Thermodynamics Midterm 1 Review
Sigma Gamma Tau

Section 1:
Topics:

- Energy Balance
- Pv and Tv Diagrams

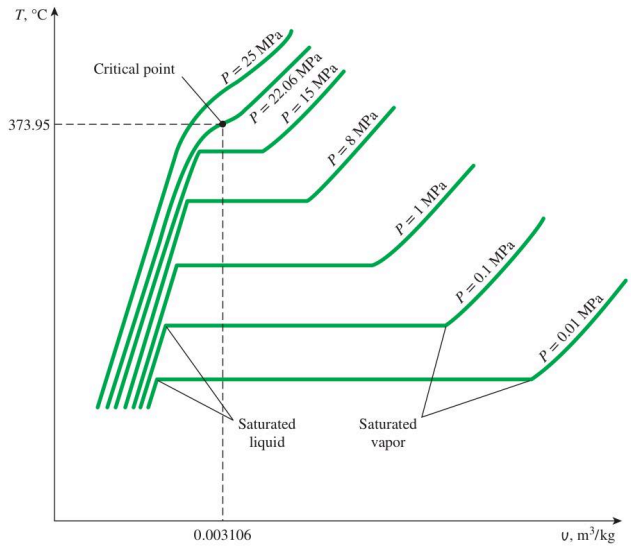
Equations:

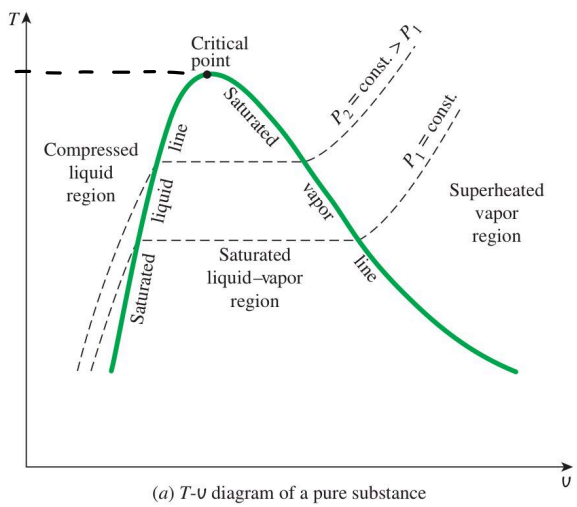
- $\upsilon = \frac{V}{m} = \frac{1}{\rho}$
  - ν: Specific Volume, V: Volume, m: Mass, ρ: Density
  - Remember that specific volume and density account for the same intensive property.
- Force Equilibrium for Pressure: $\sum F = 0 = P_1 + \sum \Delta P = P_2$
  - Note that the units here allow for cross sectional area to cancel out, so the equation becomes only a function of height as a distance.
  - $\Delta P = \rho \Delta h g$, or density times change in height times acceleration due to gravity.
  - Pick a starting point, moving down is a positive ΔP and vice versa.
- Energy: e = u + ke + pe
  - u: specific internal energy, ke: specific kinetic energy, pe: specific potential energy
  - For a fixed, closed system KE = PE
- Mass Flow: $m' = \rho A V$
  - $m' = mass\ flow$
- Specific pressure energy: $e = P\nu$
- Energy Balance: $\Delta E_{sys} = \Delta E_{in} - \Delta E_{out} = \Delta U + \Delta KE + \Delta PE$
  - Stationary System: $\Delta E_{in} - \Delta E_{out} = \Delta U$
  - Primary Form: $\Delta E_{sys} = (Q_{in} - Q_{out}) + (W_{in} - W_{out}) + (E_{mass,in} - E_{mass,in})$
  - $\Delta U = m\Delta u$
  - Constant pressure: $W_b + \Delta U = (P_1 v_1 + U_1) - (P_2 v_2 + U_2) = \Delta H$
  - Mass dependent Δ can be rewritten as $m\Delta$: i.e. $\Delta U = m\Delta u$

Concepts:

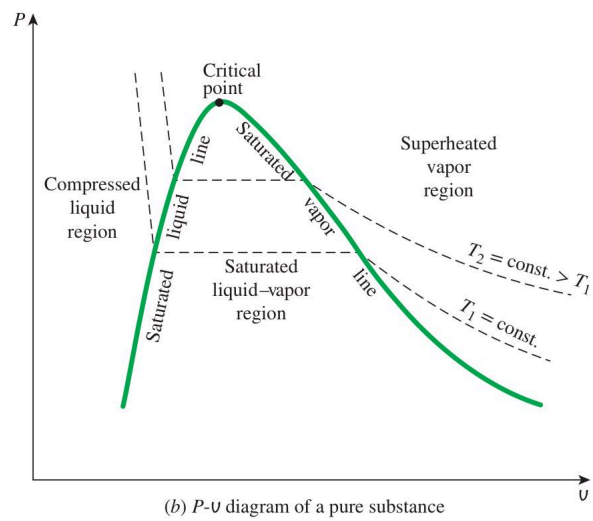
- Intensive properties: Independent of mass (Temperature, Pressure, Density, Specific values)
- Extensive properties: Dependant on mass (Mass, Volume, total Energy)

- State Postulate: A state of a system can be completely defined by TWO INDEPENDENT, INTENSIVE PROPERTIES
- Adiabatic: Isentropic and Reversible; No heat transfer across a boundary.
- Stationary System: KE = PE
- <u>PV and TV Diagrams:</u>





(*a*) *T*-*v* diagram of a pure substance



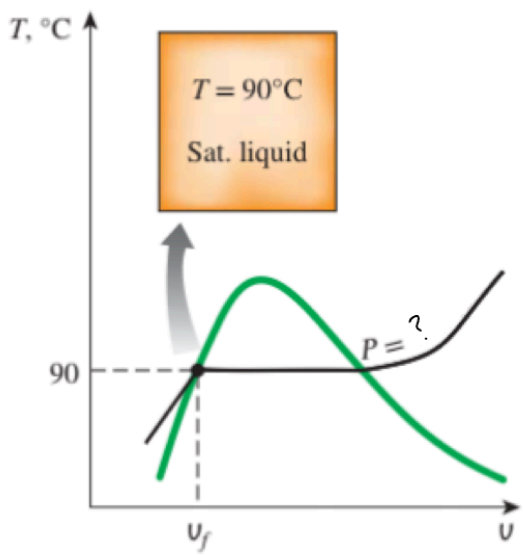
(*b*) *P*-*v* diagram of a pure substance

- Critical Point - Point at which the saturated liquid and saturated vapor states are identical.
    - Values associated with the critical point (Pcr, Tcr, vcr) can be found using your thermo tables
- Superheated Vapor - Substance where its temperature has exceeded the critical temperature (T > Tcr)
- Compressed Liquid - Substance where its temperature is below the critical temperature (T < Tcr)
- Following the Ideal Gas Law, Tsat $\propto$ Psat

- When P > Pcr - There is no distinct phase change & no mixture

Practice Problem 1:
A chip in a circuit radiates heat at 50 KJ/min. Additionally two fans blow cool air over the circuit, each cooling at a rate of 45W. If the temperature of the circuit rose enough to have a total energy change in the system of 15W, how much heat is the rest of the circuit radiating. Give your answer in J/s. [ANS: 21.67]

Practice Problem 2:
A rigid tank contains 50 kg of saturated liquid water at 90 degrees Celsius. Determine the pressure in the tank and the volume of the tank. [ANS: 70.183 kPa; 0.0518 m^3]



$Q_{in} = 50\ kJ/min + x = 83.33\ J/s + x$

$Q_{out} = 2(45)W = 90W$

$\Delta U = 15W$

$$(Q_{in} - Q_{out}) + (\cancel{W_{in}}^{\,0} - \cancel{W_{out}}^{\,0}) = \Delta U + \cancel{\Delta KE}^{\,0} + \cancel{\Delta PE}^{\,0}$$

$$83.33 + x - 90 = 15$$

$$x = 21.67W = 21.67\ J/s$$

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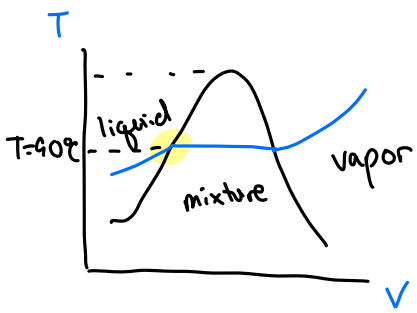
2) Given: $m = 50\ kg$ Find: P & V

$T = 90°C$

Saturated liquid



$P = P_{sat\ @\ 90°C} = 70.183\ kPa$ (Table A-4)

$v = v_{f\ @\ 90°C} = 1.036 \times 10^{-3}\ \frac{m^3}{kg}$ (Table A-4)

$V = mv = (50)(1.036 \times 10^{-3})$

$V = 0.0518\ m^3$

Section 2:

- Liquid, Saturated, and Vapor States
- Reading Thermodynamic Tables

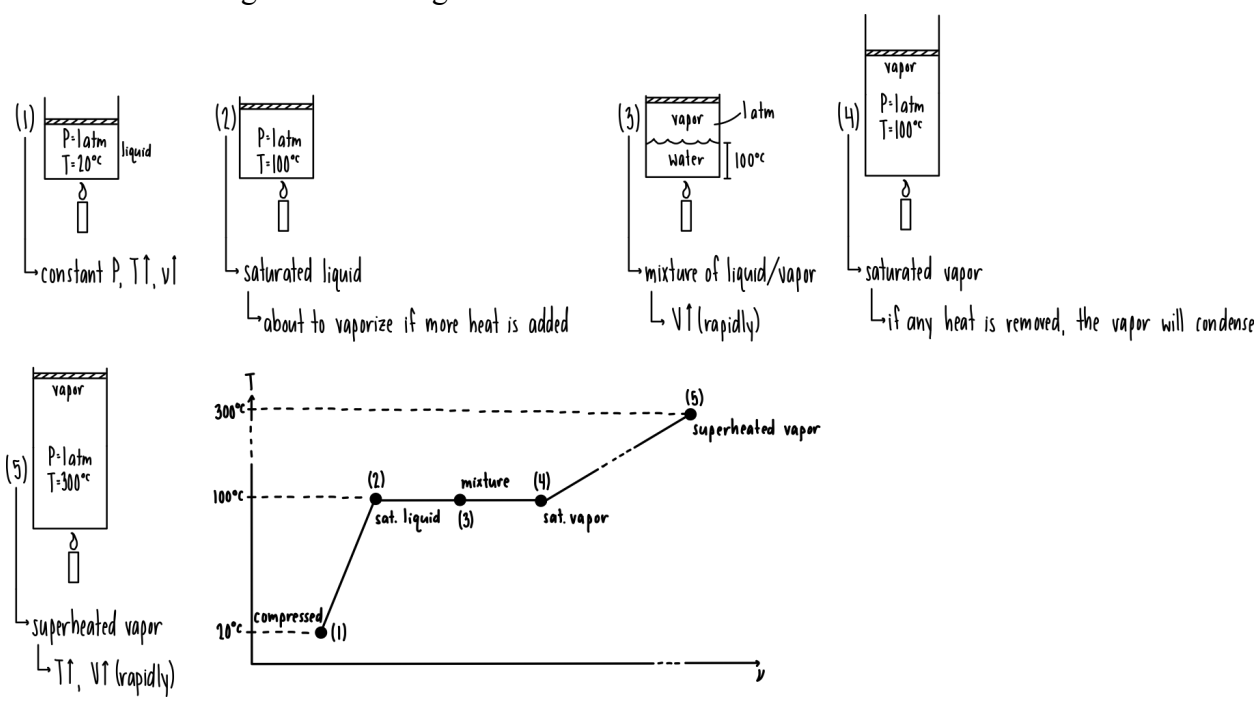
Chapter 3: Properties of a Pure Substance

<u>3.1: Pure Substance</u>

- *Pure substance*: fixed (homogeneous) chemical composition throughout
- 3 phases: solid, liquid, and vapor
    - *Latent energy:* amount of energy absorbed or released during a phase-change process.
        - There is no increase in temperature during a phase change.

<u>3.3: Phase-change Processes of Pure Substances</u>

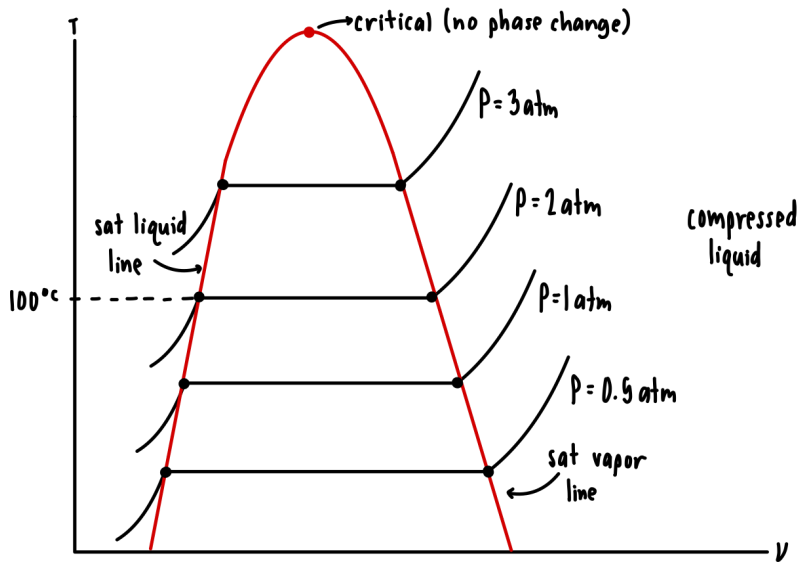
- *Compressed liquid*: a liquid that is not about to vaporize.
- *Saturated liquid*: a liquid about to vaporize.
- *Saturated liquid-vapor mixture*: the liquid and vapor phases coexist in equilibrium.
- *Saturated vapor*: a vapor about to condense.
- *Superheated vapor*: a vapor not about to condense.
- *Saturation temperature (T_{sat})*: the temperature at which a pure substance changes phase.
- *Saturation pressure (P_{sat})*: the pressure at which a pure substance changes phase.
- Phase change of water diagrams:

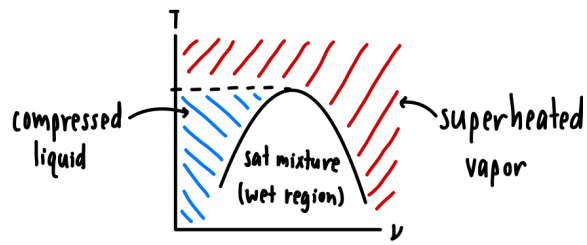


<u>3.4: Property Diagrams for Phase-Change Processes</u>

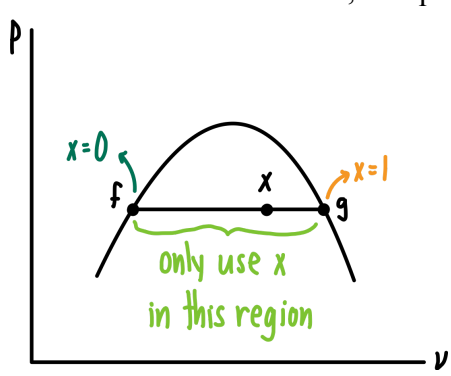
- T-v diagrams
    -

- P-v diagrams
  -
- *Critical point:* Point at which the saturated liquid and saturated vapor lines are the same.
  - $P>P_{cr}$: There is no distinct phase change, no mixture, and only one phase exists.
  - $T>T_{cr}$: Superheated vapor.
  - $T<T_{cr}$: Compressed liquid.
    - P_{cr}, T_{cr}, and v_{cr} are in Table A-1 for various substances.





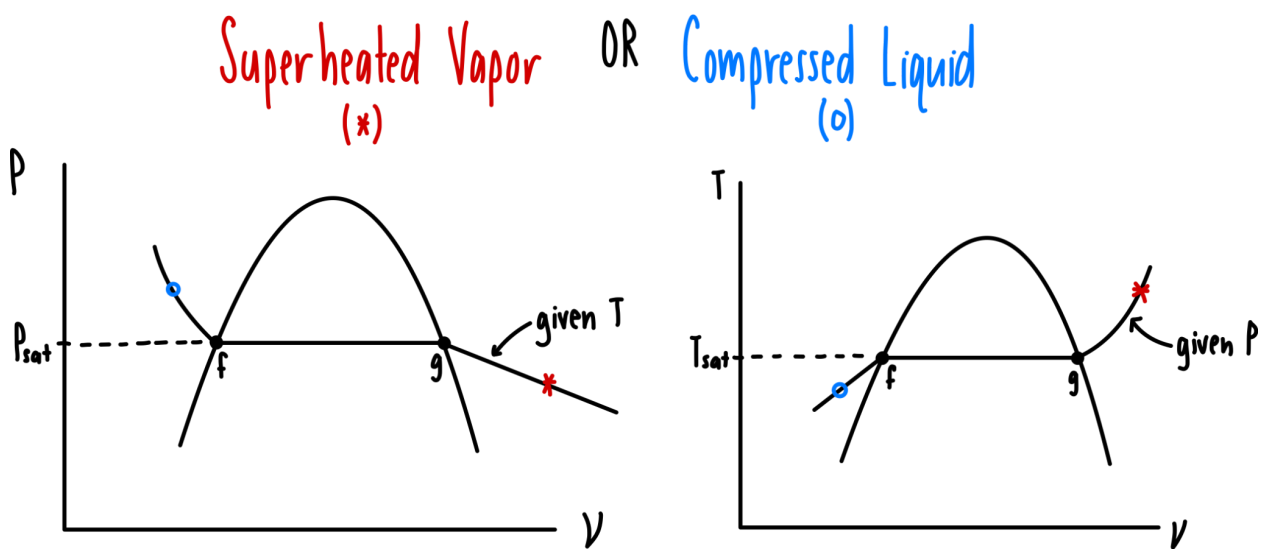
<u>3.5: Property Tables</u>

- Quality of a Mixture
  - $x = \frac{m_{vapor}}{m_{total}}$
    - x=0 means no vapor → saturated liquid
    - x=1 means 100% vapor → saturated vapor
    - For unsaturated conditions, the quality *x* is meaningless.
    - 

  - Total volume: $V_{total} = V_{fluid} + V_{gas}$
  - Total mass: $m_{total} = m_{fluid} + m_{gas}$

- Average specific volume $v_{avg} = v_f + x(v_g - v_f) = v_f + xv_{fg}$
    - Find specific volume values in the saturated water tables (A4 and A5)
- Average internal energy $u_{avg} = u_f + xu_{fg}$

- How to tell if it's a superheated vapor or a compressed liquid?
    - For a superheated vapor:
        - For a given T, $P<P_{sat}$
        - For a given P, $T>T_{sat}$
        - $(\boldsymbol{v},u,h)>(\boldsymbol{v},u,h)_g$
            - Use Table A-6
    - For a compressed liquid:
        - For a given T, $P>P_{sat}$
        - For a given P, $T<T_{sat}$
        - $(\boldsymbol{v},u,h)<(\boldsymbol{v},u,h)_f$
            - Use Table A-7, but if there is no data use Table A-4. The liquid properties do not change much with pressure.



<u>3.6: The Ideal-Gas Equation of State</u>

- Ideal gas equation of state: $Pv = RT$
- Relate two different states with $\frac{P_1 v_1}{T_1} = \frac{P_2 v_2}{T_2}$
- Water vapor can be approximated as an ideal gas at pressures below 10 kPa

Practice Problem 2 (Example 3-5):

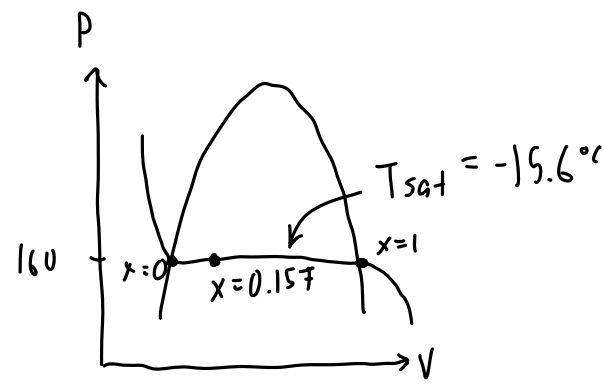
An 80-L vessel contains 4 kg of refrigerant-134a at a pressure of 160 kPa. Determine (a) the temperature, (b) the quality, (c) the enthalpy of the refrigerant, and (d) the volume occupied by the vapor phase

$$V = 80L \cdot \left(0.001 \frac{m^3}{L}\right) = 0.080 m^3$$

$$m = 4 kg$$

$$P = 160 kPa$$

$$v = \frac{V}{m} = \frac{0.080 m^3}{4 kg} = 0.02 \frac{m^3}{kg}$$



(a) Table A-12 @ $P = 160 kPa$

$$v_f = 0.0007435 \frac{m^3}{kg}$$

$$v_g = 0.12355 \frac{m^3}{kg}$$

$v_f < v < v_g \rightarrow$ saturated mixture

$$T_{sat}(P = 160 kPa) = -15.60°C$$

(b) $v = v_f + x(v_g - v_f) \rightarrow x = \frac{v - v_f}{v_g - v_f} = \frac{0.02 - 0.0007435}{0.12355 - 0.0007435} = 0.157$

(c) Table A-12 @ $P = 160 kPa$

$$h_f = 31.18 \frac{kJ}{kg}$$

$$h_{fg} = 209.96 \frac{kJ}{kg}$$

$$h = h_f + x h_{fg} = 31.18 \frac{kJ}{kg} + 0.157\left(209.96 \frac{kJ}{kg}\right) = 64.1 \frac{kJ}{kg}$$

(d) $x = \frac{m_{vapor}}{m_{total}} \rightarrow m_{vapor} = x m_{tot} = 0.157(4kg) = 0.628\ kg$

$$V_g = m_g v_g = (0.628kg)\left(0.12355 \frac{m^3}{kg}\right) = 0.0766 m^3$$

Section 3:

- Work and Power
- Piston-Cylinder

Chapter 4: Energy Analysis of a Closed System

<u>4.1: Moving Boundary Work</u>

- *Moving Boundary Work (or Boundary Work)* - work done by expansion or compression, often done in a piston-cylinder device.
    - Think of a car engine!
    - Also commonly called *PdV work*
- *Quasi-equilibrium Process* - A system that is close to being at equilibrium at all times.
    - This is important for boundary work problems involving engines since they are not actually in equilibrium.
- Differential work done on the boundary:

$$\delta W_b = PdV$$

- Boundary work is positive during an expansion process and negative for a compression process:
- Total work done on the boundary:

$$W_b = \int_1^2 PdV$$

    - This allows for the area under the curve of a P-V diagram to be used to find the magnitude of the total work. During quasi-equilibrium expansion or compression of a closed system.
- Generalized boundary work relation:

$$W_b = \int_1^2 P_i dV$$

<u>4.2: Energy Balance for Closed Systems</u>

- Energy Balance for Any System Undergoing a Process:

$$E_{in} - E_{out} = \Delta E_{system}$$

- The rate form of the energy balance for any system undergoing a process uses an E dot instead.
- For a closed system undergoing a cycle, with identical initial and final end states, the change in energy of the system is zero.
- Energy Balance for Closed System:

$$Q_{net,in} - W_{net,out} = \Delta E_{system}$$

$$Q_{net,in} = Q_{in} - Q_{out}$$

$$W_{net,out} = W_{out} - W_{in}$$

- Heat is assumed to be transferred into the system and work is assumed to be done by the system traditionally.

4.3: Specific Heats

- *Specific Heat* - The energy required to raise the temperature of a unit mass of a substance by one degree.
- Two kinds of specific heats:
  - *Specific Heat at Constant Volume*

$$c_v = \left(\frac{\partial u}{\partial T}\right)_V$$

  - *Specific Heat at Constant Pressure*

$$c_p = \left(\frac{\partial h}{\partial T}\right)_P$$

  - These equations are property relations and are independent of the type of process.

4.4: Internal Energy Enthalpy, and Specific Heats of Ideal Gases

- The change in internal energy for an ideal gas from state 1 to 2:

$$\Delta u = u_2 - u_1 = \int_1^2 c_v(T)dT$$

- The change in ~~internal energy~~ enthalpy for an ideal gas from state 1 to 2:

$$\Delta h = h_2 - h_1 = \int_1^2 c_P(T)dT$$

- With the assumption that the variation of specific heat function is small over a temperature interval, the above equations become:

$$u_2 - u_1 = c_{v,avg}(T_2 - T_1)$$
$$h_2 - h_1 = c_{p,avg}(T_2 - T_1)$$

$$C_{v,avg} = \frac{C_{v,1} + C_{v,2}}{2}$$

- Gas Constant Relation:

$$c_p = c_v + R$$

- Specific Heat Ratio:

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

4.5: Internal Energy Enthalpy, and Specific Heats of Solids and Liquids

- For incompressible substances (liquids and solids):

$$c_p = c_v = c$$

$$\Delta u = \int_1^2 c(T)dT \simeq c_{avg}(T_2 - T_1)$$

$$\Delta h = \Delta u + V\Delta P$$

Practice Problem 3

Boundary Work for a Constant-Volume Process

A rigid tank contains air at 500 kPa and 1508C. As a result of heat transfer to the surroundings, the temperature and pressure inside the tank drop to 658C and 400 kPa, respectively. Determine the boundary work done during this process.

$V =$

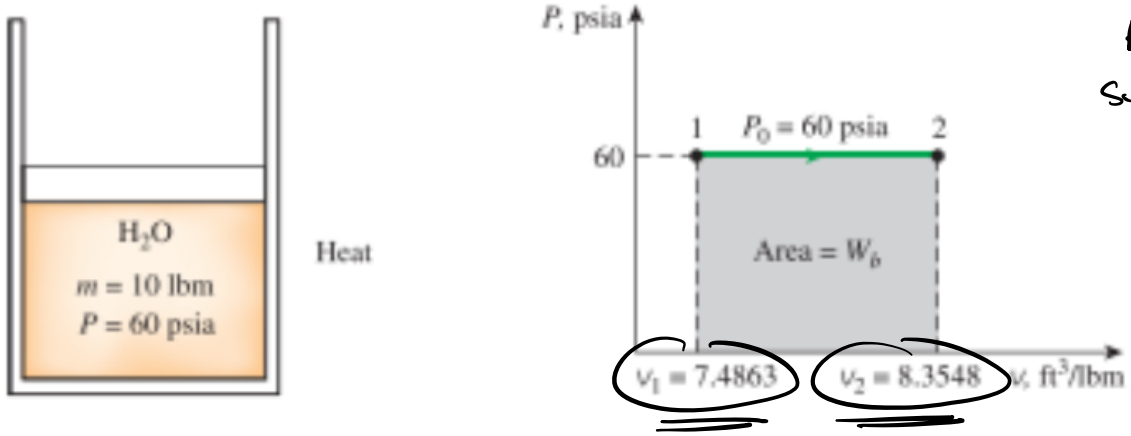
$w = P(\cancel{V_2 - V_1})^{0}$

$\underline{w = 0}$

Practice Problem 4

Boundary Work for a Constant-Pressure Process

A frictionless piston–cylinder device contains 10 lbm of steam at 60 psia and 320°F. Heat is now transferred to the steam until the temperature reaches 400°F. If the piston is not attached to a shaft and its mass is constant, determine the work done by the steam during this process.



A-6
superheated vapor

$$w = P(v_2 - v_1)$$

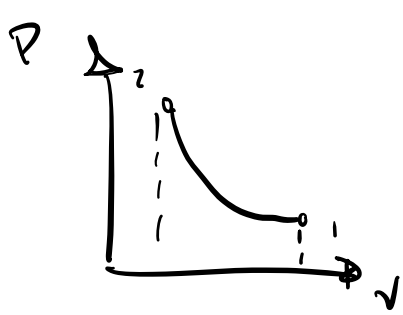
$$w_b = mP(v_2 - v_1)$$

$$V = mv$$

$$(10)(60)(8.3548 - 7.4863)\left(\frac{1\ \text{Btu}}{5.404\ \text{psia}\cdot\text{ft}^3}\right)$$

$$w_b = 96.4\ \text{Btu}$$

isothermal → No change in temperature



$$w_b = PV\ln\left(\frac{V_2}{V_1}\right)$$

Work/Energy

SGT Review

2/14/2024

First Law of Thermodynamics (4.2)

From energy balance,

$$E_{in} - E_{out} = \Delta E_{sys}$$

$$\dot{E}_{in} - \dot{E}_{out} = \Delta \dot{E}_{sys}$$

$$E_{in} = E_{out} + \Delta E_{sys}$$

Consider the components of each energy:

$$\Delta E_{sys} = \cancel{KE}^{0} + \cancel{PE}^{0} + \underline{IE} = \Delta U$$

$$E_{in} = Q$$

$$E_{out} = W$$

Comments on the First Law

$Q = \Delta U + W$ $\qquad$ $q = \Delta u + w$

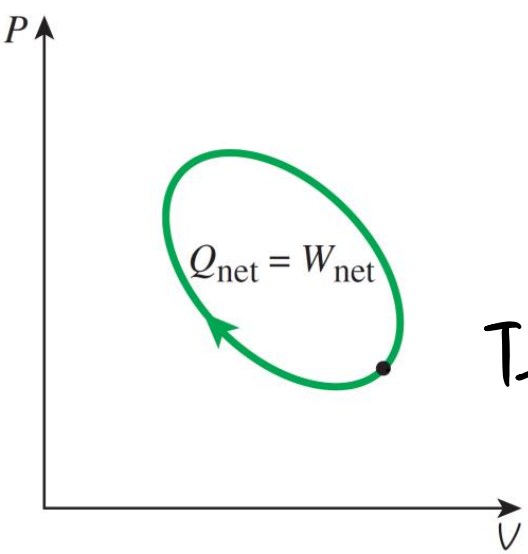
$\delta q = du + \delta w$

Reference Kinetic Theory of Gases if necessary

$du \longrightarrow$ internal energy $\propto$ k_B moles

$u \propto$ Temp $\Longleftrightarrow$ $u(T)$

$\Delta u = \frac{3}{2} k_B \Delta T$



$T_i = T_f$ $\qquad$ $\Delta u = 0$

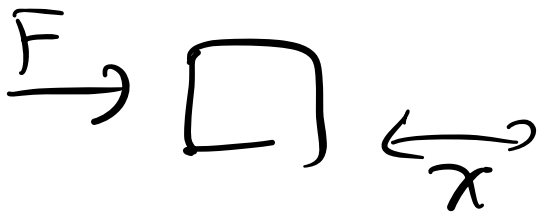
$Q = \cancel{\Delta u}^{\,0} + w$

FIGURE 4–11
For a cycle $\Delta E = 0$, thus $Q = W$.

Definition of Work (4.1)

From physics, the definition of work is

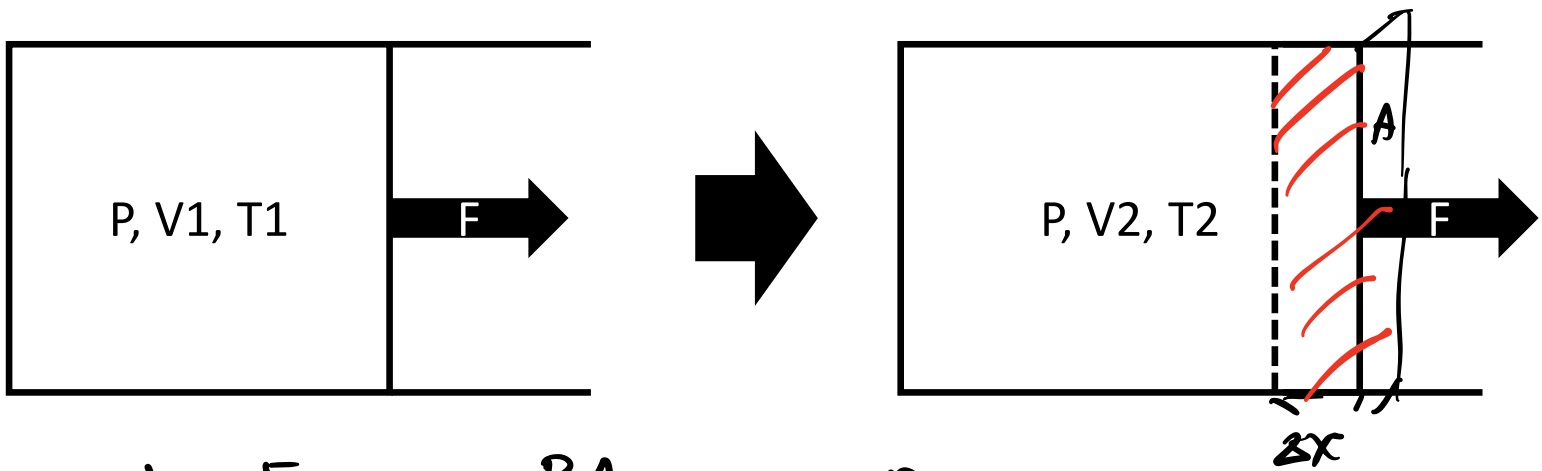
$$W = Fx$$



$$W = \mathbb{F} \cdot \mathbb{x}$$

Definition of Work in Thermo

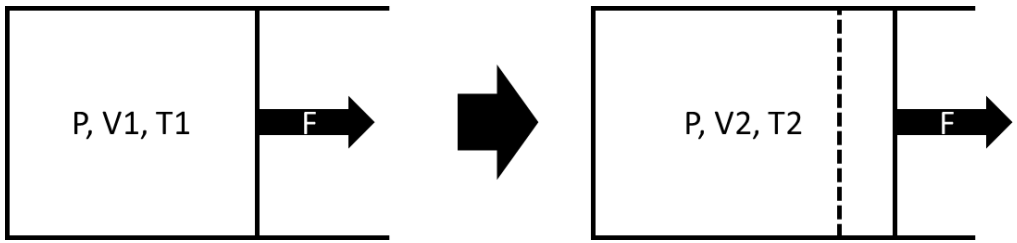
Consider a following piston with constant pressure expansion, ΞP

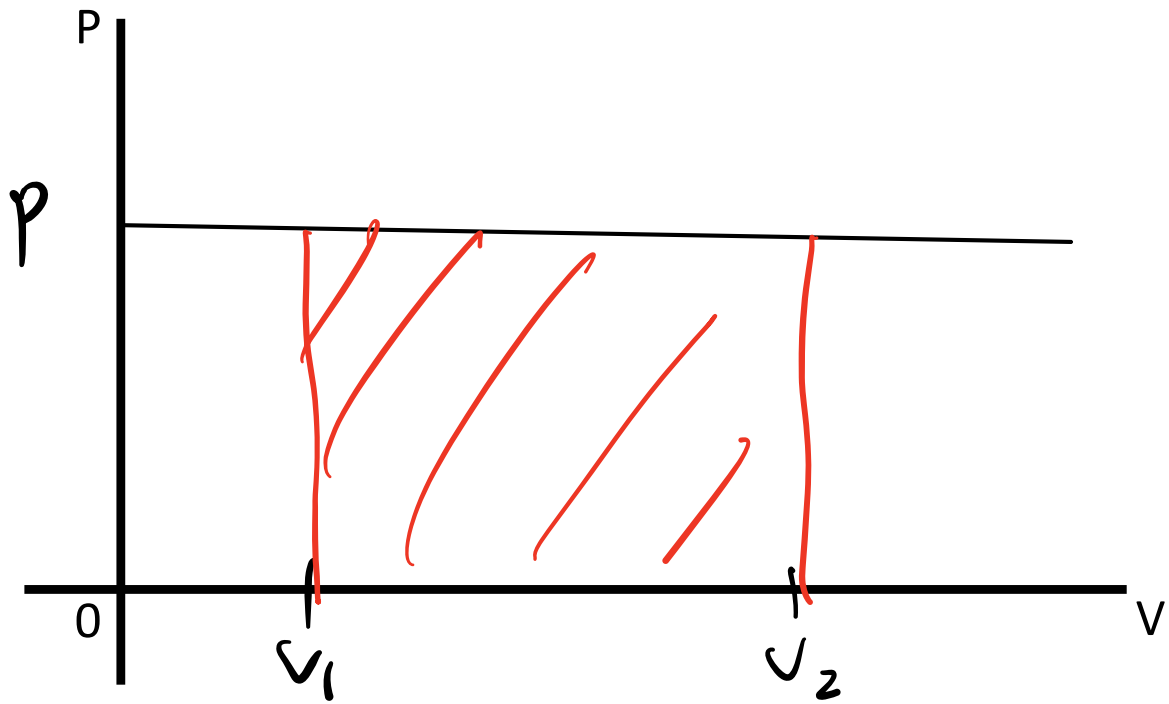


$$W = F\Delta x = P\underbrace{A\Delta x} = P\Delta V = P(V_2 - V_1)$$

Definition of Work in Thermo

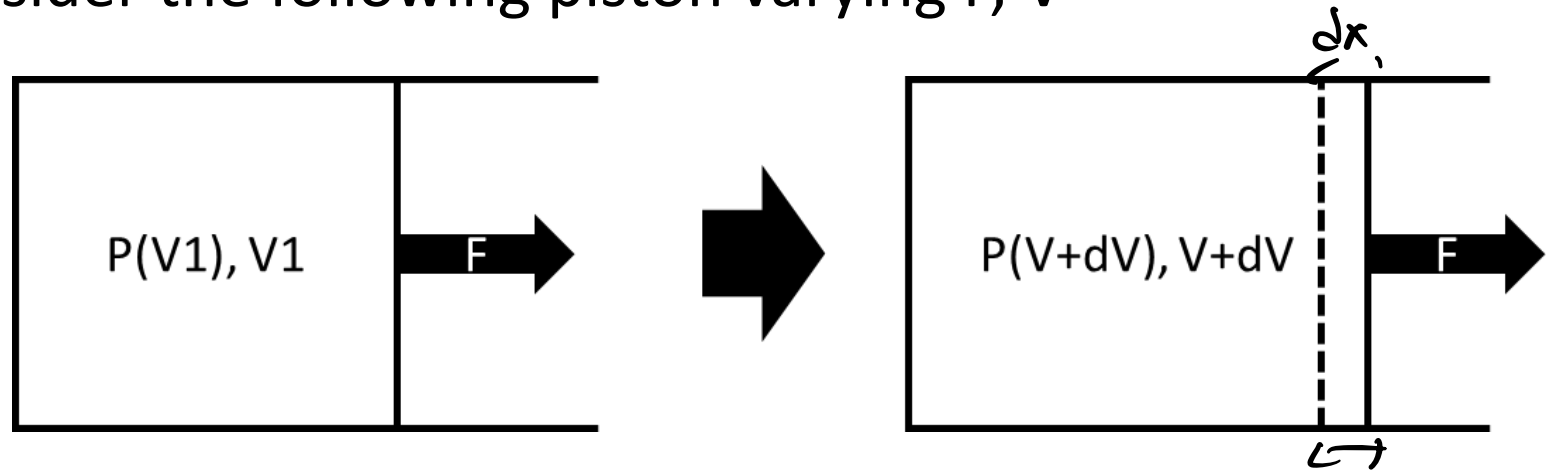
Consider a following piston with constant pressure expansion, ΞP





Definition of Work in Thermo

Consider the following piston varying P, V

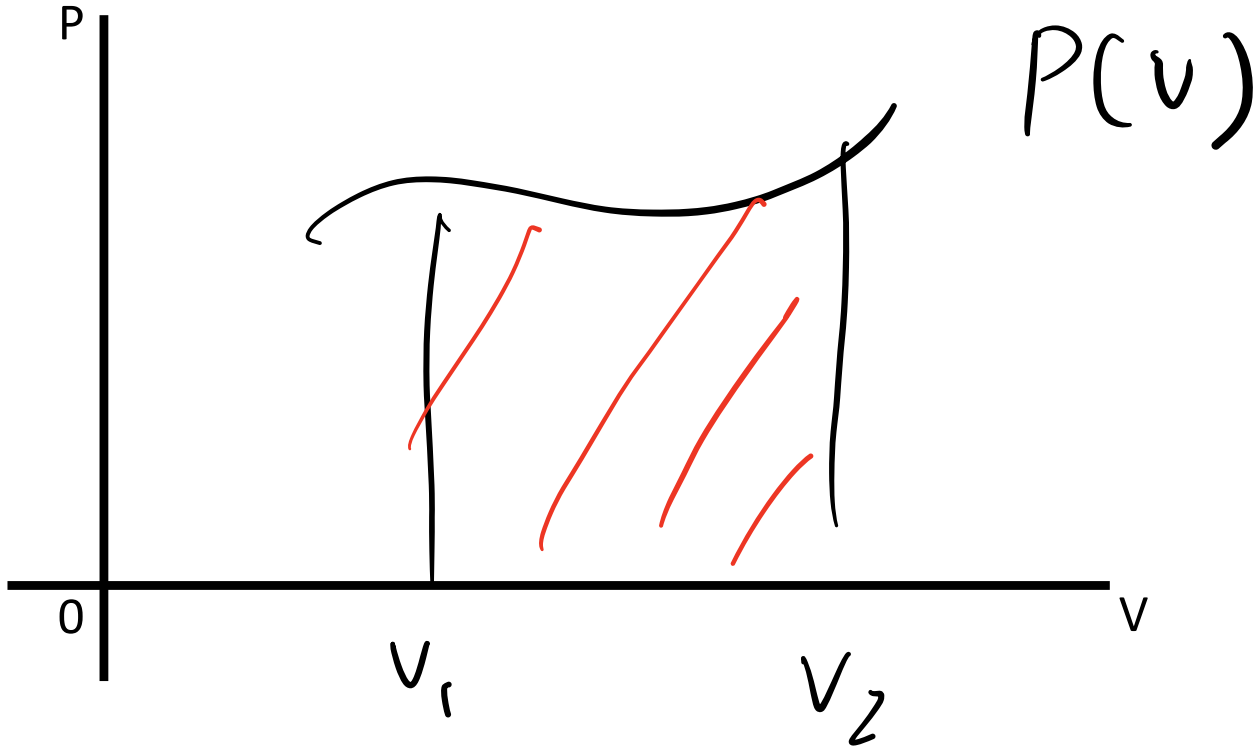


$$\delta W = \underline{A}P\,\underline{dx} = P\,dV$$

$$\int_{W_1}^{W_2} \delta W = \int_{V_1}^{V_2} P\,dV$$

$$W = \int_{V_1}^{V_2} P\,dV$$

Definition of Work in Thermo



Definition of Work in Thermo

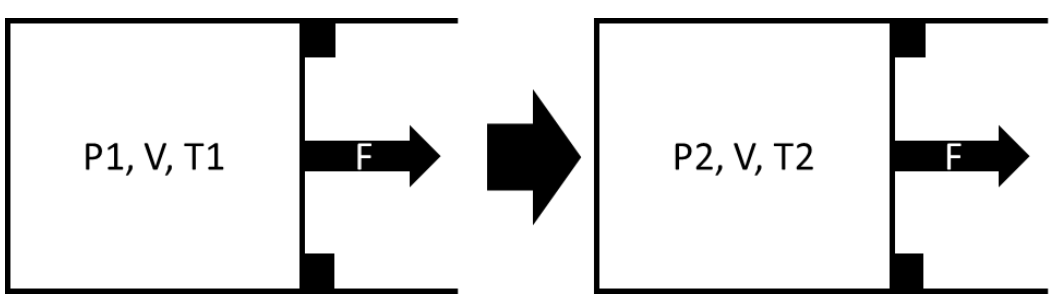
Looking back at a constant pressure piston,

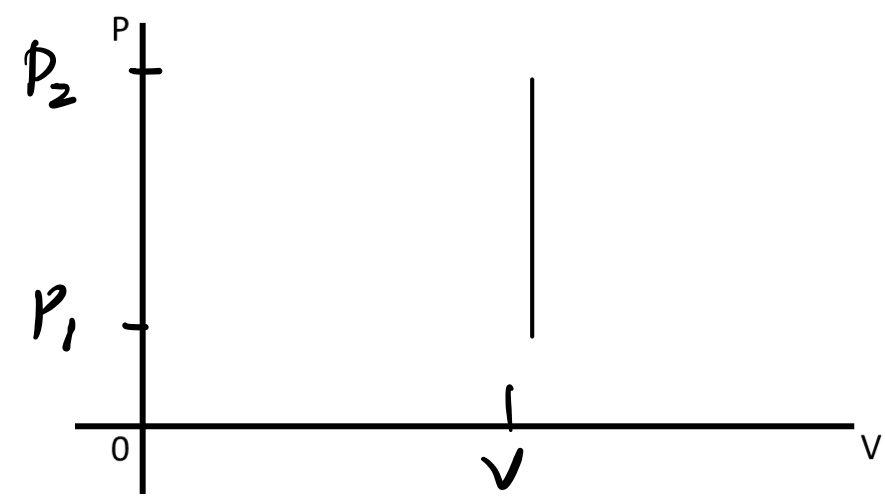
$$W = \int_{V_1}^{V_2} P\,dV = P\int_{V_1}^{V_2} dV = P(V_2 - V_1)$$

For a constant volume process

$x = 0$

$W = 0$





Definition of Work in Thermo

Constant Temperature process?

$$W = \int_{V_1}^{V_2} p \, dV \qquad p = \frac{RT}{V}$$

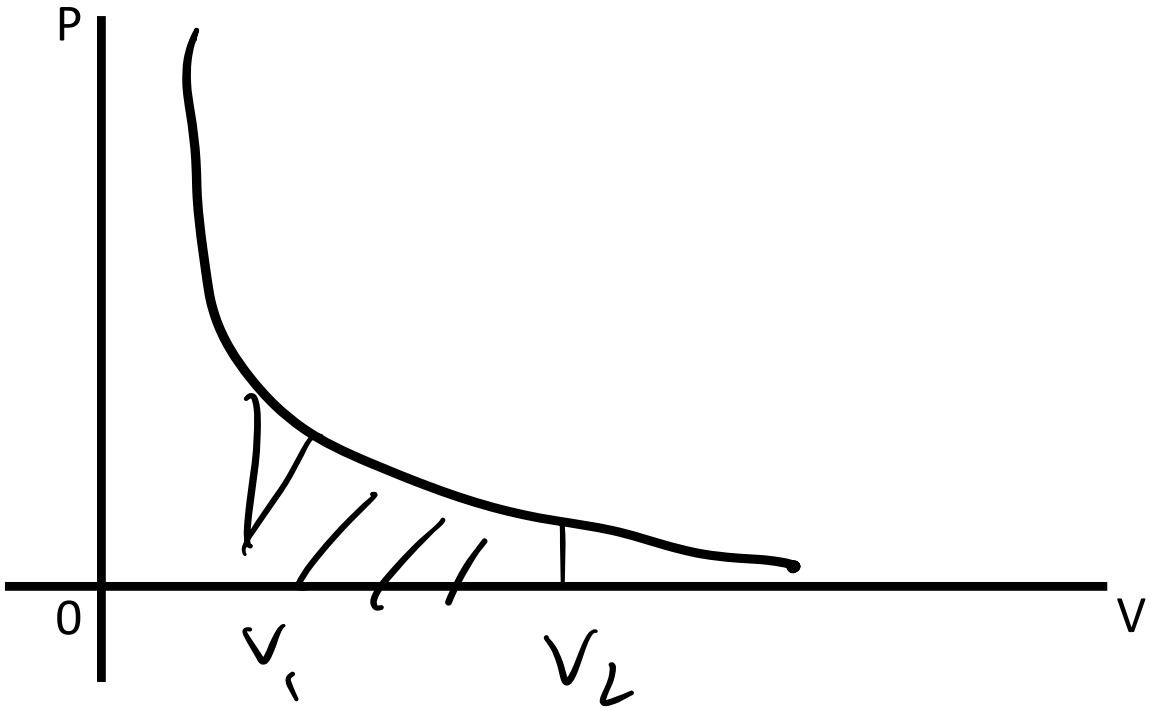
$$= \int_{V_1}^{V_2} RT \frac{dV}{V} = RT \int_{V_1}^{V_2} \frac{dV}{V}$$

$$= RT \left(\ln(V_2) - \ln(V_1) \right)$$

$$RT \ln(V_2/V_1)$$

Definition of Work in Thermo

$y = \frac{1}{x}$

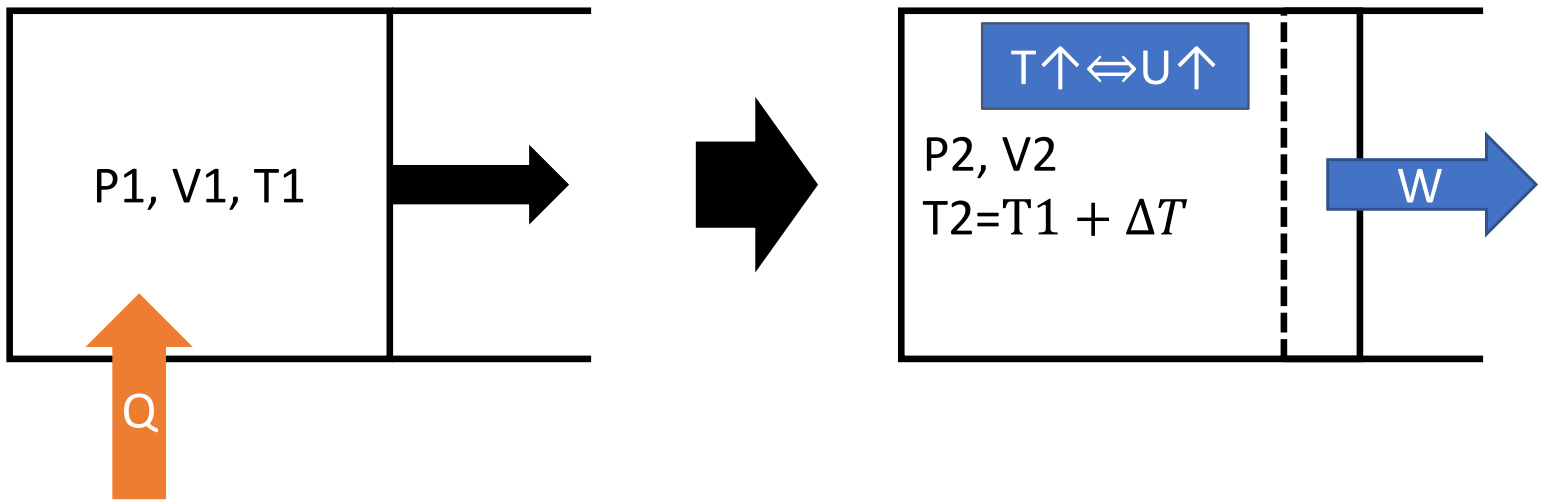


Polytropic process: $P \cdot V^n = C$

$$P = \int \frac{C}{V^n} \, dV$$

$n = -1$

Definition of Work in Thermo



Path dependency and independency (state quantity)

Q , W , ΔU

Specific Heats (4.3)

Define C (J/kgK)

req. energy (J) to inc 1K, 1kg

For Constant Volume Process

$$q_v = C_v \Delta T$$

$$q_v = \cancel{w}^{0} + \Delta u$$

$$q_v = \Delta u$$

$$\Delta u = C_v \Delta T$$

Specific Heats (4.3)

Define enthalpy, H $(\mathrm{kg} \cdot m^2/s^{-2})$

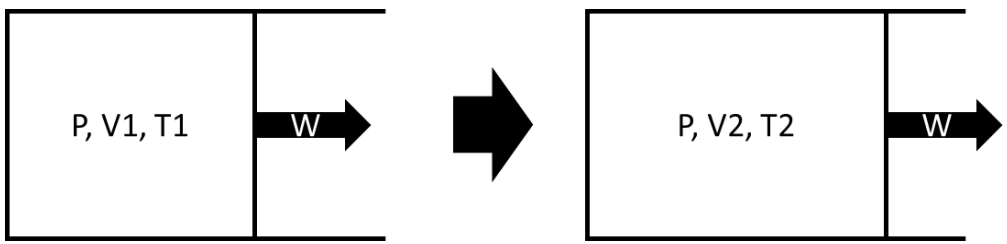
$$H = U + PV$$

$$h = u + pv$$

$$q_p = c_p \Delta T$$

For Constant Pressure Process

$$\Delta h = c_p \Delta T$$



$$h_1 = u_1 + pv_1 \qquad h_2 = u_2 + pv_2$$

$$\Delta h = \Delta u + p(v_2 - v_1)$$

$$= \Delta u + \underbrace{p\Delta v}_{w} = \Delta u + w = q$$

Specific Heats (4.3)

Cv Relationship

$$\Delta u = c_v \Delta T$$

$$c_v = \frac{\Delta u}{\Delta T} \xrightarrow[\Delta \to 0]{\lim} \frac{\partial u}{\partial T}$$

Cp Relationship

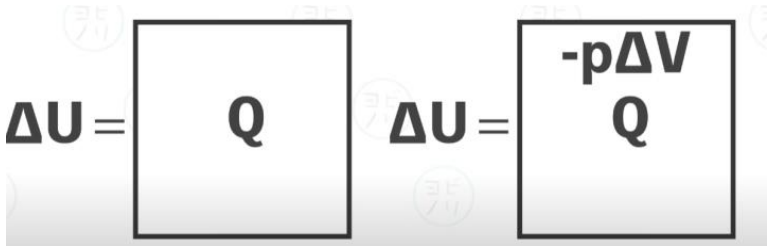
$$\Delta h = c_p \Delta T$$

$$c_p = \frac{\partial h}{\partial T}$$

Note on the path independency;

Comments on Specific Heats (4.4)

Finding Δu and Δh using specific heat

Mayer's relation:

Cv (720 J/kgK) vs Cp (1008 J/kgK). Why is cp larger?