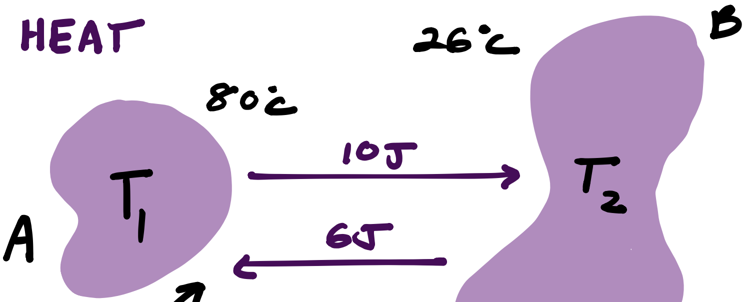
HEAT



NET heat transfer = 4J

Thermal contact (transfer of heat energy) → from higher to lower temp.

× physical contact

T_1 release heat
T_2 absorb heat } Net!

* both release and absorb heat simultaneously

* Heat transfer from higher to lower temperature regions
* Thermal equilibrium and the zeroth law of thermodynamics
* Kinetic model explanations for melting and boiling without temperature change
* Specific latent heat:
  - Vaporization vs fusion
* Specific heat capacity:
  - Definition, application, and determination using electric methods
* Specific latent heat definition and application

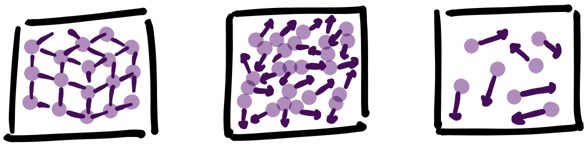
No Heat Transfer ≠ 0 Net Heat Transfer

Thermal Equilibrium

$T_1 = T_2$

Heat Energy (transfered)	vs	Internal Energy (stored) ← mass!
A > B		B > A

STATES OF MATTER

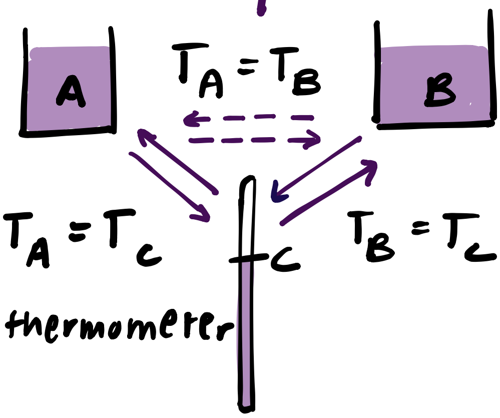


Solid	Liquid	Gas
• closely packed	• slightly farther apart	• far apart
• high density	• lower density	• lower density
• fixed shape & volume	• fixed volume, variable shape	• no fixed shape or volume
• vibrate about equilibrium	• has random restricted motion	• move randomly at high speed
• strong intermolecular force	• weaker IM force	• negligible IM force

melting →, boiling → } absorb heat

← freezing, ← condensation } release heat

Zeroth Law of Thermodynamics



Phase transition at BC and DE

No temp change = No KE change

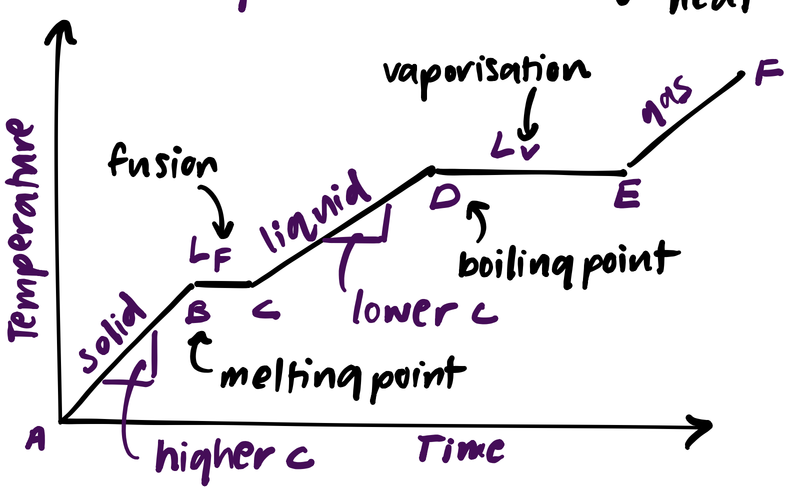
Heat transferred → Internal energy

Heat absorbed at

BC < DE

BC: to overcome intermolecular forces

DE: to overcome atmospheric pressure



Specific Heat Capacity, c

heat required to increase 1 kg of substance by 1°C

$$c_{H_2O} = 4.2 \times 10^3 \text{ J kg}^{-1} (C°)^{-1}$$

$$\boxed{c = \frac{Q}{m\Delta T}}$$

$|T| = °C$

$|\Delta T| = C°$

$\text{J kg}^{-1} (C°)^{-1}$

$Q = mc\Delta T$

$Q = C\Delta T$

Heat Capacity, C

$$C = \frac{Q}{\Delta T}$$

Specific Latent Heat of Fusion / of Vaporisation

heat required to change 1 kg of mass from solid to liquid / from liquid to gas without temperature change

$$\boxed{L_f = L_v = \frac{Q}{m}}$$

J kg^{-1}

$Q = mL$

APPLICATION OF IDEAL GAS LAWS IN PHYSICS

absolute pressure — no of moles — absolute temperature

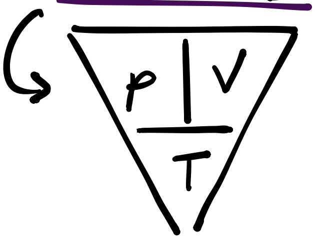
$$\boxed{pV = nRT}$$

Kelvin!

volume of container — gas constant

- Boyle's Law, Charles' Law, and Pressure Law
- Graphical representation of gas laws
- Relationship between gas laws and the equation of state
- Ideal gas equation: $pV = nRT$ or $pV = nkT$

State Variables



① $k = nRT$

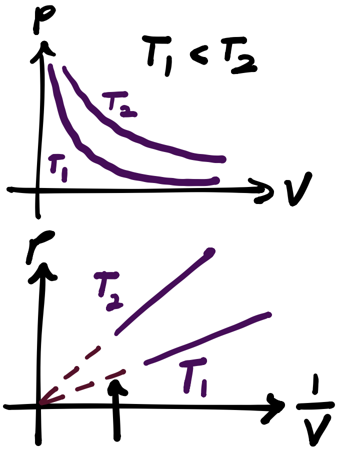
② $k = \frac{nR}{p}$

③ $k = \frac{nR}{V}$

① Boyle's Law

$\Delta T = 0$

$p \propto \frac{1}{V}, pV = k$

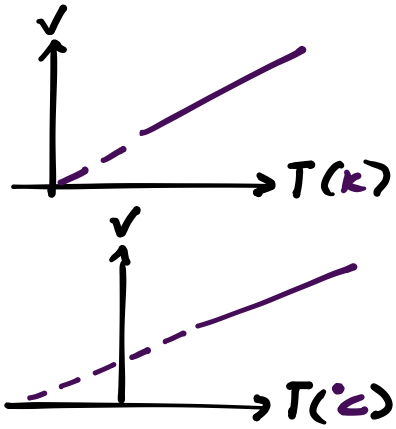


does not exist as gas

② Charle's Law

$\Delta p = 0$

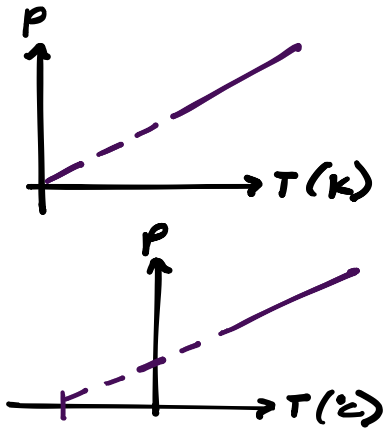
$V \propto T, \frac{V}{T} = k$



③ Pressure Law

$\Delta V = 0$

$p \propto T, \frac{p}{T} = k$



-273.15

$$\frac{pV}{T} = \text{constant}$$

$= nR$

$8.31\ JK^{-1}mol^{-1}$

$$\boxed{pV = NkT}$$

$\frac{\text{mass, } m}{\text{Molar Mass, } M}$ $\quad N_A = 6.02 \times 10^{23}\ mol^{-1}$

$$= \left(\frac{N}{N_A}\right)R$$

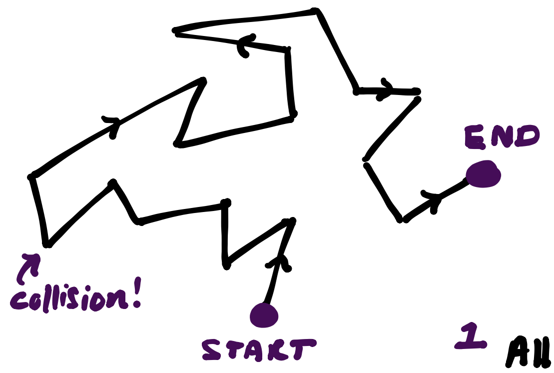
$$\frac{pV}{T} = Nk$$

Boltzmann constant

$$k = \frac{R}{N_A} = 1.38 \times 10^{-23}\ JK^{-1}$$

Brownian Motion

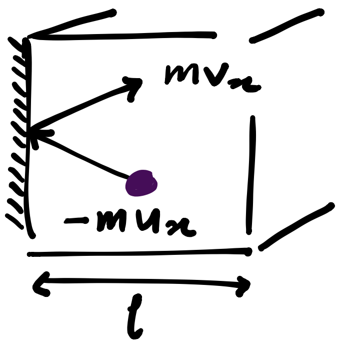
the random movement of particles in a fluid due to collisions with surrounding molecules



- Brownian motion and molecular movement
- Assumptions of the kinetic theory of gases
- Relationship between molecular movement and gas pressure: $P = \frac{1}{3}\rho\overline{v^2}$
- Boltzmann constant: $k = \frac{R}{N_A}$
- Comparison of $pV = \frac{1}{3}Nm\overline{v^2}$ and $pV = NkT$, linking translational energy to T
- Root mean square speed: $v_{rms} = \sqrt{\frac{3kT}{m}}$
- Maxwell distribution of speeds and its dependence on temperature
- Most probable speed: $v_p = \sqrt{\frac{2kT}{m}}$
- Average speed: $\bar{v} = \sqrt{\frac{8kT}{\pi m}}$

Ideal Gas Assumptions:

1. All gases are made up of atoms or molecules
2. ↳ move randomly & haphazardly
3. Volume of atoms & molecules <<< Volume occupied by gas
4. negligible intermolecular forces (except during collision)
5. elastic! (constant K_E)
6. time of collision <<< time between collision
7. constant velocity (straight)



$v = u$

$$\Delta(mv_x) = mv_x - (-mu_x) = 2mv_x$$

$$\Delta t = \frac{2l}{v_x} \text{ (time per collision)}$$

$$F = \frac{\Delta mv}{\Delta t} \text{ (force on the wall)}$$

$$F = \frac{mv_x^2}{l} \text{ (due to one molecule)}$$

$$\overline{v_x^2} = \frac{v_{x1}^2 + v_{x2}^2 + \dots + v_{xN}^2}{N}$$

↳ Mean Square Speed

$$\overline{v^2} = \frac{v_1^2 + v_2^2 + \dots + v_N^2}{N}$$

$$F = \frac{m}{l}N\overline{v_x^2} \text{ (due to N molecules)}$$

$$\overline{v^2} = \overline{v_x^2} + \overline{v_y^2} + \overline{v_z^2}$$

$$\overline{v_x^2} = \overline{v_y^2} = \overline{v_z^2}, \quad \overline{v^2} = 3\overline{v_x^2}$$

$$F = \frac{m}{l}N\frac{\overline{v^2}}{3}$$

density

$$\boxed{P = \frac{1}{3}\frac{Nm\overline{v^2}}{Al} = \frac{1}{3}\rho\overline{v^2}}$$

Root-Mean-Square Speed

$$\Longrightarrow v_{rms} = \sqrt{\overline{v^2}}$$

Average Translational Kinetic Energy of Molecules

$$\boxed{\frac{1}{2} m\overline{v^2} = \frac{3}{2} kT}$$

Boltzmann constant

Boltzmann constant:

$$k = \frac{R}{N_A}$$

$$k = 1.38 \times 10^{-23}\ JK^{-1}$$

m, mass of 1 molecule
M, molar mass
N, number of molecules

$$\overline{v^2} = \frac{3kT}{m}$$

$$\boxed{V_{rms} = \sqrt{\frac{3kT}{m}}}$$

$$\left(\frac{1}{2} m\overline{v^2}\right)N_A = \frac{3}{2} k N_A T$$

$$\frac{1}{2} M\overline{v^2} = \frac{3}{2} RT$$

$$\overline{v^2} = \frac{3RT}{M}$$

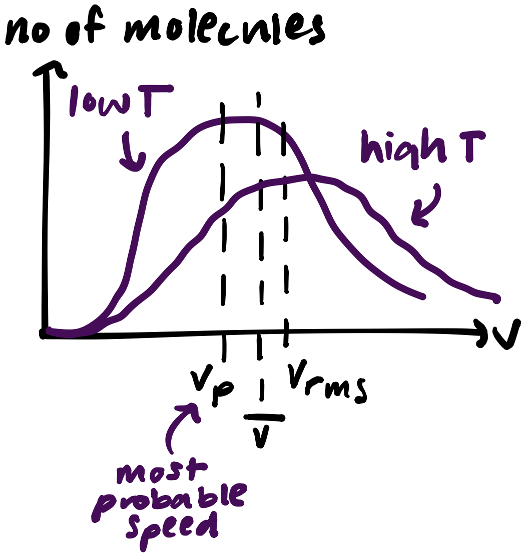
$$\boxed{V_{rms} = \sqrt{\frac{3RT}{M}}}$$

$$\left(\frac{1}{2} m\overline{v^2}\right)N = \frac{3}{2} NkT$$

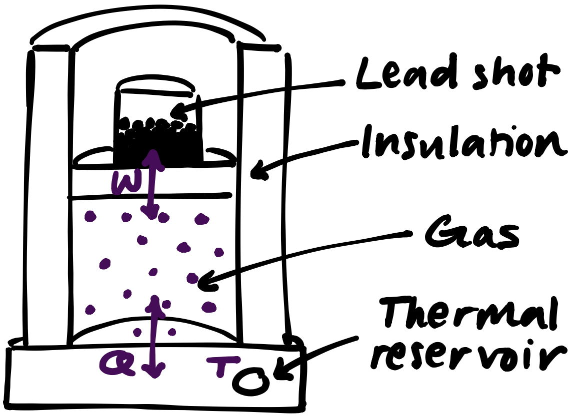
$$\boxed{k_{Total} = \frac{3}{2} NkT}$$

$$p = \frac{1}{3} \rho \overline{v^2}$$

$$\boxed{V_{rms} = \sqrt{\frac{3p}{\rho}}}$$



$$\left.\begin{aligned} v_p &= \sqrt{2\frac{kT}{m}} \\ \bar{v} &= \sqrt{\frac{8}{\pi}\frac{kT}{m}} \\ v_{rms} &= \sqrt{3\frac{kT}{m}} \end{aligned}\right\}$$ for large number of molecules



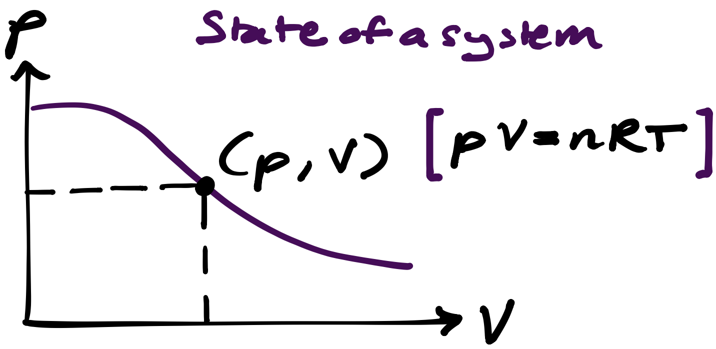
$$\boxed{Q = \Delta E_{th} + W}$$

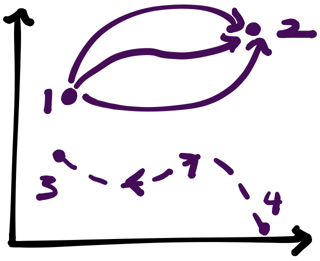
- Represent gas states in a pV-diagram
- Differentiate between reversible and irreversible processes
- Relate internal energy to temperature
- Derive $W = p\Delta V$ and interpret work from a pV-diagram
- Recognise path dependance of work and path independance of internal energy change
- Deduce $c_p = c_v + R$ and explain why $c_p > c_v$
- Determine c_v, c_p and $\gamma = \frac{c_p}{c_v}$ for different gas types

Heat supplied = Internal energy + External work done

	+	−
Q	absorb	release
ΔE_{th}	increase	decrease
W	by system	on system
ΔV	increase	decrease

State of a system





Irreversible

Reversible

Monoatomic Gas

$\Delta E_{th} = K_E$ (translational)

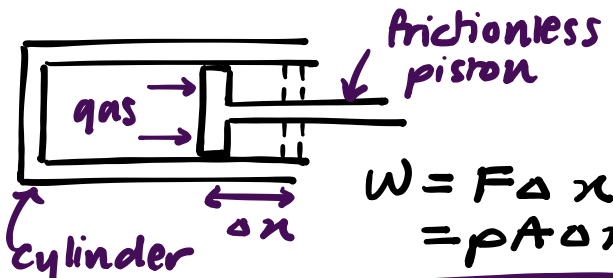
Diatomic & Polyatomic Gas

$\Delta E_{th} = K_E$ (translational & rotational)

$E_{th} \propto T$

$\Delta E_{th} \propto \Delta T$

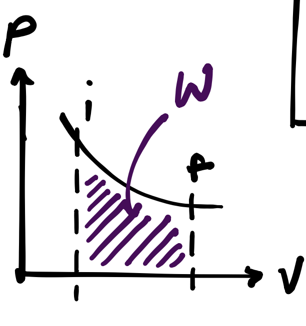
E_{th} is a function of state (independent of path)

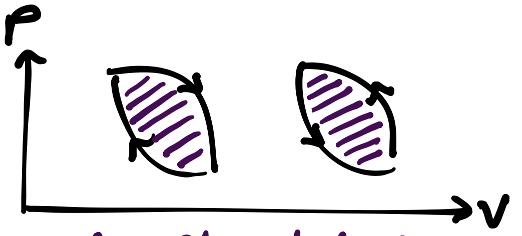


$W = F\Delta x$
$= pA\Delta x$

$$\boxed{W = p\Delta V}$$

*p is constant!





A = net work done

Clockwise, $W > 0$

Anticlockwise, $W < 0$

Molar specific heat

Heat required to raise the temperature of 1 mol of gas

At constant pressure, c_p

At constant volume, c_v

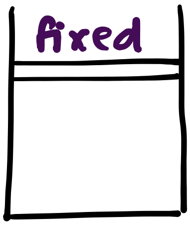
$$\boxed{c = \frac{Q}{n\Delta T}}$$

unit: $J\,mol^{-1}K^{-1}$

$c_p > c_v$

energy provided → heat + work (c_p)

energy provided → heat (c_v)

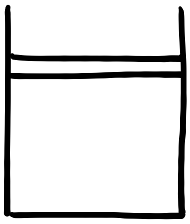


$Q = \Delta E_{th} + W$

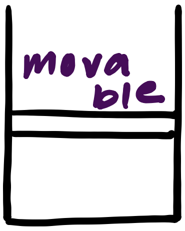
$\Delta V = 0$

$Q = \Delta E_{th}$

$Q = nc_v\Delta T$



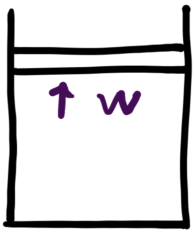
$$\boxed{\Delta E_{th} = nc_v\Delta T}$$



$Q = \Delta E_{th} + W$

$Q = nc_p\Delta T$

$\Delta E_{th} + W = nc_p\Delta T$



$nc_v\Delta T + W = nc_p\Delta T$

$nc_v\Delta T + p\Delta V = nc_p\Delta T$

$nc_v\Delta T + nR\Delta T = nc_p\Delta T$

$$\boxed{c_v + R = c_p}$$

$\bar{E}_k = \frac{3}{2}kT$

$E_k = N\bar{E}_k$

$= \frac{3}{2}NkT$

$= \frac{3}{2}N\left(\frac{R}{N_A}\right)T$

$E_k = \frac{3}{2}nRT$

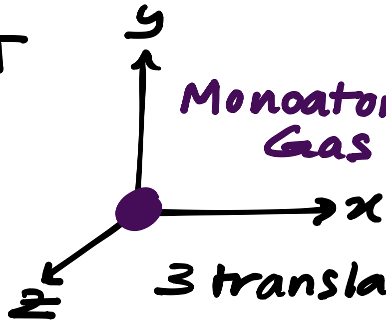
$E_{th} = E_k$

$= \frac{3}{2}nRT$

$\Delta E_{th} = \frac{3}{2}nR\Delta T$

$\Delta E_{th} = nc_v\Delta T$

$$\boxed{c_v = \frac{3}{2}R}$$



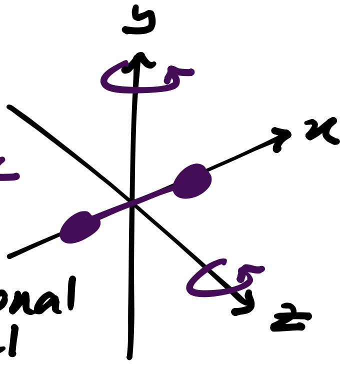
Monoatomic Gas

3 translational

$c_p = c_v + R$ $\qquad \gamma = \frac{c_p}{c_v}$

	c_v	c_p	γ
Mono	$\frac{3}{2}R$	$\frac{5}{2}R$	$\frac{5}{3}$
Di	$\frac{5}{2}R$	$\frac{7}{2}R$	$\frac{7}{5}$
Poly	$3R$	$4R$	$\frac{4}{3}$

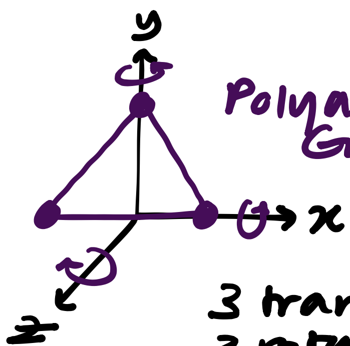
Diatomic Gas



3 translational
2 rotational

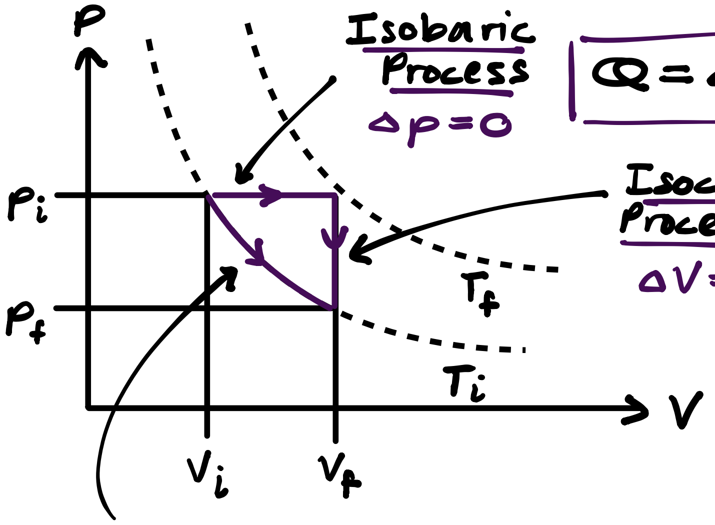
Principle of Equipartition of Energy

energy is shared equally among all degrees of freedom



Polyatomic Gas

3 translational
3 rotational



Isobaric Process

$\Delta p = 0$

$$\boxed{Q = \Delta E_{th} + W = nC_p \Delta T}$$

Isochoric Process

$$\boxed{Q = nC_v \Delta T}$$

$\Delta V = 0 \Rightarrow W = 0$

Adiabatic Process

$Q = 0$

$$\boxed{\Delta E_{th} = -W}$$

$pV^{\gamma} = \text{const}$

$TV^{\gamma - 1} = \text{const}$

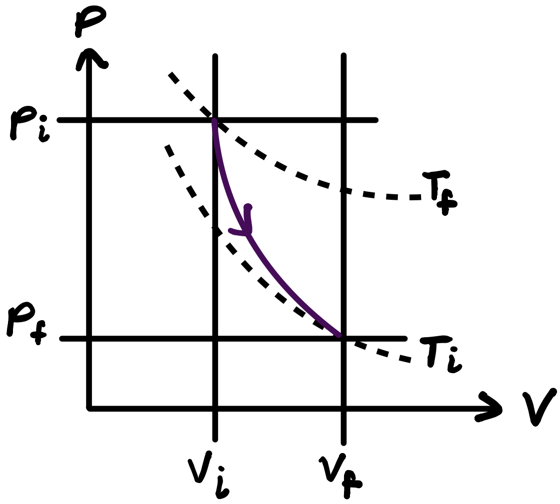
$T^{\gamma} p^{1-\gamma} = \text{const}$

$$\boxed{W = \frac{p_1 V_1 - p_2 V_2}{\gamma - 1}}$$

Isothermal Process

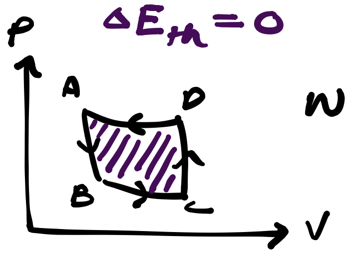
$\Delta T = 0$

$$\boxed{W = nRT \ln \frac{V_f}{V_i}}$$



Cyclic Process

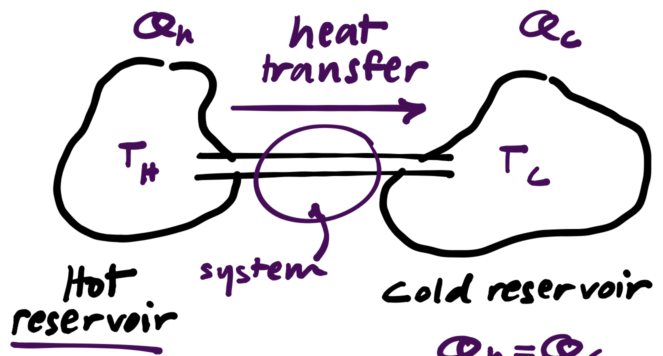
$\Delta E_{th} = 0$



W = area bounded by the curves

$-ve \qquad +ve$

$W_{out} = W_{AB} + W_{BC} + W_{CD} + W_{DA}$



temperature does not change

$Q_h = Q_c$
+ve

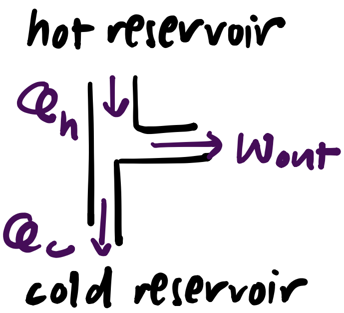
* Clausius statement of the second law of thermodynamics
* Kelvin–Planck statement of the second law of thermodynamics
* Energy-transfer diagram of a heat engine
* Analysis of heat engines and the Carnot cycle
* Entropy change in a simple system
* General statement of the second law in terms of entropy

Clausius:

[Heat can flow spontaneously from a hot object to a cold object
Heat will not flow spontaneously from a cold object to a hot object]

"Heat engine"

· closed-cycle device



heat energy → work

$\Delta E_{th} = 0$

$W_{out} = Q_{net}$

$$\boxed{W_{out} = Q_h - Q_c}$$

Thermal efficiency

$$\boxed{\eta = \frac{W_{out}}{Q_H} = 1 - \frac{Q_c}{Q_H}}$$

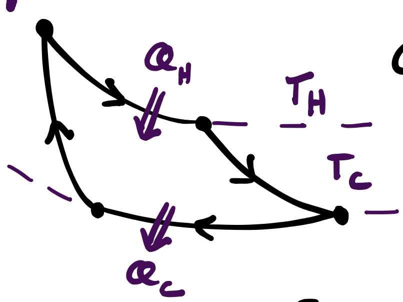
heat source & heat sink
ie fuel — ie cooling water

Kelvin–Planck:

[There are no perfect heat engines, $\eta = 1$]

"Carnot engine"

· ideal gas cycle
· two adiabatic and two isothermal
· perfectly reversible



Carnot Thermal efficiency

$$\boxed{\eta_{carnot} = 1 - \frac{T_c}{T_H}}$$

Carnot's theorem:

[no heat engine can exceed carnot efficiency]

From η and η_{carnot}, $\frac{T_c}{T_H} = \frac{Q_c}{Q_H}$

entropy, S

constant temperature

$$\boxed{\Delta S = \frac{Q}{T}}$$

varying temperature

$$\boxed{\Delta S = \int_a^b \frac{dQ}{T}}$$

$dQ = mc\,dT$

$$\Delta S = \int_{T_i}^{T_f} \frac{mc\,dT}{T}$$

$$\Delta S = mc \ln \frac{T_f}{T_i}$$

always positive! (total)

General statement:

[the entropy of an isolated system never decreases]

$\Delta S_{syst} + \Delta S_{env} > 0$