XVII. "Preliminary Note on the Use of the Piezometer in Deep-Sea Sounding." By J. Y. BUCHANAN, Chemist to the 'Challenger' Expedition. Communicated by Professor WILLIAMSON, Foreign Secretary R.S. Received June 14, 1876.

In order to determine the depth of the sea independently of the length of sounding-line used, piezometers filled with distilled water were frequently attached to the line along with the deep-sea thermometers. The combined effects of change of temperature and change of pressure were registered by a steel index of ordinary form. The temperature of the bottom-water being given by the deep-sea thermometer, the effect of temperature on the apparent volume of water in the piezometer could easily be calculated; and from the residual effect, the pressure, and therefore the height, of the column of water to which the instrument had been subjected could be deduced.

The piezometer did not differ materially from the ordinary ones used for the determination of the compressibility of liquids. A minute description of the fittings necessary for their safe use on the sounding-line cannot be given without reference to a drawing or model, and must therefore be postponed.

It is manifest that if the apparent compressibility of water is accurately known, we shall be in a position to determine, by means of our instrument and a deep-sea thermometer, the depth to which it has been sunk, independently of the lengths of sounding-line used; for the indications of the instrument depend solely on the temperature of the water at the depth in question, and on its vertical distance from the surface.

The determination of the effect of change of temperatnre on such an instrument does not demand explanation. It is, however, otherwise with the effects of pressure. In submitting an instrument of the kind to high pressures in an hydraulic machine, we encounter difficulty in accurately determining the pressure to which it is exposed, and also, although in a minor degree, in making our observations at the low temperature usually obtaining in deep ocean waters. I have therefore taken as basis for the determination of the apparent compressibility of water the results obtained when the instrument has been sent down on the sounding-line, either to the bottom or to intermediate depths, in positions where there has been no apparent disturbance from currents, and where the amounts of compression produced have been proportional to the depths recorded by the sounding-lines. Where currents are absent, and their presence is at once detected by the behaviour of the sounding-line, the depth, as determined according to the method of sounding adopted on board the 'Challenger,' gives an excellent measure of the pressure exercised on the instruments. As the variations in the temperature, the salinity, and the compressibility of sea-water with the depth have been thoroughly inves-

tigated for the soundings in question, the weight of a column of sea-water in any of these localities can be calculated with great accuracy.

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 effect of pressure being thus known, we are in a position, by comparing the indications of the instrument with those of a trustworthy deep-sea thermometer, to determine the absolute depth to which it has been sunk beneath the surface; and assuming the depth as indicated by the sounding-line to be correct, we should be able to determine the temperature at the depth in question from the indications of our instrument, and without the use of a thermometer. For the latter purpose, however, the instrument, as above described, is useless, because the dilatability of water at the low temperatures obtaining in deep water is so small as to be negligible compared with its elasticity.

The application, however, of the principle above indicated would manifestly present some very great advantages in the determination of deep-sea temperatures.

In the open ocean, where, as a rule, the temperature diminishes constantly as the depth increases, the Millar-Casella thermometer gives sufficiently accurate results. In the case of enclosed seas, or in the neighbourhood of ice, however, this is not always the case. 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 is different for different seas; and at all greater depths the Millar-Casella 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 Millar-Casella 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. It would therefore be of great advantage if the piezometer could be adapted for the determination of temperatures at known depths. An efficient instrument for this purpose has been obtained by filling the bulb of the piezometer with mercury

instead of water. The portion of the stem in which the index moves is filled with water, and, as in the other, the open end dips into a cup of mercury. We have thus an instrument filled with a very large quantity of mercury and a very small quantity of water; and after 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 pressure 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 has been in use since the beginning of November last year, and which is designated XVII. *a*, contains 256·61 grammes of mercury in the bulb and stem immediately above it; the volume of the part of the stem filled with water is 0·1935 c. c. The apparent contraction of this mass of mercury and water is 0·000581 cubic centimetres per 100 fathoms, and 0·0025 c. c. per degree respectively. A fall therefore of one degree in temperature produces 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 amount of temperature and the column of water, which produce the same effect on the apparent volume, is a constant for every instrument; in our one 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 XVII. *a* was intended principally for bottom-waters, the above ratio ($\frac{1}{430}$) was considered sufficient, and it has 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.

By attaching a combination of one, or better of two, of each of these instruments close to the weight at the end of the sounding-line, the depth of the sea and the temperature of the water at the bottom at any locality can be accurately determined, provided that sufficient evidence is afforded, either by the presence of a sample of bottom in the sounding-tube, or by the rate at which the line runs out, that the instruments have been at the bottom; otherwise the depth which they have attained and the temperature at that depth will be correctly given. For this purpose it is necessary first to let the line run out until, from observations on its velocity, it is evident that the weight has reached the bottom; the length

of line which has so run out will give the depth approximately, but more or less in excess of the truth according to circumstances. Allowing for the contraction which would be produced by this depth in the case of the mercury piezometer, a first approximation to the temperature of the bottom-water is at once obtained; and it is sufficiently accurate for the purpose of correctly determining the contraction produced on the water piezometer by the change of temperature, and consequently for deducing the depth to which the instrument has been sunk. By now applying the more correct depth to the reading of the mercury instrument, we obtain the correct temperature, and if necessary the approximation might be carried still closer.

As an example of the use of the combined instruments, the observations made on the 29th February, 1876, may be taken. The position of the sounding was lat. 36° 9′ S., long. 48° 22′ W., and the depth by line was 2800 fathoms. The sea was quite calm, but there was a strong current setting to the south-east, rendering it probable that the depth, as determined by line, was considerably in excess of the true depth. The mercury instrument (XVII. *a*) registered 166·2 millims. In order to clear this reading for a depth of 2800 fathoms, we have to subtract 16 millims., and we obtain 150·2 millims. as the corrected reading, from which we determine the temperature to be +0°·2 C. The reading of the water instrument was 283·8 millims. Assuming the temperature to have been 0°·2 C., this would indicate that the water had suffered an apparent contraction, owing to pressure alone, of 0·1923 c. c., which would be produced by a column of 2480 fathoms of sea-water. Assuming now 2480 fathoms to be the true depth, we find the corrected reading of the mercury instrument (XVII. *a*) to be 152·1 millims., which indicates a temperature of −0°·5 C. The Millar-Casella thermometers gave the temperature as −0°·4. Assuming this as the correct bottom temperature, and reducing the reading of the water instrument (C. No. 1) accordingly, we find the contraction produced by pressure to be 0·1924 c.c., which agrees sensibly with that found on the assumption of the higher bottom-temperature of +0°·2 C.

It will thus be seen that the two instruments fulfil the conditions required of them; namely, that the one which is to indicate the temperature of the water shall be independent of great accuracy in the determination of the depth, and the one which is to indicate the depth shall be equally independent of accurate determination of the temperature; whilst by combining the results obtained by the two, an accurate determination is obtained both of the depth and of the temperature of the water at that depth.