Ideal Gas Thermometer

[Also see E&R pp 4-6 and Dickerson pp. 77-80]

In launching our study of thermodynamics we require precise definitions for the variables used to specify the state of a system. For variables such as density, force, volume, and pressure we will rely on concepts from physics and from introductory chemistry and assume a 'seat of the pants' knowledge of measuring devices such a rulers, manometers, and balances. However temperature plays a special role in thermodynamics and will be especially important later when we study the second law of thermodynamics. Here we will see that the thermodynamic temperature "$\mathcal{T}$" provides what we will call an 'integrating denominator' (but this is way ahead of our story!).

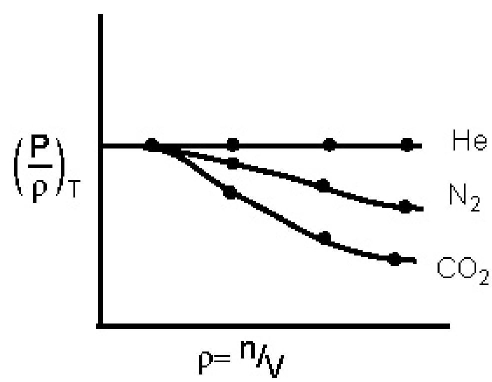
This handout specifies how operationally we will define temperature **T** using the properties of a gas. Once this is demonstrated, the ideal gas thermometer could be used to calibrate any of the normal modern thermometers. This handout will get us accustomed to the precision necessary in specifying thermodynamic systems as well as laying the groundwork for later showing the equivalence between $\mathcal{T}$ and **T** !!

A. *Thermal equilibrium* (often called the zeroth law of thermodynamics):
bring two 'bodies' together and they will equilibrate or reach a common temperature without (necessarily) an exchange of mass. This property of temperature **T** is transitive: $T_A=T_B$ and $T_B=T_C \Rightarrow T_A=T_C$

B. *Observe the following universal property of all gasses which gives a measurable quantity that will operationally define **T**:*
Measure

$$\frac{P}{\rho}=\frac{P}{n/V}=\frac{PV}{n}=P\overline{V}$$ (pressure divided by density)

and, for all gasses at thermal equilibrium with one another (i.e. at "some T"), this ratio will give a universal result in the limit $\rho \to 0$. *[n.b. curves below for various gasses are 'cartoons' but actual data would converge to limit]*



C. *Operationally define **T** as proportional to this value of (P/ρ):* $RT = \lim_{\rho \to 0}\left(\frac{P}{\rho}\right)_T$

where R is a proportionality constant.

D. *Place bulb of gas in thermal equilibrium with boiling water and then with ice-water:* using the measure values of P/ρ, one gets

$$RT_b = \underset{\rho \to 0}{\text{limit}} \left(\frac{P}{\rho} \right)_b$$

$$RT_i = \underset{\rho \to 0}{\text{limit}} \left(\frac{P}{\rho} \right)_i$$

E. *Define (T_b-T_i)=100 to agree with history (Celsius):*

$$R\left(T_b - T_i\right) = 100\,R = \underset{\rho \to 0}{\text{limit}} \left[\left(\frac{P}{\rho} \right)_b - \left(\frac{P}{\rho} \right)_i \right]$$

F. *When these measurements are made:*
R= 0.083145 liter bar mol^{-1} K^{-1}
R= 0.08206 liter atm mol^{-1} K^{-1}
R= 1.9872 cal mol^{-1} K^{-1}
R= 8.3145 joule mol^{-1} K^{-1}
and
PV=nRT for all gasses (n/V) $\rightarrow$ 0 (ideal gas law)

G. *Calibrate other thermometers (volume of liquid, thermocouples, expansion of metals, etc) using this definition of* **T**