XIII.—REPORT ON THE THERMOMETERS OF THE U. S. COMMISSION OF FISH AND FISHERIES.

By J. H. Kidder, M. D.

CORRECTION.

In the earlier operations of the Commission its thermometers were used as they came from the makers, without previous comparison with standards. As the number of temperature observations increased, and their importance became more evident, instrumental errors were reported from time to time, which tended to discredit some of the observations, and to weaken the force of the inferences deduced from them. In the comparison of temperatures observed at considerable depths in the sea, where the differences recorded are small, instrumental errors become particularly important, and it was decided by the Commissioner that all the thermometers used by the Commission should be compared and their errors noted before their issue.

This duty was assigned to me early in the autumn of 1883, and the report which follows covers the period from December 12, 1883, when the first corrections were made, to May 1, 1885.

At the outset comparisons were made with two standard thermometers, manufactured by L. Casella, of London, one graduated according to the Fahrenheit and the other to the centigrade scale. These instruments had been procured through the London agent of the Smithsonian Institution, and had been verified at the Kew Observatory. The tubes were certified to by the maker as having been thoroughly "seasoned" before pointing, and the centigrade which survives (the Fahrenheit was broken December 20, 1883), shows no change in the zero point up to this writing.

Subsequently (February 28, 1884), two fine standards, both graduated according to the Fahrenheit scale, were received from J. Hicks, of London, which had also been verified at the Kew Observatory. One of these instruments has been used in all comparisons since the day of receipt. They are pointed to fifths of a degree, allowing a good reading to tenths of a degree, and cover the range from 10° to 120° F.

The corrections were got at first by immersing the instruments to be compared, together with the standard, in water contained in a large cylindrical glass vessel, provided with a ring stirrer and covered by a block of wood perforated so as to allow the instruments to pass through and to hold them in place. By agitating this stirrer, which was covered with muslin to guard against breakage of the thermometers, up and down, the water contained in the vessel was thoroughly mixed, and an uniform temperature obtained throughout.

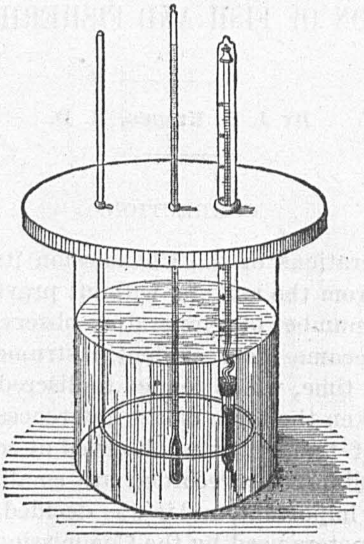

FIG 1.—Small comparing jar.

This simple contrivance answers very well for ordinary thermometers, the bulbs of which are exposed directly to the water, but admits only two or three instruments at a time, owing to the comparatively small volume of water which it contains. A square aquarium tank, with plate-glass sides and slate bottom, was therefore procured from E. W. Taxis, of Philadelphia (received February 26, 1884). This tank is 18 inches square by 16 inches high, and contains about 22 gallons of water. Within the tank is a circular brass frame, to which a large number of thermometers may be attached at once, and which may be revolved about a central spindle by means of a winch-handle at the top. The water is stirred to an uniform temperature by turning the winch-handle, and is in sufficiently large volume to maintain a sensibly constant temperature for five minutes. The temperatures of the thermometers to be compared and of the standard can be read in this apparatus through the plate-glass sides, and a full series of readings, from 32° to 100°, can be taken without removing the thermometers from the frame.

For the "zero point," or 32° F., the thermometers to be tested are immersed in finely broken ice, contained in large glass percolators, 12 inches wide by 12 inches deep, with a small opening at the bottom for the escape of water as fast as the ice melts. These percolators are supported upon suitable iron tripods, and will hold eight thermometers each, without so crowding the instruments that one shall affect another.

For deep-sea thermometers, which are protected against water pressure by a double glass bulb, and which are therefore slow, and require exposure to a constant temperature for at least ten minutes, a contrivance is used, for the plan of which I am indebted to Mr. T. Russell, of the U. S. Signal Service, and which is illustrated by the sectional diagram, Fig. 2. A is a galvanized-iron can (in this case a 3½ gallon lard can), 13½ inches high by 11 inches wide; B is an earthenware jar, 11 inches high by 8 inches wide; C is a tinned copper pot, fitting pretty closely into B, and suspended by a flange at the top. Inside of C is a copper frame, movable about a central spindle, to which the thermometers are attached. A ring stirrer moves in the space between A and B, and another in the space between C and the thermometer frame. When the temperatures to be observed are below that of the air, the spaces between A and B and within C are filled with water, that in the outer space being from 5° to 10° colder than that in contact with the thermometers. It is advisable that these latter should be immersed for a time in water near the temperature sought, before transferring them to the comparing jar. By agitating both bodies of water briskly with the stirrers, and observing the standard thermometer (in the inner jar) from

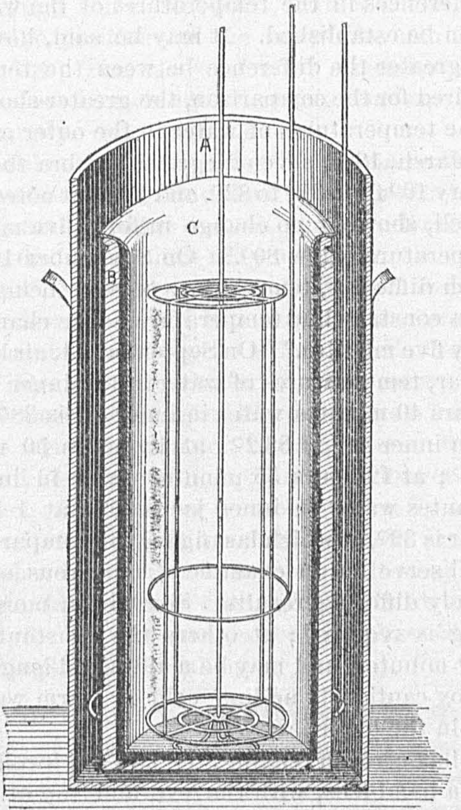

FIG. 2.—Comparing jar for deep-sea thermometers.

time to time, a sensibly constant temperature will at length be reached, at which the gain in temperature of the water in the inner jar by contact with the warmer air at its surface is very satisfactorily compensated by its loss through the air space between B and C and the badly conducting walls of B. For temperatures higher than that of the air, the water in the outer jar must be warmer than that in the inner. No positive rule for differences in the temperatures of the water in the inner and outer jar can be established. It may be said, however, in general terms, that the greater the difference between the temperature of the air and that desired for the comparison, the greater should be the difference between the temperatures of water in the outer and inner jars.

On the 13th March, 1884, seven Negretti-Zambra thermometers were compared at every 10° from 32° to 82°, and I find it noted that "the apparatus worked well, showing no change in forty-five minutes exceeding 0.1° at any temperature below 80°." On September 10, it is noted that "there was much difficulty, temperature of room being 86°, in keeping the water near a constant low temperature. The change was very regularly 0.2° every five minutes." On September 11, air being 82°, ice and water in outer jar, temperatures of water in the inner jar varied as follows: At 12 hours 40 minutes water in inner jar is 38°; at 12 hours 45 minutes water in inner jar is 38.2°; at 12 hours 50 minutes water in inner jar is 38.6°; at 12 hours 55 minutes water in inner jar is 38.6°; at 1 hour 0 minutes water in inner jar is 39°; at 1 hour 10 minutes water in inner jar is 39°, at which last figure the comparisons were made.

The above will serve as an example of numerous series of observations, with widely differing results. Sometimes more than an hour's patient watching is required; at others the constant temperature is reached in a few minutes, and may be maintained long enough for practical purposes by cautiously adding cold or warm water, as the case may be, to that in the outer jar.

To avoid parallax error in reading, the jars are levelled, and readings taken by aid of a hand-lens, with the eye and top of the mercury column at the level of the top of the outer jar, across the two sides of which the reading is "sighted," the thermometer being held in contact with one of the walls of the jar, and parallel with the central spindle of the frame, to insure its perpendicularity. Comparisons of readings taken in this simple way with readings taken by cathetometer, the thermometer being secured in a perpendicular position, show no perceptible error.

Since none of the thermometers in general use by the Commission are pointed to divisions less than 1° F., or need to be corrected for its purposes at temperatures above 100°, the contrivances above described have been found to afford as great accuracy as is practically required.*

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* For a good description, with illustrations, of the more exact methods followed at the Kew Observatory, see Mr. Francis Galton's paper in the Proceedings of the Royal Society of London for March 15, 1877 (vol. xxvi, p. 84), entitled "A description of the process for verifying thermometers at the Kew Observatory."

Corrections are furnished to the nearest (estimated) 0.1°, with a probable error in estimation not exceeding 0.2°.

I have tested a number of different observers, and find that the probable parallax error in reading, by those who use the thermometers in practice, is not far from 0.3°. It seems to be a difficult thing to hold a thermometer perpendicularly opposite the eye, some observers tipping it forward a little, and some backward, with a consequent change in the apparent relative positions of the top of the mercury column and of the scale behind it. This cause of error applies to all observations made previous to last June, when a reading lens was contrived which now insures uniformity. (See p. [28].)

There is a probable small inaccuracy in the comparisons of "Miller-Casella" thermometers, due to the difficulty of reproducing in laboratory comparisons the great pressures met with at considerable depths in the sea, which will be discussed more fully hereafter.

Up to May 1, 1885, 185 thermometers have been compared in one or other of the ways described. Of this number, 60 were Negretti-Zambra deep-sea thermometers; 15 were Miller-Casella deep-sea thermometers; 31 were Wilder protected water thermometers; 16 Wilder deck thermometers; 14 were salinometer thermometers; 7 were Green deck thermometers; 12 were hygrometer thermometers; 6 were standard thermometers; and 24 were various patterns no longer in use.

When issued each thermometer is accompanied by a printed blank, corresponding to a stub slip in the rating book, and filled out for each point at which a comparison is made. Following is a copy of one of these comparison blanks, with corresponding stub slips, the corrections being stated, for convenience, on the blank issued, at intervals of 10°, near the readings actually taken.

U. S. COMMISSION, FISH AND FISHERIES.

THERMOMETER RATING.

F. C. No......

Maker's No...............

By ....

U. S. COMMISSION, FISH AND FISHERIES.

FAHRENHEIT. THERMOMETER RATING. CENTIGRADE.

Rated with attachments.

F. C. No................ MAKER'S No...............

By........................, ...

Corrections to be applied to the scale readings, determined by comparison with the standard instruments of the Fish Commission.

NOTE I.—When the sign of the correction is +, the quantity is to be *added* to the observed reading, and when —, to be *subtracted* from it.
II.—This instrument should be returned within two years to be tested again.

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THE INSTRUMENT.

The following are the kinds of thermometers principally used by the Commission:

(1) *Deck thermometers* (Fig. 3).—These are in form like the "brewer's thermometers" of the trade; plain tubes with round bulbs, graduated upon a white metal scale to divisions of 2° F., and ranging from — 30° to + 120° F. They are inclosed in plain copper cases, open in front, with a cup at the bottom, perforated by a central hole. This cup can be closed by a cork and will then hold water. Made by Charles Wilder, of Peterborough, N. H., in two sizes, 10 inches and 14 inches long, used mostly for air temperatures and for temperatures of surface water.

These instruments, although cheap and not pointed to less than 2°, are now very trustworthy, the maker furnishing the Commission with "seasoned" tubes. The first seven received showed a maximum error of 1.1°, minimum 0°, and mean of 0.32°, between 32° and 92°. The last nine are much better, showing a maximum error of 0.5°, minimum of 0°, and mean of 0.1°. The spaces in graduation are wide, and might profitably be divided so as to indicate single degrees.

Six deck thermometers, of similar form to those above described, made by J. & H. J. Green, of New York, are graduated upon the stems to intervals of 1°, and rate with remarkable uniformity, with a maximum error of 0.3°, minimum of 0°, and mean of 0.1°.

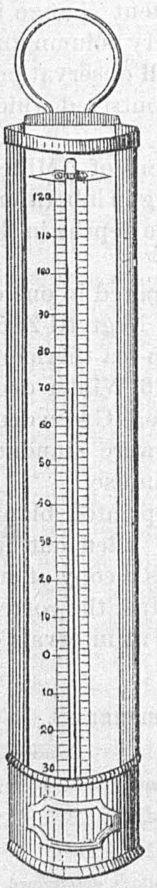

FIG. 3.—Deck thermometer.

(2) "*Protected" thermometers*, with round bulbs, graduated upon a white-metal scale to 1° intervals, and ranging from — 30° to 120° F. These thermometers are inclosed in cylindrical copper cases (devised by Professor Baird in 1873), with a hinged door in front. There is no perforation in the bottom of the cup, which is 3 inches long by 1¾ inches wide (Fig. 4); total length 12 inches; a stout ring at each end; made by Charles Wilder, of Peterborough, N. H.; used mostly for reading water temperatures at light-houses, and at shore stations of the Commission. For depths down to five fathoms these thermometers will indicate closely the temperature of the water below the surface, some of the water being caught and held by the cup at the bottom. The cylindrical copper cases protect the tubes from damage by striking against rocks, &c.

These thermometers also show a considerable improvement in accuracy since the maker has been furnishing seasoned tubes. The first four compared gave a maximum error of 1.3°, minimum of 0°, and mean of 0.58°. The next fifteen showed a maximum error of 1°, minimum 0°, mean 0.34°.

The last eleven showed a maximum error of 0.3°, minimum 0°, mean 0.07°. A single instrument gave the very large error of maximum 1.8°, minimum 1°, mean 1.5°, due to the sliding of the tube on the scale, the tip of the tube holding it at the top having been broken off. These instruments would be greatly improved by being pointed also upon their stems.

(3) *Thermometers attached to the Coast Survey "salinometer" cans.*—Simple tubes, with round bulbs, protected by a perforated brass cage, graduated to 1° intervals upon a white-metal scale. Since March, 1885, graduated also upon the stems; range from 30° to 100°. Fitted to slide into the front of the Coast Survey salinometer cups; made by Giuseppe Tagliabue and John Tagliabue, of New York. Used only in connection with salinometers.

Three of these thermometers (old) made by G. Tagliabue, show a maximum error of 1.2°, minimum of 0°, and mean of 0.5°. Five made by J. Tagliabue show a maximum of 1.1°, minimum of 0°, and mean of 0.67°. Six last received from J. Tagliabue, pointed on stems, and of improved quality, show maximum error of 0.6°, minimum of 0°, and mean of 0.26°.

(4) "*Miller-Casella" deep-sea thermometers.*—These instruments are a modification of Sixe's self-registering thermometer, consisting essentially in the protection of the larger bulb, which contains the expansible fluid acted upon by changes of temperature, by an inclosed sealed glass cylinder nearly filled with alcohol. By this device the effect of pressure at great depths below the surface of the sea is neutralized, the pressure being taken up by the fluid and vapor contained in the outer cylinder.

The following description, condensed from Lieutenant-Commander Sigsbee's Deep-Sea Sounding and Dredging (Washington, 1880, page 108), will explain the construction and operation of the instrument. (See Fig. 5.)

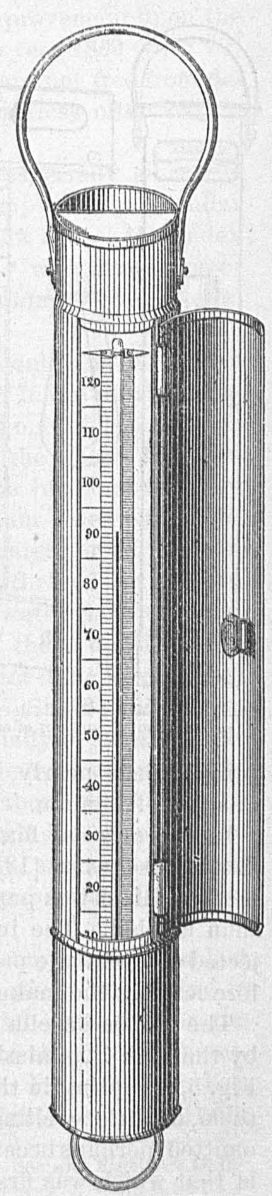

FIG. 4.—Professor Baird's protected thermometer.

A thermometer tube, bent in the form of **U**, is fastened to a vulcanite frame and backed by a white glass slab, marked by graduated scales. The limbs terminate in bulbs, one much larger than the other, and the **U** is occupied by a column of mercury which serves as an index. The large bulb and part of limb not occupied by mercury are wholly filled with a mixture of creosote and water.* The smaller bulb and limb are partly filled with the same mixture and partly with compressed air. On each side, in the tube above the mercury, is a small steel index, having a human hair tied around its upper end to keep it in place. The fluid acted upon by temperature is that in the larger bulb. As the temperature rises the mercurial column is forced over into the other limb, driving the index before it. As the temperature falls the compressed air in the smaller bulb acts as a spring to send the mercury back again, driving the other index before it, and leaving the first index at the highest point it had reached. It is thus a self-registering maximum and minimum thermometer, and the scales are therefore graduated in opposite directions. The steel indices are set by means of a small magnet, grooved across its poles to permit close coaptation to the tubes. The larger bulb is made double, according to the recommendation of Dr. W. A. Miller, vice-president of the Royal Society (in April, 1869), being surrounded by another bulb, and the intervening space nearly, but not quite, filled by alcohol. Made by Mr. L. Casella, of London.

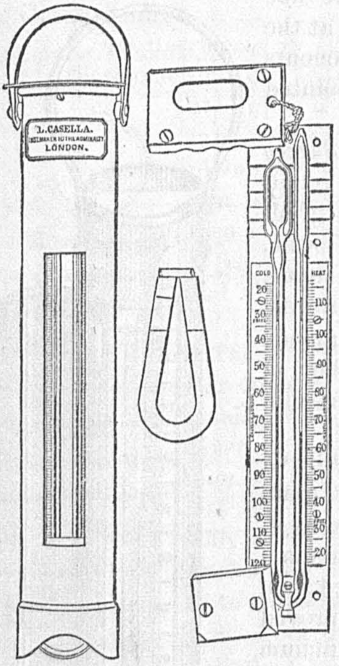

FIG. 5.—The Miller-Casella deep-sea thermometer, in and out of case.

In the original form of this instrument, invented by Negretti and Zambra (see page [13]), this space between the larger bulb and its protecting shield was partly filled with mercury, a better conductor of heat than alcohol. The instruments are advertised as having been subjected to hydraulic pressures equal to five tons to the square inch, before leaving the makers' hands.

The Miller-Casella thermometers now in stock and recently in use by the Fish Commission agree with the foregoing description and with Fig. 5, excepting in that the "aneurisms,"† as Professor Tait has called them, or little swellings of the tube near the bends of the **U** have been omitted, perhaps because of Professor Tait's criticisms. The form figured is that which was first used in the cruises of the Porcupine in 1869 and 1870, of the Pomerania in 1872, by the Norwegian expedition in 1876–'78,

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* In the Challenger Narrative, vol. i, p. 86, it is stated that the bulb contains creosote and *alcohol.*

† From ἀνεύρυσμα, a swelling (ἀνὰ and εὐρύς), not ἄ—νευρος, as more commonly derived. (*Scientific Results Voyage of Challenger, Narrative, vol. 2, Appendix A, p. 1.*)

in the cruises of the Valorous in 1875, of the Challenger in 1873–'76, of the Nares Arctic Expedition in 1876, and by the U. S. Coast Survey and Fish Commission up to a recent date.

Although justly regarded as a most important improvement upon the unprotected Sixe's thermometers used prior to the year 1869 (with exceptions to be hereafter noted), these instruments are not free from defects and individual peculiarities, which have doubtless often led to erroneous readings.

In the first place, the indices are likely to *slip*, especially since the use of steam winches and of wire for sounding, imparting a peculiar jarring motion to the whole line. "Even a slight jerk causes the index to move up or down," says Sir Wyville Thomson, * who found one or two thermometers to be wrong from this cause "in almost every serial temperature sounding."

Then, again, since these thermometers register only the maximum and mininimum temperatures which they encounter, in the possible case of a warmer stratum of water underlying a colder one of less specific gravity, or in the case that the air is colder than the water, the final registration may not be a correct indication of the temperatures met with, the instruments registering on their minimum sides either the temperature of the colder overlying stratum of water, or of the air, which may be inadvertently or ignorantly read as that of the greatest depth measured. When the air is colder than the water the thermometers may be artificially warmed before sending them down, but a colder overlying stratum of water offers much greater difficulties, which were fully recognized by the Challenger observers. Sir Wyville Thomson says, to this point:† "Very frequently, especially at considerable depths, where the differences were very slight, thermometers sent to greater depths gave indications higher than those above them. * * * I have no hesitation therefore in saying that a single indication with a thermometer on Sixe's principle is not trustworthy, and that a fact in temperature distribution can only be established by a series of corroborative determinations."

Another peculiarity, which fortunately tends to compensate that last described, is that these instruments are extremely *slow*. According to my laboratory observations quite twenty minutes are required for the change from the temperature of the air (60°–70°) to the freezing-point, the thermometers being immersed in melting ice.‡ It is possible that, inasmuch as a self-registering thermometer in actual use is recording

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*Voyage of the Challenger. The Atlantic, vol. 2. p. 259. See also Sigsbee's Deep-Sea Sounding and Dredging, p. 110.

†*Op. cit.*, vol. 2. p. 260; also Sigsbee, p. 112. "From what has been said it is seen that a maximum and minimum thermometer is not well adapted to ascertaining the temperature of intermediate warm or cold strata."

‡See also Commander Beardslee's observations, Rep. Com. Fish and Fisheries, 1877, App. C., and Coast Survey comparisons, quoted by Sigsbee, *op. cit.*, pp. 114-119.

during its descent through the water, the time figures deduced from laboratory observations may be too large; but it seems hardly safe to rely upon seven minutes' exposure, as directed by Sigsbee, in the operations of the Blake (*op. cit.*, p. 23), and still less upon five minutes' exposure, as was directed and followed in the Challenger work.*

Unless the thermometers are always kept bulb uppermost (for which reason the makers ship them in cases of a pyramidal form), the mercury is very likely to get above the indices. In such an event the index may be drawn by the magnet into the small enlargement just below the bulb, when the mercury will free itself and drop back into the tubes; but it will not always be easy to get the index back into the tube again, as it is likely to tip under the influence of the magnet, and to catch against the sides of the small enlargement. In the course of the tapping upon a table and swinging the thermometer about the head, which are to be tried in case of such an accident, it is very likely that the tube will be started a little from its right place upon the scale, since the fastening which is intended to secure the tube at the bend of the U is a soft copper band, fastened by *one end only*, probably to allow for expansion or contraction of the glass, under wide variations of temperature or pressure.

As to breaks in the mercurial column, an accident common to all mercurial thermometers, and other small mischances which may be remedied by the observer himself, I cannot do better than refer to Sigsbee's monograph, already often quoted (p. 110), for clear and practical directions as to all that may be safely done without sending the instruments back to the maker for repair.

Pressure errors.—In the Challenger observations a subtractive correction of about ½° F., applied to the maximum side, was assigned by Dr. Wyville Thomson for every mile of depth below the surface of the sea. This correction was the result of a series of careful observations made, with the aid of a powerful hydraulic press, by Capt. J. E. Davis, R. N.,† assisted by Prof. W. Allen Miller and others. Since the return of the Challenger, and during the three years preceding July, 1881, the pressure-error of these thermometers has been made the subject of especial examination by Prof. P. G. Tait, whose conclusions are published as Appendix A of the second volume of the narrative part of the "General Report on the scientific results of the voyage of H. M. S. Challenger," already cited. In the experiments of both Captain Davis and Professor Tait, the thermometers were subjected to heavy pressures in a hydraulic press, and the phenomena presented were similar in both series. Professor Tait concludes, however, that Captain Davis's corrections (and consequently those of the Challenger report) are too large, for the following reasons: In the first place the water in the press is heated by com-

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* Challenger Narrative, vol. 1, p. 120.

† See his paper on "Deep-sea thermometers" in Proceedings of Meteorological Society, April, 1871.

pression, but the *amount* of heat developed is dependent in a very curious manner upon its original temperature. If compressed at the temperature of its maximum density, the water is neither heated nor cooled, but is heated when compressed at a temperature above, and cooled when compressed at a temperature below its maximum density; and the wider the divergence of its original temperature from that of its maximum density, the greater is the effect produced. Captain Davis combined one set of observations taken near, but below, the temperature of maximum density, with a number taken near 55° F., striking out (unfortunately), as probably erroneous, all observations which differed much from the majority of the others. By an interesting graphic diagram Tait shows that the true figures for temperature correction, according to Davis's experiments, lie in a line coinciding much more nearly with that indicated by his rejected observations than by those which he adopted.

Professor Tait found by experiment that a Phillips self-registering mercurial thermometer,[*] wholly inclosed in a sealed glass tube, nearly filled with alcohol, as suggested by Sir William Thomson,[†] was "absolutely perfect, so far as regards immunity from pressure" (p. 7). So that the pressure error of the Miller-Casella thermometer, the bulb of which is protected in precisely the same way, is due almost, if not quite, entirely to pressure upon the stem. For tubes of uniform caliber throughout, it was found by experiment that the effect of pressure upon a tube similar to those of these thermometers would be an elongation of about $\frac{1}{1000}$ of the length of the column of mercury for each ton weight applied to the outside of the tube (or about 800 fathoms of depth). As the elongation will occur in both legs of the U, and as increase in pressure is in practice (at sea), associated with decrease in temperature, this correction for pressure should have been applied also to the minimum scale, instead of, as was the fact, to the maximum only.

As the instruments used by the Challenger were actually constructed, each leg of the U contained an "aneurism," or small enlargement,[‡] near the bend, intended to facilitate recovery of the steel index when it had been lost in the mercury. These swellings appear to be larger than they really are in the ratio of 1.6 (the refractive index of glass) to unity, but were actually found by Tait, in several instances, to contain five times as much mercury as a similar length of thermometer tube, and, consequently, to produce five times as great an error.

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[*] A mercurial thermometer, self-registering by an index produced by a break in the column. Invented by Prof. John Phillips, of Oxford. First used at Kew in 1851. The principle is now universal in clinical thermometers.

[†] "The effect of pressure in lowering the freezing point of water." Proc. R. S. E. February, 1850.

[‡] The "aneurisms" were first added to Sixe's thermometers by Aimé, in 1844, to prevent the mercury from passing by the indices. *Ann. de Chimie et de Physique, Ser.* 3, *t.* xv, p. 5 (1845).

I have gone somewhat fully into this matter of pressure error because, if Professor Tait's results are to be accepted as correct (a conclusion strongly favored by internal evidence), the pressure corrections applied to observations made with the Miller-Casella thermometer hitherto may safely be disregarded, and the laboratory corrections under ordinary atmospheric pressures, which I was at first disposed to regard as of little value, because of the difficulty in reproducing the conditions prevailing at great depths under the sea, may be accepted as practically exact. For the outcome of Professor Tait's inquiry (the details of which would be too voluminous for this report) is that Captain Davis's corrections, although corresponding closely with those obtained in similar experiments by Tait, are misleading, because of certain facts brought out for the first time by the later inquiry. Not only is there some error in the allowance by Davis for the heating of water by compression in the press, but there are errors due to the heating of the vulcanite mounting and of the glass protecting bulb, by pressure,* discovered for the first time by Tait, which could not have been known by the former experimenter. Professor Tait concludes that for thermometers without aneurisms the correction will not exceed 0.05° for every ton of pressure (nearly a mile in depth of water) applied to the minimum scale, and that in no case need the correction to the minimum scale exceed 0.14° per mile in depth; a correction which, considering the probable parallax error in reading on the unsteady deck of a ship, may be safely disregarded as less than the probable error of observation for the depths usually explored.

At present, and since the year 1877, the Miller-Casella form of deep-sea thermometer has been very seldom used by the Fish Commission, its place being filled by the Negretti-Zambra thermometer, constructed on a quite different principle. Only fifteen in all have passed through my hands, and of these the first six were called for immediately, as a reserve supply for the winter cruise of the Albatross in 1883-'84. They were compared only at 32° F., at which point none of them showed any error. The other nine, still on hand, are a lot of old instruments which had been more or less damaged by careless handling, and have been repaired by the makers. Some of these show rather unusually large errors, apparently because of displacements of the stems upon the scale-plates. One is unserviceable from the jamming of its index in the small enlargement at the top of the minimum tube. One marks 31° in melting ice on the maximum side (31.5° on the minimum side). Of the eight still serviceable the maximum error is 1°, minimum 0°, and mean 0.18°.

When used with a due regard to the causes of error already noted,

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* All of these heating effects are of course peculiar to the laboratory experiments, and do not affect observations at sea, where the heat is at once conducted away by the surrounding water.

these instruments answer well the purpose of their construction, and have, in fact, been the means by which most of the best modern temperature observations beneath the sea have been made. Now that the small aneurisms near the bends of the U have been given up by the makers, it appears that the pressure error may be safely disregarded in practice (excepting at very great depths, when Professor Tait's tables will be found useful), and that the laboratory corrections, under ordinary atmospheric pressures, will answer every practical purpose.

This form of deep-sea thermometer, under its present name, is a curious example of *re-invention* within a shorter time than usual after the original publication of its conception. As now advertised and used, it is commonly supposed to be the invention of the late Dr. W. A. Miller, vice-president of the Royal Society in 1869, and to have been first used in the cruise of the Porcupine in that year. The invention consisted, as has been already said, in the protection of the larger bulb of a Sixe's thermometer by another cylindrical glass tube, hermetically sealed about it and partly filled with alcohol. There is no reason to doubt that Dr. Miller promulgated his invention in good faith, but there is also no reason to doubt that an exactly similar, and perhaps more effective, instrument of the same sort had been made so early as 1857.

In that year the late Admiral Fitzroy, acting under a suggestion by Mr. Glaisher, requested Messrs. Negretti and Zambra to endeavor to protect the bulb of Sixe's thermometer against sea pressures, which was successfully accomplished by inclosing the bulb in an air-tight glass shield, nearly filled with mercury to promote conduction of heat.* Some fifty of these instruments were made for and purchased by the hydrographic office of the admiralty. It appears to be certain that these instruments were used by Captain Pullen, in the voyage of the Cyclops, which began in 1857. Forty-one important observations were taken in the North and South Atlantic, the Indian Ocean, and the Red Sea, at depths from 2,400 to 16,000 feet, with "Negretti and Zambra's protected Sixe's thermometers."† Pullen noted that the *maximum index* often shifted, indicating that he used the instrument provided with both maximum and minimum scales.

From an account published by the makers in 1864,‡ I infer that the original form was precisely like Sixe's thermometer§ with a double curve,

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* Meteorological Papers, No. 1, July 5, 1857.

† J. Prestwich, on Submarine Temperatures, &c. Phil. Trans. Roy. Soc. Vol. clxv (1875), p. 608.

‡ A Treatise on Meteorological Instruments, Negretti and Zambra. London, 1864.

§ Invented by James Six (or Sixe) of Canterbury (or Colchester), in 1782. In the original account (Trans. R. S., vol. lxxii, p. 72, 1782) Mr. Six states that "our thermometer resembles in some respects those of M. Bernoulli and Lord Charles Cavendish," the invention claimed consisting in the mode of registration. A thread of glass was at first used, instead of a hair, to hold the index in place.

excepting in that the larger bulb was protected as described above. (Fig. 6.) A smaller and more compact instrument, with the tube bent but once, in U-shape, was constructed for the registration of minimum temperatures only. The copper case inclosing this last-named instrument was made, by a poppet valve at the top and bottom, opening up ward, to serve also as a water-bottle. (Fig. 7.)

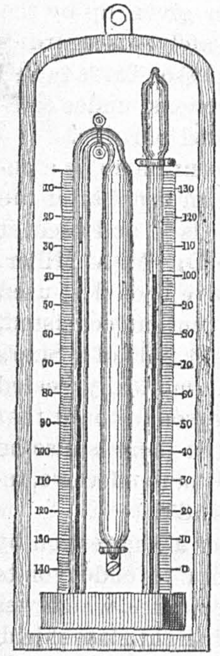

FIG. 6.—Sixe's self-registering maximum and minimum thermometer.

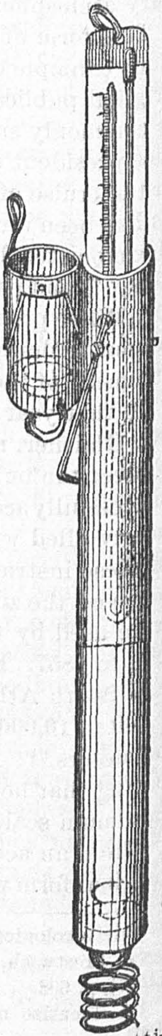

FIG. 7.—Negretti-Zambra self-registering minimum deep-sea thermometer.

After the appearance of the form now in common use, under the name of the "Miller-Casella" or "Casella-Miller" deep-sea thermometer, the question of its authorship was made the subject of a somewhat acrimonious correspondence in *Nature* (October and November, 1873), between Mr. Casella and the Messrs. Negretti and Zambra, which resulted in satisfying the editor of that periodical that "the whole credit of the double bulb belongs to Negretti and Zambra." This statement, although conclusive as regards the controversy between the two firms, is somewhat too positive to be accepted as establishing absolute priority of invention, since the use of a double cylinder to meet pressure error was made sufficiently familiar by Sir William Thomson's paper on the "Effect of pressure in lowering the freezing point of water," published in 1850,* in which his "thermometer was entirely inclosed and hermetically sealed in a glass tube," and had been known to marine investigators at least as early as 1822, when Sir Edward Sabine used a strong iron cylinder for this purpose;† if not, as has been supposed by Sir Wyville Thomson and the authors of the Challenger Narrative, to Sir John Ross, in 1818.

The Negretti-Zambra deep-sea thermometer, as at present used, is represented by Fig. 8. Mercury is the thermometric fluid, and the bulb is about 2 inches long by one-half inch in diameter. Just beyond the bulb the tube is curved like the Greek ϑ laid upon its side, the convexity of the curve being widened into a small reservoir, beyond which the tube is constricted in a particular manner. At the upper end of the tube is a small pyriform enlargment. The

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* Proc. R. Soc. Ed., January 2, 1849, and January 1, 1850.

† Phil. Trans. R. Soc., vol. cxiii (April 17, 1823), 1823.

instrument is graduated upon its stem *towards* the bulb in intervals of 1° F., and a white enamel backing facilitates readings. The whole tube, including the bulb, is surrounded by a glass protecting cylinder, sealed at both ends, to take up the pressure of the sea water, and is 9½ inches in length. That portion of the protecting cylinder which covers the bulb is nearly filled with mercury, confined by a partition cemented about the neck of the bulb, to promote conduction of heat between the bulb and the surrounding water. Made by Messrs. Negretti and Zambra, of London.

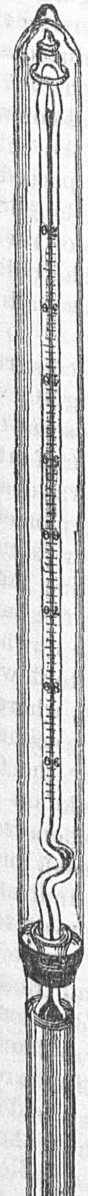

FIG. 8.—The Negretti-Zambra self-registering deep-sea thermometer, modern form.

When in use, the thermometer is attached to a sounding line, and lowered into the water bulb downward. At the desired depth, after a sufficient delay to insure its having taken on the temperature of the surrounding water, it is overset; the portion of mercury contained in the tube above the constriction breaks off at that point and stands opposite the scale-reading corresponding to the temperature. It may be read at any time, provided that it be kept in a reversed position, the enlargement at the end of the tube farthest from the bulb being too small to be seriously affected by ordinary temperature changes.

The first form of this valuable invention, as presented to the Royal Society of London, by Henry Negretti and Joseph Warren Zambra, March 12, 1874,* was a siphon tube, with parallel legs and a considerable enlargement at the bend. (Fig. 9.) Instead of the double curve, small reservoir, and constriction in the tube of the later forms, there was a single funnel-shaped curve above the bulb, containing a small glass plug, similar to that used in Negretti and Zambra's patent maximum thermometer. The office of this plug was to close the tube on reversal and cause the column of mercury to break off at that point. The instrument was

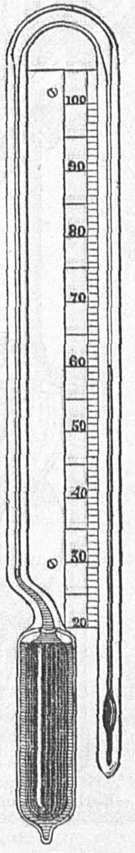

FIG. 9.—Negretti and Zambra's self-registering deep-sea thermometer, earliest form.

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* Proc. Royal Society, 1874. Vol. 22.

pivoted near its center, upon a frame, and a small rudder or fan was geared to the pivot. This rudder pointed upward during the descent of the instrument, and downward during its ascent, making a half revolution at the moment of reversing the direction of motion, which produced a complete revolution of the thermometer. The broken part of the mercurial column in the tube dropped first into the enlargement at the bend, and then passed over into the other leg, where its height, and the temperature at the time of reversal, could be read on the scale. The bulb was protected as in the Miller-Casella instrument.

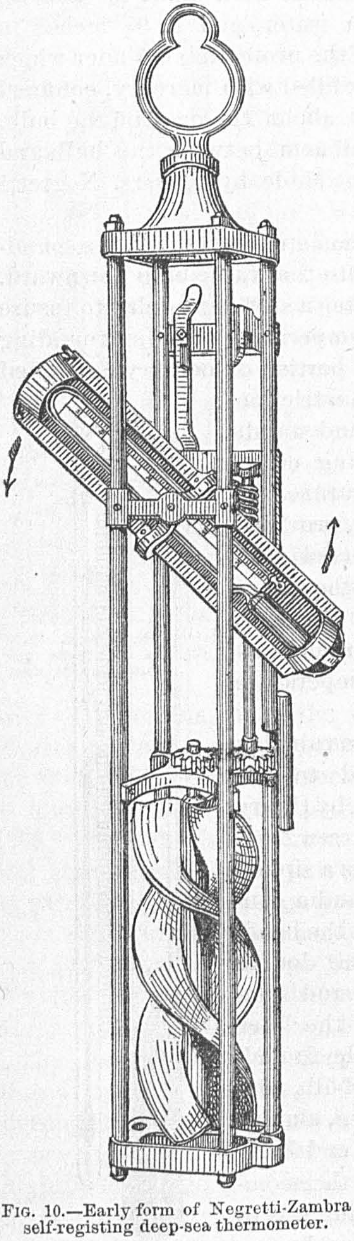
FIG. 10.—Early form of Negretti-Zambra self-registing deep-sea thermometer.

Subsequently a frame was constructed carrying a screw-propeller (Fig. 10), which revolved freely during the descent of the instrument but engaged a train of ratchet-work as soon as the direction was changed to ascent, and caused the thermometer to revolve once upon an axis near its center, first to bulb uppermost, catching the separated column of mercury in the bend of the siphon, and then to bulb downward again, allowing the mercury to flow into the other limb of the tube, where the temperature was read. A specimen of this form was purchased by the Coast Survey and tried by the Blake in 1875, "but it was so cumbersome, expensive (the advertised price was 10 guineas), and left so much open to doubt in its indications, that it was reported on adversely to the Superintendent."* Several were also sent out to the Challenger and tried during the cruise. At first, Staff Commander Tizard reports that† "it was found in practice that the propeller being arrested over the thermometer, after it had overturned, brought such a strain on the cog-wheel as to twist it off its spindle and cause its loss." This difficulty was remedied by the chief engineer of the Challenger, Mr. Ferguson, but the record of the instruments was not found to be satisfactory. Four that were tried

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* Sigsbee, *op. cit.*, p. 114.

† Narrative, vol. 1, p. 89.

in the Sulu Sea (p. 91), disagreed materially with the Miller-Casella instruments sent down at the same time.

In the stock of old thermometers belonging to the Commission I find one of the form represented by Fig. 11, which appears to be intermediate between that just described and the form now in use, although, as the bulb is not protected, it seems to have been intended for use in shallow water only. The tube is bent twice upon itself, making an **S**-shaped curve just above its bulb, and leaving the bulb inclined to the stem at an angle of 10 degree. Here I first find a small reservoir in the curve of the bend, and a constriction above, instead of a glass plug, for breaking the column on reversal. The single specimen on hand is inclosed in a wooden case, which will be described further on.

The Negretti-Zambra deep-sea thermometers were first used in this country by the U. S. Fish Commission early in 1877, and were then of the form described on page [15], Fig. 8. The construction is necessarily handwork, and requires very expert glass-blowing, in which a decided improvement has been noticed. Thus, in 1879, I reported that the instruments then under observation "have sometimes a trick of breaking the column in the wrong place, and so giving a false indication. In one instance I noticed that the break was diagonal, instead of being directly horizontal, as it should have been. Professor Hind, of Halifax, informs me that he has noticed the same defect, and has brought it to the attention of the makers, who have assured him that it has been corrected in their more recent form of instrument."*

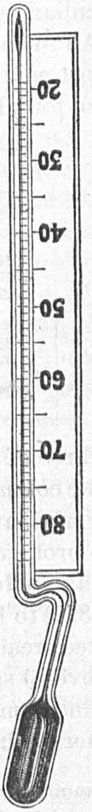

FIG. 11.—Negretti-Zambra self-registering thermometer, intermediate form.

On the 18th of April, 1884, I note that of twelve Negretti-Zambra thermometers compared to date at 32°, six show no error, four show +0.1°, one shows +0.2°, one shows +0.63°. Maximum error (for the twelve), +0.60°; minimum, 0°; mean +0.2° (nearly).

Twelve compared on the 16th of September, 1884, at 32°, show a mean error of 0.57°, of which two show +1°, three show +0.7°, three show +0.5°, two show +0.3°, one shows +0.1°. The mean errors of all thermometers of this pattern examined are given in full in the appendix.

The errors recorded are, as I think, larger than they should be, and make it very dangerous to rely upon unseasoned instruments which have not been recently compared. Some of the error is doubtless due to rise in the zero point, the natural result of "seasoning"; another part

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* On the Temperature of Fishes. J. H. Kidder, M. D., surgeon, U. S. Navy, Proc. Nat. Museum, March 25, 1880, p. 310.

(perhaps) to the difference in *pull* between a long and a short column of mercury, upon the main body at the breaking point. The possible operation of this cause, tending to break the column a little nearer or a little farther away from the narrowest constriction, is not made very obvious by the comparisons, although it may explain some individual peculiarities which have been noted.

As to such individual peculiarities the following notes may be of interest as illustrating the frequency with which these instruments have been found to break column in the wrong place:

Fish Commission number..	Maker's number	Notes.
5149	50302	Error 0.2° to 1°, column breaks unequally.
5151	50306	Error 0° to 0.4°, column breaks unequally at 42°.
5276	54812	Column broke in wrong place once at 49. 8°; broke correctly in five repetitions of observation.
5280	54821	Very slow in breaking.
5285	54822	Very slow in breaking.
5325	52729	Column broke wrong *once* at 60° and once failed to break at 92°; correct on repetitions.
5284	54823	Very slow in breaking.

Three of the instruments were noted as very slow in breaking; two broke column frequently in the wrong place; one did not break at all, on one trial, at 92°, but broke correctly on repetitions of the experiment; two broke colum *once* in the wrong place (one at 49.8°, one at 60°), but not again during frequent repetitions of the experiment. One was found (at 32°) to hold back the separated part of the column after being inverted, read, and returned to the bulb-downward position.

Several series of experiments were made to determine the *slowness* of the instruments. Thus, Fish Commission No. 5206 (maker's No. 51452), immersed in melting ice, fell:

	°
In 1 minute from 64° to 43.1°	20.9
In 2 minutes from 64° to 42°	22.0
In 3 minutes from 67.5° to 33.8°	33.7
In 4 minutes from 68° to 33.8°	34.2
In 5 minutes from 68.2° to 35°	33.2
In 5 minutes from 66° to 35.8°	30.2
In 6 minutes from 66° to 33. 8°	32.2
In 7 minutes from 67° to 32.4°	34.6
In 8 minutes from 65.5° to 32.4°	33.1
In 9 minutes from 66.6° to 32.4°	34.2

The true reading (32.4°) was in this case reached in 7 minutes. Fish Commission No. 5184 (maker's No. 47995), inclosed in a metallic case, as in use at sea, and immersed in melting ice, fell:

	°
In 1 minute from 71° to 64.2°	6.8
In 2 minutes from 62° to 41°	21.0
In 3 minutes from 62° to 40°	22.0
In 4 minutes from 76° to 39°	37.0

	°
In 5 minutes from 62° to 35.5°	26.5
In 6 minutes from 58° to 43°	15.0
In 7 minutes from 68° to 38.8°	29.2
In 8 minutes from 58° to 37°	21.0
In 9 minutes from 50° to 36°	14.0
In 10 minutes from 60° to 37°	23.0
In 10 minutes from 72° to 32.6°	39.4
In 11 minutes from 58.5° to 32.4°	26.1
In 15.5 minutes from 60° to 32.4°	27.6

The change is rather irregular, depending somewhat upon the temperature marked by the thermometer at the beginning of each experiment, and partly upon the more or less close coäptation of the melting ice to the outer case of the thermometer. The rapidity with which the instrument is overset may also sometimes influence the position of the breaking point, as in the following instance: Fish Commission No. 5157 (maker's No. 52752), immersed in water at 45.3°, overturned by a quick movement read 45.6°, by slow movement 46.5°. In water at 46°, overturned by quick movement it read 46.1°, by slow movement 46.3°. Even when compared without the investing metallic case now used at sea, it seems that the reading cannot be safely depended upon with less than ten minutes exposure, in laboratory comparisons. In practice, at sea, since the thermometers are changing on their way down, and the water in contact with them is continually renewed, it is probable that a less time may serve. The use of self-oversetting cases insures uniformity in the quickness of the turn. The present rule in the work of the Commission is to leave the thermometers down for ten minutes.

An annoying defect in construction, which might easily be remedied, is the wide variation in graduation on the scales. In twelve thermometers of this pattern, compared September 12, 1884, for example, the range of graduation varied between 63° (+32° to +95°), and 112° (—25° to +87°). The degree spaces in the first-named instrument are nearly twice as wide as those in the last, and, since there is no pointing to fractions of a degree, estimations of fractional parts are made much more difficult by these inequalities in spacing, the eye gaining nothing by practice with one thermometer when another is substituted for it.

The Negretti-Zambra thermometer, as at present constructed, leaves little to be wished for as a deep-sea temperature recorder, beyond some improvement in the details of construction. The mode of protection absolutely does away with pressure error, and the use of mercury in the bulb-case has raised its sensitiveness to a point considerably above that of the Miller-Casella. With a little greater certainty in the formation of the column-breaking contrivance, and a good deal more uniformity in the graduation of the stem, there need be no fear of erroneous indications from any depth that the glass protecting tube will stand. With due care in noting untrustworthy instruments by laboratory comparisons, there should never be any possibility of recording an error exceeding one-half a degree. By increasing the length of the stem and restricting the graduation to the range between 32° and 90°, it would be possible to point the stem to fifths of a degree, for special observations at great depths, where the variations of temperature are small.

With the exception of the single specimen tried and reported adversely upon by the Coast Survey in 1875 (see p. [16]), the earlier forms of reversing gear for these thermometers have never, to my knowledge, been used in this country. As first used by the Fish Commission in 1877, the thermometers were inclosed in wooden cases, about 13 inches long, secured to the sounding line by a lanyard about 6 feet long attached to the bulb end. The case was hollowed out inside, and contained a quantity of small shot, movable from end to end, sufficient to nearly, but not quite, overcome its buoyancy in sea water. On sending the case down the shot fell to its bulb end and tended to keep it upright in the water. On reversing the motion and hauling in the line, the case was overset, the shot ran to its other end, and tended to keep its bulb uppermost. (Fig. 12.)

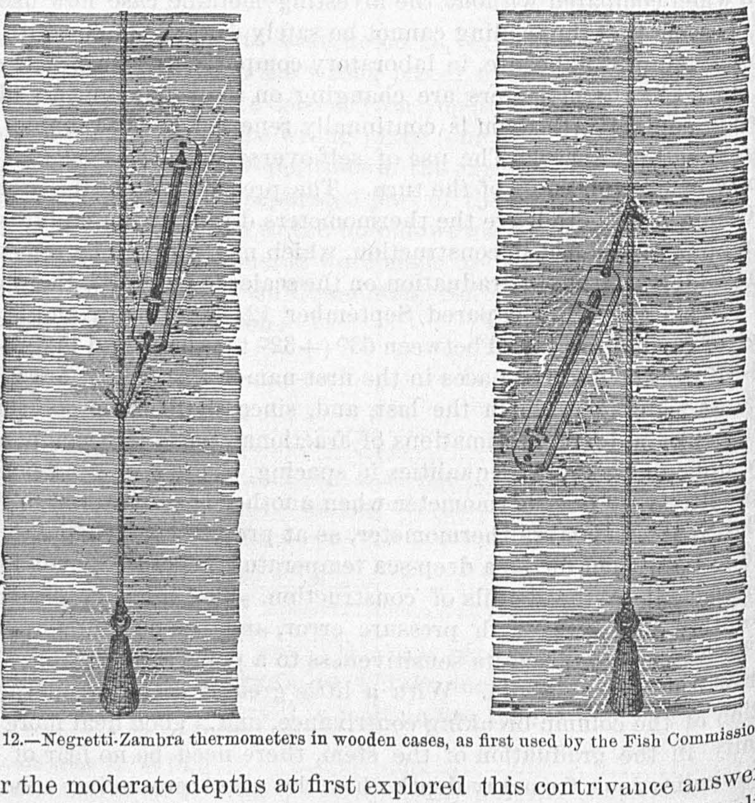

FIG. 12.—Negretti-Zambra thermometers in wooden cases, as first used by the Fish Commission.

For the moderate depths at first explored this contrivance answered very well, due care being taken that the acts of lowering and hauling in were continuous. At 800 fathoms, however, Commander J. R. Bartlett, U. S. Navy, found the wooden cases shriveled and compressed* (the pressure at 800 fathoms is about a ton to the square inch), so that their buoyancy was quite lost. Professor Hilgard, of the Coast Survey, suggested the use of a metal case, filled with paraffine, but I do not know that the suggestion was ever carried out.

Lieut.-Commander (then lieutenant) Z. L. Tanner, U. S. Navy, commanding the Fish Commission steamer Fish Hawk, noted in 1880 that, "The bottom and intermediate temperatures were unreliable, owing to the use of the Negretti-Zambra deep-sea thermometer in a sea-way, the motion of the vessel being liable to capsize it at any time. It was the results of this day's work [September 4, 1880] that led us to devise some plan by which this admirable thermometer could be used under all conditions of wind and weather. * * *

"Several devices were tried, and finally a simple gas-pipe, seven-eighths of an inch inside diameter, was adopted. Several holes were drilled in the end inclosing the bulb, a slit cut in the side to expose the scale, and a pair of slip-hooks held in position by a small spring placed in the opposite end. The thermometer was then inserted, the rubber guards used to protect the shield in the wooden frame serving not only to hold it securely in place but to protect it from sudden jars, and a lanyard of cod-line, spliced into the end carrying the bulb, completed the arrangement.

"The messenger used for capsizing the thermometer is of cast brass, cylindrical in form, with rounded ends. It is about 2 inches in length, 1 in diameter, and has a three-eighths inch hole through its center, well rounded at the ends to prevent catching on splices. Its weight is from 3 to 4 ounces.

"Fig. 13 shows both forms of the Negretti-Zambra thermometer arranged for descent. In the modified form it is held firmly in position by the slip-hooks through which the stray-line passes.

"Having attained the proper depth, and sufficient time elapsed for the thermometer to indicate the temperature, the messenger, which has

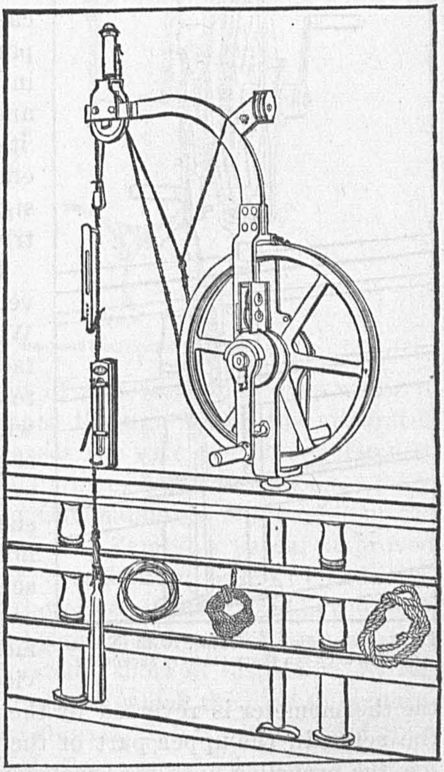

FIG. 13.—Sounding machine, with Negretti-Zambra deep-sea thermometers descending. Shows the wooden case and the Tanner metallic case.

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* Sigsbee, *op. cit.*, p. 116.

been resting in its cradle under the guide-pulley, is sent down the wire and capsizes the thermometer by striking the slip-hooks and forcing them open, when, having lost its support, the instrument promptly reverses, as shown in Fig. 14, where both forms are represented as on the ascent.

"All buoyancy being destroyed by substituting a metal case, the thermometer is independent of the motions of the vessel, either from rolling, pitching, or drifting. The line may be stopped on the ascent or lowered again without affecting the instrument in any way. We have taken hundreds of temperatures with the apparatus described, under varying conditions of wind and weather, with the most satisfactory results."*

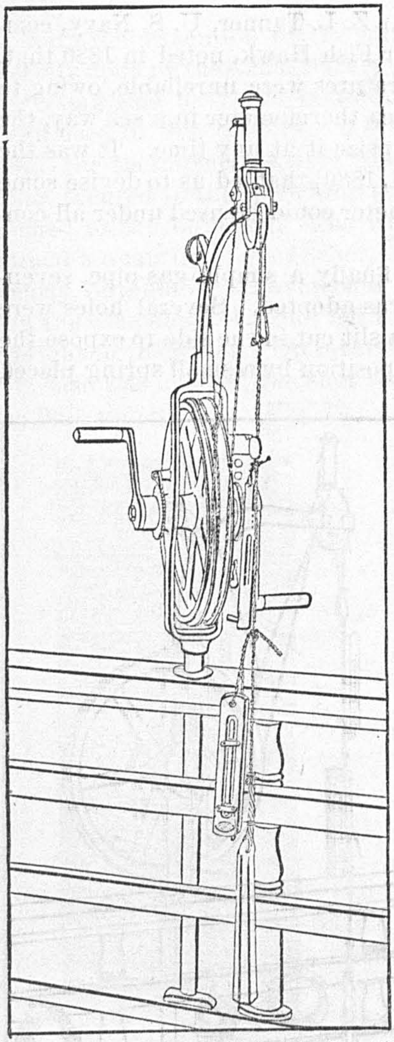

FIG. 14.—Sounding machine, with Negetti-Zambra deep-sea thermometers ascending.

This device of Mr. Tanner's is the first instance of the use of a metallic case as a protective and reversing apparatus that I find record of. Although invented on the spur of the moment, and to meet an unforeseen emergency, it was found to answer its purpose as effectually, if with less elegance of design, as any that has been since contrived.

The next improvement was the invention of Passed Assistant Engineer William L. Bailie, U. S. Navy, attached to the Fish Hawk, and appears to have been about contemporaneous with the invention of the Magnaghi case, adopted and sold by Negretti and Zambra in the year 1882. It consists essentially of a propeller and slip-hook, inclosed in a metal case, which screws to the upper end of the Tanner case, its slip-hook having been removed for the purpose. By this device, which is illustrated by Fig. 15, the thermometer is reversed by the action of the propeller, "bringing the screw in the upper part of the spindle into action, gradually raising the propeller until the small part of the spindle at the lower end allows the hook to open, releasing the wire, when the thermometer

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[*] Report on the construction and work in 1880 of the Fish Commission steamer Fish Hawk, by Lieut. Z. L. Tanner, U. S. N., commanding. (In Report of the Commissioner, 1881, pp. 32, 26.)

capsizes and registers the temperature by breaking the column of mercury."*

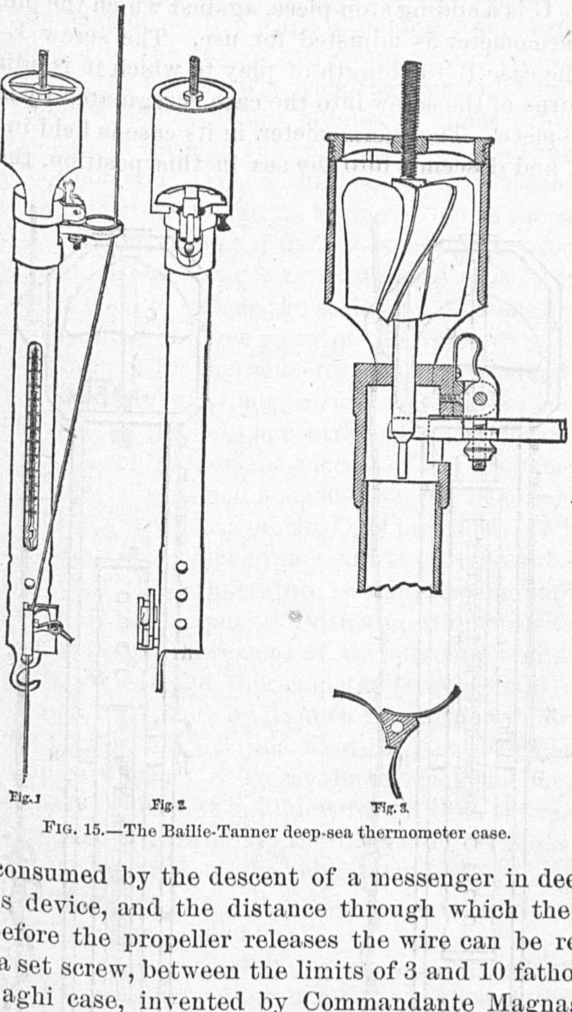

Fig. 1 Fig. 2 Fig. 3.

FIG. 15.—The Bailie-Tanner deep-sea thermometer case.

The time consumed by the descent of a messenger in deep water is saved by this device, and the distance through which the apparatus must pass before the propeller releases the wire can be regulated at pleasure, by a set screw, between the limits of 3 and 10 fathoms.

The Magnaghi case, invented by Commandante Magnaghi, of the Italian navy, and sold as "Negretti and Zambra's patent improved frame standard deep-sea thermometer," was found to be not well adapted for use on a sounding wire, and was therefore not often used in the work of the Commission. It is described by the makers as follows:

"The apparatus will be best understood, short of inspection, by reference to Fig. 16. 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

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*Report on the work of the U. S. Fish Commission steamer Fish Hawk for the year ending December 31, 1882, and on the construction of the steamer Albatross, by Lieut. Z. L. Tanner, U. S. N., commanding. (In Report of the Commissioner, 1882, p. 11.)

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 to which it is adjusted. 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 this position, the fan C not

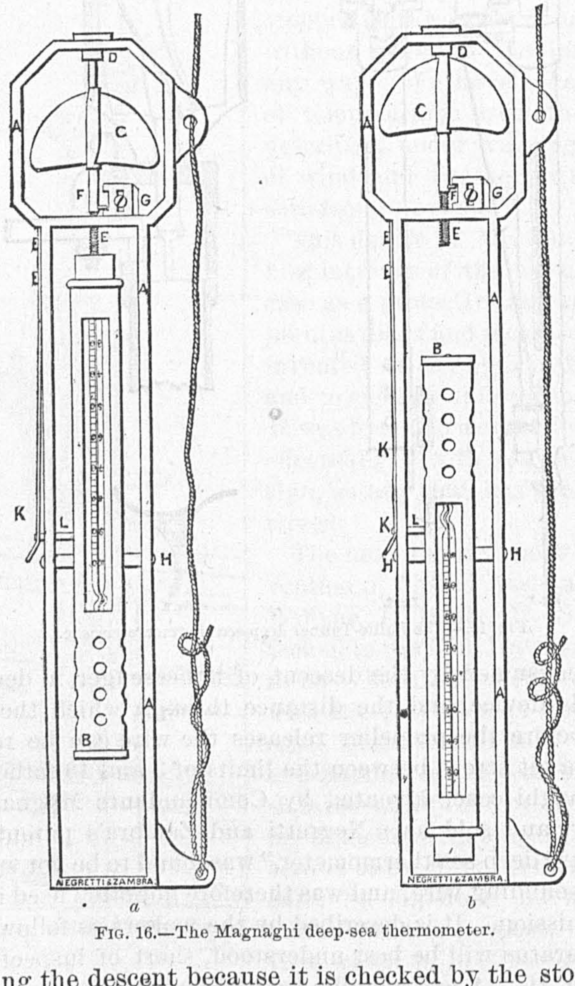

FIG. 16.—The Magnaghi deep-sea thermometer.

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 of that spot, owing to the axis H being below the center 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 upward, so that the whole play of the screw requires 70 or 80 feet 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 turn over of the thermometer, the lateral spring K forces the spring L into a slot in the case B and clamps it 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 construction of the thermometer will be understood by reference to the figure. The bulb is cylindrical, and mercury is the thermometrical 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 is 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 upward from C. To set the thermometer for observation it is only necessary to place it bulb downward, then the mercury takes the temperature just as 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."

To insure the prompt reversal of this instrument, which was found sometimes to stick, an india-rubber band was applied during the cruise of the Triton, in the summer of 1882.*

In the voyage of the Talisman a frame was used "*construit d'après les indications* de M. Alphonse Milne-Edwards,"† which closely resembled the Magnaghi frame, without the revolving propeller. The detaching apparatus consisted in a lever attached to the sounding weight by a light hempen string, and holding the thermometer in place. When the weight was released the lever was pulled down by the string, setting the thermometer free to the action of a spring, which caused it to over-

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* Challenger Narrative, vol. 1, part first, page 95.

† Explorations Sous-Marines. Voyage du Talisman. H. Filhol, in *La Nature*, No. 556, January, 1884, page 135.

turn. The hempen string was so slight as to be easily broken when the lever had reached the limit of its excursion. (Fig. 17.)

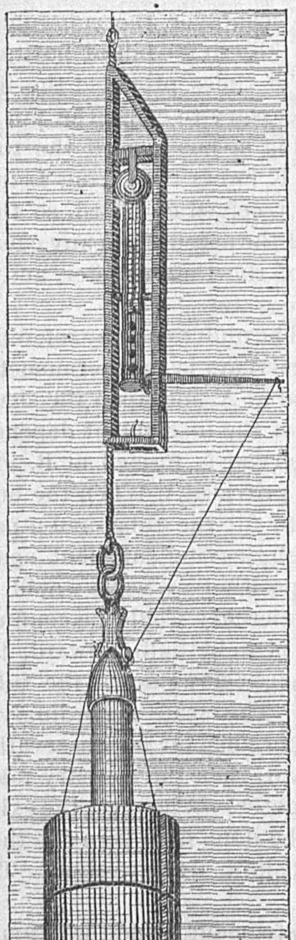

FIG. 17.—The Talisman thermometer frame and sounding-lead.

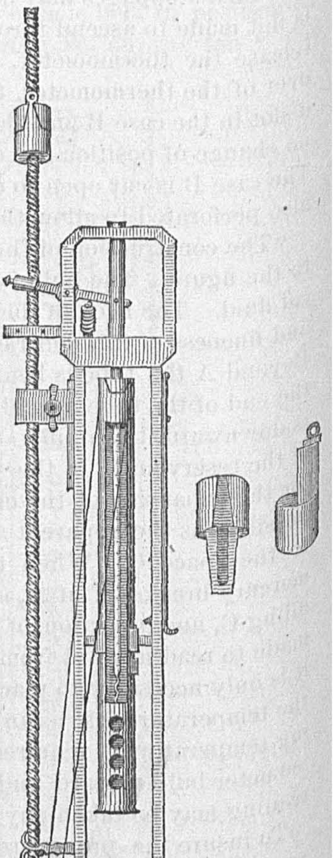

FIG. 18.—The Scottish thermometer frame.

In the work at the Scottish marine station, at Granton, Edinburgh, the Magnaghi case is modified in still another way by the substitution, for the propeller, of a detaching lever at the top, as shown by Fig. 18.

"The thermometer T is supported on pivots, *p p*, in the frame F, and kept in its upright position by the pin P, which dips into a groove in the top of the instrument, and moves freely through two holes, *h h*, in the frame. A lever, L, turning on a pivot in the frame, works in a slot in the pin P, and when its outer end is depressed the pin is raised out of the groove G. A spiral spring, S, keeps the pin in position when not counteracted by the lever. The forked end of the lever embraces the sounding line, to which the whole apparatus is attached when in use. * * * When the pin P is raised, the thermometer turns on its pivots by its own weight, and is retained in the inverted position by the tooth *t*, attached to the spring *s*, and fitting into a hole in the projection *f*.

"The lever is depressed by the fall of a weight, B, called a messenger, along the line. The messenger is the invention of Captain Rung, of the Meteorological Institute, Copenhagen. It is made in two parts, so that it can be fitted on the line at any point without the trouble of reeving.

"When the temperature is to be ascertained at two or more depths simultaneously, a messenger is hung by a cord to the top of each thermometer, except the lowest, as shown in the figure. Thus, when the first thermometer is inverted, a messenger is released, which inverts the next, and so on."[*]

This contrivance is called by its inventors "the Scottish thermometer frame," and was described by Mr. Hugh R. Mill in the Proceedings of the Royal Society of Edinburgh, vol. xii, p. 929, July, 1884.

The new pattern "Tanner case," which is now used by the Fish Commission and Coast Survey, was invented by Lieut.-Commander Tanner in 1884. (Fig. 19.)

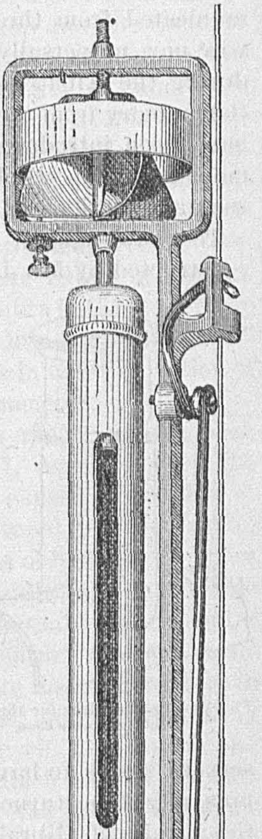

FIG. 19.—The Tanner thermometer case, new form.

It is a modified combination of the Bailie-Tanner and Magnaghi cases, retaining the propeller gear and clutches for the sounding wire of the former and one of the upright side bars of the latter. The thermometer is pivoted at the bottom, and when reversed comes up hanging clear of the

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[*] The Scottish Marine Station for Scientific Research, Granton, Edinburgh; its work and prospects. Edinburgh, 1885, p. 35.

frame altogether. There is a longitudinal slit in the case, uncovering the thermometer scale, and a corresponding slit on the opposite side, so that the temperature can be read by holding the instrument up against the light. To guard against the "jiggling" motion communicated from the reeling engine along the wire rope or sounding wire now universally used by the Fish Commission, which was found during the Albatross cruise of 1883–'84 to have in some cases jarred the mercury from the bulb into the tube after reversal, spiral springs have been introduced into the metal case above and below the thermometer. The whole instrument is heavily nickel-plated to prevent rust, and works well in practice.

To guard against parallax errors in reading (see p. [5]) I have had constructed by Mr. Joseph Zentmayer, of Philadelphia, a reading lens of about 3 inches focal length, fitted at right angles to the center of a brass saddle adapted to the convex surface of the thermometer case, and provided with a short draw-tube for focussing. The eye-piece opening is made smaller than the pupil of the eye, and there is therefore no variation in the reading, whatever be the inclination to the perpendicular at which the scale is viewed. (See Fig. 20.) The slight magnifying power of the lens makes it much easier than formerly to read the temperature to fractions of a degree.

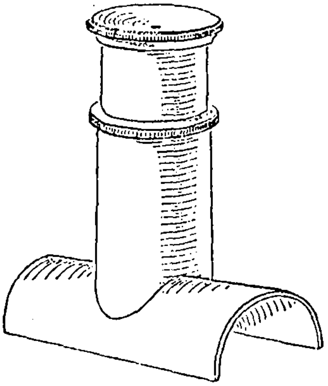

FIG. 20.—Reading lens for the Tanner thermometer case.

The abandonment of the propeller reversing-gear by French and Scottish observers seems to have been due partly to a fear that the propeller-fans might be turned by a strong lateral current, as for example in the Straits of Gibraltar (see Challenger Narrative, vol. 1, p. 95), and partly, as stated in M. Filhol's report on the work of the Talisman, by the observation that the fans have sometimes failed to revolve at all. In the Bailie-Tanner case the protecting shield around the propeller would meet the former objection (so long as the instrument remained in a perpendicular position) if currents strong enough to affect the fans should ever be met with in the open sea. No instance of the latter defect in construction has yet been noted in the instruments of the Fish Commission. Up to the present time the propellers of the new Tanner case, although not so well protected as the earlier forms against lateral currents, have not yet failed to answer the purpose for which they were designed. In deep-sea work the saving in time by dispensing with messengers becomes an important consideration.

Many of the features which are combined in the modern apparatus for observing deep-sea temperatures are revivals or re-inventions of old devices which had been once used and forgotten. Thus the outer protective shield to the bulb of the Miller-Casella thermometer, its only important distinction from Sixe's form of a century ago, was certainly tried by Sir Edward Sabine as early as 1822 (see p. [14]), and thought of by Péron* about 1804. Aimé suggested and appears to have used an outer glass case, sealed by the blowpipe, some time before 1845,† and the same device for meeting and avoiding the pressure error at great depths was made public property by Sir William Thomson's well-known paper upon the effect of pressure upon the freezing-point of liquids in 1850. Aimé also used messengers for detaching weights and for oversetting self-registering thermometers prior to 1845 (*op. cit.*, p. 5), and devised several different patterns of thermometers for registering deep-sea temperatures by being overset at the depth to be investigated, which, when protected by his closed glass or metal tubes, gave excellent results. The propeller was used by Messrs. Negretti and Zambra in 1874 to reverse their earlier form of thermometer, and the same firm, as has been explained, preceded Dr. Miller by about twelve years in the application of a protecting shield to Sixe's self-registering thermometer.

The first practical self-registering thermometers appear to have been the inventions of Lord Charles Cavendish in 1757, registering by the measurement of a portion of fluid which had been caused to overflow at the maximum or minimum temperature encountered by the instrument. Mr. Sixe, who expressly acknowledges his obligations to these inventions, improved them in form and by the addition of a movable steel index. The idea of protection against pressure by an outer shield first appears about the beginning of this century and was practically perfected about 1845, as early as which date messengers were in use for detaching weights, for closing water bottles, and for oversetting thermometers. Revolving propellers have been used, abandoned, and taken up again in very recent times, and the latest novelty appears in the modern Negretti-Zambra thermometer, in the use of the same fluid for the measurement and the registration of temperature, and in breaking the column, when overset, by means of a peculiar narrowing of the tube at a particular place. From the time of Lord Cavendish to the present the progress of improvements in the form of deep-sea thermometers has been by a very natural and regular process of evolution and of survival (or sometimes revival) of the variations best suited to their purpose.

CENTRAL STATION, WOOD'S HOLL, MASS., *July* 31, 1885.

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* Voyage de Découvertes aux Terres Australes. Vol. II, Paris, 1816, p. 330, *note*.

† Ann. de Chimie et de Physique, Ser. 3, t. xv, p. 10, 1845.

APPENDIX.

Maximum, minimum, and mean errors of fifty-one Negretti-Zambra deep-sea thermometers, by comparison with Fish Commission standards.

Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.
°	°	°	°	°	°	°	°	°
0.5	0.0	0.14	0.38	0.0	0.19	0.7	0.1	0.4
0.7	0.0	0.2	0.5	0.0	0.15	0.5	0.0	0.3
0.8	0.0	0.2	0.5	0.0	0.23	0.5	0.1	0.25
1.0	0.2	0.5	0.34	0.1	0.21	0.5	0.0	0.2
0.7	0.2	0.3	0.3	0.1	0.2	1.0	0.0	0.4
0.4	0.0	0.13	0.3	0.1	0.2	0.2	0.0	0.1
0.6	0.1	0.27	0,5	0.2	0.27	1.0	0.0	0.4
0.6	0.0	0.34	0.4	0.0	0.2	0.4	0.0	0.2
0.6	0.0	0.3	0.4	0.0	0.2	0.5	0.2	0.3
0.3	0.0	0.16	0.6	0.1	0.25	0.5	0.0	0.2
0.7	0.0	0.2	0.4	0.1	0.3	1.0	0.0	0.27
0.3	0.0	0.17	0.5	0.4	0.45	0.4	0.1	0.2
0.4	0.0	0.1	0.7	0.1	0.4	0.2	0.1	0.15
0.5	0.05	0.10	0.3	0.0	0.2	0.5	0.2	0.4
0.8	0.12	0.33	0.5	0.2	0.3	0.7	0.1	0.3
0.3	0.0	0.12	0.6	0.0	0.2	0,2	0.0	0.1
0.3	0.0	0.15	0.8	0.1	0.4	0.8	0.1	0.5