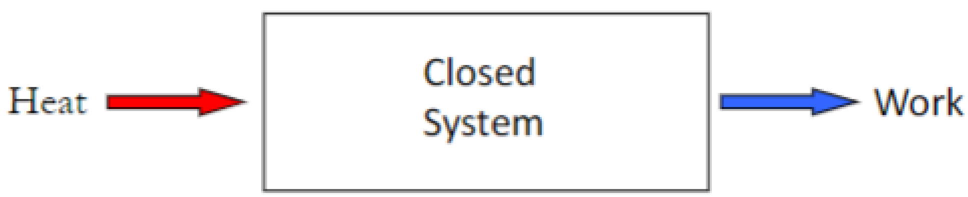
XIV: The First Law

1: First Law of thermodynamics

1.1: Definition

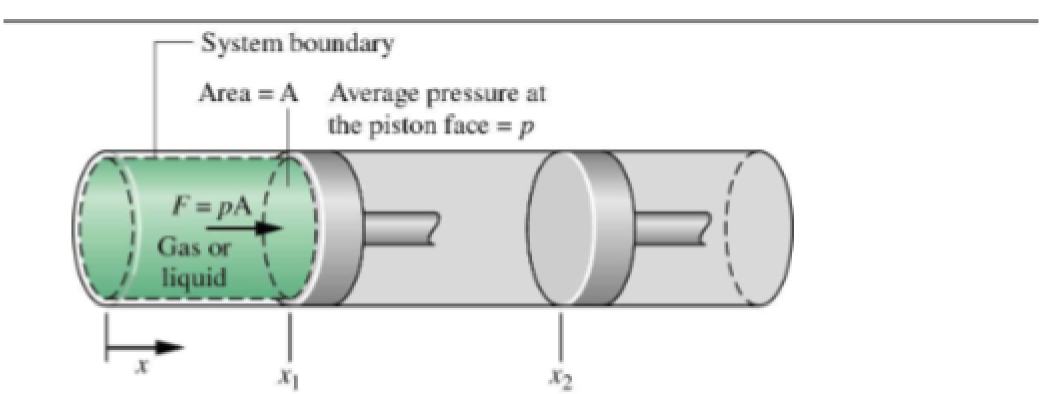
- Usually referred as the Law of Conservation of Energy: **Energy cannot be created or destroyed, but can be transformed from one state to another**.

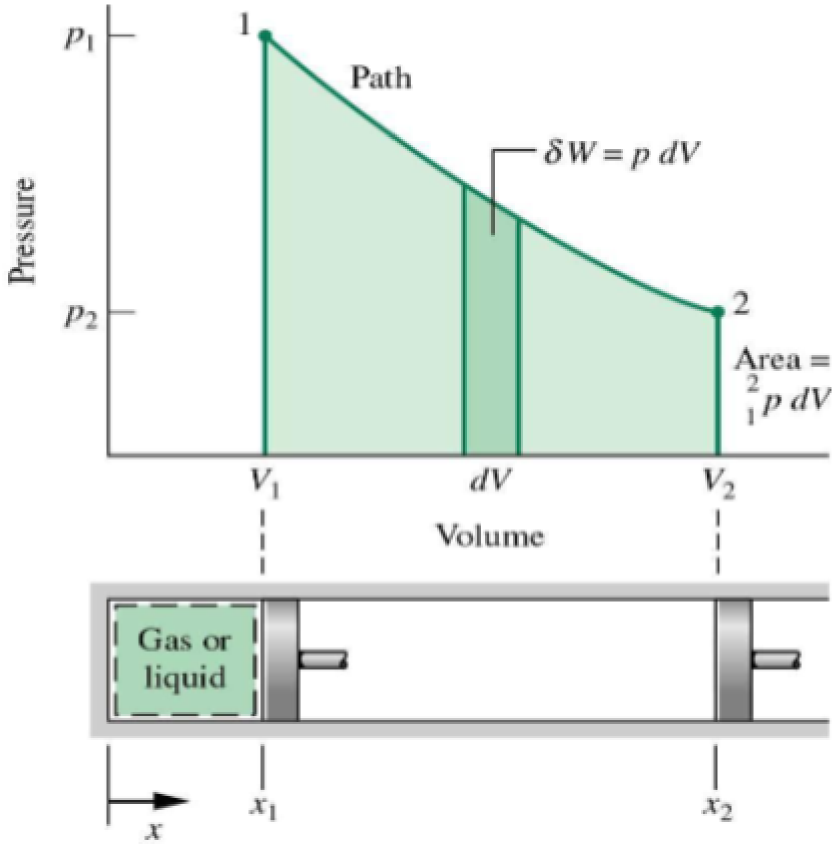
1.2: Balance for a closed system

- 

- $\Delta E = Q - W$ or $\Delta E = Q + W$
- $\Delta E = Q - W$, which is used for sign convention of Clausius.
- $E = U + KE + PE$
- $Q - W = \Delta U$
- We use specific terms(per unit mass):
  $q - w = \Delta u$

1.3: Work for a closed system

- 

- Total work for the sum of all the little changes.
  $\int_1^2 pdV$
- 

1.4: Enthalpy,H

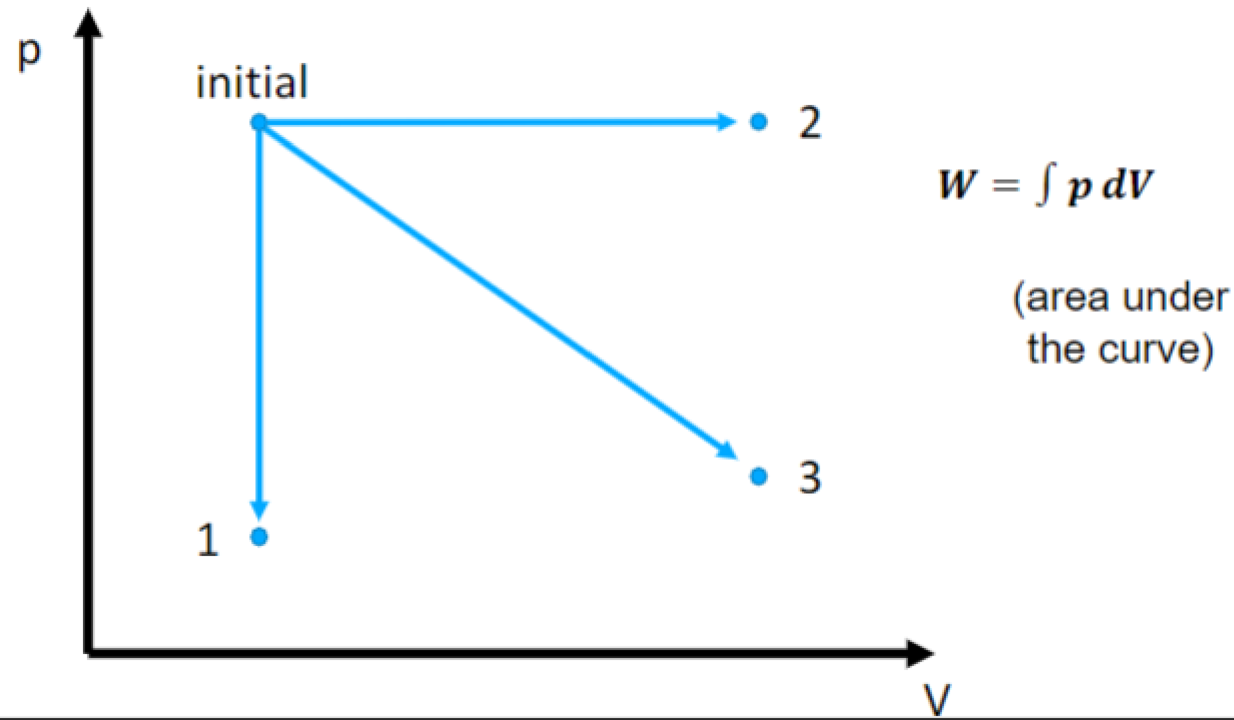
- $H = U + PV$, where U is internal energy and PV is work of the fluid.
- It we marks the q as the heat of a reaction:
  $\Delta H = q$
- Note it is under the constant pressure conditions.

1.3: Specific heat capacity

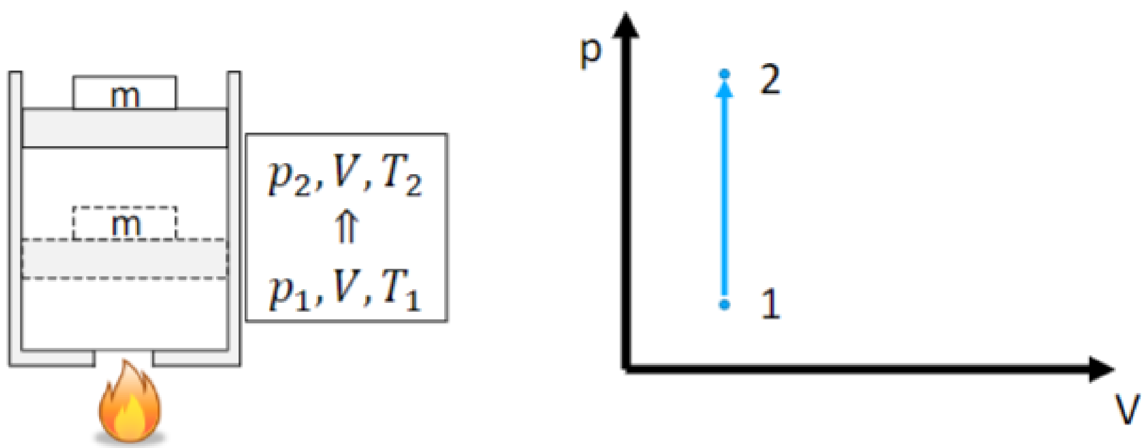
- $Q = cm\Delta T$ or $q = c\Delta T$
- For ideal gases at constant volume: $\Delta U = c_v m\Delta T$
- Use the ideal gas law, $p\Delta V = mR\Delta T$
- Then, $Q = mc_v\Delta T + mR\Delta T$
- So we can find the specific heat capacity in constant pressure: $c_p = c_v + R = \dfrac{\Delta h}{\Delta T}$
- $H = U_pV$ and $h = u + pv$

2: Polytropic processes

2.1: Boundary work

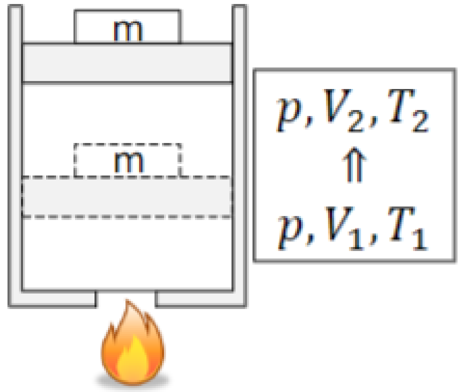
- 

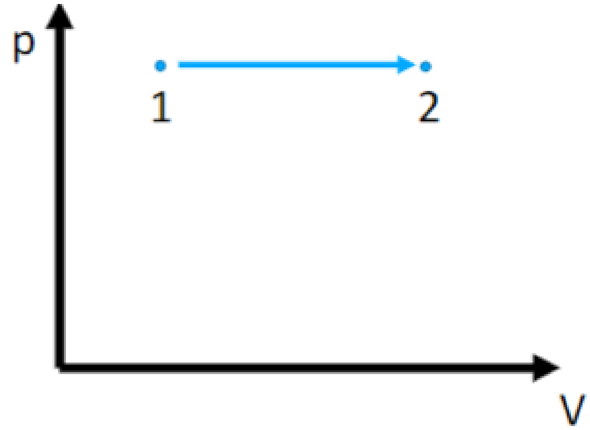
2.2: Isochoric process (V=constant)

- 

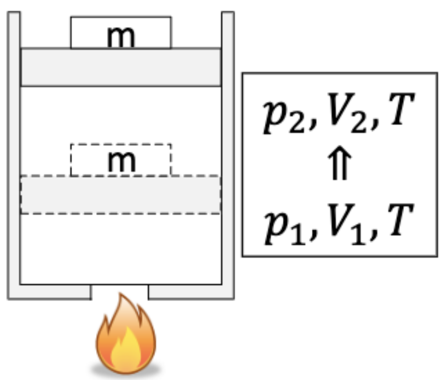
- Work done $W_{12} = \int_{V_1}^{V_2} p\, dV = 0$
- Heat transfer $Q = \Delta U = mc_v \Delta T$
- For gases with constant c_v $Q = mc_v(T_2 - T_1)$

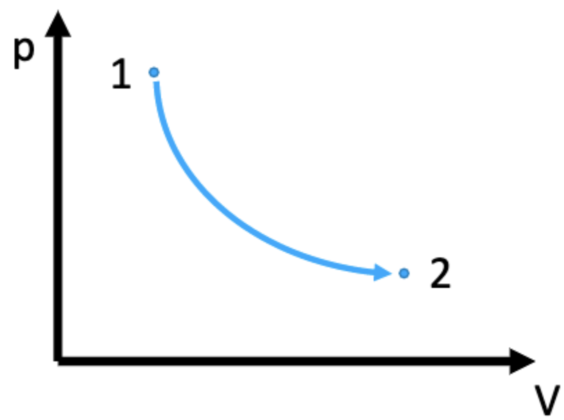
2.3: Isobaric process (P=constant)

- 



  - Work done $\quad W_{12} = \int_{V_1}^{V_2} p\, dV = p(V_2 - V_1)$
  - Change in internal energy $\quad \Delta U = mc_v \Delta T$
  - Heat transfer $\quad Q = mc_p \Delta T$

- 



  - Work done $\quad W_{12} = \int_{V_1}^{V_2} p\, dV$
  - For an ideal gas $\quad pV = nR_0T$

$$W_{12} = \int_{V_1}^{V_2} \frac{nR_0T}{V} dV = nR_0T \int_{V_1}^{V_2} \frac{1}{V} dV = nR_0T \ln \frac{V_2}{V_1}$$

2.4: Isothermal process (T=constant)

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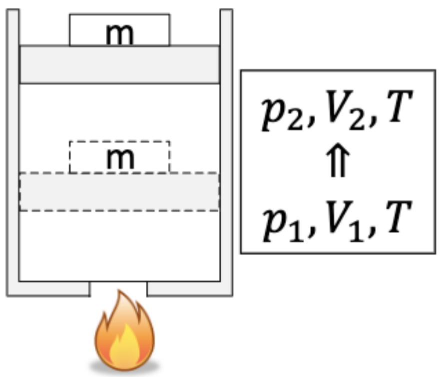
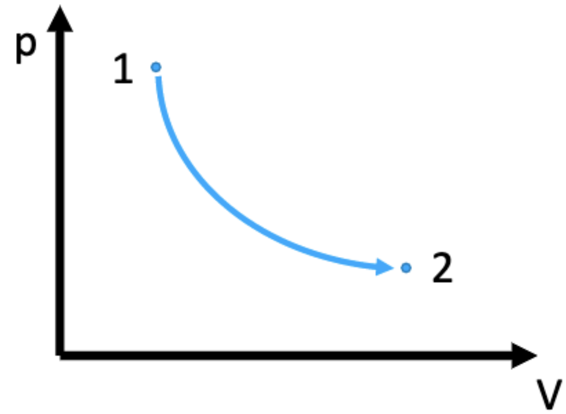
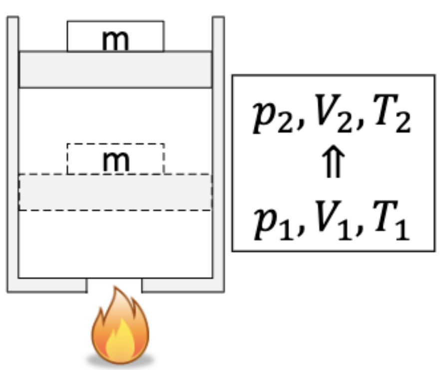


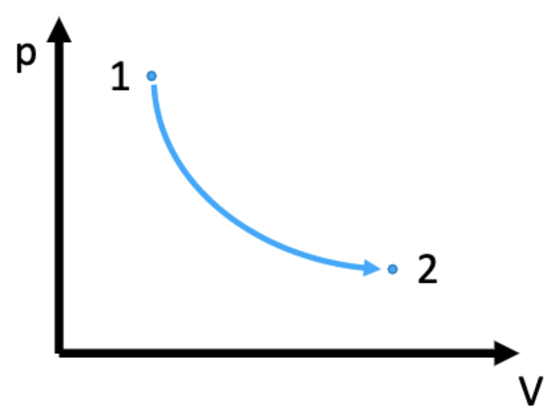


- Work done $\quad W_{12} = \int_{V_1}^{V_2} p\, dV$
- For an ideal gas $\quad pV = nR_0T$

$$W_{12} = \int_{V_1}^{V_2} \frac{nR_0T}{V} dV = nR_0T \int_{V_1}^{V_2} \frac{1}{V} dV = nR_0T \, ln \frac{V_2}{V_1}$$

2.5: Polytropic process (multiple process)





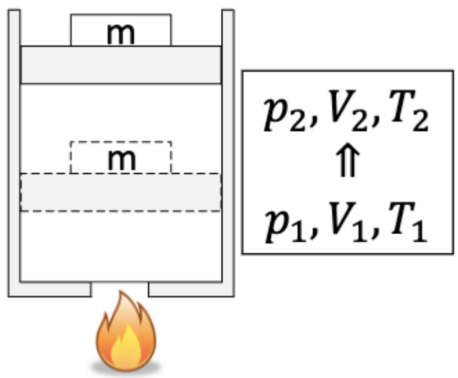
- Many real processes follow $\quad pV^n = \text{const}$
- Equivalent to $\quad pv^n = \text{const}$
- Or using the ideal gas law

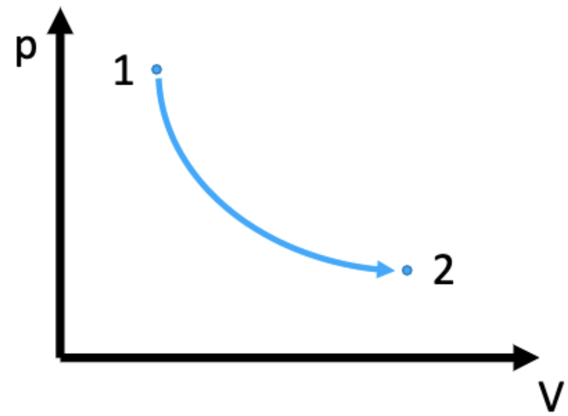
$$TV^{n-1} = const \qquad pT^{-n/(n-1)} = const$$

- Work done (using $\boldsymbol{pV^n = \alpha}$)

$$W_{12} = \int_{V_1}^{V_2} p\,dV = \alpha \int_{V_1}^{V_2} V^{-n}\,dV = \alpha \left[\frac{V^{-n+1}}{1-n}\right]_{V_1}^{V_2} = \frac{p_2 V_2 - p_1 V_1}{1-n}$$

2.6: Isentropic process (entropy process)

- 



  - Adiabatic means no heat crosses the system boundary
  - An adiabatic process that is reversible is called isentropic
  - Special case of a polytropic process where

$$n = \gamma = \frac{c_p}{c_v} \qquad \text{(note } \gamma = 1.4 \text{ for air)}$$

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  - Adiabatic means

$$Q_{12} = 0$$

  - From polytropic work (with $\boldsymbol{n = \gamma}$)

$$W_{12} = \frac{p_2 V_2 - p_1 V_1}{1-\gamma}$$

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Value of n	Process	Description	Result of IGL
∞	isochoric	constant volume ($V_1 = V_2$)	$\frac{p_1}{T_1} = \frac{p_2}{T_2}$
0	isobaric	constant pressure ($p_1 = p_2$)	$\frac{V_1}{T_1} = \frac{V_2}{T_2}$
1	isothermal	constant temperature ($T_1 = T_2$)	$p_1 V_1 = p_2 V_2$
$1 < n < \gamma$	polytropic	-none-	$\frac{p_1}{p_2} = \left(\frac{V_2}{V_1}\right)^n = \left(\frac{T_1}{T_2}\right)^{\frac{n}{n-1}}$
γ	isentropic	constant entropy ($S_1 = S_2$) adiabatic & reversible	

2.7: Polytropic work

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Process	Boundary Work
isochoric	$W_{12} = p(V_2 - V_1) = 0$
isobaric	$W_{12} = p(V_2 - V_1)$
isothermal	$W_{12} = RT \ln \frac{V_2}{V_1}$
polytropic	$W_{12} = \frac{p_2 V_2 - p_1 V_1}{1-n}$
isentropic	