Chapter 19 Temperature

19.1 Temperature and the 0th Law of Thermodynamics

0th Law: If objects A + B are separately in thermal equilibrium with a third object C, then A + B are in thermal equilibrium with each other if placed in thermal contact.

$$A \Leftrightarrow C \Leftrightarrow B$$

$$\therefore$$

$$A \Leftrightarrow B$$

We say ~~that~~ A + B are at the same temperature.

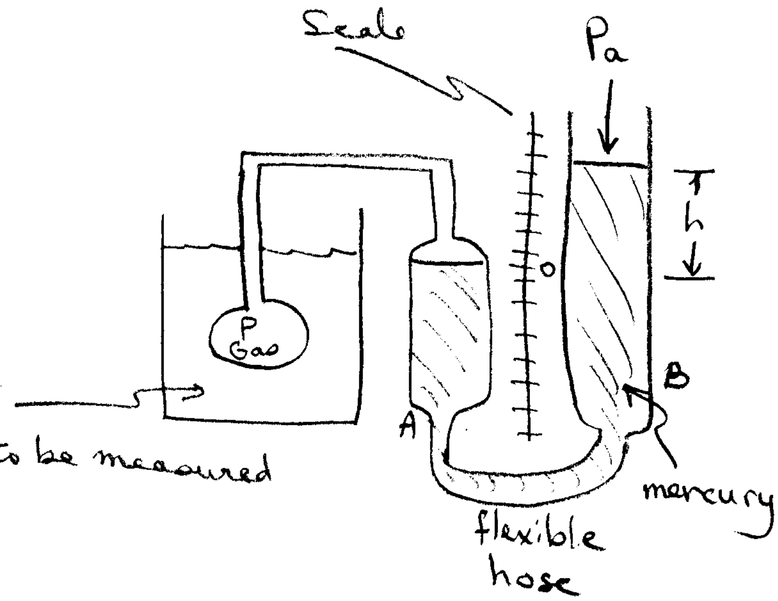
If A is not in thermal equilibrium with B then $T_A \neq T_B$.

19.2 Thermometers and Temperature Scales

Traditional thermometers, like mercury or alcohol thermometers have limited ranges and may not be sufficiently accurate between the calibration points.

We use the gas thermometer to get around these limitations.

19.3 The Constant-Volume Gas Thermometer and the Kelvin Scale



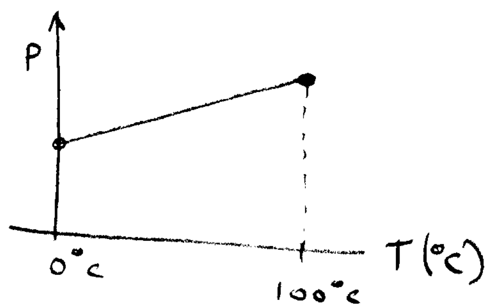
Calibration Procedure:

- Place flask in an ice bath + raise or lower B until gas is at same volume, say 0 on the scale.

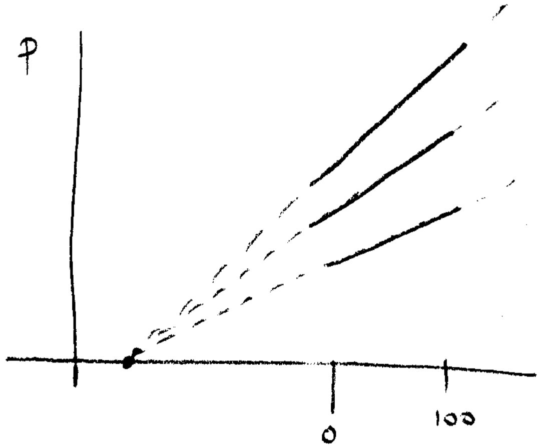
$\therefore P_{gas}^{(0)} = P_a + \rho g h_{0°C}$

- Repeat with a boiling bath; raise h to get the same volume of gas.

$\therefore \quad P_{gas}(100) = P_a + \rho g h_{100°C}$



- For an unknown temperature, get P + interpolate.



Using different volumes of dilute gas, we find that all lines extrapolate back to T = − 273.15°C

We call this absolute zero.

$$T_{kelvin} = T_{celsius} + 273.15$$

19.4 Thermal Expansion of Solids and Liquids

Generally, objects expand when heated:

$$L = L_0 + \alpha L_0 (T - T_0) \quad , \; T \text{ in } {}^\circ C$$

L_0 ← length at T_0; α ← average coefficient of linear expansion. $({}^\circ C^{-1})$

or $\Delta L = \alpha L \Delta T$

For a volume, all 3 dimensions expand,

$$\therefore \quad \Delta V = \beta V \Delta T = 3 \alpha V \Delta T$$

(Note: $V = l \times w \times h$

$$\therefore \frac{dV}{dT} = \frac{\partial V}{\partial l}\frac{dl}{dT} + \frac{\partial V}{\partial w}\frac{dw}{dT} + \frac{\partial V}{\partial h}\frac{dh}{dT}$$

$$= wh(\alpha l) + lh(\alpha w) + lw(\alpha h)$$

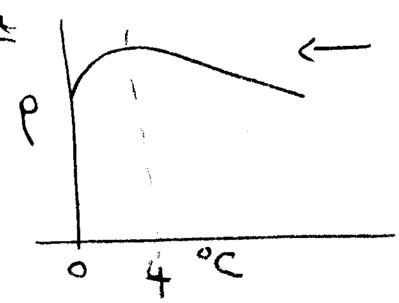
$$= 3 \alpha V \;)$$

~ for area, $\Delta A = 2 \alpha A \Delta T$

Applications

Bimetal strips in thermostats and relays.

Water



Water contracts as it cools down to 4°C but then expands as it further cools to 0°C.

Hence ice floats.

This is essential for life as we know it.

Example: Expansion of a Railroad Track

Track length = 20.0 m at 0°C.
what is length at 40°C ?

$$\Delta L = \alpha L \Delta T = (11\times10^{-6}\ 1/°C)(30.0\,m)(40°C)$$
$$= 0.013\,m$$

$$\therefore L = 30.013\,m.$$

If the rail is pinned at the ends at 0°C, what is the thermal stress at 40°C ?

$$\text{Tensile stress} = \frac{F}{A} = Y\frac{\Delta l}{l}$$

↑ Young's modulus

$$= 20\times10^{10}\,\frac{N}{m^2} \times \frac{0.013}{30} = 8.7\times10^{7}\,N/m^2.$$

If the cross-sectional area = 30 cm²,

$$F = 8.7\times10^{7} \times 30\times10^{-4}\,m^2 = 2.6\times10^{5}\,N$$
$$= 58\,000\ lb_f$$

[Recall: $1\,N = 1\,kg \cdot 1\,m/sec^2$

$\therefore$ 1 kg weighs 9.81N

$= 2.205\,lb_m \equiv^{nt} 2.2\,lb_f$

$\therefore 1\,N = \frac{2.2}{9.8}\,lb_f = .2248\,lb_f$]

19.5 Macroscopic Description of an Ideal Gas

For an ideal gas (approximated by a dilute real gas):

$$PV = nRT = N k_B T$$

$R = 8.31 \ J/mol \cdot K$

n = # of moles $\left(= \dfrac{\text{\# of molecules, } N}{\text{Avogadro's Number, } N_A}\right)$

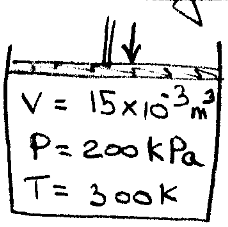
P = pressure, Pa

V = volume, m^3

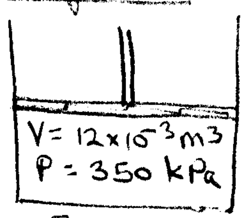
T = K

$k_B = \dfrac{R}{N_A}$ = Boltzmann's constant $= 1.38 \times 10^{-23} \ J/K$

Example: Squeezing a Tank of Gas



INITIAL STATE



T = ?

FINAL STATE

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \quad \therefore \quad T_2 = \frac{P_2 V_2}{P_1 V_1} T_1$$

$$= \frac{350 \times 12 \times 10^{-3}}{200 \times 15 \times 10^{-3}} \times 300$$

$$= \underline{\underline{420 \ K}}$$