A LABORATORY HYPSOMETER*

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A very simple form of hypsometer, consisting of a nearly closed space into which steam from a boiler can be admitted, will serve to maintain, in the steam space, a temperature which differs, at most, by a few hundredths of a degree from that corresponding to saturated steam at atmospheric pressure. The well known Rudberg or Regnault hypsometer is a very simple piece of apparatus and is capable of serving the requirements of all but the most precise thermometric measurements.

Of the various more elaborate forms of hypsometers which have been devised for precise measurements two were designed at the International Bureau, while most of the remainder originated at the Reichsanstalt. In the Chappuis hypsometer[1] which was an improved and simplified form of a very elaborate instrument devised by Pernet,[2] the design was determined almost entirely by the requirement for facility in changing the position of the thermometer from vertical to horizontal, while in the steam. In this hypsometer, the steam is lead from the boiler through piping to a tube in which the thermometer is placed, thence into an annular space surrounding the tube, and thence to the condenser. A water manometer is used to measure the difference between the pressure in the steam space and that of the atmosphere. A copy of this instrument has been in use for many years at the Bureau of Standards, and the only feature of it to which objection might properly be made, is the water manometer.

Thiesen, Scheel and Sell[3] describe a very elaborate hypsometer, which was a modification of an earlier instrument described by Pernet, Jaeger and Gumlich.[4] The hypsometer as modified con-

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[1] Described by Guillaume, Trav. et mem. du Bur. Int., *5*, p. 39; 1886.

[2] Trav. et Mem. du Bur. Int., *1*, p. B-15; 1881.

[3] Wiss. Abh. der Phys. Tech. Reichsanstalt *2*, p. 138; 1895.

[4] Wiss. Abh. der Phys. Tech. Reichsanstalt *1*, p. 87; 1894.

sisted of a large gas heated fire tube steam boiler, from which the steam was piped through a pressure regulator, to the space in which the temperature was to be measured. In the bottom of this space was a water seal, through which the entering steam was made to pass in order to ensure saturation. The steam escaped from the steam space through a second pressure regulator. An important feature was the manometer for measuring the excess pressure in the steam space. The one limb of this manometer which was in contact with the steam, was surrounded by water which was kept boiling violently by means of steam supplied by a separate boiler. The other limb of the manometer included a water surface of large area.

In the description of this apparatus, the errors due to possible superheating, and to incorrect measurement of the pressure in the steam space, are emphasized, and it is evident that elaborate measures were considered necessary to eliminate such errors. It is reported that the apparatus functioned satisfactorily.

A later apparatus described by Guitzmacher[5] has the general appearance of the Regnault hypsometer, but differs from it in provision of special means to eliminate superheating. The steam from the boiler flows through a number of short tubes, through a water seal forming the bottom of the thermometer space, and thence past the thermometers. A number of water manometers were connected for indicating the excess pressure of the steam, but evidently it was not considered necessary to boil them as in the apparatus previously described.

It does not appear necessary to refer to all of the various other forms which may be found described in the literature. It will be sufficient to refer to the hypsometer used by Henning & Heuse[6] in their recent determination of the expansion of gases. Steam was generated in a small boiler, heated by an electric heating coil immersed in the water. The steam was piped to the top of the annular space surrounding the thermometer space, flowed downward in the annular space and up past the thermometer

[5] Wiss. Abh. der Phys. Tech. Reichsanstalt, *3*, p. 259; 1900.
[6] Zs. für Physik *5*, p. 295; 1921.

and thence to the condenser. The excess pressure was read on a water manometer. All parts were thoroughly insulated to avoid fluctuations of temperature due to drafts.

The last two forms of apparatus are noteworthy as indicating a tendency to depart from the somewhat monumental form attained in earlier instruments. It is also noteworthy that the last apparatus while omitting the very elaborate precautions observed in the design of earlier forms, was used with platinum resistance thermometers, which would have made it possible to detect errors and irregularities so small as to escape detection entirely in work with mercurial thermometers.

The above brief review will indicate that in the design of hypsometers, in addition to the essential precaution of steam jacketing for the space in which the thermometer is placed, which is the feature that makes the distinction between the Rudberg or Regnault hypsometer and an ordinary tin can, the refinements which have been emphasized are (1) avoidance of superheated steam in the space around the thermometer, (2) accurate measurement of the pressure in this space, (3) provision for securing constancy of pressure and temperature in this space. To these the authors would add purity of material as an essential feature, to be attained by rapid and thorough removal of air from the steam.

In designing a new hypsometer[7] for general laboratory use, it appeared that an improvement on the instruments already described could be obtained by introducing the steam into the thermometer space and the surrounding annular space at the top, allowing the steam to flow downward in parallel in the two spaces. This arrangement secures steam jacketing of the thermometer space, avoidance of superheat in the steam, since the boiler is located at a distance and ample cooling surface can be provided between boiler and thermometer space, and eliminates entirely the necessity for a water manometer to measure the excess pressure of the steam. The density of steam being less than that of air, a column of steam flowing downward in a pipe

[7] Briefly described in Jour. Wash. Acad. *11*, p. 167; 1921.

open to the air at the bottom, is stable, while if the steam is flowing upward in a pipe, stability can only be attained by restricting the escape of steam sufficiently to cause the pressure in the pipe to exceed that of the atmosphere. The downward flow of the steam also greatly facilitates the removal of air from these spaces.

The details of construction will be evident upon reference to the photograph, Fig. 1 and the schematic line drawing, Fig. 2. Electric heating was chosen for convenience. The boiler is made of a brass tube 5 cm in diameter and 20 cm high, the outside reservoir serving to maintain a nearly constant water level. The steam pipe from the boiler is a 13 mm brass tube, which enters the steam space around the thermometer tangentially. The small boiler makes it possible to heat up rapidly, and its small cross section and the small steam pipe provide for relatively rapid steam flow in these portions thus facilitating rapid removal of air. The upper 5 cm of the thermometer space are uninsulated to provide surface for condensation, while the remainder of the space is provided with an air jacket which is apparently sufficient to prevent fluctuations due to drafts. The steam after passing through the thermometer space, escapes into the air or may be condensed and returned to the boiler.

All parts in contact with steam or water were tinned. The heating coil consists of two sections which may be connected by means of the switch, either in series or parallel. With the coils in series on a 110-volt circuit the input is about 125 watts which is sufficient to maintain just a trace of steam escaping into the air. Increasing the input up to 640 watts produced no determinable change in the indications of a resistance thermometer in the steam, thus indicating the absence, both of superheating and of excess pressure.

A series of steam point determinations with a resistance thermometer, using both the new hypsometer and the Chappuis hypsometer, indicated no systematic difference between the two, although the precision was slightly in favor of the new instrument. Fortuitous errors of about 0.005° persisted and are apparently due

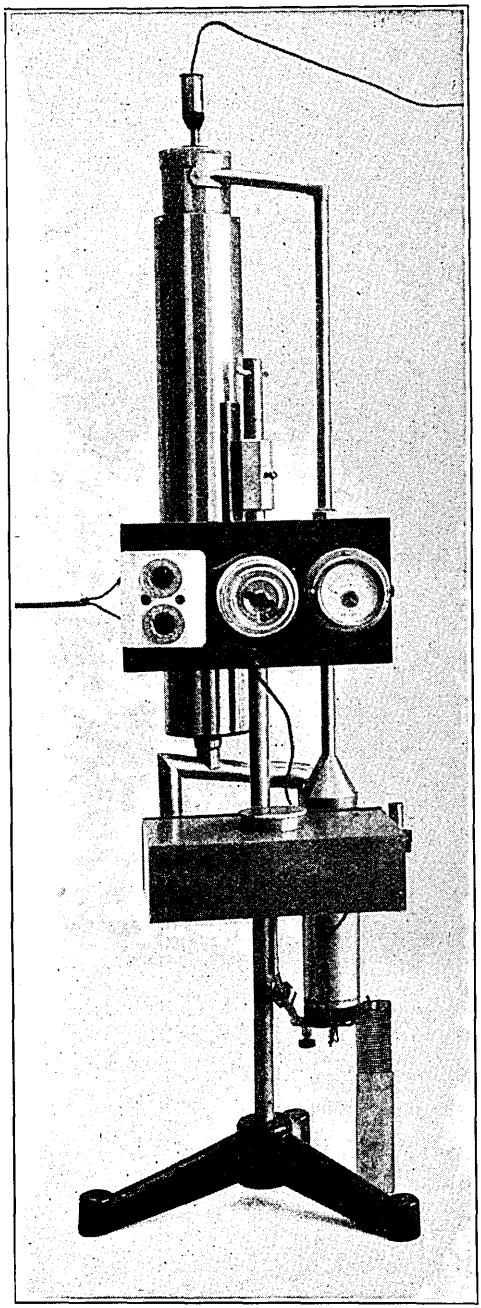

FIG. 1. *Laboratory Hypsometer*

to irregular fluctuations in atmospheric pressure or to errors in measurement of barometric pressure indicating that improve-

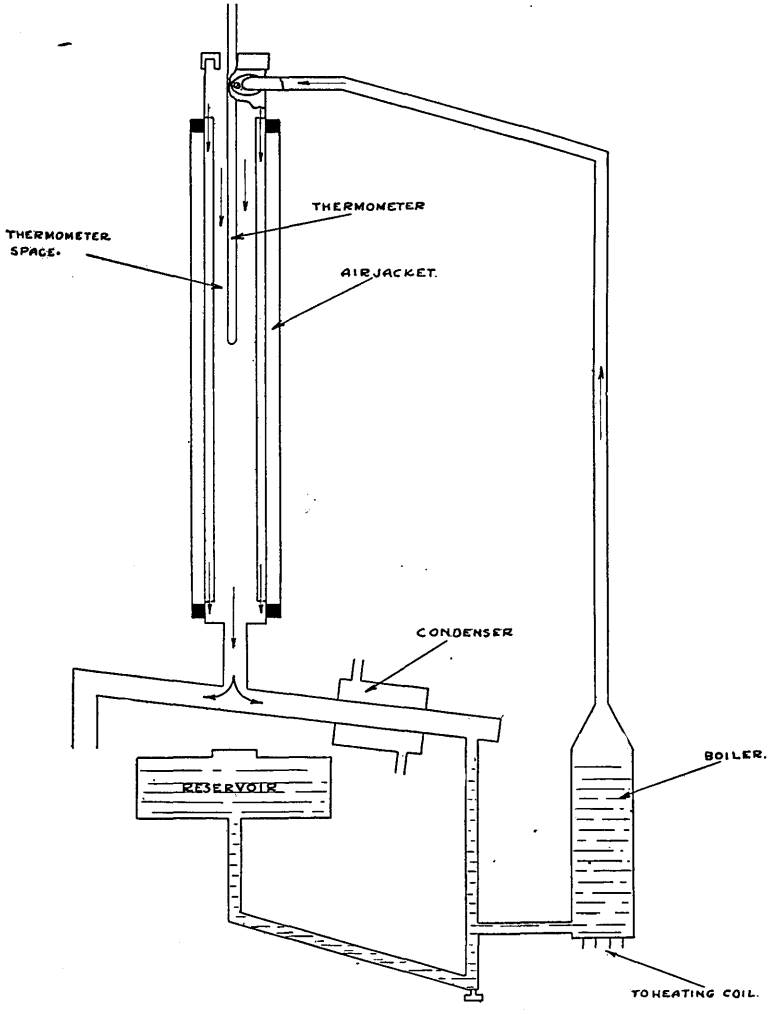

FIG. 2. *Schematic Diagram of Hypsometer*

ments in this respect will require the use of a closed system and better temperature control of the barometer.

While there is no indication that results hitherto obtained with other hypsometers are in error, it is believed that the principles

applied in the design of the present instrument can be used to advantage in the construction of new equipment.

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