

CALIBRATION FACTORS FOR VACUUM PRESSURE GAUGES

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Gauges are used for a wide range of reasons within vacuum systems, including: pressure determination (is the UHV pressure low enough to optimize the experiment?), to act as system 'inter-locks' or 'switches' (e.g. when a secondary pump can be started) and to 'control' production processes.

Factors such as gauge reproducibility, accuracy, stability, resolution, linearity, response time, dynamic range and robustness as well as cost are all important considerations in choosing a gauge.

Vacuum gauges are either Total - the total pressure is the sum of the partial pressure of each gas: Daltons law.

$$P = P_1 + P_2 + \dots = (n_1 + n_2 + \dots) \frac{RT}{V}$$

or Partial pressure gauges, which measure the (partial) pressure of individual gas species.

Additionally, absolute gauges are termed 'primary' in that they can be calibrated from their own fundamental physical properties or 'secondary' for gauges which require separate calibration.

Gauges can also be subdivided into two principle groups: those that directly measure pressure (the force exerted by impinging gas molecules) and those that measure pressure indirectly by exploitation of the properties of gases which vary with pressure. Indirect gauges must be calibrated (or have their readings adjusted) for the specific gas present – their readings are thus "gas type dependent".

Commercially available direct gauges have a practical lower limit of 10^{-4} mbar so the use of indirect gauges is necessary at these and lower pressures.

Direct gauges further sub-divide into those where the difference between the measured pressure and a reference displaces a liquid or elastic/mechanical element.

Indirect gauges are often calibrated for nitrogen. For example, if the sensitivity for nitrogen is S_{N_2} and the indicated (measured) pressure = P_{N_2} then if the gas is known the true gas pressure (= P_{gas}) is:

$$P_{True(gas)} = \frac{S_{N_2}}{S_{gas}} \times P_{N_2}$$

S_{gas} = relative sensitivity for the gas.

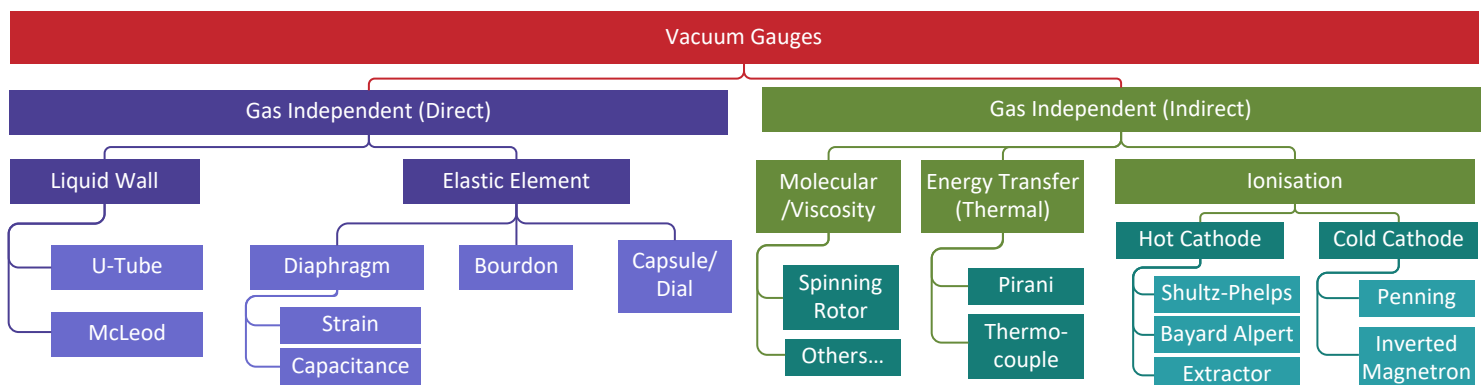
In the case where $S_{N_2} = 1$ then simply

$$P_{true(gas)} = P_{indicated(N_2)} / S_{gas}$$

Where there are multiple gas species present then the situation becomes complicated*. In the first instance the percentage composition of the gases needs to be known. Then from first-principles for a range of constituent gases where $r_i = P_i/P_{N_2}$ is the relative constituent of the i th gas and the relative sensitivity of the i th gas is $s_i = P_{indicated(N_2)} / P_{true}$, the relationship between the 'true' (or real) pressure and the indicated pressure is given by:

$$P_{True(gas)} = \frac{\sum_{i=1}^n r_i}{\sum_{i=1}^n s_i r_i} \times P_{indicated}$$

Classification for common gauge types



Indirect gauges can be further sub-divided into:

- Those that measure molecular drag (or viscosity)
- Those that measure heat transfer through the gas
- Those that attempt to measure number density directly by ionising gas molecules, moving them to an electrical contact and measuring the resultant current.

Pirani and thermocouple gauges are very commonly used in rough and medium vacuum, because they are inexpensive and relatively robust. However, many users forget or do not know that they are gas dependent; there can be large errors at the high and low extremes of their quoted measurement range.

Chart 1 shows a typical non-linear reading for a range of gases of a Pirani gauge.

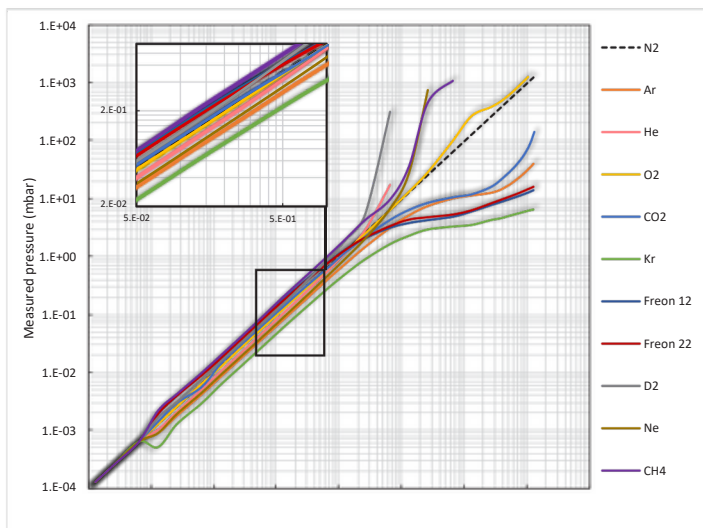


Chart 1: Range of gases in a Pirani gauge (non-linear)

‘Hot’ cathode gauges are linear and generally more accurate and repeatable than ‘cold’ cathode gauges. They are commonplace in high and ultra-high vacuum systems, particularly in analytical and R&D applications, mainly for this reason.

$$GS = \frac{I^+}{I^- P}$$

- Here we define Ion Gauge Sensitivity (GS: not to be confused with sensitivity factor) in units of reciprocal pressure unit. For a Bayard Alpert Ion gauge then gauge sensitivity is typically 10 to 25 mbar⁻¹
- Emission current (I⁻) is kept constant
- Collector current measured (I⁺) which is proportional to Pressure

Gas	S _{gas}	Gas	S _{gas}
Air	0.97 - 1.00	CH ₄	1.40 - 1.62
CO ₂	1.3 - 1.45	Kr	1.72 - 1.94
He	0.14 - 0.25	N ₂	1
H ₂	0.36 - 0.60	H ₂ O	0.86 - 1.25

In summary, knowing the gas composition and their relative amounts in a vacuum system and the corrections required for the types of (indirect) gauges used is essential to making an accurate determination of the pressure. Reference to a gauge calibration history is also critical.

*For a more in depth study see the article by Rebecca Grinham and Andrew Chew, ‘Gas Correction Factors for Vacuum Pressure Gauges’ Vakuu in Forschung und Praxis, 29 (2) page 25 (2017)