AN EXTENSION OF THE RANGE OF THE McLEOD GAUGE.

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SYNOPSIS.[1]

Modification of the McLeod Gauge.—In order to extend the range of a McLeod gauge, the pressure of the gas which is forced into the capillary is measured by means of *a hot-wire gauge*. Since the ratio of the compression is known, it is possible to determine the true pressure. The hot-wire gauge consists of a loop of tungsten wire, sealed into the closed end of the capillary and connected so as to form part of a Wheatstone bridge. The hot wire gauge is calibrated directly against the McLeod gauge. Because of the fact that the cooling effect varies with the character of the gas, a separate calibration for each gas is necessary.

Tests Made on the Gauge with Air.—Careful tests prove that the results obtained for air, the only gas used, are reliable. *The limit of the hot-wire McLeod gauge* was found to be 1.7×10^{-7} mm. hg. or 2.25×10^{-4} bar, while that of the unaided McLeod gauge was found to be 5.26×10^{-5} mm. Hg. The range of the McLeod gauge is therefore extended three hundred fold. By using a sensitive wall galvanometer in place of the portable galvanometer, a sensibility of 3.4×10^{-10} mm. or 4.5×10^{-1} bar was realized.

THE sensibility limit of a McLeod gauge has been reached when the length of the trapped air column and the difference in level of the two mercury columns are of the order of magnitude of 1 mm. Under these conditions, however, the trapped air is subjected to the pressure of 1 mm. of merucry—which is large from the standpoint of high vacua. If it were possible to measure the pressure of this trapped air, then, knowing the ratio of compression, it would be possible to extend greatly the range of the McLeod gauge.

This idea is realized by sealing a fine loop of tungsten wire into the top of the closed capillary. Using this arrangement (which is the well-known "hot-wire" gauge) in conjunction with a Wheatstone Bridge and a portable galvanometer, it is possible to extend the range of the McLeod gauge about 300-fold.

DESCRIPTION OF APPARATUS.

The apparatus used is shown in Fig. 1. This particular form of the gauge was adopted because of the convenience of baking out the glass. This is accomplished by inverting a small electric furnace over the top of the gauge. The filament (f) was made of 2 mil tungsten wire and had an over-all length of 6 mm. The resistances r_1, r_2, r_3, forming part of a simple Wheatstone bridge, were made of No. 22 chromel wire. While

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no definite information can be given as to the highest temperature reached by the tungsten filament in a high vacuum, it may be stated that when the current flowing through the filament was increased to 130 m.a. the tip of the filament appeared faintly red in a darkened room. The filament current actually used was about 100 m.a. For several reasons

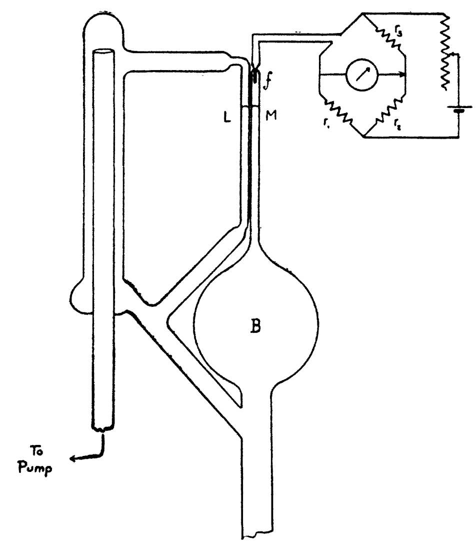

Fig. 1.

the bore of the capillary was chosen large: 2.0 mm. Not only is the range of the gauge on the high-pressure side increased but such defects as mercury sticking to the walls, negative pressures, etc,. are reduced to a minimum. Careful tests showed that no measurable amount of gas was caught between the rising column of mercury and the glass walls of the closed capillary. No difficulty was experienced in sealing in the filament without distorting the adjacent portions of the capillary. In fact, filaments were sealed successfully into capillaries having a bore less than 1 mm. The large bulb (*B*) had a volume of about 60 c.c. and the ratio of the volume of a length of 1 mm. of capillary to that of the bulb was 5.26×10^{-5}. A Gaede mercury pump was used to produce a moderately high vacuum while a liquid-air trap containing cocoanut charcoal, introduced between pump and gauge, was used to attain the highest vacua.

Calibration of Hot-wire Gauge.

Unfortunately, the indications of the hot-wire gauge are dependent upon the character of the gas used. This shortcoming is, however, not a vital defect, since this gauge may be calibrated against the McLeod gauge itself. The mode of procedure consisted in surrounding the charcoal bulb with liquid air so as to remove all vapors, hydrocarbon, water, etc., from the air which had been admitted into the pump. After measuring the pressure by means of the McLeod gauge, the resultant steady galvanometer deflection was noted (bulb and capillary empty). By carrying out a number of such pairs of observations at different pressures, a calibration curve of the type shown in Fig. 2 was obtained.

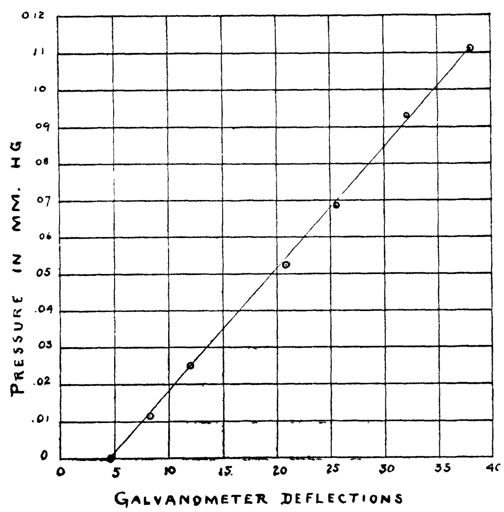

Fig. 2.

It is apparent that the points plotted lie, very approximately, on a straight line. Since mercury vapor is always present, it is evident that only partial pressures, to the exclusion of that of mercury vapor, are being measured.

Reliability and Accuracy.

Upon reducing the pressure below the point at which any difference of level in the two mercury columns L and M (Fig. 1) is discernible, the hot-wire gauge still shows large deflection. As previously stated, this is due to the fact that the original, large volume of gas, after having been forced into the capillary, now exists at a relatively high pressure and hence cools the hot tungsten filament. Since the hot-wire gauge is *used* when the gas is compressed into a limited volume, while it is *calibrated* when capillary and bulb are empty, it is entirely possible that the original calibration does not apply under the conditions attendant upon the actual use of the gauge. To test this point, a certain volume of air was compressed so that it filled the entire capillary; then, by successive steps, the volume was decreased until the mercury stood 2 mm. below the tip of the tungsten filament. Galvanometer readings, corresponding to these successive volumes were recorded. A characteristic series of results is presented in Table I.

TABLE I.

h	Galvanometer Reading.	P' *mm.*	P_0 *mm.*
∞	4.6		
60 mm.	7.0	0.0084	2.66×10^{-5}
30	10.0	0.0175	2.76
15	15.0	0.035	2.76
10	19.9	0.051	2.68
8	23.7	0.064	2.70

h = length of air-column in closed capillary.
P' = pressure of gas in closed capillary.
P_0 = pressure in system outside of gauge.

Referring back to the original calibration curve (Fig. 2) the pressures P' in the capillary were evaluated. Since the ratio of a compression is known in each case, it is possible to calculate P_0, the true pressure of the gas in the vacuum system outside the gauge. If the complications, previously referred to, exist, then P_0 might be expected to vary pronouncedly. As a matter of fact P_0 remains nearly constant even though the top of the mercury in the closed capillary is at widely different distances from the filament.

While the constancy of P_0 *points* to the conclusion that the gauge-readings are correct, it does not *establish* the proof. Most fortunately, the McLeod and hot-wire gauges overlapped in a small range of pressures, so that a decisive test was possible. The results are presented in Table II

TABLE II.

	McLeod Gauge.			Hot-wire Gauge.
	h	Δ	P_0	
I.	8.0	1. mm.	2.3×10^{-4} mm.	2.0×10^{-4} mm.
II.	6.0	0.8	3.35×10^{-4}	4.0×10^{-4} mm.

h = length of trapped air-column in mms.
Δ = difference in level of the two mercury columns in mm.
P_0 = true pressure in mm.

The agreement is well within experimental error which is rather large in the case of the McLeod gauge because of the fact that differences in level (Δ) amounting to a millimeter or less must be read.

An attractive feature of the mode of procedure here presented is the ease with which the hot-wire gauge may be calibrated. It is only necessary to obtain galvanometer deflections (bulb and capillary empty) at two known pressures, preferably as far apart as possible. As a final test, the two pressures were respectively near the upper and lower limits of the McLeod gauge. Upon laying off these two points on coordinate paper, as in Fig. 2, and connecting them by a straight line, a calibration curve was obtained which, when tested for constancy of P_0, showed an average deviation from the mean of only 2.2 per cent.

The range of pressures which may be measured with this arrangement and the magintude of the lowest pressures detectable are rather remarkable. Since the scale divisions on the portable galvanometer were about 3 mm. long, it was easy to read deflections to one-tenth division. Readings were reliable only to .2 divisions so, calculating the galvanometer sensibility on this basis it turned out to be 2.4×10^{-6} amperes. With this combination of gauges as used, it is possible to cover the entire range of pressures extending from 0.275 mm. to 1.7×10^{-7} mm Hg (or 2.25×10^{-4} bars). It is, of course, obvious that the limit of sensibility is determined only by that of the galvanometer. Since the limit of the unaided McLeod gauge is 5.26×10^{-5} mm. it appears that, through the addition of the hot-wire gauge, pressures as low as 1/300th of the above may be measured.

At a time when the true pressure P_0 was 8.4×10^{-7} mm. and the portable galvanometer yielded a deflection of 1 division, a wall galvanometer of sensibility 5×10^{-9} amp. was substituted. As might have been foreseen, a deflection too large to read was obtained. While the calculated sensibility was 3.4×10^{-10} mm. or 4.5×10^{-7} bars it is not feasible to use so sensitive a galvanometer unless the Wheatstone bridge, hot-wire gauge, etc., are surrounded by constant temperature oil-baths, as is customary in bolometer practice.

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