

Chapter 1

Thermal equilibrium - state when the macroscopic variables of two objects stop changing

→ achieved by an exchange of energy ← claim

temperature - is a measure of the tendency of an object to spontaneously give up energy

How do we measure temperature?

- volume (constant pressure) (mercury/alcohol)
- pressure (constant volume)
- electrical resistance
- thermal emf (thermocouple)
- radiation

HW#1 | 1, 2, 7

1.) $C_0 = 0$ $F_0 = 32$ $0 = m \cdot 32 + b$ $100 = m(212) + b$
 $C_1 = 100$ $F_1 = 212$
 $C = mF + b$ $m = \frac{5}{9}$ $b = 32$

7.) $\beta = \frac{\Delta V / V}{\Delta T} \rightarrow$ fractional change in volume \propto change in temp
 $\frac{V_f - V_i}{V_i} = \frac{\Delta V}{V} = \beta \cdot \Delta T$

(a) estimate mercury bulb volume \rightarrow cylinder diameter
 $\left(\frac{1}{4} \text{ cm diameter}\right)^3 \approx \frac{1}{64} \text{ cm}^3 \cdot \frac{10^3 \text{ mm}^3}{1 \text{ cm}^3} = 10 \text{ mm}^3 = V$
 ≈ 100

ΔV from 1°C

$$8] \frac{\Delta L}{L} = \alpha \cdot \Delta T$$

$$T_F = 100^\circ F \quad T_C = 10^\circ F$$

$$\Delta T_F = 90^\circ F$$

$$(a) \alpha = 1.1 \cdot 10^{-5} K^{-1}$$

$$\frac{\Delta T_F}{\Delta T_C} = \frac{9}{5} \quad \frac{\Delta T_C}{\Delta T_F} = \frac{5}{9}$$

$$\Delta T_C = \frac{5}{9} (90^\circ F)$$

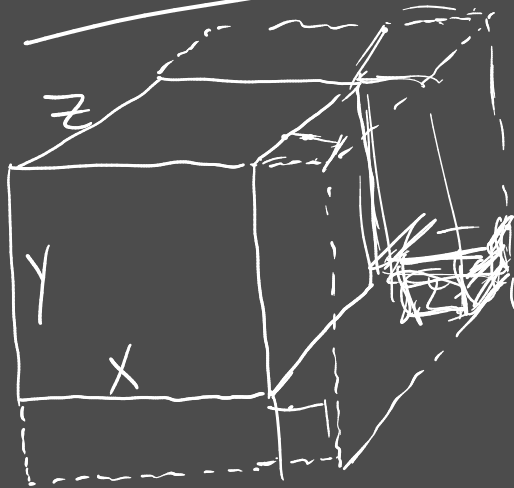
$$\Delta T_C = 50^\circ C$$

$$\Delta L = \alpha \Delta T \cdot L$$

$$= 1.1 \cdot 10^{-5} \cdot 50^\circ C \cdot 1000 m$$

$$= 50000 \cdot 10^{-5}$$

$$L = 0.5 m$$



$$\alpha \Delta T = \frac{\Delta L}{L}$$

$$\alpha_x \Delta T = \frac{\Delta x}{x}, \quad \alpha_y \Delta T = \frac{\Delta y}{y}, \quad \alpha_z \Delta T = \frac{\Delta z}{z}$$

$$\beta \Delta T = \frac{\Delta V}{V}$$

$$\Delta V = V_f - V_i = (x + \Delta x)(y + \Delta y)(z + \Delta z) - xyz$$

$$\Delta V = (xy + y\Delta x + x\Delta y + \Delta x\Delta y)(z + \Delta z) - xyz$$

$$\Delta V = \cancel{xyz} + xy\Delta z + yz\Delta x + y\Delta x\Delta z + xz\Delta y + x\Delta y\Delta z + z\Delta x\Delta y + \Delta x\Delta y\Delta z - \cancel{xyz}$$

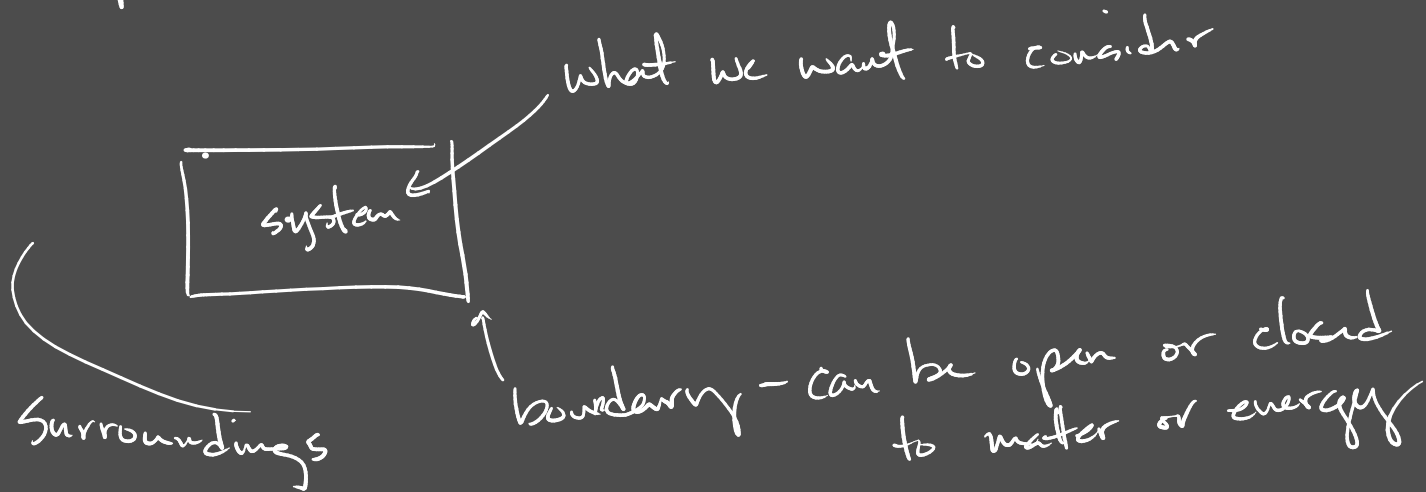
$$\beta \Delta T = \frac{\Delta V}{V} = \frac{\Delta V}{XYZ} = \frac{\Delta Z}{Z} + \frac{\Delta X}{X} + \frac{\Delta X \Delta Z}{XZ} + \frac{\Delta Y}{Y} + \frac{\Delta Y \Delta Z}{YZ} + \frac{\Delta X \Delta Y}{XY} + \frac{\Delta X \Delta Y \Delta Z}{XYZ}$$

$\underbrace{\quad}_{\alpha_z \Delta T} \quad \underbrace{\quad}_{\alpha_x \Delta T} \quad \underbrace{\quad}_{\alpha_y \Delta T}$

$\nearrow XYZ$

$$\beta \Delta T = (\alpha_x + \alpha_y + \alpha_z) \Delta T$$

Macroscopic View



- Goal:
- ① describe the behavior of system
 - ② describe interactions w/ surroundings
 - ③ BOTH!

Macroscopic description: variables at human scale or larger
 \hookrightarrow easy to measure in a lab

Microscopic description: variables at molecular scale or smaller
↳ very hard to measure directly

Take a cylinder of a gas: (what does it take to describe it)

- mass & composition
- volume
- pressure
- temperature

these form macroscopic coordinates

1. no special assumptions about structure of matter
2. fewest possible to provide description
3. fundamental → suggested by sensory perception.
4. directly measurable

Microscopic view treated w/ statistical mechanics has nearly the opposite of these conditions

$P, V, T \rightarrow$ two can be varied but third is determined by those

An equation that relates the thermodynamic coordinates
 \hookrightarrow equation of state

for a closed system, the equation of state relates temp to two other variables.

Other examples

stretched wire \rightarrow force, length, temperature

1.2 The ideal gas law

$$p \cdot V = N k_B T$$

→ total number of particles
→ Boltzmann's constant → $1.381 \cdot 10^{-23} \frac{\text{J}}{\text{K}}$
→ absolute temp → Kelvin

↳ volume
↳ pressure = $\frac{\text{Force}}{\text{Area}}$

This is experimental. An approximation of low density gases

$$p = n k_B T$$

↳ number density $n = \frac{N}{V}$ $\rho = \frac{M}{V}$

Form used in chemistry (useful large numbers + mixtures)

$$pV = n_m R T$$

→ gas constant
↳ number of moles

$$N = n_m \cdot N_A \rightarrow n_m = \frac{N}{N_A}$$

$$N k_B = n_m R$$

or

$$R = k_B N_A = 8.31 \frac{\text{J}}{\text{K} \cdot \text{mol}}$$

$$N_A = 6.022 \cdot 10^{23} \text{ things/mole}$$

$$k_B = 1.381 \cdot 10^{-23} \text{ J/K}$$

Problem 1.9. What is the volume of one mole of air, at room temperature and 1 atm pressure?

$$PV = N k_B T$$

$$V = \frac{N k_B T}{P}$$

$$V = 0.024 \text{ m}^3$$

$\hookrightarrow \sim 30 \text{ cm cube}$
 $\sim 24 \text{ liters}$

$$N = N_A \quad T = 20^\circ\text{C} = 293$$

$$P = \underline{1 \text{ atm}} = 1.013 \cdot 10^5 \text{ Pa} \left[\frac{\text{N}}{\text{m}^2} \right] = [\text{Pascal}]$$

Problem 1.12. Calculate the average volume per molecule for an ideal gas at room temperature and atmospheric pressure. Then take the cube root to get an estimate of the average distance between molecules. How does this distance compare to the size of a small molecule like N_2 or H_2O ?

$$1 \text{ mol at 1 atm at } 293\text{K}, V = 0.024 \text{ m}^3$$

(N_A)

$$\frac{V}{N_A} = \frac{0.024 \text{ m}^3}{6.02 \cdot 10^{23}} = 4 \cdot 10^{-26} \text{ m}^3 / \text{molecule}$$

$$\downarrow \sqrt[3]{}$$

side length

$$\sqrt[3]{4 \cdot 10^{-26}} = 3.4 \cdot 10^{-9} \text{ m}$$

$$= 3.4 \text{ nm}$$

$$= 34 \text{ \AA}$$

$$\text{H}_2 = 289 \text{ pm} = 2.89 \text{ \AA}$$

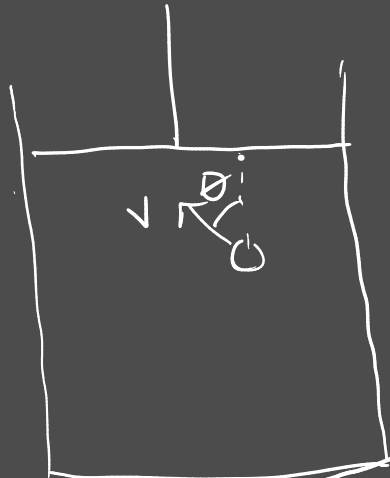
$$\text{N}_2 = 364 \text{ pm} = 3.64 \text{ \AA}$$

HW: ★ 12, ★ 13, ★ 14, ★ 16, ★ 17

we want pressure from a microscopic model:
(elastic collisions)

$$\text{pressure} = \frac{F}{A} = \frac{\Delta p}{A \cdot \Delta t} \rightarrow \frac{2mv \cos \theta}{v_y}$$

pressure = $\frac{2mv \cos \theta}{dA dt}$. number of particles hitting
Area dA w/ velocity v
in time dt



number of atoms
traveling in this
this particular
direction in the
entire volume.

fraction of those
that are within
striking distance
in time dt .

