracticable when dealing with water from any considerable depth. This will be seen from the following considerations. The absolute compressibility of sea water may be taken at 0·00085 per 100 fathoms, which means that one litre contracts by 0·85 c.c. for every hundred fathoms of depth; consequently, every litre of water collected below, expands by about 0·85 c.c. per hundred fathoms of ascent. In a water-bottle of two litres capacity, and to be used at no greater depth than 1000 fathoms, the plunger would have a play involving a volume of 16 c.c. As from the nature of the instrument it is important to have the ratio of the diameter of the stop-cocks to that of the cylinder as large as possible, there is no room for a wide plunger in the cover of the instrument, and if it is made narrow, its length puts it out of the question. Since the close of the cruise, experiments made by Mr. Buchanan on board the "Mallard," have resulted in a fairly satisfactory practical solution of the problem. The water-bottle as altered is shown in fig. 42. In it the spring safety valve is replaced by a nozzle K, screwed water-tight into the top. To this nozzle inside the bottle is attached an elastic vessel capable of collapsing under slight pressure, and returning to its original volume when the pressure is relieved. For most purposes a piece of india-rubber tube, closed at the end as represented in the cut, suffices. Before sending the bottle down, the inside of the india-rubber tube and nozzle is filled up with water. When it reaches the required depth the bottle closes on its own volume of water. As it rises the water expands, and the collapsible vessel easily makes room for the increased volume. After having arrived at the surface, the small pet-cock P is opened, and the water escaping is caught in a graduated vessel. Water runs out of this cock until the internal india-rubber tube has dilated to its original

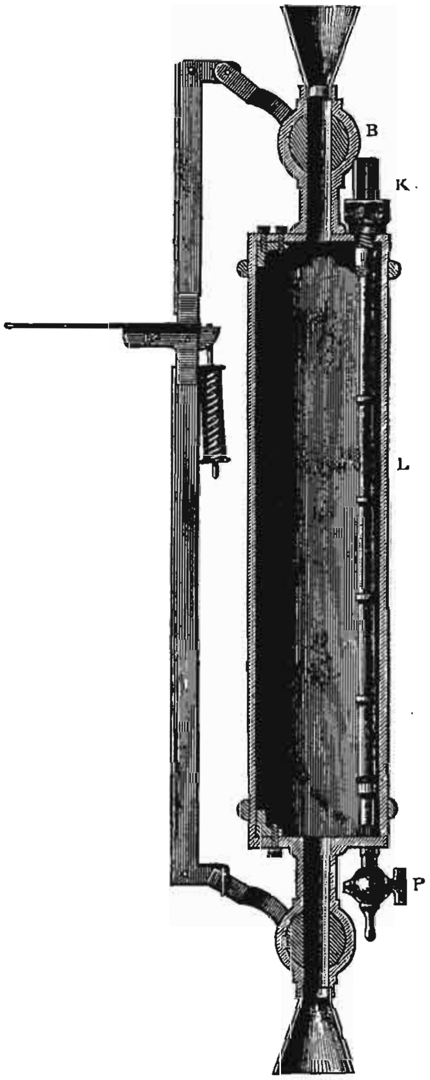

Fig. 42.—Buchanan's Improved Stop-cock Water-Bottle in section.

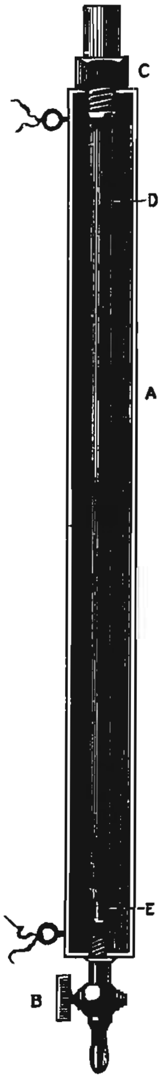

Fig. 43.—Depth Gauge.

volume, being kept itself full of water. From the volume of the overflow as compared with that of the bottle the depth at which it closed can be readily calculated.

The same principle has also been applied in the construction of a sounding machine for ascertaining the depth. A straight brass tube A (fig. 43) is closed at the lower end by a stop-cock B, and at the upper end by a nozzle C, to which the india-rubber tube D is attached inside the tube A. D is closed by a valve E, opening downwards. As this instrument sinks, water enters through C, D, and E into the brass tube A. When it begins to ascend, the water cannot get back through the valve E, and in expanding it crushes the tube D. On arrival at the surface, the excess of water is tapped off through B, and the depth calculated, regard being had to the temperature.

A water-bottle of peculiar and ingenious construction, used by Jacobsen in the German North Sea Expedition in the "Pommerania" in 1872,[1] was supplied to the Challenger, but was unfortunately mislaid at the fitting out, and notwithstanding repeated searches was not found till the ship returned. It is described by Dr. Jacobsen in the report of the above voyage, and also in Liebig's Annalen for May 1873.

Buchanan's Combined Sounding Tube and Water-Bottle.—Figs. 44, 45, 46, 47, represent a sounding tube with detaching weight, suitable for ordinary sounding with wire. With it good samples of the mud and of the bottom water are obtained without trouble. The instrument consists of the "water bottle" A, a tube about 18 inches long and $2\frac{1}{4}$ inches in diameter, of about one litre capacity. It has at each end a valve H, K, made of india-rubber, on a metal seating, opening upwards. Above the upper valve H, the shank C is screwed into the tube A, and below the lower one K, the mud tube B, which is 12 inches long and 1 inch in diameter, is screwed to A. Into the lower end of the mud tube B can be inserted the valve L, which consists of a piece of thin sheet brass, cut out like a comb, and bent round into a cylindrical shape. It is soldered to a stouter piece of brass tube, which fits into the end of B and is retained by a bayonet-joint. At the upper end of the shank C the tumbler D supports the weight E by the sling F, and is in its turn supported by the sounding line M.

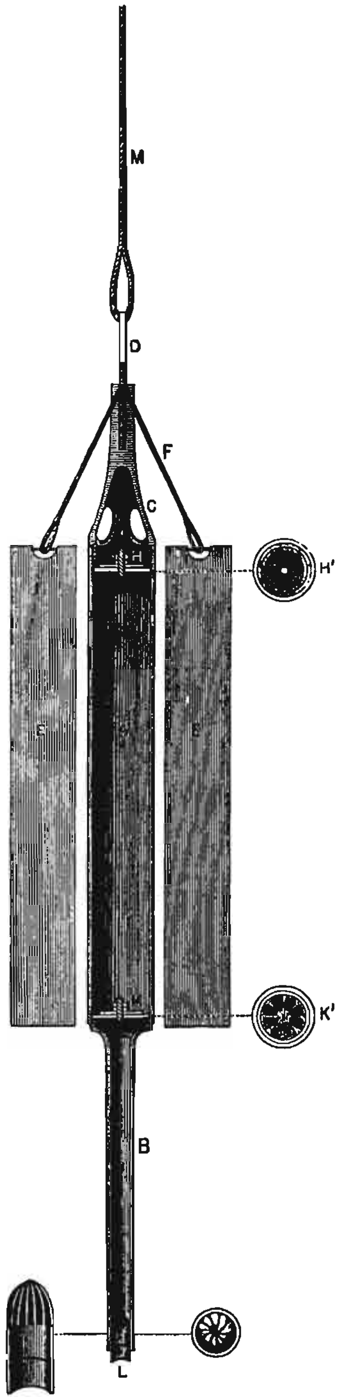

Fig. 44.—Buchanan's Combined Sounding Tube and Water-Bottle.

The details of the tumbler are shown in figs. 45, 46, 47. It will be seen that at its upper end it

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[1] Die Expedition zur physicalisch-chemischen und biologischen Untersuchung der Nordsee im Sommer 1872, Berlin, 1875.

has the hole *a*, into which the eye of the sounding line is spliced. At the lower end it has three notches, *b*, *c*, and *d*. If it is not wished to detach the weight, the sling supporting it is hooked into the notch *d*, which is considerably below the suspending axis. Consequently, when the tube reaches the bottom and the sounding line above slackens, the tumbler still preserves its upright attitude, and on heaving up, the sinker is recovered along with the tube. If the sinker is not to be recovered, the sling is hooked in the notch *b*, which is above the axis. When the tube reaches the bottom and the sounding line slackens, the pressure of the sling upsets the tumbler, which falls over into the position fig. 46. In getting into this position the weight drags the sling out of the notch *b*, and it falls into the notch *c*. Here it remains as long as the tube is at the bottom, exerting all its weight in pushing it into the ground. On heaving in, the tumbler is drawn into an upright position, when the sling slips free and the tube is brought up without the sinker. When it has been brought to the surface, it is found that the mud tube B is filled with a compact cylinder of mud, which by its weight has kept the india-rubber valves closed by drawing them tight down on their seats, and has therefore insured that the water enclosed at the bottom has not been contaminated by admixture with other water on the way up.

Fig. 45.

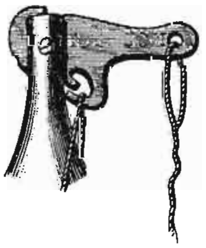

Fig. 46.

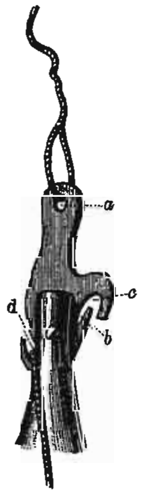

Fig. 47.

Disengaging Apparatus for Buchanan's Water Bottle.

The localities, even in mid ocean, where the bottom is "hard ground" are by no means rare, and if the tube just described be dropped on it with a 50 lb. sinker, the mud tube will be much disfigured; but if there be any loose material at all, such as gravel or coral, a little of it will be nearly sure to get entangled behind the comb valve. In the absence, however, of a mud plug, the bottom water will be valueless. As a rule, the bottom of the sea, whether deep or shallow, consists of mud sufficiently soft and tenacious to fill the mud tube throughout the greater part of its length with a compact plug, and if the tube B be screwed water-tight into the lower part of the tube A, it is retained in it just as a liquid is retained in a pipette. In soft mud, clay, Globigerina ooze, and the like, it is better to discard altogether the comb valve L, because it always offers some resistance to the entrance of the mud, and is not wanted to keep it in. In fact it not only offers resistance to the entrance of the mud, but as its diameter is necessarily somewhat smaller than that of the tube B, the mud cylinder is also of less diameter than B, and rests on the valve L, leaving a passage between the mud and B. This interferes with the action of the instrument as a mud-pipette, on which its efficiency as a water-bottle depends. The instruments are fitted with mud tubes of two sizes, namely, the smaller of 1 inch diameter, and the larger of 1¾ inches diameter. In the ordinary routine work of running a line of soundings the smaller size should be used and without the comb valve. It is screwed into A on the top of a thin leather washer to make the joint tight. At each sounding a sample of the mud and of the bottom water will be obtained. When the tube is brought on board the mud tube is unscrewed, any water that may be on the top of the mud cylinder is poured off, and the mud cylinder itself pushed out by a metal plunger which just fits the tube. The water is simply poured out of the bottle into any convenient vessel. If the gases dissolved in the water are to be examined, then it must be drawn off by a siphon passed through the upper valve and down to the bottom of the tube.

This sounding tube has been very successfully used on board the ships "Dacia" and "International," belonging to the India-rubber, Gutta-percha and Telegraph Works Company, while surveying the route for the cable from Cadiz to the Canary Islands. It has the advantage that on board such ships, where rapidity of work is of the greatest importance, good samples of mud and of bottom water are obtained in the course of the ordinary routine work, and without having to use any extra instruments. The weight of the sinkers used was 60 lbs., but 50 lbs. is quite heavy enough. When the sinker is to be recovered its weight should not exceed 30 lbs.

Method of Taking Temperatures.—The actual method adopted on board the Challenger for obtaining the temperature below the surface was as follows :—A temperature line, of No. 1 sounding rope, 1500 fathoms in length, was kept on a separate reel, and a set of accumulators, twenty in number, fitted with a patent block at their end for the line to reeve through, was attached to either the fore or main yardarm, generally the main, so as to prevent the rolling of the ship bringing an undue strain on the line, and to keep it well clear of the ship's side. The rope was marked at every 10 fathoms for the first 200 fathoms, at every 25 fathoms for the next 100, and at every 50 fathoms to 700 fathoms, after which it was only marked at the 100 fathoms. Fifty fathoms were allowed for stray line at the beginning. It was first rove through a leading block on the deck, for the convenience of bringing it to the drum of the engine, then through the block attached to the accumulators, and then through the thimble of a "lizard," after which a cup lead was attached to it, of from ½ to 1½ cwt. according to circumstances. The weight was then lowered into the water 50 fathoms, or until the first mark on the line was level with the hammock rail, when the bight of the line was hauled in to the rail by means of the lizard, and a thermometer "bent on"; the bight of the line was then carefully eased out by the lizard until it hung perpendicularly from the yardarm, when 100 fathoms were veered and another thermometer attached, and so on until eight had been "stopped on." Only that number of thermometers was used at a time, as there is always a risk of the sounding line parting and the instruments being lost. As a rule it was not deemed necessary to obtain temperatures at every 100 fathoms below 1500 fathoms, as the difference of temperature between that depth and the bottom is very small. The observations were generally first made between 800 and 1500 fathoms. When 1500 fathoms of line had been "paid out," and the mark on the line carefully brought level with the surface of the water, the line was secured and kept quite perpendicular for five minutes, each thermometer then registered the temperature of the water at the depth to which it had been lowered. The line was then hove in, and as each thermometer reached the level of the sounding platform, or hammock rail, it was hauled in by the lizard, unbent, carefully read off, and registered. The temperatures were then taken from the surface to 700 fathoms in the same manner, or when they varied much they were taken at intervals of 25 or even 10 fathoms between the thermometers.

The results of these temperature observations were then corrected for errors of zero point, after which they were plotted on a paper of equal squares, specially provided for that purpose, and a curve of temperatures drawn, so that the temperature at any depth could be ascertained. The curve shows directly whether any of the results disagree with the temperatures shown by the main body of the thermometers, and if such were the case, the temperatures at those depths were taken again. When the temperature observations between any two places had been completed, a section was constructed from the temperature curves showing the relative positions of the isotherms from the surface to the bottom. The observations and curves used in the production of the Diagrams of Temperature given in this volume are published as Part III. of the Physics and Chemistry of the Expedition.