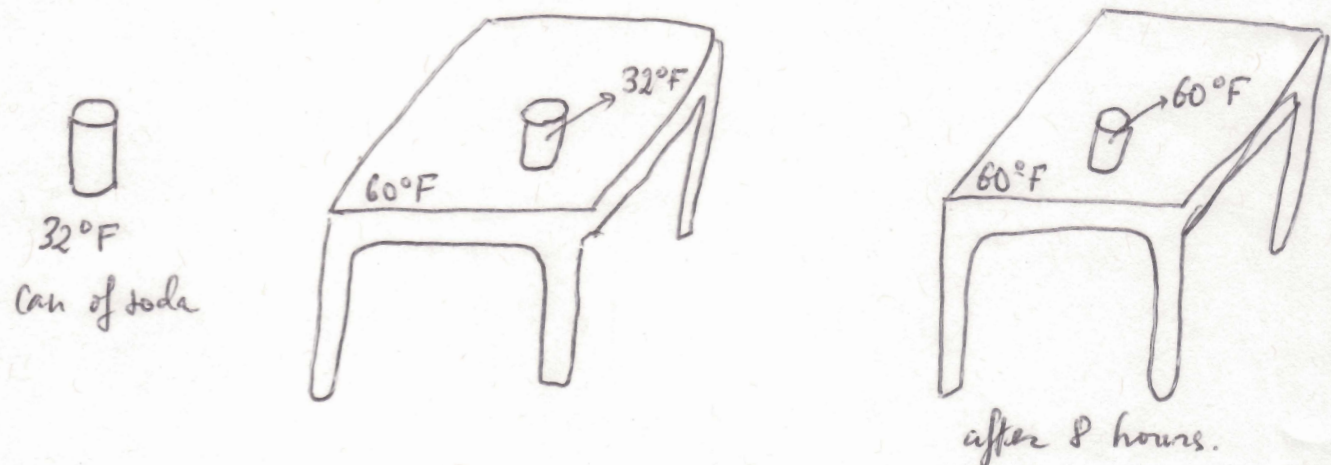


Ch 16 Temperature & Heat

Temperature: a macroscopic property; a consequence of the microscopic behavior of matter.
we can sense & measure



Two objects in thermal contact can exchange heat to arrive at a thermodynamic equilibrium (TD, same temperature)

Temperature can be measured with a thermometer (mercury; gas at constant volume; electronic, etc....)

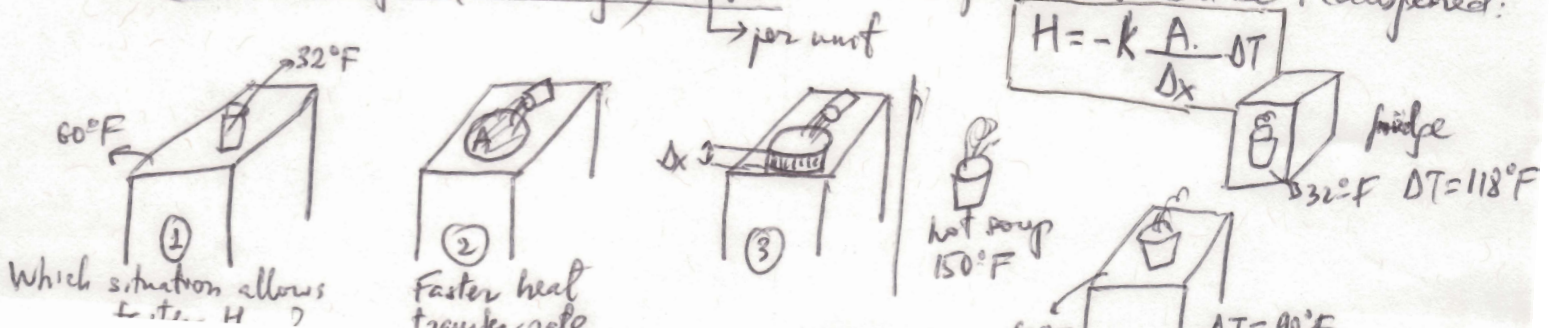
body temp $\sim 100^\circ\text{F}$ \leftarrow Fahrenheit $^\circ\text{F}$ $\rightarrow T_F = \frac{9}{5}T_C + 32$

water boils at 100°C \leftarrow Celsius $^\circ\text{C}$ $\rightarrow T_C = \frac{5}{9}(T_F - 32)$

absolute zero is 0°K \leftarrow Kelvin $^\circ\text{K}$ $T_C = T_K - 273.16^\circ\text{K}$

Triple point of water

H = Heat transfer (exchange) rate: how fast heat can be transferred.



k: properties of materials → thermal constant → depends on materials (metallic materials conduct heat well, etc..)

Units: S.I.

- L → length: m
- M → mass: kg
- T → temperature: °K
- T → time: s
- E → energy: J → Joule
- Power → a heat → W → (watt)

dimension of H

$$[H] = [k][A] \frac{[\Delta T]}{[\Delta x]}$$

\downarrow \downarrow \downarrow
 E L² Temp
 Time K

$$[k] = \frac{[H][\Delta x]}{[A][\Delta T]} = \frac{\frac{E}{Time} K}{L^2 Temp}$$

Unit = $\frac{\frac{J}{s}}{m^2 \text{ } ^\circ K} = \frac{W}{m^2 \text{ } ^\circ K}$ (S.I.)

Unit = $\frac{Btu \cdot in}{h \text{ } ft^2 \text{ } ^\circ F}$ (British system)

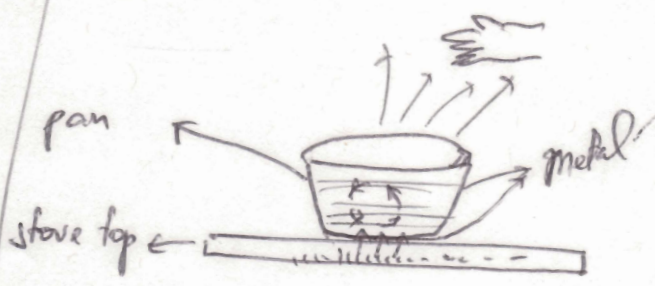
$$H = -kA \frac{\Delta T}{\Delta x} \longrightarrow H = -\frac{A \cdot \Delta T}{R}$$

R: R-factor : $R \equiv \frac{\Delta x}{k}$ (insulation → higher R better insulation)

units

- S.I.: $\frac{m^2 \text{ } ^\circ K}{W}$
- British: $\frac{ft^2 \text{ } ^\circ F}{Btu/h}$

Mechanisms of heat transfer :



- a) conduction (electrons in atoms & molecules in the metal)
- b) convection (fluids: liquids & gases)
- c) radiation: Sun to Earth: heat travels in empty space

a) electrons received energy → go faster → collide with others: transferring momentum & energy.

Stove top to bottom of metallic pan : by conduction (many free electrons)

b) heat transfer from water at bottom of pan to water at top of pan → by convection: hot molecules & atoms (allowed to move around in a fluid) tend to rise pushing cooler one to bottom making a convection current.

↓
higher Temp (more energy) → larger separation b/w molecules → lower density → pushed up by buoyancy

c) Radiation:

Stefan - Boltzman Law : heat loss rate (per unit time) by radiation of an object of area A & temperature T

$$P = e \sigma A T^4 \quad (4)$$

emissivity (no unit)

Stefan - Boltzman constant

$$\sigma = 5.67 \times 10^{-8} \frac{W}{m^2 K^4}$$

Participation Points Set #1 Q 2:

Piece of Copper @ 300°C dropped into 1 kg water @ 20°C . Final temp was $25^\circ\text{C} = T_f \rightarrow$ Find mass of copper.

Heat balance: (heat loss by copper = heat gain by water)

$$\Delta Q_{\text{copper}} + \Delta Q_{\text{water}} = 0 \quad \left| \begin{array}{l} \Delta Q = mc \Delta T \\ \downarrow \text{mass} \quad \downarrow \text{change of temp} \\ \text{specific heat} \end{array} \right.$$

$$m_{\text{copper}} c_{\text{copper}} (T_f - T_{\text{copper}}) + m_w c_w (T_f - T_w) = 0$$

or heat loss by copper
or heat gain by water

$$\rightarrow m_{\text{copper}} = \frac{m_w c_w (T_f - T_w)}{c_{\text{copper}} (T_{\text{copper}} - T_f)} = 0.197 \text{ kg.}$$

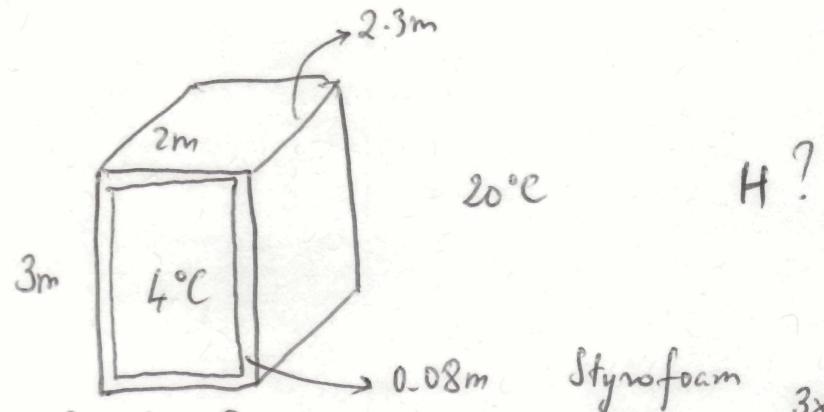
Specific heat

$$\left\{ \begin{array}{l} c_{\text{copper}} = 386 \frac{\text{J}}{\text{kg} \cdot \text{K}} \\ c_{\text{water}} = 4184 \frac{\text{J}}{\text{kg} \cdot \text{K}} \end{array} \right.$$

$$H = \text{heat transfer rate} \rightarrow \text{unit: } \frac{\text{J}}{\text{s}} \text{ or } \text{W}$$

per unit time

16.56



- 1) Sketch with all information
- 2) Identify correct equation:

$$H = - \frac{A \Delta T}{R}$$

$3 \times 2 \times 2 + 3 \times 2.3 \times 2 + 2 \times 2.3 \times 2 = 35 \text{ m}^2$
 $20^\circ\text{C} - 4^\circ\text{C} = 16^\circ\text{K}$

$$R = \frac{\Delta x}{k} = \frac{0.08}{0.029} = 2.76$$

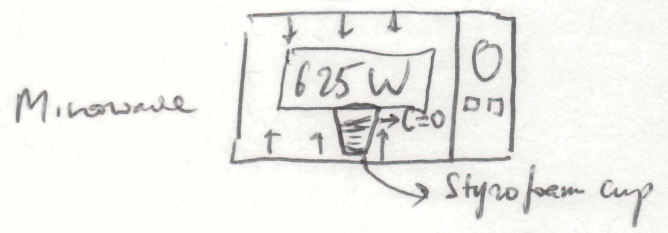
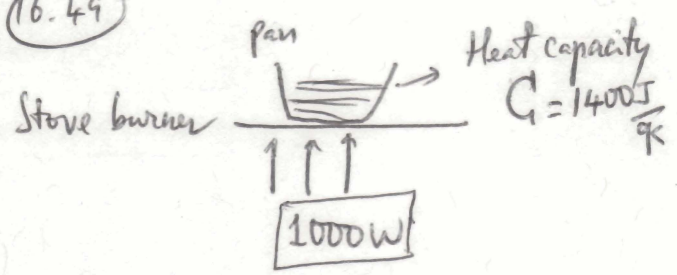
Table 16.2 ←

$$T_k = T_c + 273.16^\circ \rightarrow \begin{cases} T_{\text{inside}} = 4^\circ + 273.16^\circ \text{ K} \\ T_{\text{room}} = 20^\circ + 273.16^\circ \text{ K} \end{cases}$$

$$\begin{aligned} \Delta T &= T_{\text{room}} - T_{\text{inside}} = \\ &= 20 + 273.16 - 4 - 273.16 \\ &= 16^\circ\text{K} \end{aligned}$$

$$H = - \frac{35 \times 16}{2.76} = - 203 \text{ W}$$

16.49



Heat capacity $C = c \cdot m$ → $\Delta Q = \frac{C \Delta T}{cm}$

(c: specific heat) ↑ mass

How much water before it's quicker to heat w/ stove burner?

Compare time to heat same mass of water: M ~~same~~
so its temp increases ΔT

Stove burner:

$$H_s = 1000 \text{ W}$$

$$\frac{\Delta Q}{\Delta t_s} \downarrow \text{time}$$

$$\begin{aligned} \Delta t_s &= \frac{\Delta Q}{1000} \\ &= \frac{(C_w + C_{pan}) \Delta T}{1000} \\ &= \frac{(m_w c_w + C_{pan}) \Delta T}{1000} \end{aligned}$$

Microwave:

$$H_m = 625 \text{ W}$$

$$\frac{\Delta Q}{\Delta t_m} \downarrow \text{time}$$

$$\begin{aligned} \Delta t_m &= \frac{\Delta Q}{625} \\ &= \frac{C_w \Delta T}{625} \\ &= \frac{m_w c_w \Delta T}{625} \end{aligned}$$

$$\frac{m_w c_w + C_{pan}}{1000} \Delta T < \frac{m_w c_w \Delta T}{625}$$

$$\left\{ \begin{aligned} C_w &= 4184 \frac{\text{J}}{\text{kg} \cdot \text{K}} \\ C_{pan} &= 1400 \frac{\text{J}}{\text{K}} \end{aligned} \right.$$

$$(m_w c_w + C_{pan}) < m_w c_w \frac{1000}{625}$$

$$C_{pan} < m_w c_w \left(\frac{1000}{625} - 1 \right)$$

$$\frac{C_{pan}}{c_w \left(\frac{375}{625} \right)} < m_w$$

$$\frac{1400}{4184 \frac{375}{625}} < m_w \rightarrow \boxed{0.558 \text{ kg} < m_w}$$

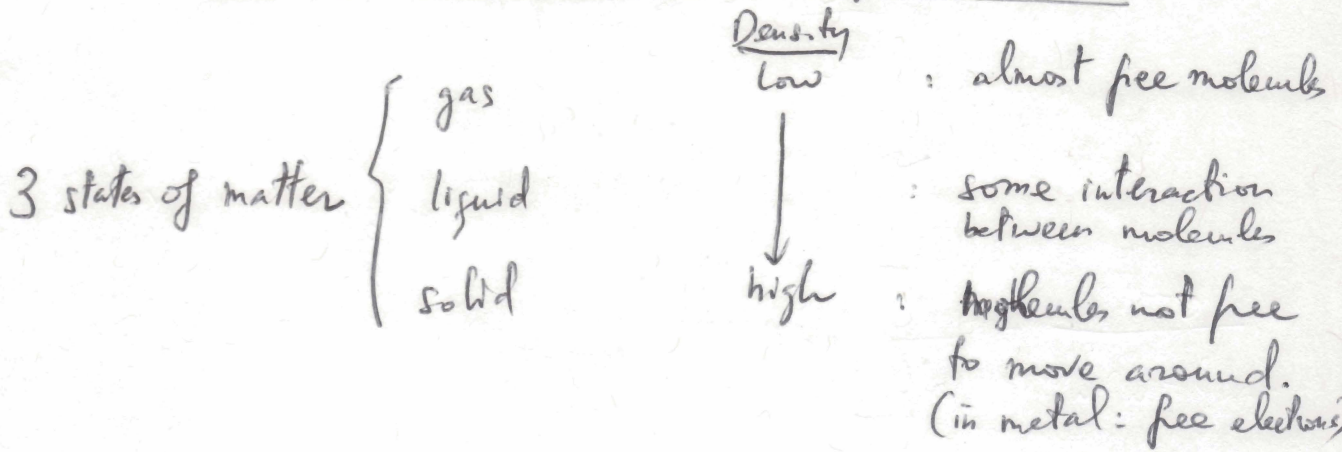
4) Rate of temperature increase = $\frac{\Delta T}{\Delta t}$

$m_w = 0.558 \text{ kg} \rightarrow$ use stove burner
or more

$$\Delta t_s = \frac{(m_w c_w + C_{pan}) \Delta T}{1000} \rightarrow \left[\frac{\Delta T}{\Delta t_s} \right] = \frac{1000}{m_w c_w + C_{pan}}$$

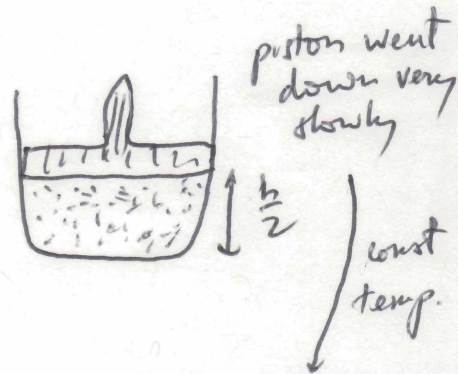
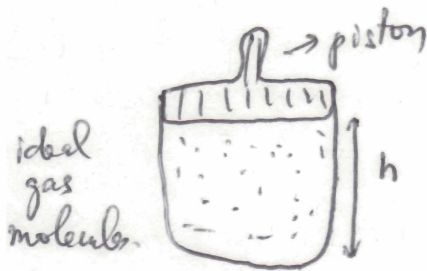
$$\frac{\Delta T}{\Delta t_s} = \frac{1000}{0.558 \times 4184 + 1400} = 0.268 \text{ } ^\circ\text{K/s}$$

Ch17 Thermal Behavior of Matter:



Ideal gas: completely free molecules

↳ Equation of state:



Gas: macroscopic properties:



number of molecules volume pressure

$$\begin{matrix} N_1 = N \\ V_1 = V \\ P_1 = P \\ T_1 = T \end{matrix}$$

State ①

$$\text{State ②} \begin{cases} N_2 = N \\ V_2 = \frac{V}{2} \\ P_2 = 2P \\ T_2 = T \end{cases}$$

some combination of these variables stay constant!

$$\begin{cases} kN_1T_1 = kN_2T_2 = kNT \\ P_1V_1 = P_2V_2 = PV \end{cases}$$

→ $PV = kNT$ Ideal Gas Law

k : Boltzmann constant
 $= 1.38 \times 10^{-23} \frac{J}{^\circ K}$

$$N = n \frac{N_A}{\text{\# of mole}} ; N_A = 6.022 \times 10^{23} \text{ Avogadro \#}$$

$$\rightarrow PV = n \underbrace{k N_A}_{R} T \rightarrow \boxed{PV = nRT}$$

ideal gas

$$R = 8.314 \frac{\text{J}}{\text{K mol}}$$

When we take into consideration some interaction b/w gas molecules: \rightarrow Real Gas Law or Van der Waals Law

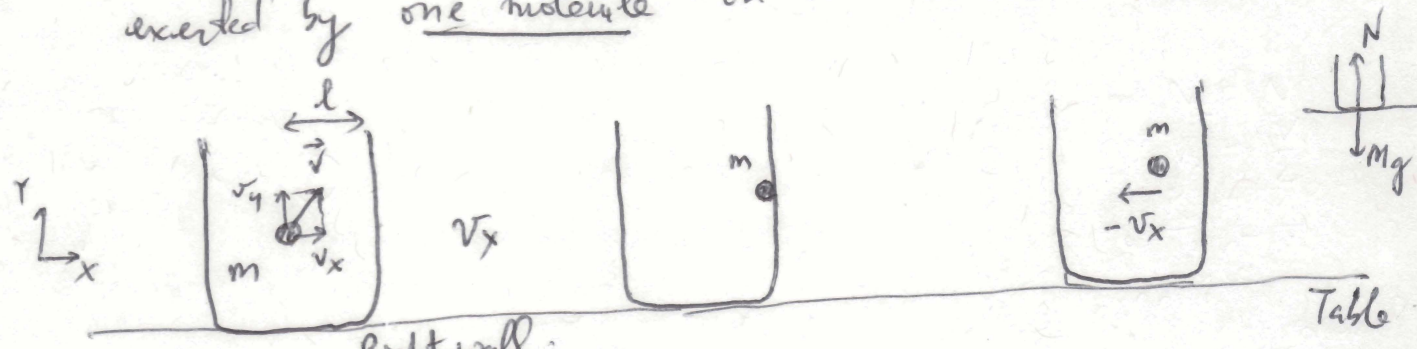
$$\boxed{\left(P + \frac{n^2 a}{V^2} \right) (V - nb) = nRT}$$

a, b are constants (given)

Ideal Gas: connection b/w microscopic behavior & macroscopic property:

Mechanic of gas molecules: calculate the pressure

exerted by one molecule on the container wall:



Right wall:
only v_x will exert a pressure on right wall

System: 1 gas molecule & wall: \rightarrow external force on system $\stackrel{?}{=} 0$
 \rightarrow is negligible \rightarrow in the x direction is zero $\rightarrow F_{net,x} = 0 = \frac{dp_x}{dt}$
 \rightarrow p_x of the system is constant

$$p_x \text{ before (molecule hits wall)} = p_x \text{ after.} \quad (1)$$

$$\underbrace{mv_x}_{\text{original momentum of molecule}} = \underbrace{-mv_x}_{\text{new mom. of molecule}} + \underbrace{2mv_x}_{\text{new momentum of wall}}$$

↳ Mom. transferred to wall → pressure on wall: P_i

$$P_i = \frac{F_i}{A} = \frac{\frac{Dp_i}{dt}}{A} = \frac{\frac{\sum m v_{xi}}{\Delta t}}{A} = \frac{mv_{xi}^2}{Al}$$

↳ Pressure by N molecules: $P = \sum_{i=1}^N P_i = \frac{mN}{\text{vol}} \left[\frac{\sum_{i=1}^N v_{xi}^2}{N} \right]$

volume or vol
↓
 $\overline{v_x^2}$
↓
average of v_x^2

$$P = \frac{\overbrace{m}^{\text{molecular mass}} N}{\text{Vol}} \left(\overbrace{\overline{v_x^2}}^{\text{average } v_x^2 \text{ of one molecule}} \right)$$

macroscopic microscopic

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

↓
one of 3 components of velocity in 3D

↓
total velocity in 3D

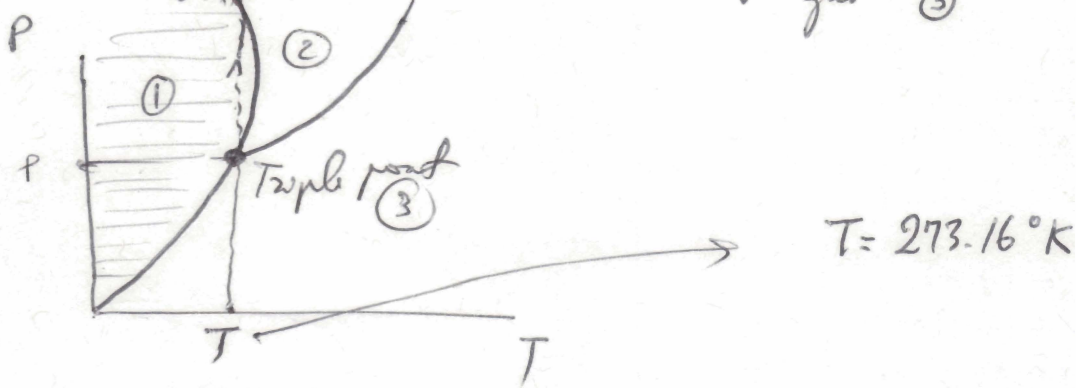
$$P = \frac{mN}{3V} \overline{v^2} \rightarrow \boxed{PV = mN \frac{\overline{v^2}}{3}}$$

↑
vol.

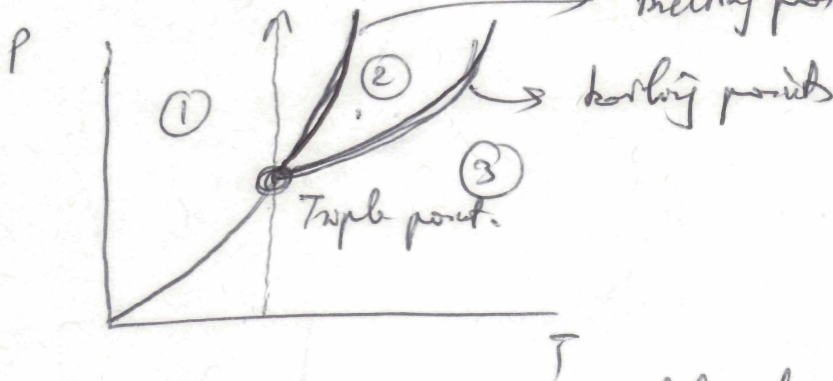
Now comparing this with ideal gas law: $PV = kNT$

Phase diagram for water

- solid ①
- liquid ②
- gas ③



Phase diagram for rest of materials



@ fix T: ↑ P : can melt a solid only if it was water,

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

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

macroscopic property of gas

microscopic property of molecule

Average K.E of one gas molecule in 3D.

(v = total velocity in 3D).

→ What is the average KE of a gas molecule in 1D?

$$\rightarrow \frac{1}{2} kT$$

or per degree of freedom

(two atoms connected in a molecule → 5 degrees of freedom)



→ average KE per diatomic molecule is $\frac{5}{2} kT$

Thermal behavior of matter:

When heat is supplied to matter ΔQ , consequences or behaviors


solid → gas


L_s
L.H. of sublimation

- 1) ΔT (Temp. is changed)
 $\Delta Q = mc\Delta T$
- 2) Change of phase
 $\Delta Q = mL$
solid → liquid → gas
 L_f L_v
Latent heat of L.H. of
fusion vaporization

16.54

12

 milk $\rightarrow m_m = 2 \text{ kg}$ $T_m = 3^\circ\text{C}$

 cocoa $\rightarrow m_c = 6 \text{ kg}$; $T_c = 90^\circ\text{C}$

} T_f ?
equilibrium temp.

$$\Delta Q_m + \Delta Q_c = 0$$

$$m_m c_m (T_f - T_m) + m_c c_c (T_f - T_c) = 0$$

$$\rightarrow c_m = c_c = c_w = 4184 \frac{\text{J}}{\text{kg}^\circ\text{C}}$$

$$T_f = \frac{m_c c_w T_c + m_m c_w T_m}{m_m c_w + m_c c_w} =$$

$$\frac{6(90 + 273.16) + 2(3 + 273.16)}{2 + 6}$$

$$= ~~63.3^\circ\text{C}~~$$

$$341.46 \text{ }^\circ\text{K}$$

\updownarrow

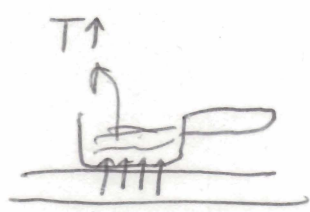
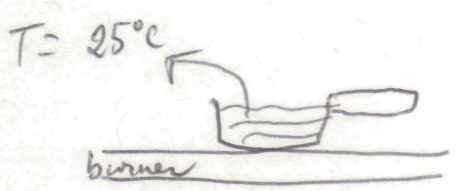
$$63.3^\circ\text{C}$$

3) Expansions :

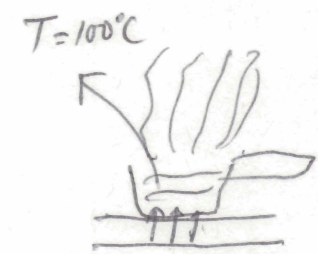
Linear $\alpha = \frac{\frac{\Delta L \leftarrow \text{length.}}{L}}{\Delta T \leftarrow \text{temp.}}$

volumic $\beta = \frac{\frac{\Delta V \leftarrow \text{volume}}{V}}{\Delta T \leftarrow \text{temp.}}$

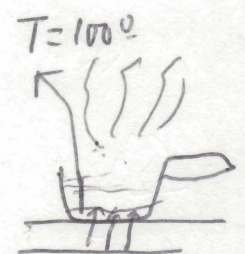
Change of phase :



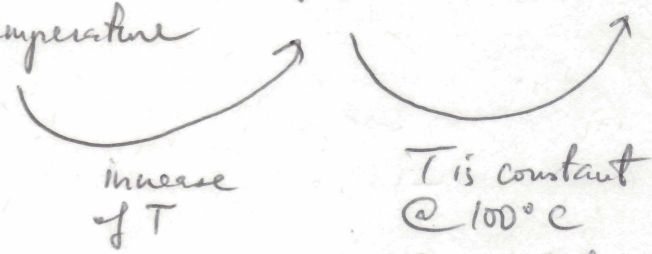
$\Delta Q = mc\Delta T$
 $\Delta Q \rightarrow$ increase in temperature



water starts to boil after 2 min



$\Delta Q = mL_v$

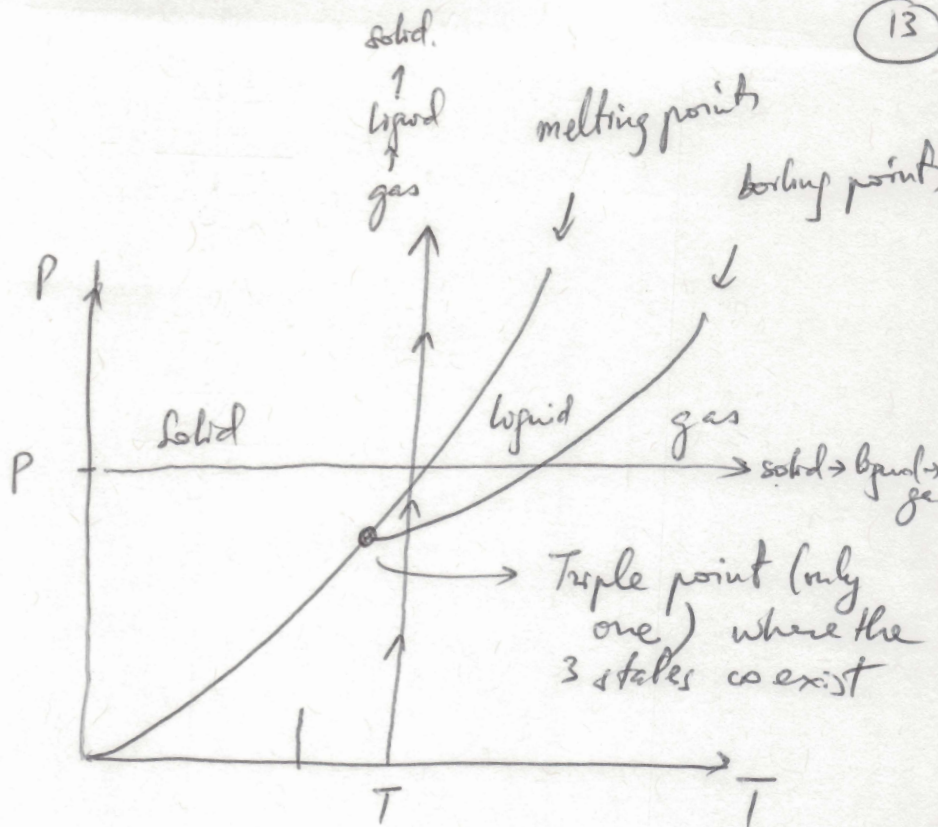


- Gas : very low bonding
- liquid : some bonding
- solid : lots bonding

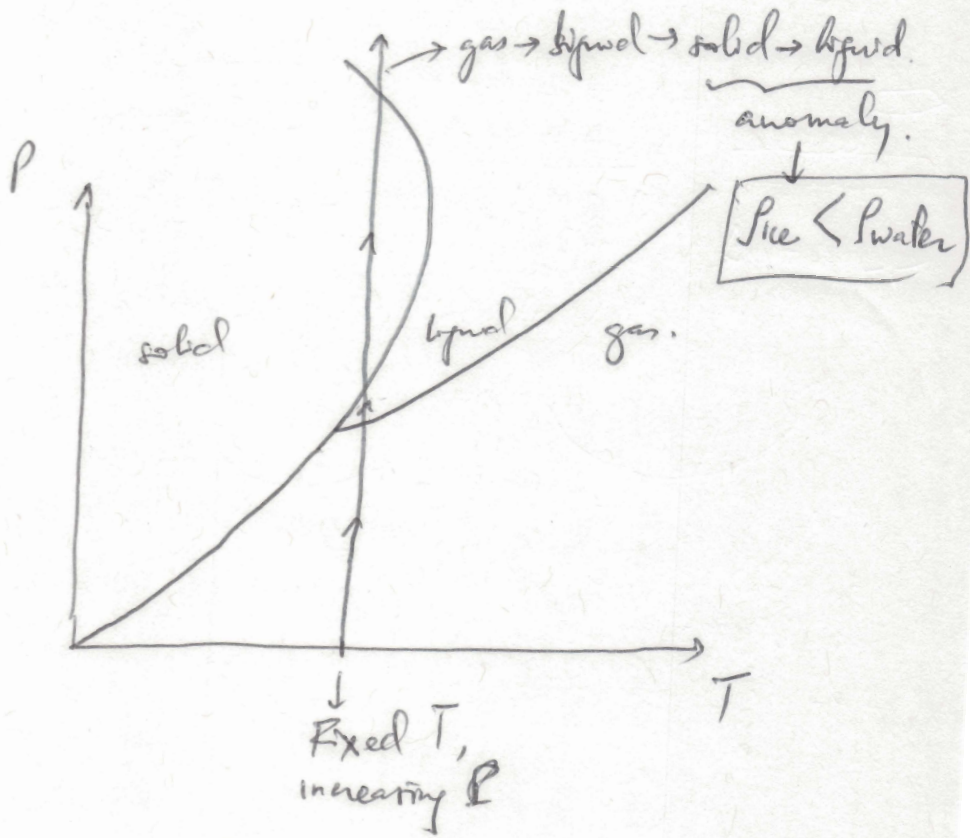
T is constant @ 100°C
 ΔQ goes in to change of phase
 liquid \rightarrow gas.

Phase diagram:

Normal matter



Water



16.44 16.75
17.51 ; 17.63
17.65

16.75

14

$$m_w = 5.4 \times 10^6 \text{ kg}$$

$$T_i = 10^\circ\text{C} \quad \text{to} \quad T_f = 350^\circ\text{C}$$

$$\text{Power} = 1.42 \text{ GW} = 1.42 \times 10^9 \text{ W} = 1.42 \times 10^9 \frac{\text{J}}{\text{s}}$$

time?

$$\text{Power} = \frac{\Delta Q \leftarrow \text{heat}}{\Delta t \leftarrow \text{time}} \rightarrow 1.42 \times 10^9 = \frac{m_w c_w \Delta T}{\Delta t}$$

$$\rightarrow \Delta t = \frac{m_w c_w \Delta T}{1.42 \times 10^9} = \frac{5.4 \times 10^6 \times 4184 \times 340^\circ\text{K}}{1.42 \times 10^9}$$
$$= 5400 \text{ s} \times \frac{14}{3600 \text{ s}} = 1.5 \text{ h.}$$

17.51

$$H = 200 \times 10^6 \text{ W} \quad (\text{from core reactor})$$

\rightarrow 420 m^3 of water @ 20°C : how long to boil it
 $\rho = \frac{m}{\text{Vol}} \rightarrow m = \rho \text{Vol} \rightarrow \rho = 1000 \text{ kg/m}^3$ dry?

Using heat supplied by core reactor to

- 1) increase water temp from 20°C to 100°C
- 2) vaporize all water @ 100°C

How long?

\hookrightarrow How much heat ΔQ would be needed for steps 1 & 2

$$\Delta Q = m_w c_w \Delta T + m_w L_v = 420 \times 10^3 (4184 \times 80^\circ\text{K} + 2257 \times 10^3)$$
$$= 1088522.4 \times 10^6 \text{ J} \quad \uparrow \text{Table 17.1} \rightarrow 2257 \text{ kJ}$$

How long? = $\frac{WQ}{H} = \frac{1088522.4 \times 10^6 \text{ J}}{200 \times 10^6 \frac{\text{J}}{\text{s}}}$
 = $5442 \frac{\text{s}}{3600 \frac{\text{s}}{\text{h}}} = 1.51 \text{ h.}$

17.63

Gas 10°C → 25°C
 underground tank tank of car

Expansion: $\beta = \frac{\frac{\Delta V}{V}}{\Delta T}$ → $\beta = \frac{\Delta V}{V \Delta T}$ → $\Delta V = \beta V \Delta T$

← volume
 ↑ temp.

$V_{\text{Total}} = V + \Delta V$
 $= V + \beta V \Delta T = V(1 + \beta \Delta T)$

Capacity of gas tank in the car.

actual volume to pump in > 1 to accommodate gasoline expansion

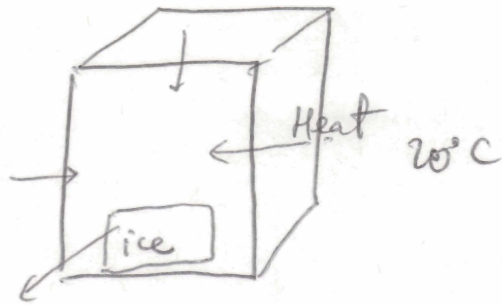
$V = \frac{V_{\text{Total}}}{1 + \beta \Delta T} = \frac{60\text{L}}{1 + 95 \times 10^{-5} \times 15^\circ\text{K}} = 59.2\text{L}$

Table 17.2

$\beta_{\text{gasoline}} = 95 \times 10^{-5} \text{ } ^\circ\text{K}^{-1}$

17.65

Thermal resistance $R = 0.12 \frac{^{\circ}\text{K}}{\text{W}}$



0°C
 $m_{\text{ice}} = 15 \text{ kg}$

How long will the ice last? $\rightarrow \frac{\Delta Q}{H}$

heat needed to melt the ice

$$H = -kA \frac{\Delta T}{\Delta x} = -\frac{A \Delta T}{R} = -\frac{\Delta T}{R}$$

↳ only R

$\frac{R}{A} \equiv R$
R-factor

thermal resistance

Table 17.1
334 kJ/kg

$$\Delta t = \frac{m_{\text{ice}} L_f}{\frac{\Delta T}{R}} = \frac{15 \times 334 \times 10^3 \text{ J}}{\frac{20^{\circ}\text{K}}{0.12 \frac{^{\circ}\text{K}}{\text{W}}}} = 3.01 \times 10^4 \text{ s} = 8.35 \text{ h}$$

17.71 Brass pendulum $L = 20\text{cm}$ @ 20°C → good.



@ 18°C → how long before 1 min error? too fast or too slow?

$$\omega = \sqrt{\frac{g}{L}} \rightarrow \omega = \frac{2\pi}{T} \rightarrow T = 2\pi\sqrt{\frac{L}{g}}$$

linear expansion: $\alpha = \frac{\frac{\Delta L}{L}}{\Delta T}$ Table 17.2 $\alpha = 19 \times 10^{-6} \text{K}^{-1}$

↖ temp.

→ $\Delta L = \alpha L \Delta T$

$$T_{20^\circ\text{C}} = 2\pi\sqrt{\frac{L}{g}} \quad ; \quad T_{18^\circ\text{C}} = 2\pi\sqrt{\frac{L + \Delta L}{g}} = 2\pi\sqrt{\frac{L(1 + \alpha\Delta T)}{g}}$$

$$T_{18^\circ\text{C}} < T_{20^\circ\text{C}} \rightarrow T_{20} - T_{18} = \frac{2\pi}{\sqrt{g}} \left[\sqrt{L} - \sqrt{L(1 - 2\alpha)} \right]$$

$$= 2\pi\sqrt{\frac{L}{g}} \left[1 - \sqrt{1 - 2\alpha} \right]$$

$\alpha \ll 1$

$(1+x)^{1/2} \approx 1 + \frac{1}{2}x + \dots$ → $(1-2\alpha)^{1/2} \approx 1 - \alpha$

Taylor expansion for $x \ll 1$

$$T_{20} - T_{18} = 2\pi\sqrt{\frac{L}{g}} [1 - (1 - \alpha)] = 2\pi\alpha\sqrt{\frac{L}{g}} = \alpha T_{20}$$

(error per period)

How long for error to become 1 min

$$\frac{1 \text{ min}}{\alpha T_{20}} = \frac{60\text{s}}{19 \times 10^{-6} T_{20}} \rightarrow \text{how long} \rightarrow \frac{60}{19 \times 10^{-6}} \times T_{20} =$$

$5.76 \times 10^4 \times 60 \text{ s} = 36.5 \text{ days}$

$\frac{1}{19 \times 10^{-6}} \approx 5.26 \times 10^4$

Ch 18 Heat, Work, and the 1st Law of Thermodynamics

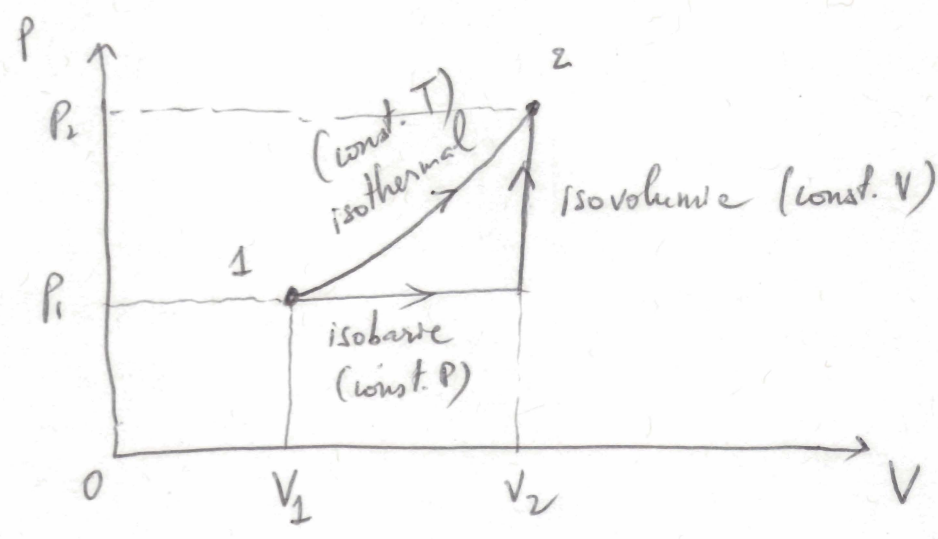
1st Law of Thermodynamics

Heat absorbed by a system Q
 Work done by system W
 Change of internal energy of system ΔU

} $\Delta U = Q - W$
 Conservation of energy

$\Delta U, T, P, V$ are state variables (they don't depend on a particular process)

Q, W are NOT state variables (they depend on a particular process).



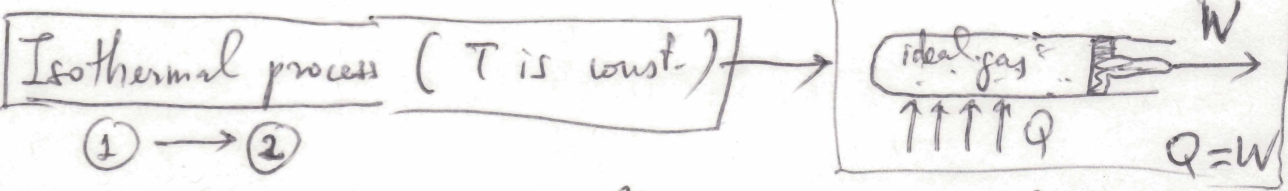
isobaric
 isochoric
 isothermal
 adiabatic $\rightarrow Q=0$

PV diagram:

Work done by system = $W = \int P dV$

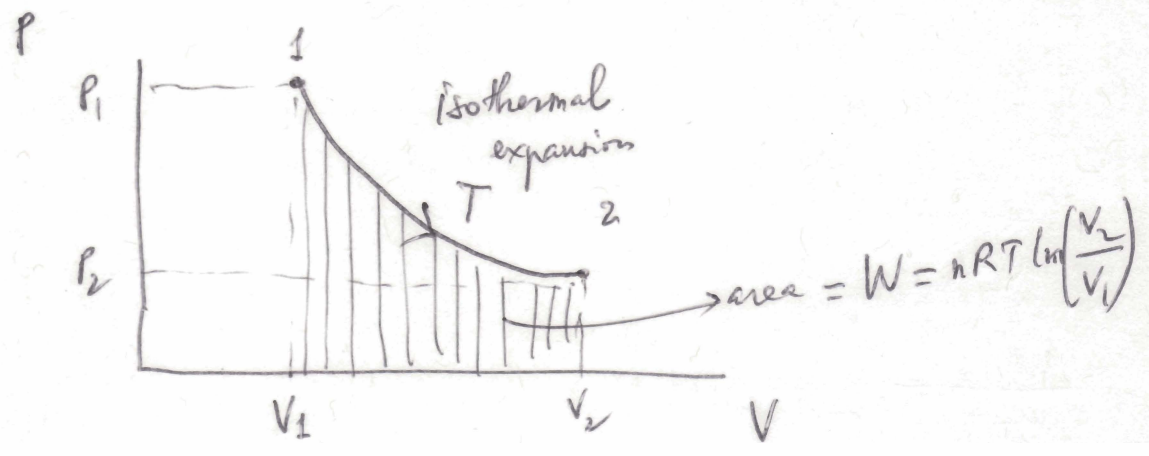
$W = F \cdot \Delta x = \underbrace{P \cdot A \Delta x}_{\Delta V}$

in a PV diagram:
 work done is the area under the pressure curve vs. volume



$$W = \int_1^2 P dV = nRT \int_1^2 \frac{dV}{V} = nRT [\ln V]_1^2 = nRT \ln \left[\frac{V_2}{V_1} \right]$$

Ideal gas Law: $PV = nRT \rightarrow P = \frac{nRT}{V}$



What is ΔU in an isothermal process?

Ideal gas: 1) no interaction b/w molecules: → Its internal energy comes only from: their KE

$$2) \quad \frac{1}{2} m \bar{v}^2 = \frac{3}{2} kT$$

microscopic average KE per molecule

macroscopic temperature of the gas.

3) ΔU when $T_1 = T_2$ (isothermal) → $\Delta U = 0$

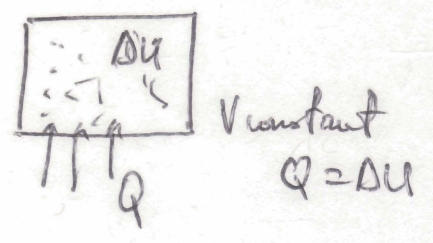
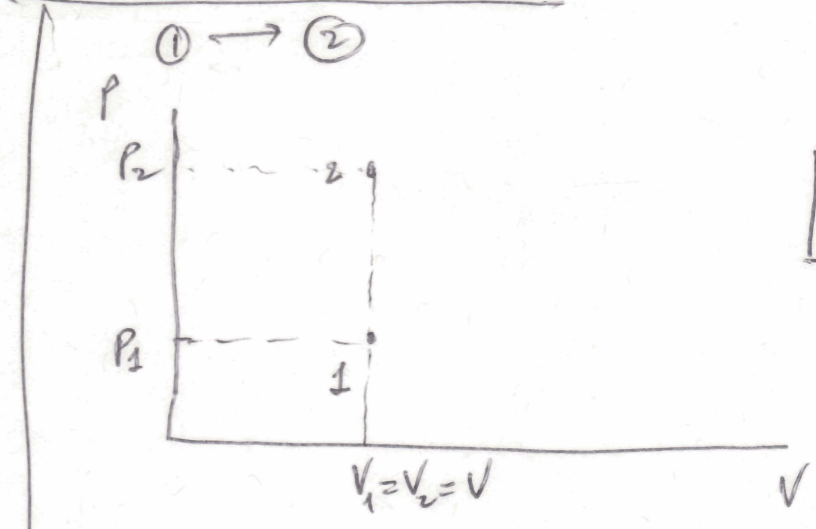
What is Q in an ideal gas in an isothermal process?

1st Law of TD: $\Delta U = Q - W \rightarrow Q = \Delta U + W$

$Q = W$

Ideal gas under isothermal expansion would absorb heat returning as work done

Isovolumic Process (const. V)



$$W = \int P dV = 0$$

1st Law of TD: $\Delta U = Q - W \Rightarrow \Delta U = Q$

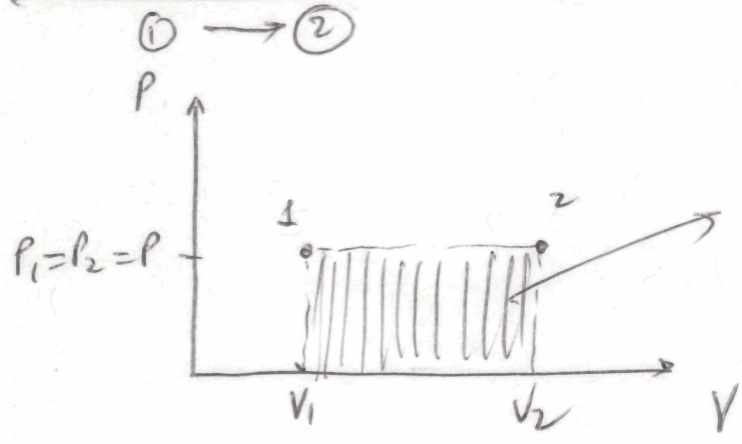
Heat supplied \rightarrow increase gas temp \rightarrow increasing av. KE per molecule.

Specific heat at constant V: $c_v = \frac{1}{n} \frac{Q}{\Delta T} = \frac{1}{n} \frac{\Delta U}{\Delta T}$

\leftarrow change of internal energy.
 ΔT
 \leftarrow change of temp.

$$Q = n c_v \Delta T$$

Isobaric Process (const. P)



$$W = \int_1^2 P dV = P \int_1^2 dV = P \frac{(V_2 - V_1)}{\Delta V}$$

Specific heat at const. P : $c_p = \frac{1}{n} \frac{Q}{\Delta T}$

$Q = n c_p \Delta T$

For an ideal gas:

$P \Delta V = n R \Delta T$
 \downarrow
 W

1st Law of TD:

$\Delta U = Q - W$

$n c_v \Delta T = n c_p \Delta T - n R \Delta T$

$c_v = c_p - R$

$c_p = c_v + R$
 $R = 8.314 \frac{J}{mol \cdot K}$

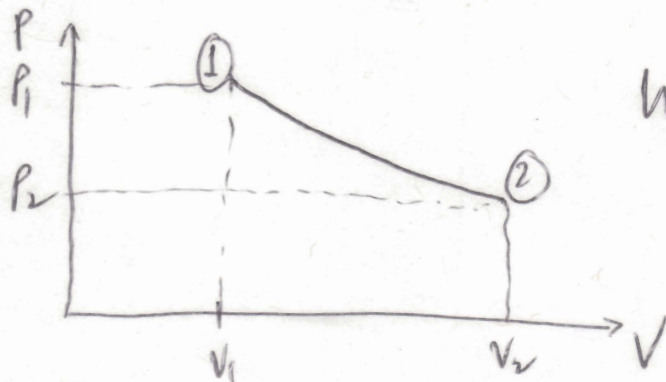
$c_p > c_v$

$Q = \Delta U + W$ $\left\{ \begin{array}{l} \text{const P: } Q = \Delta U + W \\ \text{const V: } Q = \Delta U \end{array} \right.$

more heat absorption capacity at const P.

Adiabatic process: ($Q = 0$) $\rightarrow \Delta U = -W$

① \rightarrow ②



$W = \frac{P_1 V_1 - P_2 V_2}{\gamma - 1}$

γ dimensionless coefficient depending on the type of gas: monatomic or diatomic

adiabatic process: PV^γ is constant
① → ②

$$P_1 V_1^\gamma = P_2 V_2^\gamma$$

Ideal gas: $PV = nRT$

$$\rightarrow T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$$

What are possible values for γ ?

$$\gamma = \frac{C_p}{C_v}$$

$$\gamma = \frac{C_v + R}{C_v} = \begin{cases} \text{Monatomic ideal gas} \\ \text{(molecule = one atom)} \\ \text{d.o.f} = 3 \end{cases}$$

$$\rightarrow \gamma = \frac{\frac{3}{2}R + R}{\frac{3}{2}R} = \frac{5}{3} = 1.67$$

$$\begin{cases} \text{Diatomic ideal gas} \\ \text{(molecule = two atoms)} \\ \text{connected.} \end{cases}$$

$$\rightarrow \gamma = \frac{\frac{5}{2}R + R}{\frac{5}{2}R} = \frac{7}{5} = 1.4$$

$\frac{1}{2}m\bar{v}^2 = \frac{3}{2}kT$ (monatomic)

$\text{d.o.f} = 6 - 1 = 5$

Monatomic ideal gas $C_v = \frac{1}{n} \frac{\Delta U}{\Delta T} = \frac{1}{n} \frac{N \frac{3}{2} k \Delta T}{\Delta T} = \frac{1}{\frac{N}{N_A}} \frac{3}{2} k = \frac{3}{2} k N_A = \frac{3}{2} R$

$$\begin{cases} R = k N_A \\ n = \frac{N}{N_A} \end{cases}$$

Diatomic gas: $C_v = \frac{1}{n} \frac{\Delta U}{\Delta T} = \frac{5}{2} R$

$\text{d.o.f} = 5$

$\frac{1}{2}m\bar{v}^2 = \frac{5}{2}kT$

18.33 ; 18.42 ; 18.49
 18.52 ; 18.57 ;

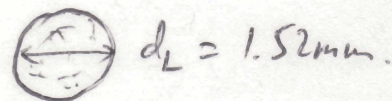
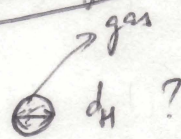
spherical gas bubbles. (22)

18.33

Blood artery

$$\begin{cases} P_H = 125 \text{ mmHg} \\ P_L = 80 \text{ mmHg} \end{cases}$$

gauge pressures
 (not including atmospheric pressure)



1 Atm → 760 mmHg

a) d_H ? Gas inside bubble is ideal $PV = nRT$

$$\begin{cases} P_H V_H = nRT \\ P_L V_L = nRT \end{cases}$$

same body temp

$$P_H V_H = P_L V_L$$

$$P_H \frac{4}{3} \pi \left(\frac{d_H}{2}\right)^3 = P_L \frac{4}{3} \pi \left(\frac{d_L}{2}\right)^3$$

$$d_H = \left[\frac{P_L}{P_H} d_L^3 \right]^{1/3}$$

Vol of a sphere is $\frac{4}{3} \pi R^3$

$$d_H = \left(\frac{P_L}{P_H} \right)^{1/3} d_L = \left(\frac{80 + 760}{125 + 760} \right)^{1/3} 1.52 \text{ mm} = 1.49 \text{ mm}$$

$$1 \text{ Atm} = 1.013 \times 10^5 \text{ Pa} ; \quad 1 \text{ mmHg} = 133.3 \text{ Pa}$$

$$\frac{1 \text{ Atm}}{101300 \text{ Pa}} \cdot \frac{133.3 \text{ Pa}}{1 \text{ mmHg}} = \frac{1 \text{ Atm}}{\frac{101300}{133.3} \text{ mmHg}} = \frac{1 \text{ Atm}}{760 \text{ mmHg}}$$

b) Assuming const. T = 37°C → Find W_{by blood}
 isothermal

or Work received by gas bubble

↓ ideal gas in bubble: (low → high P)

$$W = nRT \ln\left(\frac{V_2}{V_1}\right) = nRT \ln\left(\frac{V_H}{V_L}\right) = nRT \ln\left(\frac{P_L}{P_H}\right)$$

(73)

$$W = P_L V_L \ln \left(\frac{P_L}{P_H} \right) = (80 + 760) \frac{133.3}{1} \frac{4}{3} \pi \left(\frac{1.52 \times 10^{-3}}{2} \right)^3 \ln \frac{80+760}{125+760}$$

in Pa.

$$= -12312 \times 10^{-9} \text{ J} = -12 \mu\text{J}$$

↓
micro = 10^{-6}

Negative work done by gas in bubble → yes since it is actually receiving work by blood (and heart) to get compressed $d_L \rightarrow d_H$
 1.52mm 1.49mm.

(12.57)

Ar (Monatomic $\gamma = 1.5$) & O_2 (diatomic $\gamma = 1.4$)

Adiabatic expansion: $\left\{ \begin{array}{l} V_1 \rightarrow V_2 = 2V_1 \\ P_1 \rightarrow P_2 = \frac{P_1}{3} \end{array} \right.$

Fraction of Ar = $f \rightarrow$ Fraction of oxygen would be: $1-f$
 ($0 < f < 1$)

they will contribute to total internal energy of mixture according to this fraction:

$$\text{Mixture: } C_v = \underbrace{\frac{3}{2} R f}_{Ar} + \underbrace{\frac{5}{2} R (1-f)}_{O_2} = R \left(\frac{3}{2} f + \frac{5}{2} - \frac{5}{2} f \right) = R \left(\frac{5}{2} - f \right)$$

$$\gamma = \frac{C_v + R}{C_v} = \frac{R \left(\frac{5}{2} - f \right) + R}{R \left(\frac{5}{2} - f \right)} = \frac{\frac{7}{2} - f}{\frac{5}{2} - f}$$

How do I find γ for mixture?

$$P_1 V_1^\gamma = P_2 V_2^\gamma \rightarrow \frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^\gamma$$

$$\ln \frac{P_1}{P_2} = \gamma \ln \frac{V_2}{V_1}$$

$$\gamma = \frac{\ln \frac{P_1}{P_2}}{\ln \frac{V_2}{V_1}} = \frac{\ln \left(\frac{P_1}{P_2}\right)}{\ln \left(\frac{2V_1}{V_1}\right)}$$

$$\gamma = \frac{\ln 3}{\ln 2} = 1.58$$

$$\rightarrow 1.58 = \frac{\frac{7}{2} - f}{\frac{5}{2} - f} \rightarrow$$

$$1.58(2.5 - f) = 3.5 - f$$

$$1.58 \times 2.5 - 3.5 = (1.58 - 1)f$$

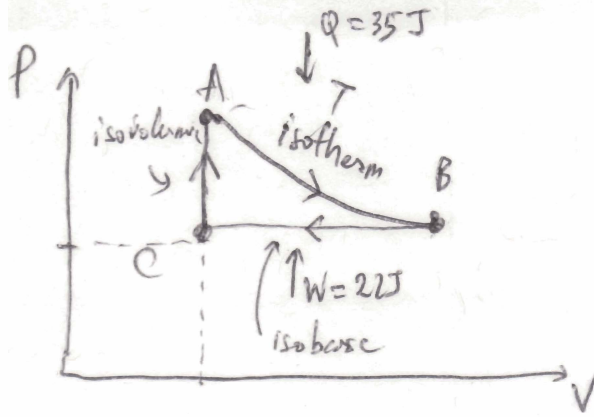
$$f = \frac{1.58 \times 2.5 - 3.5}{0.58}$$

$$f = 0.78 \rightarrow \text{Ar.}$$

$$\rightarrow 0.22 \text{ O}_2$$

18.42 /

a)



b) $W_{ABCA} = W_{AB} + W_{BC} = 35\text{ J} - 22\text{ J} = 13\text{ J}$

AB: isothermal Q : $\Delta U = N \frac{3}{2} k \Delta T = 0 = Q - W \Rightarrow W = Q$
 ideal gas, monatomic, 1st Law of TD

$\rightarrow W_{AB} = Q = 35\text{ J}$

BC: isobaric $\rightarrow W_{BC} = -22\text{ J}$

c) $Q_{BCA} = Q_{BC} + Q_{CA} = nC_p \Delta T_{BC} + nC_v \Delta T_{CA}$
 isobaric, isochoric, No info on Temperature.

$Q_{ABCA} = \Delta U_{ABCA} + W_{ABCA} = W_{ABCA} = 13\text{ J}$
 (since U is a state variable)
 1st Law TD

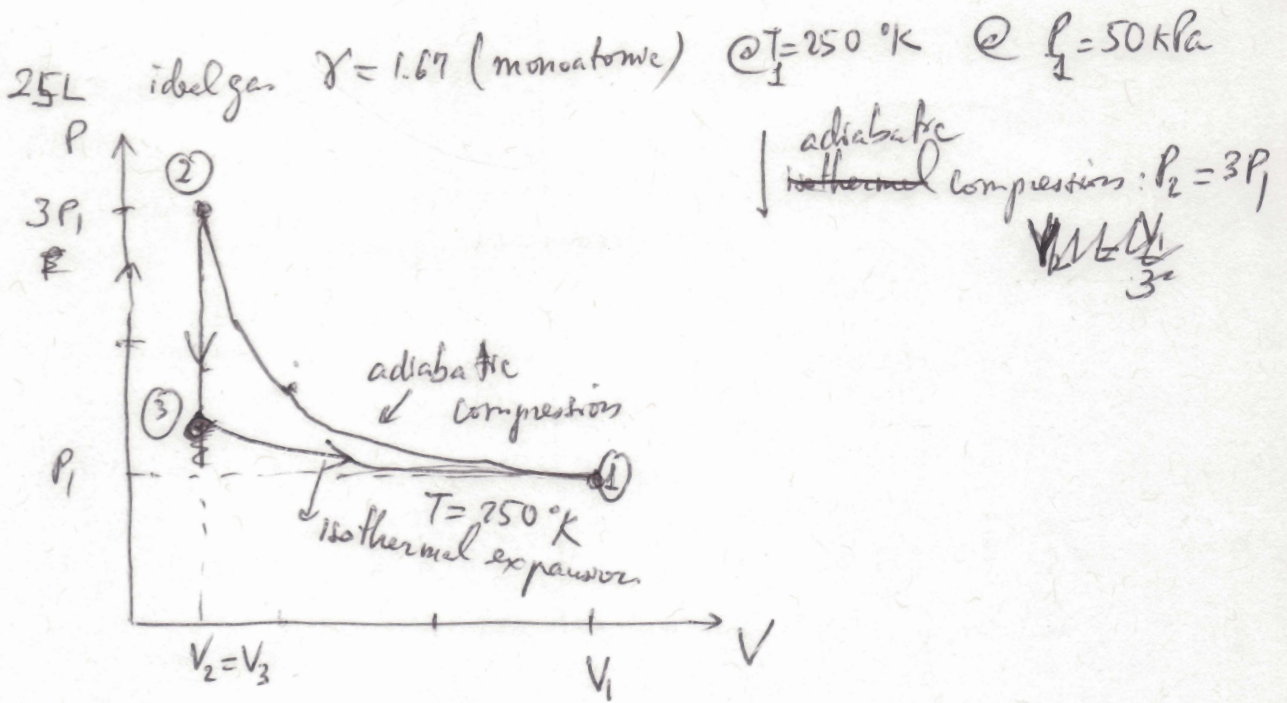
$Q_{ABCA} = Q_{AB} + Q_{BCA} = 35\text{ J} + Q_{BCA} \rightarrow Q_{BCA} = Q_{ABCA} - 35\text{ J}$

$\rightarrow Q_{BCA} = 13\text{ J} - 35\text{ J}$

$Q_{BCA} = -22\text{ J}$

gas rejected 22 J of heat in B \rightarrow C \rightarrow A.

18.49



a) How much work is done on gas? (- work done by gas)

$$W_{1231} = \underbrace{W_{12}}_{\text{adiab}} + 0 + \underbrace{W_{31}}_{\text{isothermal}} = -1033 \text{ J} + 822 \text{ J} = -211 \text{ J}$$

Work done on gas \rightarrow 1231 is +211 J

$$W_{31} = nRT \ln \frac{V_1}{V_3} = nRT \ln \frac{V_1}{V_2}$$

Need V_2 in term of V_1

① \rightarrow ② adiabatic: $P_1 V_1^\gamma = P_2 V_2^\gamma \rightarrow \left(\frac{V_1}{V_2}\right)^\gamma = \frac{P_2}{P_1} \rightarrow \frac{V_1}{V_2} = \left(\frac{P_2}{P_1}\right)^{1/\gamma}$

$$W_{31} = P_1 V_1 \ln \left(\frac{V_1}{V_2}\right) = \frac{P_1 V_1}{\gamma} \ln \left(\frac{P_2}{P_1}\right) = \frac{50 \times 10^3 \times 25 \times 10^{-3}}{1.67} \ln \left(\frac{3P_1}{P_1}\right) = 822 \text{ J}$$

Ideal gas: $nRT = P_1 V_1$

1000 L in 1 m^3

$$W_{12} = \frac{P_1 V_1 - P_2 V_2}{\gamma - 1} = \frac{P_1 V_1 - 3P_1 V_1 \frac{1}{3^{1/1.67}}}{\gamma - 1} = P_1 V_1 \frac{1 - 3^{(1-1/\gamma)}}{\gamma - 1} = 50 \times 10^3 \times 25 \times 10^{-3} \frac{1 - 3^{-0.67}}{0.67} = -1033 \text{ J}$$

adiabatic: $V_2 = \left(\frac{P_1}{P_2}\right)^{1/\gamma} V_1 \rightarrow V_2 = \left(\frac{P_1}{3P_1}\right)^{1/1.67} V_1 = \left(\frac{1}{3}\right)^{1/1.67} V_1 = \frac{V_1}{3^{1/1.67}}$

18.52

$n = 21$ mol ideal monatomic gas

transfers 15 kJ of heat to surroundings:

$\Delta T = 160$ K

$Q = -15$ kJ
heat absorbed

Work done on gas?

Work done by gas $W = -\Delta U + Q$

1st Law of TD.

Work done on gas: $-W = \Delta U - Q = \frac{3}{2}nRT - (-15$ kJ)

ideal gas: KE:
 $U = N(\frac{1}{2}mv^2) = N\frac{3}{2}kT$
 $N\frac{3}{2}k\Delta T = nN_A\frac{3}{2}k\Delta T = \frac{3}{2}nR\Delta T$
monatomic

$= \frac{3}{2} \cdot 21 \cdot 8.314 \cdot 160 + 15000 = +56900$ J