

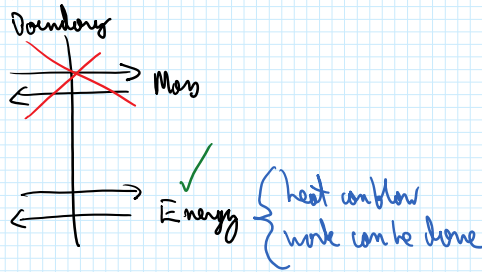
(Things highlighted should be on Formula Sheet)

### System

- part of world we want to analyze
- separated from environment by boundary

#### ① Closed System

- generally have fixed boundary
- not always (piston)



#### ② Control Volume (Open System)

- mass can flow through boundary
- boundaries can be real or imaginary

### Thermo Dynamic Properties

- microscopic numerical characterization of a system used in thermo

Intensive

vs

Extensive



Do not scale w/ size of system

(Temp, P)



vary and scale w/ size of system

(Mass, Volume)

Density  $\rho$ , Specific Volume  $v = \frac{V}{m} = \frac{1}{\rho} = \rho^{-1}$

Pressure,  $F/A$  exerted per unit area

Absolute vs Gauge Pressure



Total force  
value



Pressure relative to  
atmospheric pressure

### Ideal Gas Law

Pressure [Pa]

$Pv = RT$  ← Temp [K]

or  $PV = nRT$

↑  
Specific Volume  $\left[\frac{m^3}{kg}\right]$  constant which depends on gas

Cannot Apply Ideal Gas Law to liquids!!

- liquids / solids for the most part are considered incompressible
- temperature can lead to thermal expansion

## Thermodynamic State

- given properties of system
- usually if you are given 2 intensive properties the rest can be derived

## Thermodynamic Process

- when a thermodynamic state changes
- often associated w/ energy transfer (heat/work)

## Energy

Kinetic Energy:  $KE = \frac{1}{2}mv^2$

Potential Energy:  $PE = mgh$

## Internal Energy

- **Sensible** - KE of molecules, related to temperature } Microscopic Kinetic Energy
- **Latent** - associated with phase/state } Microscopic potential energy
- **Chemical** - associated with atomic bonds
- **Nuclear** - associated with bonds within an atom's nucleus

## Energy Interactions

- displacement work  $w = \int \vec{F} \cdot d\vec{s}$

- boundary work  $w = \int \vec{P} \cdot d\vec{V}$

- shaft work  $w = P_s = 2\pi NT$

### - Heat transfer

- between 2 systems due to temperature difference
- from hot to cold
- internal energy change

- Conduction - through an object
- convection - fluid motion triggered by temperature differences
- radiation - waves through space

## First Law of Thermodynamics

- Conservation of Energy

$$\Delta E = \Delta U + \Delta KE + \Delta PE = Q_{in} - W_{out}$$

$\uparrow$   
+Q is heat flow from environment to system

$\uparrow$   
Positive work is work done by the system

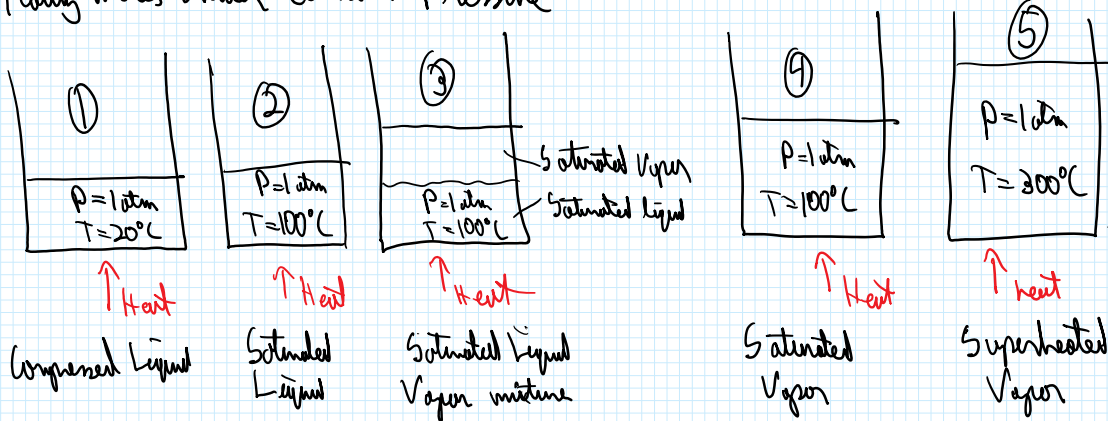
for a cycle

$$\Delta E = 0 \therefore Q_{in} = W_{out}$$

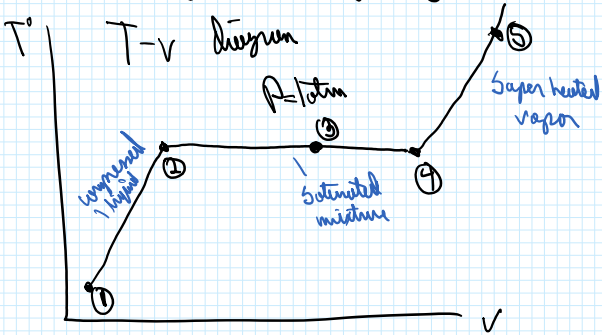
- in a cycle, net work done by atmosphere is 0

- Adiabatic (no heat transfer,  $Q=0 \therefore \Delta E = -w$ )

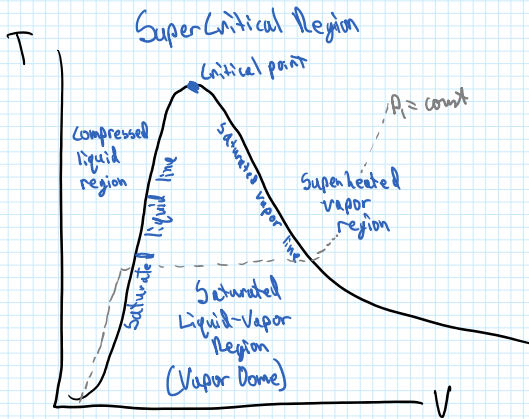
## Heating Water Under Constant Pressure



- Volume of liquid changes by 2/3 orders of magnitude after evaporation



## Vapor Dome (T-v diagram of many constant pressures)



## Mixing Under Vapor Dome

Quality  $x = \frac{m_{\text{vapor}}}{m_{\text{total}}}$

Thermo P properties from weighted average  $y_{\text{avg}} = x \cdot y_{\text{gas}} + (1-x) y_{\text{liquid}}$

## 5 steam tables

- can find properties given state and temp/pressure

-  $v_f \rightarrow$  liquid,  $v_g \rightarrow$  gas

\* Interpolate to find mid values

E mtholpg

$$H = u + Pv \text{ (KJ)}$$

$$h = u + Pv \text{ (KJ/kg)}$$

} Combs of internal energy, specific volume and pressure

$$h_{fg} = h_g - h_f$$

↑ heat of evaporation ← 0 at critical point

What do you need use ideal gas law ← Good at low P, High T, Low V

- use tables relating P, v, T (Steam Tables)
- quantify deviation from ideal gas law (Compressibility Factor)
- Van der Waals equation
- had w/ any sort of liquids, men critical point

Compressibility Factor

$$z = \frac{Pv}{RT}$$

{  $P_R = P/P_c$  ← find a value } together find z  
 $T_R = T/T_c$  ← find curve

Van Der Waals

$$\left(P + \frac{a}{v^2}\right)(v-b) = RT$$

↑ attractive forces    ↑ due to volume of particles

P-v-T Surface

- always on surface due to state equation
- path depends on process

Boundary Work and First Law

$$\Delta E = Q_{in} - W_{out} \quad W = \int PdV$$

- work done depends on paths

Equation of State vs. process Equation

← additional constraint that specifies the path on the P-v-T surface

$$Pv = RT$$

$$\left(P + \frac{a}{v^2}\right)(v-b) = RT$$

T = const (isothermal)

P = const (isobaric)

v = const (isochoric)

Pv^n = const (polytropic)

Work for Different Processes

isochoric,  $\Delta v = 0 \therefore W = 0$

isobaric  $W = \int PdV = P\Delta V$

isothermal  $W = P_1 V_1 \ln\left(\frac{V_2}{V_1}\right)$

isothermal  $W = P_1 V_1 \ln\left(\frac{V_2}{V_1}\right)$

Polytropic  $w = \frac{P_2 V_2 - P_1 V_1}{1-n}$

Not all work is useful  
- considers work done by atmosphere

in a full cycle, work done by atmosphere is 0

$W_{\text{useful}} = \int P dV - P_0 dV$   
atmospheric pressure

Specific Heat of Gas Depends on Process

$\Delta E = \Delta u = Q - w$

$Q = \Delta u + w$

Usually  $Q_p > Q_v$

Constant Volume Specific Heat

$C_v = \frac{Q}{m \Delta T} = \frac{\Delta u}{\Delta T} = \frac{du}{dT}$   
change in internal energy

For a monatomic gas,  $C_v = \frac{3}{2} R$   
 - goes up for more complex molecules by  $\frac{1}{2} R$  corresponding to extra degrees of freedom but depends on temp because degrees of freedom only active at certain temps

Constant Pressure Specific Heat

$Q = \Delta u + P \Delta V = \Delta(u + PV) = \Delta h = \frac{dh}{dT}$   
change in enthalpy

For an ideal gas  $h = u + Pv = u + RT$

$C_p = \frac{\Delta(u + RT)}{\Delta T} = \frac{\Delta u}{\Delta T} + R = C_v + R$

If Temperature Change is Small, can assume  $C_v/C_p$  is the same

If mol,  $\Delta u = u_2 - u_1$  } From table

$\Delta u = \int_1^2 C_v(T) dT$

Specific Heat - Ideal Gas, Polytropic

$C_{\text{poly}, n} = C_v + \frac{R}{1-n}$

} Can have whatever C you want if you pick the right n

