ch. 19   Temperature & Heat:

Temperature: a macroscopic property, a consequence of the microscopic behavior (statistical physics)
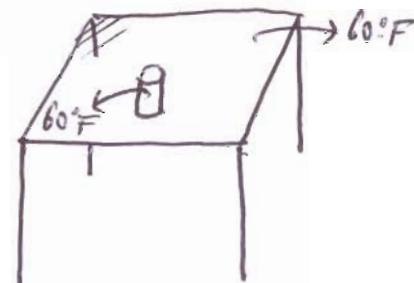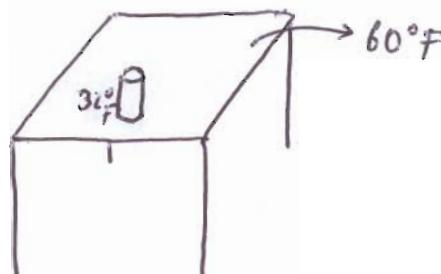
after 8 hours.

2 objects in thermal contact can exchange **heat** to arrive at a thermodynamic equilibrium (same temperature)

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

Fahrenheit: °F   → $T_F = \frac{9}{5} T_C + 32$

Celsius : °C   → $T_C = T_K - 273.16\,°K$

Kelvin : °K

Triple point (water) : $273.16\,°K$;   Absolute zero : $0\,°K$

Heat transfer rate : $H = -kA \dfrac{\Delta T}{\Delta x}$

→ Thermal conductivity

(per unit time)   materials.

(How fast heat can be transferred)

Faster Heat transfer

$\Delta T = 118°$ 32°F

hot soup 150°F   60°F

$\Delta T = 90°F$
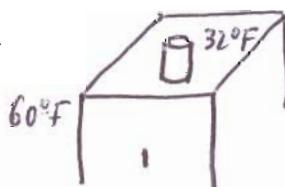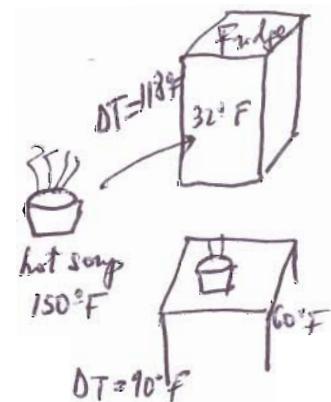
Units:

Heat: → Joules J

$$[H] = -[k][A]\frac{[\Delta T]}{[\Delta x]} \quad \rightarrow \quad [k] = \frac{\boxed{J/s}}{m \, °K}$$

$$\downarrow \qquad \downarrow \qquad \qquad \qquad = \frac{W}{m \, °K}$$

$$J/s \qquad m^2 \qquad m$$

Another system: $[k] = \dfrac{Btu \cdot in}{h \cdot ft^2 \cdot °F}$

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

R-factor: $R \equiv \dfrac{\Delta x}{k}$

$$\rightarrow \quad \frac{m^2 \, °k}{W} \qquad \left(or \quad \frac{ft^2 \, °F}{\frac{Btu}{h}} \right)$$

$$SI.$$

Mechanisms of heat transfer :
$\begin{cases} - \text{conduction} : (\text{atoms/molecule collisions}) \\ \qquad \qquad \qquad \text{electrons} \\ - \text{convection} : (\text{circulation of heat}) \\ - \text{radiation} \end{cases}$

Boil some water

Radiation

T_2

convection.
conduction

T_1 stove top

Baking

convection

oven

Broiling

conduction

oven
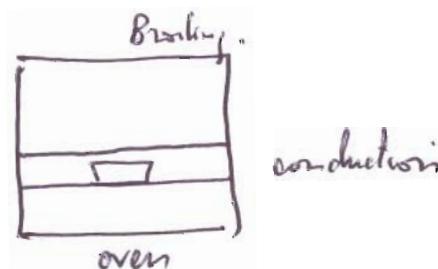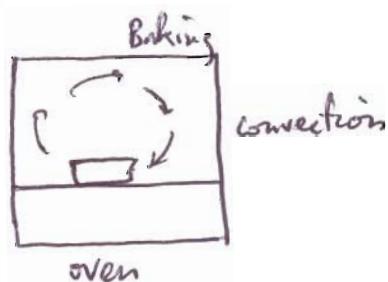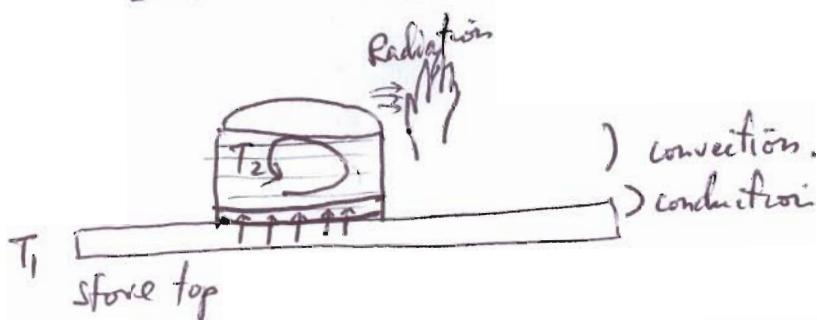
Heat exchange : $\quad \Delta Q_{Table} + \Delta Q_{soda} = 0 \quad$ (Conservation of energy)
(assuming "air" is vacuum)

$$\Delta Q = C \Delta T$$
$\qquad \downarrow$ Heat capacity $\quad = c \, m \longrightarrow$ mass
$\qquad\qquad\qquad\qquad\quad \downarrow$
$\qquad\qquad\qquad\qquad$ Specific Heat

$$\Delta Q = c m \Delta T$$

Heat by radiation : energy loss rate $\overset{by\ radiation}{\vee}$ of an object of area A
& temperature T. Stefan- Boltzman. law:

$$P = e \ \sigma A T^4 \longrightarrow \text{Temperature}$$
$\qquad\quad \downarrow \qquad\qquad\qquad\qquad\qquad\qquad\longrightarrow \text{Area}$
$\qquad$ emissivity

Stefan Boltzman const.
$\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\quad \downarrow$

SI units: W $\qquad\qquad\qquad\qquad\qquad\qquad \sigma = 5.67 \times 10^{-8} \frac{W}{m^2 k^4}$
$\qquad\qquad \downarrow \qquad\quad \downarrow \quad \downarrow$ °K
$\qquad$ dimensionless coefficient $\quad m^2$

Ch 20 Thermal Behavior of Matter

3 states of matter $\begin{cases} \text{gases} & \text{low density} : & \text{almost free molecules} \\ \text{liquids} & \Big| & : & \text{some interaction b/w molecules} \\ \text{solids} & \text{high density} : & \text{more interaction} \end{cases}$

Ideal gas

gas
molecules

N, V, P, T

macroscopic properties

piston going down very slowly

$N, \frac{V}{2}, 2P, T$

$$\boxed{PV = kNT}$$

$2P \dfrac{V}{2}$

→ Ideal gas law

k : Boltzman constant :
$k = 1.38 \times 10^{-23} \dfrac{J}{{}^{\circ}K}$
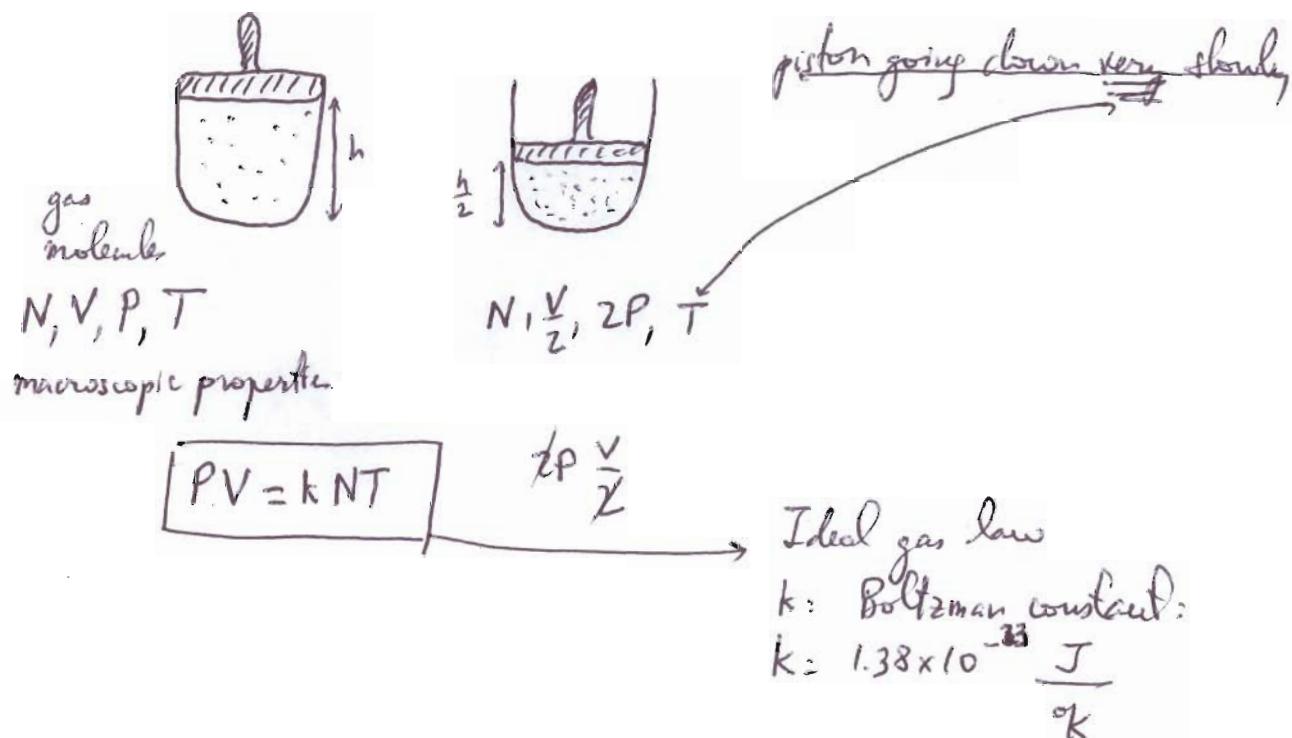
$N = n N_A$
$\downarrow$
# of moles

→ Avogadro number $= 6.022 \times 10^{23}$

$PV = kn N_A T$

$k N_A \equiv R = 8.314 \dfrac{J}{{}^{\circ}K \, mol}$

$\left. \begin{array}{c} \\ \end{array} \right\}$ $\boxed{PV = nRT}$

Free gas molecules

- When there is some interaction b/w gas molecules : "Real gas law"
or Van der Waals law : $\left(P + \dfrac{n^2 a}{V^2}\right)(V - nb) = nRT$

How are these macroscopic properties coming from microscopic properties?
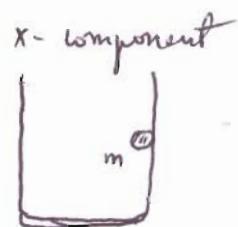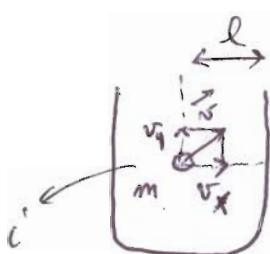
Conservation of momentum for this isolated system:

$$mv_x = -mv_x + \underbrace{2mv_x}_{\text{momentum received by wall}}$$

initial
system
↓
(gas molecule
&
wall)

$$P_i = \frac{F_i}{A} = \frac{\frac{\Delta p_i}{\Delta t}}{A} = \frac{\frac{2mv_{xi}}{\frac{2\ell}{v_{xi}}}}{A} = \frac{mv_{xi}^2}{\boxed{A\ell}} = \frac{mv_{xi}^2}{V}$$

↳ volume

Pressure
exerted
by
molecule i

Total pressure : $P = \sum_{i=1}^{N} P_i = \frac{mN}{V} \underbrace{\left(\frac{\sum_{i=1}^{N} v_{xi}^2}{N}\right)}_{\overline{v_x^2} \text{ (average of } v_x^2\text{)}}$

all molecules
have equal
mass m

Taking into consideration all velocity components. (3D)

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

↓
no preferred
direction

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

$$\longrightarrow P = \frac{mN}{V} \overline{v_x^2} = \frac{mN}{3V} \overline{v^2} \quad \rightarrow \quad \boxed{PV = mN\frac{\overline{v^2}}{3}} \ \& \ \boxed{PV = kNT}$$

$$kNT = m\cancel{N}\frac{\overline{v^2}}{3} \longrightarrow kT = \frac{1}{3}m\overline{v^2} \implies 3kT = m\overline{v^2}$$

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

Microscopic velocity $\longrightarrow$ macroscopic T

Thermal behavior of matter:

$$\Delta Q \begin{cases} 1) \ \Delta T \ \checkmark & (\Delta Q = cm\Delta T) \\ 2) \ \text{Change of phase} & \Delta Q = mL \\ 3) \ \text{Expansion} \ \Delta L \ \text{or} \ \Delta V \end{cases}$$

$\longrightarrow$ latent heat
transformation
L_f or L_v or L_s

$$\alpha \equiv \frac{\frac{\Delta L}{L}}{\Delta T} \quad ; \quad \beta = \frac{\frac{\Delta V}{V}}{\Delta T}$$

Change of phase:

25°

burner

$$\Delta Q = cm\Delta T$$

Temp. increase

burner   heat
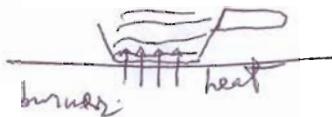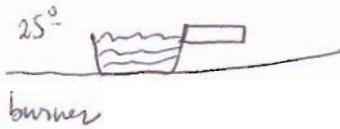
water starts to boil
during boiling $\Delta T = 0$
while heat is still being
supplied $\rightarrow$ this goes into
a phase change:
evaporation (breaking
water molecules loose into
gas)

$$\Delta Q = mL_v$$

Heat of vaporization

$$L_v(water) = 2257 \frac{kJ}{kg}$$

T = 0°C

ice cubes

T = 0°C

$$\Delta Q = m L_f$$

Heat of fusion

L_s

Solid $\longrightarrow$ liquid $\longrightarrow$ gas

Sublimation

L_f L_v

Phase diagram:

P

Solid

liquid

Triple point

gas

T

P

water

can melt the
ice faster by
pressing on it

(~ ice lower density
than water ('it floats!'))

Solid

liquid

gas

T
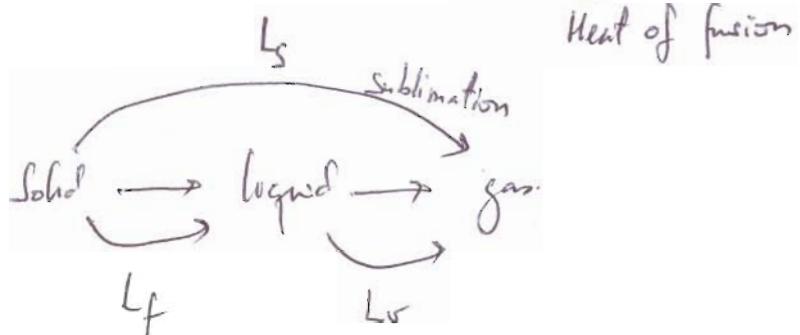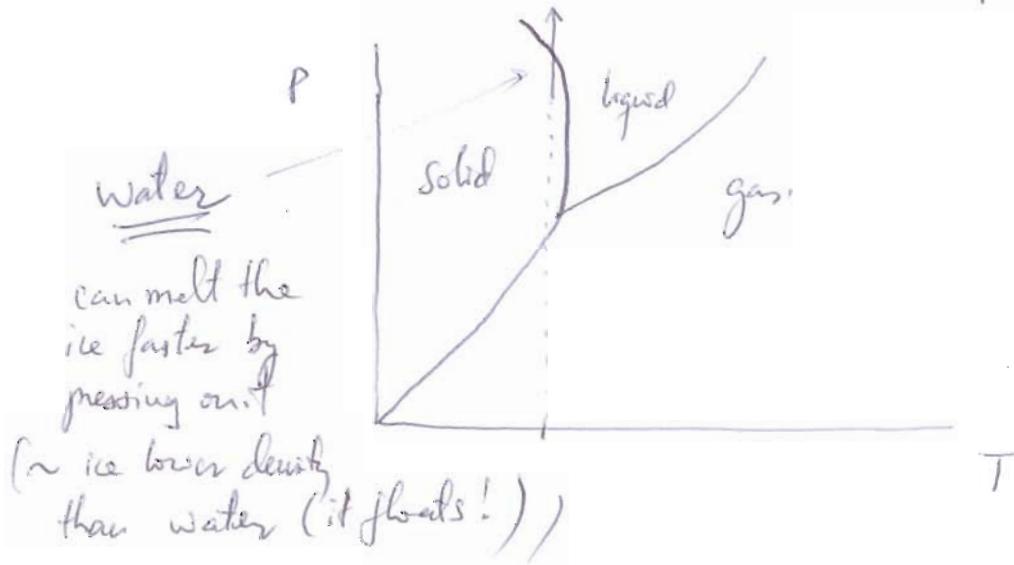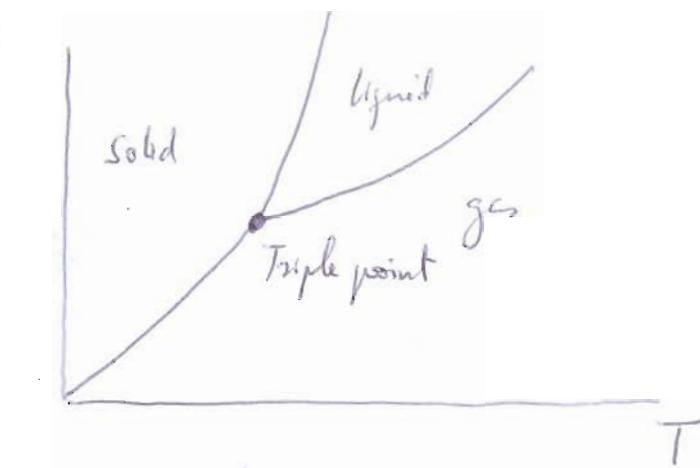
Ch. 21   Heat, Work, 1st Law of Thermodynamics

1st Law of Thermodynamics :

Heat absorbed (Q), work done by system $^{(W)}$, and the change of internal energy ΔU :

$$\Delta U = Q - W$$

$\begin{cases} \Delta U, T, P, V \text{ are } \underline{\underline{\text{state}}} \text{ variables } (\text{independent of a particular process}) \\ Q, W \qquad \text{are not } \underline{\text{state}} \text{ variables } (\text{dependent on the type process}) \end{cases}$
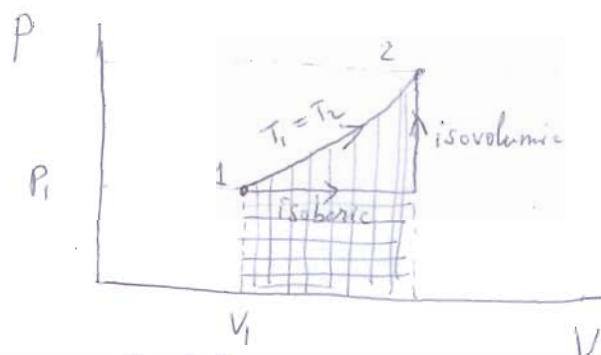
System at state 1 has (P_1, V_1, T_1); arrives at state 2 (P_2, V_2, T_2)

Work done is the area under the curve in a PV diagram.

$\begin{cases} 1 \to 2 \text{ via isothermal}: \quad W = \text{[diagram]} \\ \\ 1 \to 2 \text{ via isobaric + isovolumic}: \quad W = \text{[diagram]} \end{cases}$

Processes : $\begin{cases} \text{Reversible : if changes are made slowly} \\ \text{Irreversible : sudden changes} \end{cases}$ $\begin{cases} \text{Isothermal (at const. T)} \\ \text{Isovolumic} \\ \text{Isobaric} \\ \text{Adiabatic } (Q=0) \end{cases}$

Work done by system :

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

or $dW = P dV \rightarrow \boxed{W = \int dW = \int P dV}$ $\quad \underbrace{\Delta V}_{\to \text{ area under the curve in PV diagrams.}}$