Laws of Thermodynamics

1st Law:

$$\Delta E^{Th} = W + Q$$

- If W(+) and Q(+) : Energy into the system
- If W(-) and Q(-) : Energy out of the system
- If W(-) and Q(+) / If W(+) and Q(-) : Depends on |W| and |Q|

Side note: Nothing possesses work or heat, they are mechanisms for which to transfer energy

2nd Law:

In a closed system:

$$\Delta S \geq 0$$

Definition: Isolated systems have entropy increase until equilibrium is reached. At equilibrium, entropy is at its maximum and does not increase any more.

Entropy (S)

Micro: measure of multiplicity or order or randomness

Macro: related to energy not available to do work

- Measure of disorder
- Probability is driven by multiplicity

Heat Engines:

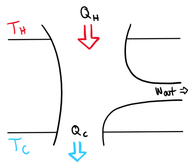
Efficiency for a cycle:

$$e = \frac{W_{out}}{Q_h} = \frac{Q_H - Q_C}{Q_H}$$

Theoretical Max:

$$e_{\max} = 1 - \frac{T_c}{T_H}$$

Converting heat into useful work



Equations of State:

Definition: Macroscopic description of how state variables relate to each other in equilibrium

Example: Ideal Gas Law

$$PV = nRT = Nk_bT$$

State Variables:

Examples:
- p = pressure
- V = volume
- T = temperature
- n = # of moles
- R = ideal gas constant

Definition: Properties that describe the equilibrium state of matter

Calorimetry:

$$Q_{total} \ \& \ W_{total} = 0$$

$$\sum Q = 0$$

Within a closed system (no exchange of energy with the environment)

Heat: amount of energy that transfers from a warmer object to a cooler one

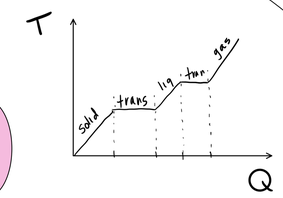
Specific Heat Transformations:

$$c = \frac{1}{m}\frac{\Delta E}{\Delta T}$$

- Material property
- For a given mass, it is the measure of how much energy per temperature the substance can absorb or emit

Heat in a Phase:

$$Q = mc\Delta T$$



Phase Transitions:

- Transition from a gas to a liquid, from a liquid to a solid, etc.
- Takes some energy for a substance to change its phase even though the temperature remains constant

$$Q_v = \pm mL_v$$

Liquid to Vapor: (+)
Vapor to Liquid: (-)

Latent Heat of Vaporization

$$Q_f = \pm mL_f$$

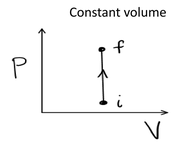
Solid to Liquid: (+)
Liquid to Solid: (-)

Latent Heat of Fusion

PV Diagrams

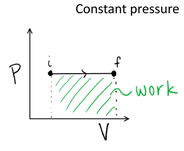
Isochoric:

Constant volume



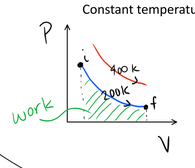
Isobaric:

Constant pressure



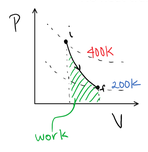
Isothermal:

Constant temperature

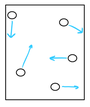


Adiabatic:

No heat transfer

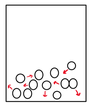


Micro/Macro View of Matter



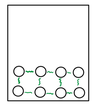
Gas

- Evenly distributed within container
- Random motion
- Compressible
- Weak/no long range interactions between particles



Liquid

- Conforms to shape of container
- Weak bonding
- Little free space
- Not easily compressible



Solid

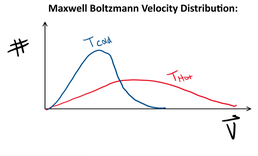
- Crystalline lattice
- Vibrating motion about a fixed point
- Strong, spring-like bonds

Kinetic Theory of Gases

Macroscopic translocation of KE of gas:

$$\frac{1}{2}M\,|V_{COM}|^2$$

Maxwell Boltzmann Velocity Distribution:



$$E^{th} = N\overline{K} = \frac{3}{2}Nk_BT$$

$$\overline{K} = \frac{1}{2}m\overline{V}^2$$

$$@\,equilibrium: \quad \overline{K_1} = \overline{K_2} \ \& \ T_1 = T_2$$

Boltzmann Constant:

$$k_B = 1.38\times10^{-23}\,\frac{Kgm^2}{s^2K}$$

Thermo Processes

Isochoric :

$$\Delta E_{TH} = \frac{3}{2}NK_B\Delta T$$

$$Q = \frac{3}{2}NK_B\Delta T$$

$$W = 0$$

Isobaric :

$$\Delta E_{TH} = \frac{3}{2}NK_B\Delta T$$

$$Q = \frac{3}{2}NK_B\Delta T + P\Delta V$$

$$W = -P\Delta V$$

Isothermal :

$$\Delta E_{TH} = 0$$

$$Q = NK_BT\ln\left(\frac{V_f}{V_i}\right)$$

$$W = -NK_BT\ln\left(\frac{V_f}{V_i}\right)$$

Adiabatic :

$$\Delta E_{TH} = \frac{3}{2}NK_B\Delta T$$

$$Q = 0$$

$$W = \frac{3}{2}NK_B\Delta T$$

Thermo Efficiency

For a Cycle:

$$e = \frac{|\sum W|}{\sum Q_{in}} = \frac{get}{pay}$$

Sum of both positive and negative work

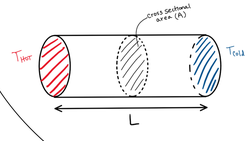
Sum of only positive heat

Heat: Transfer Mechanisms

Conduction:

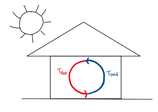
- Transfer of energy via contact and momentum transfer from thermal vibrations.

$$\frac{Q}{\Delta t} = \left(\frac{kA}{L}\right)\Delta T$$



Convection:

- Transfer of energy by a particle physically moving from a higher energy particle physically moving to a lower energy density area



Radiation:

- Transfer of energy via electromagnetic radiation

$$\frac{Q_{net}}{\Delta t} = eTA(T^4 - T_{enviro}^4)$$