IV. *On Borings through the Coral Reef in Florida:* A. AGASSIZ.

V. *On the Alkali Uranates:* WOLCOTT GIBBS.

The reports by Professors Agassiz and Gibbs were presented informally in the absence of other papers to occupy the session.

OCTOBER 30TH.

VI. *The Olindiadæ:* W. K. BROOKS.

VII. *New Campanularian Medusæ* (read by title): W. K. BROOKS.

VIII. *The Filar Anemometer:* CARL BARUS. Professor Barus in this paper discussed the sounds by the whistling wind, made whenever air in motion passes across a slender obstacle, like a wire. He showed that the velocity of the wind could be computed from the pitch of the note observed in case of a given diameter of wire and for a given temperature of the air. By aid of a special microphonic attachment such sound could be conveyed to any distance and isolated from the attendant noises at the place of exposure. So represented, the wind was given in every detail of its gusty and variable character, and the term micro-aulmometry seemed to be applicable to observations of this nature. Finally the direction of the gust could be inferred from the sounds obtained from three coördinate wires at right angles to each other.

IX. *The Countertwisted Curl Aneroid:* CARL BARUS. Professor Barus reported that he had investigated the maximum sensitiveness which an extremely thin-walled helical Bourdon tube would show. He pointed out the importance of sharp-edged tubes for the purpose of reducing the flexure of the tube to a case of pure bending, seeing that the products of the principal radii of curvature must then remain constant. He showed that for the same reason the sensitiveness could be enormously increased by untwisting the evacuated coil with an external spring. Furthermore, if the system of countertwisting spring and helical tube be so chosen that the viscosity as well as the thermal coefficients of viscosity and rigidity of the components are as nearly as possible the same, the system would possess nearly perfect elasticity at all temperatures. The paper was accompanied by a variety of data showing the behavior of simple and countertwisted helices or curls and the remarkable advantages of the latter form.

X. *On the Broadening of Spectral Lines by Temperature and Pressure:* A. A. MICHELSON. Professor Michelson's paper will be printed in the forthcoming number of the *Astrophysical Journal* and will be reported in this journal.

XI. *On the Asteroids* (read by title): A. HALL.

XII. *The Early Segregation of Fresh-water Types:* TH. GILL. [Abstract will be printed in this Journal.]

THE THERMOPHONE.

DURING the recent session of the Summer School of Civil Engineering of the Massachusetts Institute of Technology, held at Keeseville, N. Y., the writer had the pleasure of describing to the students the construction and operation of a new instrument for obtaining temperatures. This instrument, known as a thermophone,* is an electrical telethermometer of the resistance type. It is designed especially for obtaining the temperature of a distant or inaccessible place, but it embodies a principle which may often be used to advantage in scientific work for determining temperatures with greater accuracy than can be obtained with a mercurial thermometer.

The operation of the thermophone is based upon the principle that the resistance which a conductor offers to the passage of an elec-

* Invented by Henry E. Warren and George C. Whipple.

trical current depends upon its temperature, and advantage is taken of the fact that different metals have different electrical temperature coefficients. Thus the resistance of a copper wire increases about one per cent. for each 5° Fahr., while in the case of German silver the increase is only about one-tenth as great. It is a curious fact that the coefficients of most pure metals are almost the same as that of copper, but that alloys have coefficients which are much lower.

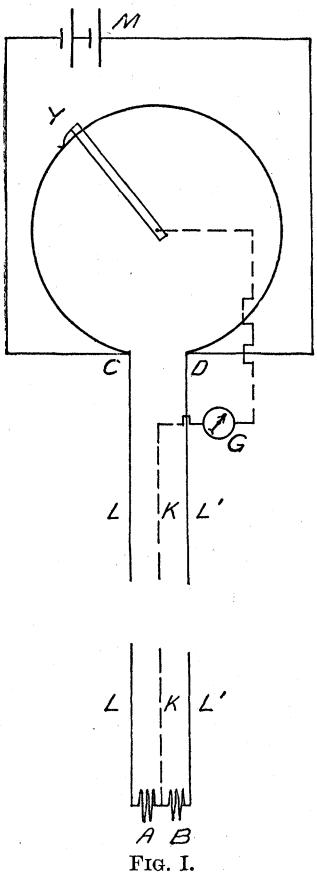

FIG. I.

The arrangement of the electrical parts of the thermophone is shown in Figure I. Students of electricity will recognize it as being a modification of a Wheatstone's Bridge. Two coils of resistance wires, A, B, one of which is copper and the other German silver, are made to form two arms of the bridge. These two coils are joined together and placed at the point where the temperature reading is desired. They are usually drawn inside a long brass tube of small diameter, coiled into a helix and hermetically sealed, the space between the wires and the walls of the tube being filled with oil to prevent corrosion and to hasten the transmission of heat between the outside of the tube and the resistance wires. The sensitive coils are connected by the leading wires L and L′ to the ends of a circular slide wire C, D, and at these points connection is also made with the battery M. A third leading wire, K, extends from the junction of the two coils to a movable contact, Y, on the slide wire. In this circuit there is interposed either a galvanometer or a telephone in connection with a current interrupter, the latter being operated by an independent battery connection. This combination of telephone and current interrupter is used in all the portable forms of the instrument and has been found to be a very cheap and efficient substitute for a galvanometer. The presence of a current is indicated by a buzzing sound in the telephone; silence corresponds to the 'zero deflection' of a galvanometer.

Bearing in mind the principle of the Wheatstone's Bridge it will be seen that the galvanometer will indicate 'zero deflection' when $A:B = CY:DY$. The coils A and B being made of metals having very different temperature coefficients will vary in resistance at different rates as their temperature changes, and consequently there will be a different value of the ratio of A to B for each degree of temperature. Thus it will be seen that with the bridge balanced there must be a different position of the contact Y for every degree of temperature, and a graduated scale may be constructed corresponding to the temperature of the sensitive coils. The slide wire is wound around the periphery of a mahogany disc, above which is another disc carrying a dial graduated in degrees of temperature. The movable contact which bears on the slide wire is attached to a radial arm placed directly under a hand on the dial, the two being moved together by turning an ebonite knob in the center of the dial. This indicator is enclosed in a brass case attached to the box containing the battery, telephone, etc., the box being about 7 inches square and 10 inches high, and furnished on the outside with binding posts for the reception of the leading wires.

It is easily seen that the temperature of the slide wire has absolutely no effect upon the reading of the instrument, for being made of one piece of metal which has the same temperature throughout its length, it will rise or fall in resistance at the same rate on both sides of Y as its temperature changes, and consequently the ratio of CY to DY will not vary. The effect of temperature changes on the leading wires will not sensibly affect the readings because the two wires L and L′ are on opposite sides of the bridge, and consequently balance each other. Compared with the resistances A and B these leading wires are of large size, and in order that they may have the same average temperature they are twisted together and covered with braided cotton.

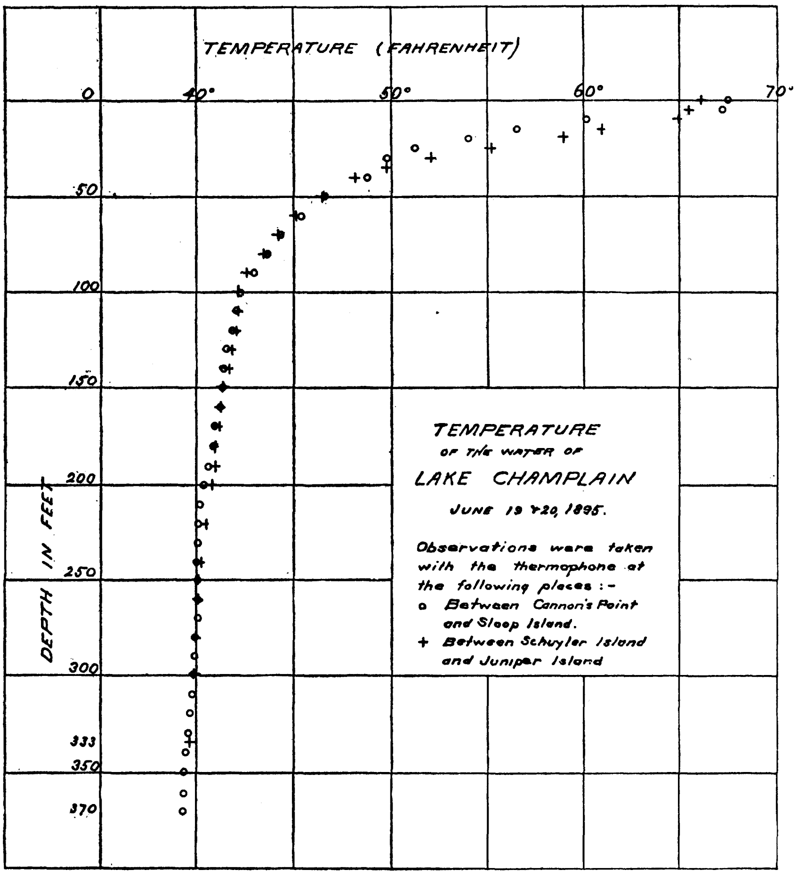

FIG. II.

The operation of taking a reading with the thermophone is as follows: The helix containing the sensitive coils being placed at the point where the temperature is desired, and the leading wires being connected to the binding posts of the indicator box, the current is turned on and the telephone held to the ear. A buzzing sound in the telephone is found to increase or diminish as the hand is made to approach or recede from a certain section of the dial. By moving it back and forth a position may be found where the telephone is silent. When at this point the hand indicates the temperature of the distant coils. The instrument is extremely senitive. An inexperienced observer may easily set it to one-tenth of a degree. With special instruments having a small range it is possible to make readings with much greater precision.

One of the uses to which the thermophone was put at the Summer School was that of ascertaining the temperature at various depths and at various places in Lake Champlain. A large number of observations were taken. The accompanying diagram, Fig. II., shows the results of two sets of observations taken where the depth was 333 and 396 feet respectively. It will be noticed that below a depth of 50 feet the readings at the two places agreed almost exactly; above that point they differed somewhat, but each curve preserved its regularity. It is interesting to observe how great a change of temperature there was in the first 50 feet below the surface, and how slight a change there was near the bottom. At a depth of 100 feet the water was but 3° warmer than at the bottom.

At the deepest place in the lake, which was found opposite Essex, N. Y., the temperature at 370 feet was 39.35° F., a point only slightly above the temperature at which water is densest. Unfortunately the thermophone wires were not long enough to reach to the bottom, which was 396 feet. The fact that this temperature so near the point of maximum density was found during the summer season indicates that the water near the bottom is in a continual state of stagnation. It is probable that there is little circulation below a depth of 200 feet.

In passing it is interesting to note the growing interest that is being taken in the study of the temperature of lakes in connection with that of the micro-organisms in the water. The seasonal occurrence of many of these forms which cause trouble in water supplies has been shown to be directly connected with the vertical circulation of the water. Knowledge of the extent and character of these vertical currents can best be obtained by observing the temperature of the water at different depths.

One of the most interesting of the special uses of the thermophone principle is in connection with the accurate measurement of distances by means of a steel tape. Heretofore the greatest objection to the use of a steel stape for the measurement of a base line has been the alterations in its length due to varying temperature and the impossibility of correctly ascertaining its temperature at the moment of use. Thermometer readings taken alongside the tape, or even with the bulb in contact with it, cannot give its exact temperature. Especially is this true when the work is done in the daytime and with the sun shining. For this reason the most accurate work has usually been done at night when the temperature of the tape is substantially the same as that of the air. By the application of the thermophone principle the tape itself may be used as a thermometer and its exact temperature easily determined. This was experimentally demonstrated at the summer school at Keeseville, where the apparatus was used for the first time.

The steel tape, 100 meters in length, was suspended a few feet above the ground between two iron poles which bore an ingenious device for keeping the tape stretched at a uniforn tension. At intermediate points, 10 meters apart, the tape was supported by insulated wire hooks. Parallel to the tape, but insulated from it, a German silver wire was suspended in a similar manner except that the tension was not regulated. At the rear end the tape and wire were electrically connected; at the forward end short flexible leads connected the tape and wire with the slide wire of the indicator. A third wire trailing along the ground, connected the junction at the rear end with the sliding contact of the indicator, having in its circuit the telephone and interrupter. The arrangement was precisely the same as in the ordinary instrument, the tape and German silver wire acting as the sensitive coils. The connections with the tape were made by adjustable clamps which could be easily removed when it was time to carry the tape to a new position. The indicator box was conveniently placed near the forward end of tape, and readings were taken in the ordinary manner by holding the telephone to to the ear and setting the hand on the dial to the point of silence. The dial bore two graduations, one showing the temperature of the tape, and the other the linear correction corresponding to the temperature. Thus it was possible, by a single reading taken at the instant when the measurement was to be made, to determine the amount necessary to be added to or subtracted from the length of the tape.

The experiments at Keeseville consisted of the measurement of a base line 900 meters in length and an accurate determination of the coefficient of expansion of the tape. The results showed conclusively that the error from temperature could be reduced to one part in 1,500,000, which was well within the precision of other portions of the work. The coefficient of expansion was determined by two sets of observations, the results being 0.00000613 and 0.00000615 respectively.

An interesting set of observations was made on the temperature of the tape at a time when clouds were passsing over the sun. The rapid fluctuations were astonishing and indicated that the tape was much more sensitive to temperature changes than a mercurial thermometer. At times when a dark cloud would suddenly obscure the sun the temperature of the tape would drop ten or fifteen degrees in half a minute. A complete account of these experiments will be published in due time.

The thermophone has also its practical uses, which are as varied as the uses of a thermometer. For use in connection with the ventilation of buildings it possesses qualities which make it more valuable than the ordinary telethermometer. Besides being accurate and comparatively inexpensive it has this further advantage that any number of sensitive coils may be connected to one indicator. Thus in a large schoolhouse a sensitive coil may be located in each room and the leading wires carried to an indicator in the janitor's office, where, by using a switch board, the janitor may read from one dial the temperature of any room in the building.

In buildings it is advisable to dispense with the telephone and current interrupter and use a galvanometer so arranged that the temperature of the distant coil is indicated by the deflections of the needle. With such an arrangement it is only necessary to press a button in order to have the needle automatically indicate the temperature.

In conclusion, it should be remarked that the thermophone is admirably adapted for obtaining high temperature, *i. e.*, up to 1,500 or 2,000° Fahr., and will doubtless find an extensive use in boilers, chimney flues, etc. It is also the purpose of the inventors to make the instrument self recording.

GEORGE CHANDLER WHIPPLE.