Experiment No. 56

Calibration of a heat conduction vacuum meter using a McLeod vacuum meter

Keywords:
Pressure measuring devices (manometers, vacuum meters), Boyle-Mariotte's law, Wheatstone's bridge circuit

Literature:
Kohlrausch "Practical Physics", Volume 1
Gerthsen, Kneser, Vogel, "Physics"

Basics:
Mercury U-tube manometers are used primarily to measure absolute pressures between 10 and 1000 mbar. In a similar way, other liquids with lower densities than mercury (e.g. water, alcohol, toluene, petroleum) can be used in U-tube manometers for the pressure range between 1 and 100 mbar. Such pressure gauges with open manometer arms on both sides are often used to measure small pressure differences at higher absolute pressures. Compression vacuum gauges with mercury filling (also called "McLeod") can be used to measure absolute pressures between 1 mbar and 10^{-5} mbar. They are often used to calibrate other (gas-type-dependent) pressure measuring devices. The operation of such a vacuum gauge is explained below (Fig. 1):

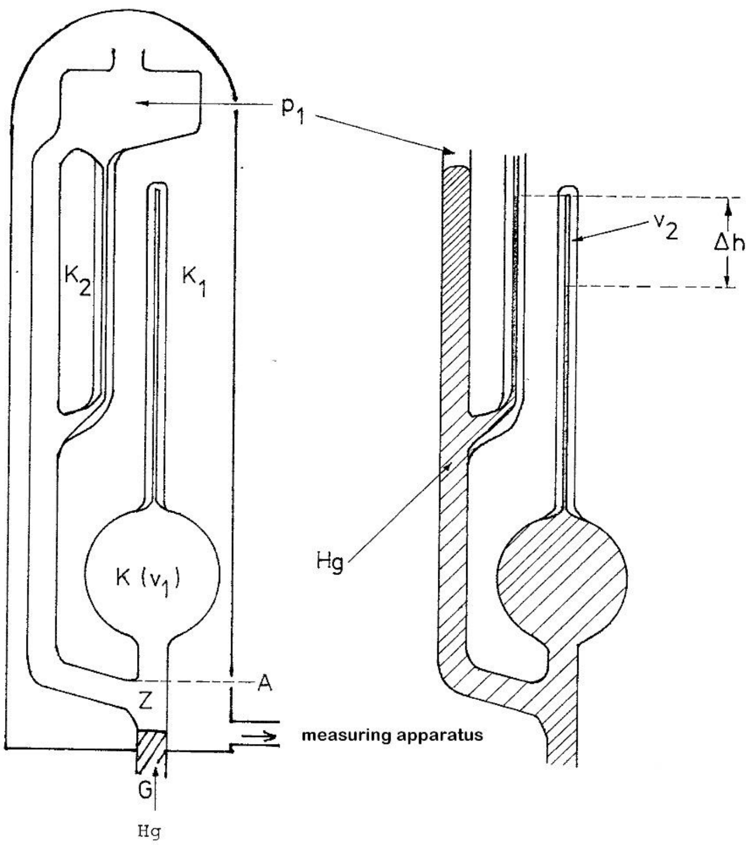


Fig. 1: How a compression vacuum gauge (McLeod) works

Mercury can be pressed from a storage vessel G with the help of a handwheel via a diaphragm pump into the supply line Z to the measuring chamber and into the sphere K with the volume v1. As the mercury level rises, Z and K are separated from each other at point A. If the mercury continues to rise into the capillary K1, the pressure in K1 increases from the low pressure p1 to be measured to the much higher pressure p2 due to the large difference in volume between K_1 and K. The pressure increased in this way can be measured as a height difference Δh, analogous to reading a U-tube manometer.

However, due to the design, the pressure p_1 is not read on a linear scale but on a square scale. According to Boyle-Mariotte's law:

(1) $p_1 \bullet v_1 = p_2 \bullet v_2$, with T = const.

And further:

(2) $v_2 = \pi \bullet r^2 \bullet \Delta h$ (where r = radius of the capillary K_1)

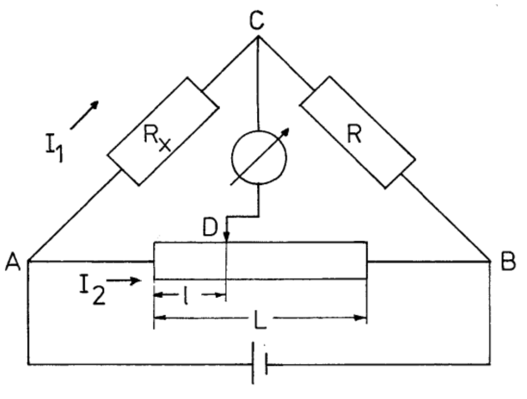
Since $p_2 \gg p_1$, the following applies:

(3) $p_2 \approx p_2 - p_1 \approx \Delta h$ (mm Hg column)

This gives:

(4) $p_1 = p_2 \bullet v_2 / v_1 = \pi \bullet r^2 \bullet (\Delta h)^2 / v_1$

Due to the strong capillary depression of the mercury, a capillary of the same diameter is also installed in the supply line to the measuring chamber. For measurement, the mercury meniscus in K_2 is therefore set to the end of the capillary K_1 (see Fig. 1). The pressures calculated according to (4) are already indicated on the display plate by the manufacturer as a scale. Compression vacuum gauges can only be used for gases whose vapor pressure is so high that no condensation occurs during the compression process. The measuring instrument does not provide a continuous pressure display. The mercury must be pumped into the measuring system again for each pressure measurement. The operation of a heat conduction vacuum gauge (Pirani vacuum gauge) is based on the fact that the thermal conductivity of gases at low pressures (< 1 mbar) depends strongly on the total pressure.



$$R_x = R \frac{l}{L-l}$$

A thin wire is stretched in the measuring cell, which is heated by a constant supply of energy and forms one branch of a Wheatstone bridge (R_x).

Fig. 2:
Circuit principle of a Wheatstone bridge

The adjustable resistor L is adjusted until the pointer instrument no longer indicates any current. Then there is no voltage between C and D. The same current then flows through R_X and R. The voltage drops at R' and l are the same, as are those at R and L - l.
The current I_1 flows through R_X, and the current I_2 through L. According to Kirchhoff's second law, the currents behave inversely to the resistances. The following therefore applies:

(5) $I_1 : I_2 = l : R_X$ and $I_1 : I_2 = (L - l) : R$

The particular advantage of a Wheatstone bridge circuit is the higher accuracy of the resistance measurements compared to determining resistance by current and voltage measurements according to Ohm's law.

The bridge is calibrated at very low pressures. As the gas pressure increases, the bridge becomes out of tune because the measuring wire becomes colder due to the higher heat dissipation through the gas. The resulting bridge current serves as a measure of the gas pressure and is displayed on a pointer instrument. While the unregulated heat conduction vacuum gauges only measure pressures between 10^{-3} and 10 mbar, regulated instruments have a measuring range of 10^{-3} to 1000 mbar.
An important property of heat conduction vacuum gauges is that the heat conduction depends on the type of gas and the display must therefore be calibrated separately for each gas. Due to the very short response time, they are particularly suitable for control and pressure monitoring tasks.

<u>Task:</u>
The scale of a heat conduction vacuum gauge for air is calibrated using a compression vacuum gauge.

<u>About the experimental setup:</u>
In addition to a two-stage rotary vane pump, the two vacuum gauges and a glass flask as a buffer volume are connected to an evacuable glass apparatus.

<u>Procedure:</u>
1) The entire apparatus is evacuated to about 1 mbar. The final pressure is checked with the McLeod.

IMPORTANT:
Only connect the McLeod when all the mercury is in the storage vessel!

2) The buffer volume is disconnected and the rest of the apparatus is evacuated to $\approx 10^{-3}$ mbar. The final pressure is checked with the McLeod.

3) The pump is disconnected and the tap to the buffer volume is opened.

4) The resulting pressure is measured with the McLeod and the corresponding pointer position on the display device of the heat conduction vacuum gauge is noted. (Pressure and scale divisions!)

5) The pressure in the entire apparatus, including the buffer volume, is reduced slightly by carefully opening the tap in front of the pump. Then proceed as in 4).

6) The pressure is gradually reduced so that around 20 measurements can be made in the range between 1 and 10^{-3} mbar.

<u>Evaluation:</u>

1) Two diagrams are drawn on millimeter paper:

a) the decimal logarithms of the pressures measured with the McLeod as a function of the corresponding scale divisions of the heat conduction vacuum gauge.
b) the logarithms of the pressures measured with the McLeod as a function of the logarithms of the pressures displayed by the heat conduction manometer.
Draw the measuring points with <u>error limits</u> in both diagrams.

2) Discuss the shape of the calibration curves and determine the useful measuring range of the heat conduction vacuum gauge.

<u>Accessories</u>:

evacuable glass apparatus, compression vacuum gauge, heat conduction vacuum gauge with display, glass flask (about 1 litre), two-stage rotary vane pump, cold trap