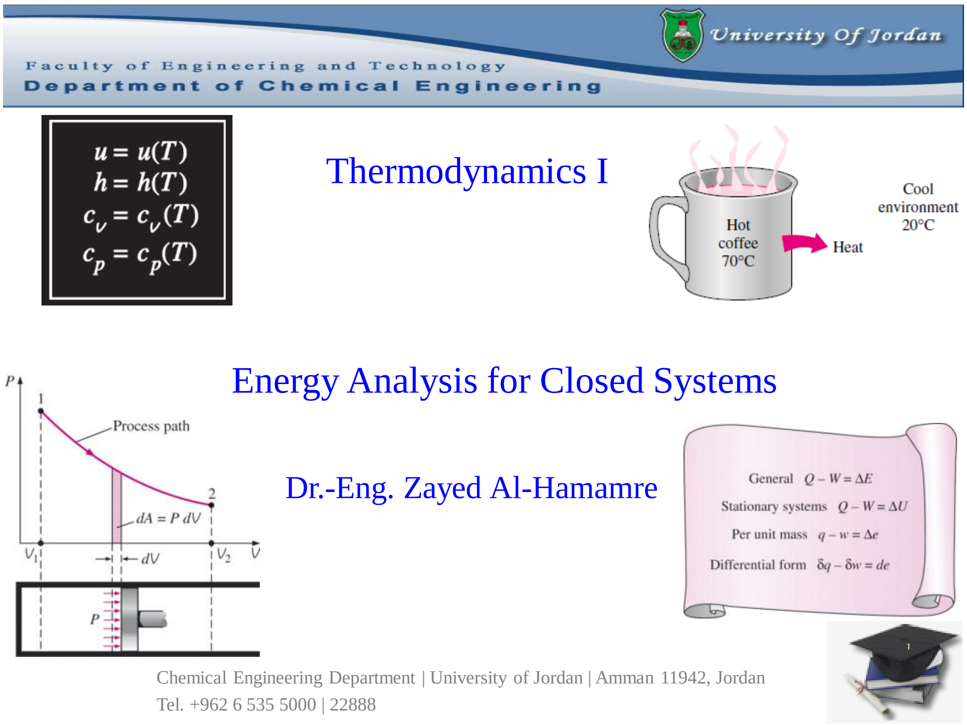


Faculty of Engineering and Technology
Department of Chemical Engineering
University Of Jordan

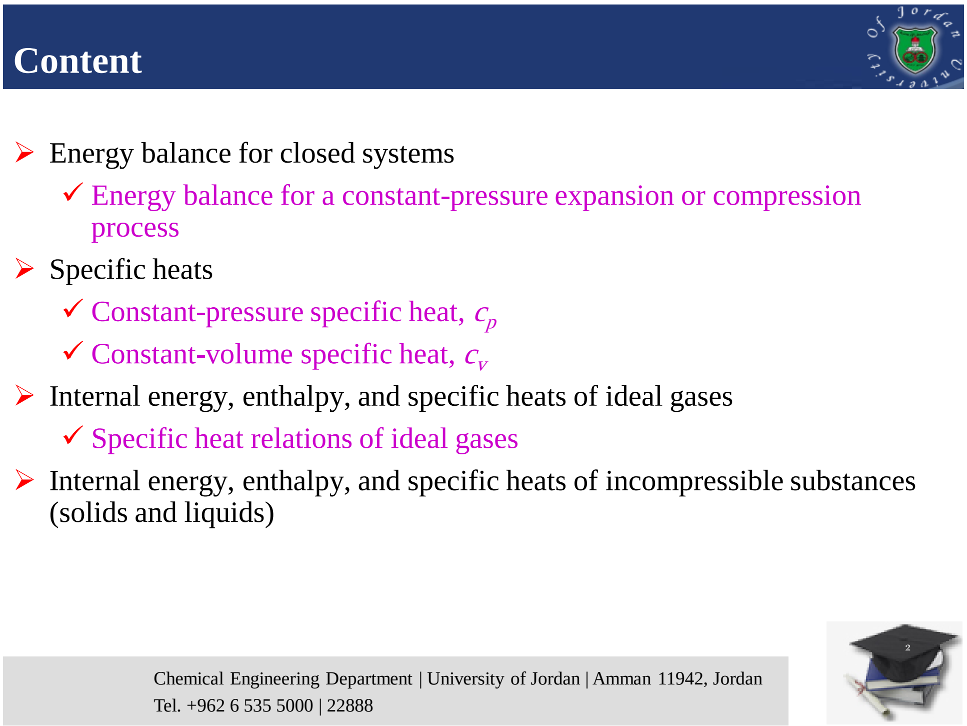
$u = u(T)$
$h = h(T)$
$c_v = c_v(T)$
$c_p = c_p(T)$

Thermodynamics I

Energy Analysis for Closed Systems

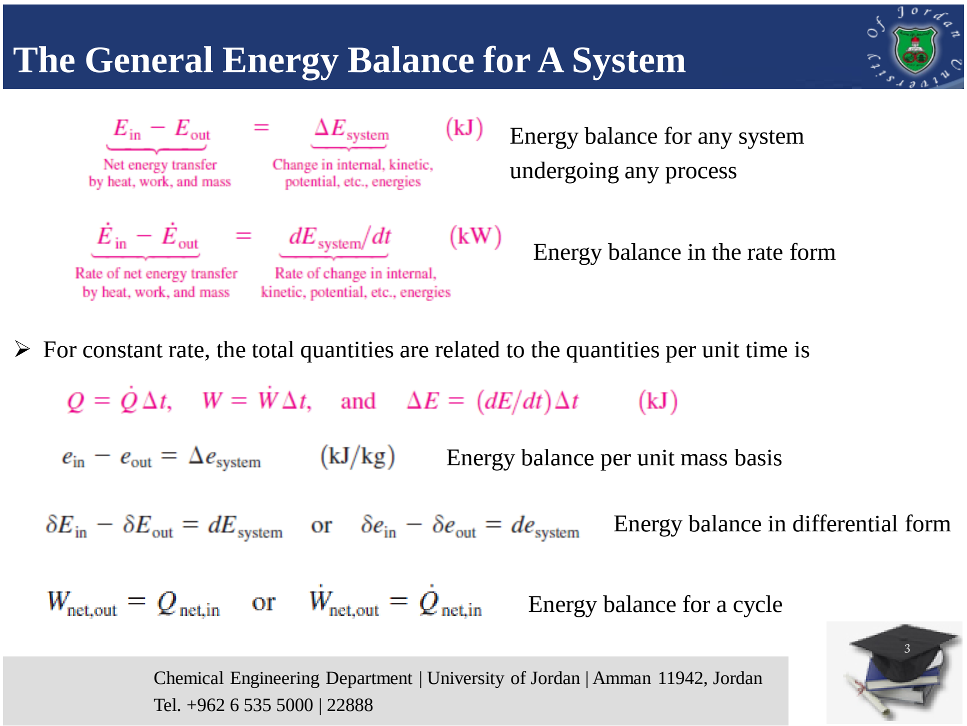
Dr.-Eng. Zayed Al-Hamamre

General $Q - W = \Delta E$
Stationary systems $Q - W = \Delta U$
Per unit mass $q - w = \Delta e$
Differential form $\delta q - \delta w = de$



Content

- Energy balance for closed systems
  - ✓ Energy balance for a constant-pressure expansion or compression process
- Specific heats
  - ✓ Constant-pressure specific heat, c_p
  - ✓ Constant-volume specific heat, c_v
- Internal energy, enthalpy, and specific heats of ideal gases
  - ✓ Specific heat relations of ideal gases
- Internal energy, enthalpy, and specific heats of incompressible substances (solids and liquids)



The General Energy Balance for A System

$$\underbrace{E_{\text{in}} - E_{\text{out}}}_{\substack{\text{Net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,}\\ \text{potential, etc., energies}}} \quad (\text{kJ})$$

Energy balance for any system undergoing any process

$$\underbrace{\dot{E}_{\text{in}} - \dot{E}_{\text{out}}}_{\substack{\text{Rate of net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{dE_{\text{system}}/dt}_{\substack{\text{Rate of change in internal,}\\ \text{kinetic, potential, etc., energies}}} \quad (\text{kW})$$

Energy balance in the rate form

- For constant rate, the total quantities are related to the quantities per unit time is

$$Q = \dot{Q}\,\Delta t, \quad W = \dot{W}\,\Delta t, \quad \text{and} \quad \Delta E = (dE/dt)\,\Delta t \qquad (\text{kJ})$$

$$e_{\text{in}} - e_{\text{out}} = \Delta e_{\text{system}} \qquad (\text{kJ/kg})$$

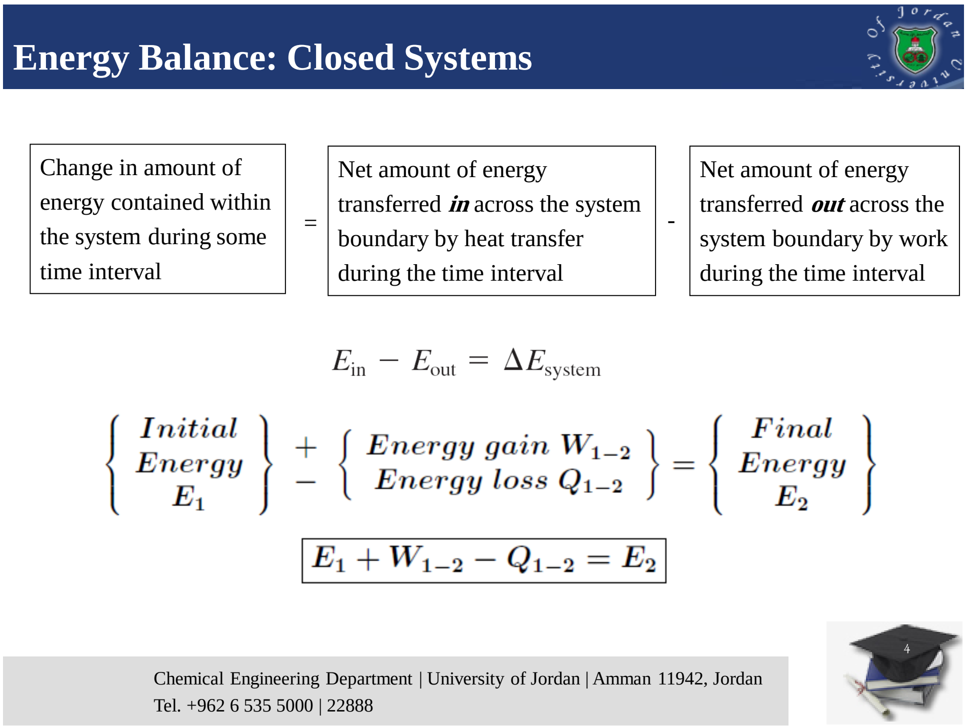
Energy balance per unit mass basis

$$\delta E_{\text{in}} - \delta E_{\text{out}} = dE_{\text{system}} \quad \text{or} \quad \delta e_{\text{in}} - \delta e_{\text{out}} = de_{\text{system}}$$

Energy balance in differential form

$$W_{\text{net,out}} = Q_{\text{net,in}} \quad \text{or} \quad \dot{W}_{\text{net,out}} = \dot{Q}_{\text{net,in}}$$

Energy balance for a cycle



Energy Balance: Closed Systems

Change in amount of energy contained within the system during some time interval	=	Net amount of energy transferred ***in*** across the system boundary by heat transfer during the time interval	-	Net amount of energy transferred ***out*** across the system boundary by work during the time interval

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

$$\left\{ \begin{matrix} \text{Initial} \\ \text{Energy} \\ E_1 \end{matrix} \right\} \begin{matrix} + \\ - \end{matrix} \left\{ \begin{matrix} \text{Energy gain } W_{1-2} \\ \text{Energy loss } Q_{1-2} \end{matrix} \right\} = \left\{ \begin{matrix} \text{Final} \\ \text{Energy} \\ E_2 \end{matrix} \right\}$$

$$\boxed{E_1 + W_{1-2} - Q_{1-2} = E_2}$$

Energy Balance: Closed Systems

$$\Delta KE + \Delta PE + \Delta U = Q - W$$

$$U_2 - U_1 + \frac{1}{2}m(V_2^2 - V_1^2) + mg(Z_2 - Z_1) = {}_1Q_2 - {}_1W_2$$

Differential Form: $dE = \delta Q - \delta W$

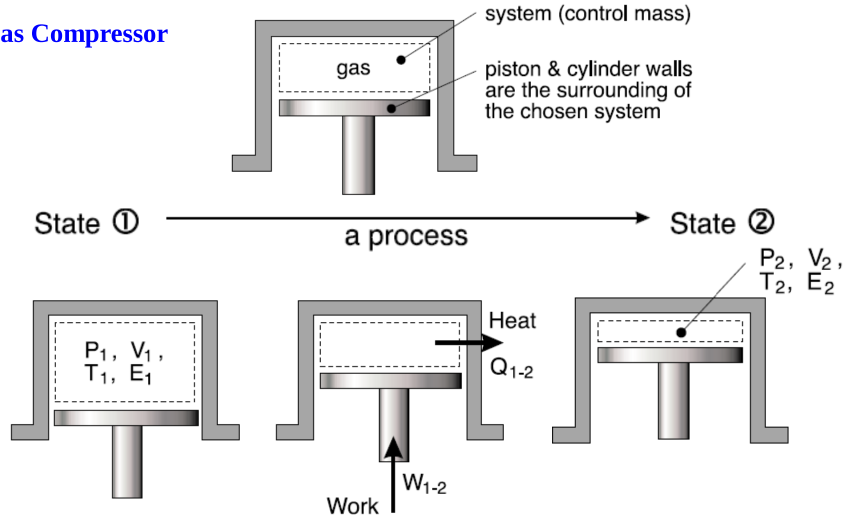
Time Rate Form: $\frac{dE}{dt} = \dot{Q} - \dot{W}$

$$\begin{bmatrix}\text{time } \textit{rate of change} \\ \text{of the energy} \\ \text{contained within} \\ \text{the system } \textit{at} \\ \textit{time t}\end{bmatrix} = \begin{bmatrix}\text{net } \textit{rate} \text{ at which} \\ \text{energy is being} \\ \text{transferred in} \\ \text{by heat transfer} \\ \textit{at time t}\end{bmatrix} - \begin{bmatrix}\text{net } \textit{rate} \text{ at which} \\ \text{energy is being} \\ \text{transferred out} \\ \text{by work } \textit{at} \\ \textit{time t}\end{bmatrix}$$

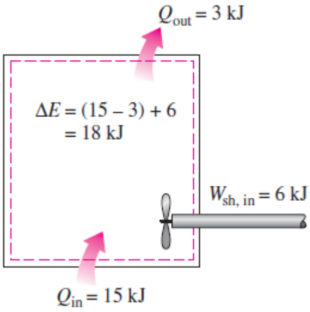
$$\Rightarrow \quad \frac{dKE}{dt} + \frac{dPE}{dt} + \frac{dU}{dt} = \dot{Q} - \dot{W}$$

Energy Balance: Closed Systems

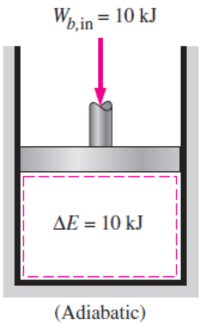
Gas Compressor



Energy Balance: Closed Systems



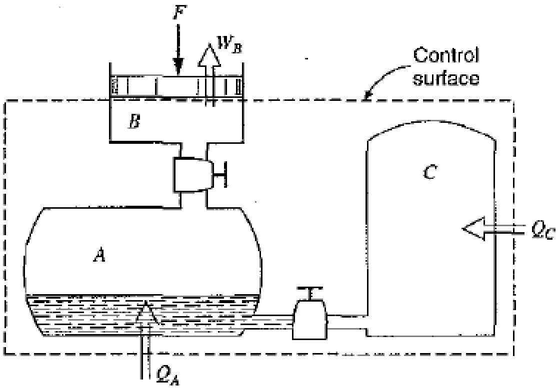
The energy change of a system during a process is equal to the *net* work and heat transfer between the system and its surroundings

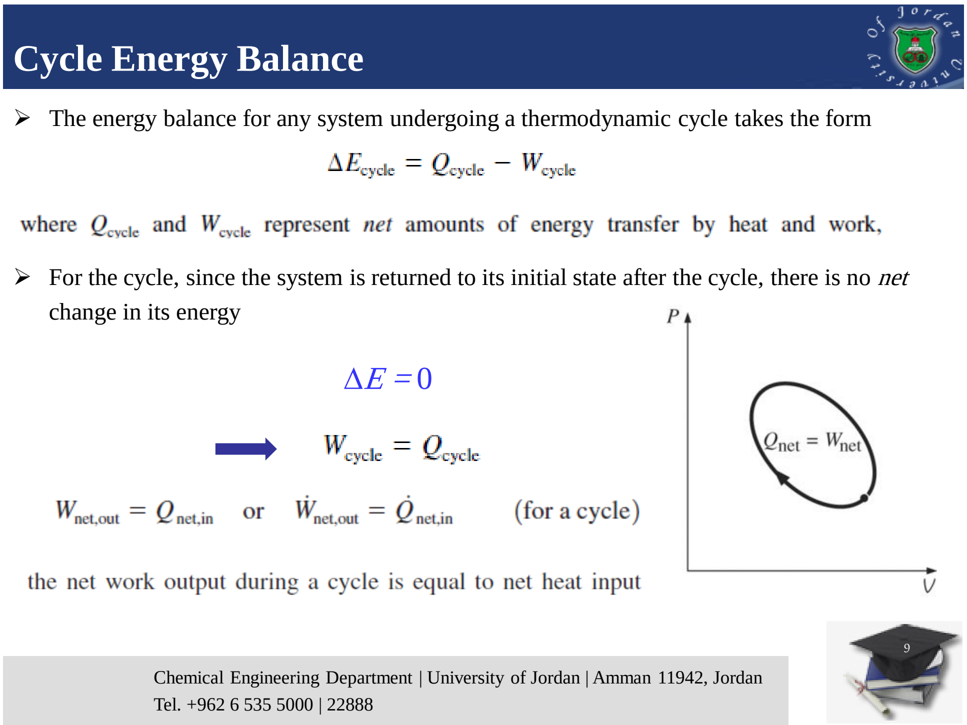


The work (boundary) done on an adiabatic system is equal to the increase in the energy of the system

Energy Balance: Closed Systems

- A control mass may be made up of several different subsystems





Cycle Energy Balance

- The energy balance for any system undergoing a thermodynamic cycle takes the form

$$\Delta E_{\text{cycle}} = Q_{\text{cycle}} - W_{\text{cycle}}$$

where Q_{cycle} and W_{cycle} represent *net* amounts of energy transfer by heat and work,

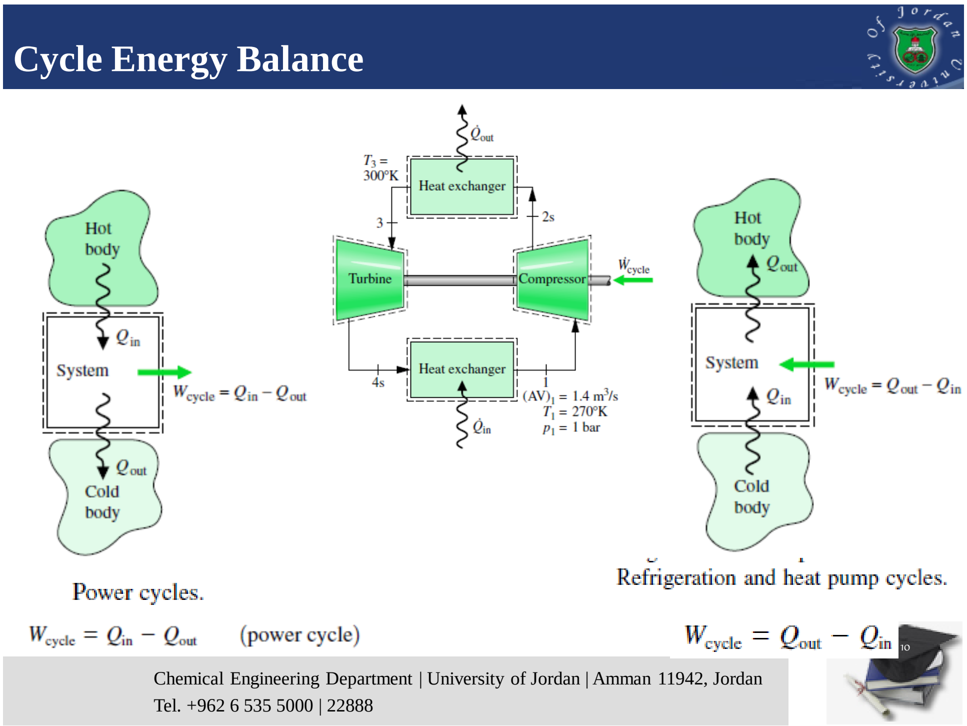
- For the cycle, since the system is returned to its initial state after the cycle, there is no *net* change in its energy

$$\Delta E = 0$$

$$\Rightarrow W_{\text{cycle}} = Q_{\text{cycle}}$$

$$W_{\text{net,out}} = Q_{\text{net,in}} \quad \text{or} \quad \dot{W}_{\text{net,out}} = \dot{Q}_{\text{net,in}} \qquad \text{(for a cycle)}$$

the net work output during a cycle is equal to net heat input



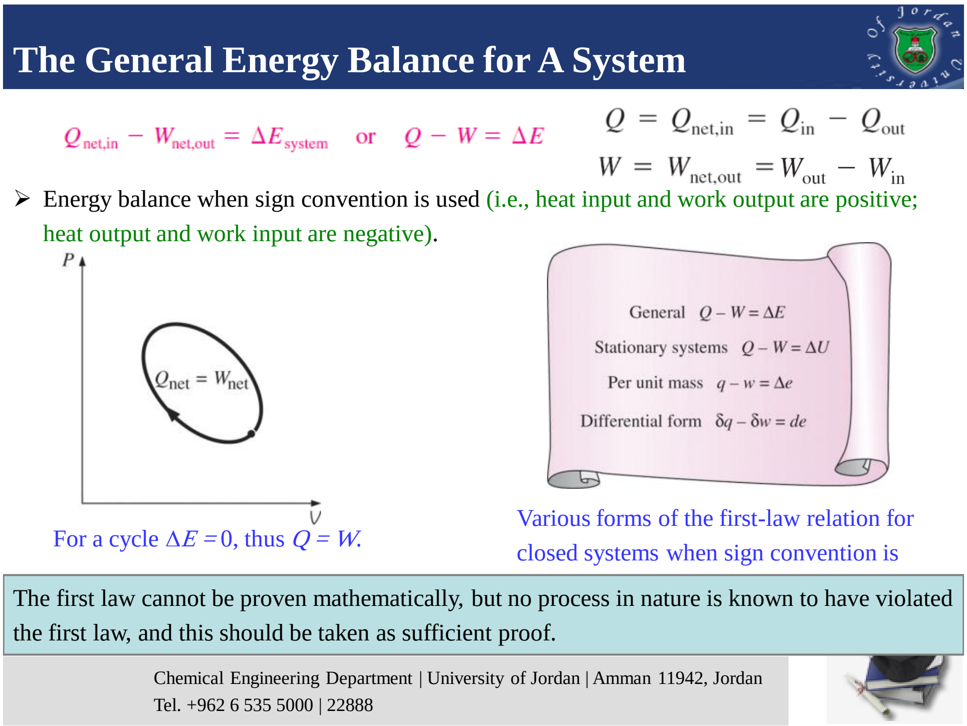
Cycle Energy Balance

Power cycles.

Refrigeration and heat pump cycles.

$$W_{\text{cycle}} = Q_{\text{in}} - Q_{\text{out}} \qquad \text{(power cycle)}$$

$$W_{\text{cycle}} = Q_{\text{out}} - Q_{\text{in}}$$



The General Energy Balance for A System

$Q_{\text{net,in}} - W_{\text{net,out}} = \Delta E_{\text{system}}$ or $Q - W = \Delta E$

$Q = Q_{\text{net,in}} = Q_{\text{in}} - Q_{\text{out}}$

$W = W_{\text{net,out}} = W_{\text{out}} - W_{\text{in}}$

- Energy balance when sign convention is used (i.e., heat input and work output are positive; heat output and work input are negative).

For a cycle $\Delta E = 0$, thus $Q = W$.

General $Q - W = \Delta E$

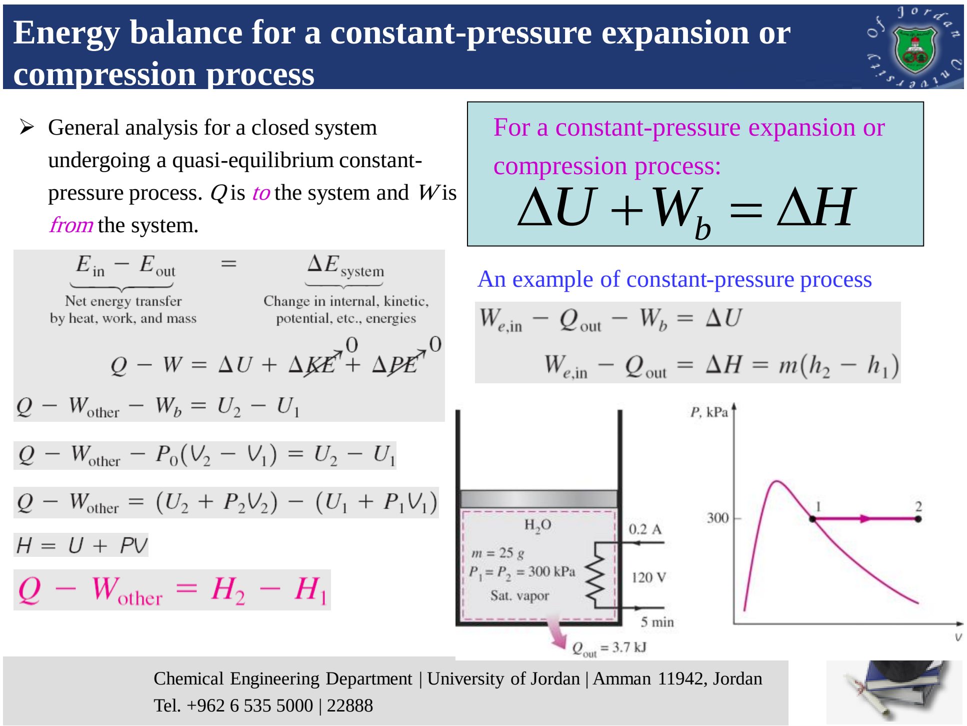
Stationary systems $Q - W = \Delta U$

Per unit mass $q - w = \Delta e$

Differential form $\delta q - \delta w = de$

Various forms of the first-law relation for closed systems when sign convention is

The first law cannot be proven mathematically, but no process in nature is known to have violated the first law, and this should be taken as sufficient proof.



Energy balance for a constant-pressure expansion or compression process

- General analysis for a closed system undergoing a quasi-equilibrium constant-pressure process. Q is *to* the system and W is *from* the system.

$$\underbrace{E_{\text{in}} - E_{\text{out}}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc., energies}}}$$

$$Q - W = \Delta U + \cancelto{0}{\Delta KE} + \cancelto{0}{\Delta PE}$$

$$Q - W_{\text{other}} - W_b = U_2 - U_1$$

$$Q - W_{\text{other}} - P_0(V_2 - V_1) = U_2 - U_1$$

$$Q - W_{\text{other}} = (U_2 + P_2V_2) - (U_1 + P_1V_1)$$

$$H = U + PV$$

$$Q - W_{\text{other}} = H_2 - H_1$$

For a constant-pressure expansion or compression process:

$$\Delta U + W_b = \Delta H$$

An example of constant-pressure process

$$W_{e,\text{in}} - Q_{\text{out}} - W_b = \Delta U$$

$$W_{e,\text{in}} - Q_{\text{out}} = \Delta H = m(h_2 - h_1)$$

Constant-Volume and Constant-Pressure Processes

The energy balance for a homogeneous closed system of n moles :

$$d(nU) = n\,dU = dQ - dW_b - dW_{\text{other}}$$

If $W_{\text{othre}} = 0.0$, then

The work of a mechanically reversible, closed-system process is

$$dW = P\,d(nV)$$

$$\Rightarrow \quad d(nU) = dQ - P\,d(nV) \qquad dQ = d(nU) + P\,d(nV)$$

the general first-law equation for a mechanically reversible, closed-system process.

- Remember that in the liquid-vapor saturation region,

$$U = U_{\text{liq}} + U_{\text{vap}} \longrightarrow mu = m_{\text{liq}}u_f + m_{\text{vap}}u_g \longrightarrow u = (1-x)u_f + xu_g$$

$$\longrightarrow u = u_f + xu_{fg}$$

and $v_{\text{avg}} = v_f + xv_{fg}$ (m^3/kg)

Constant-Volume and Constant-Pressure Processes

If the process occurs at constant total volume, the work is zero.

Since for closed systems, n is also constant

$$d(nU) = dQ - \overset{\text{zero}}{\cancel{P\,d(nV)}}$$

$$dQ = d(nU) \quad (\text{const V}) \qquad Q = n\,\Delta U \quad (\text{const V})$$

For a constant-pressure change of state:

$$dQ = d(nU) + d(nPV) = d[n(U + PV)]$$

Since $\boxed{H \equiv U + PV}$ $\qquad dH = dU + d(PV)$

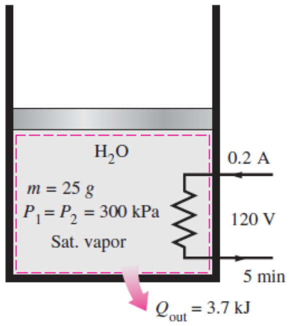
$$dQ = d(nH) \quad (\text{const P}) \qquad Q = n\,\Delta H \quad (\text{const P})$$

Example

A piston–cylinder device contains 25 g of saturated water vapor that is maintained at a constant pressure of 300 kPa. A resistance heater within the cylinder is turned on and passes a current of 0.2 A for 5 min from a 120-V source. At the same time, a heat loss of 3.7 kJ occurs.

(a) Show that for a closed system the boundary work W_b and the change in internal energy U in the first-law relation can be combined into one term, H, for a constant pressure process.

(b) Determine the final temperature of the steam.

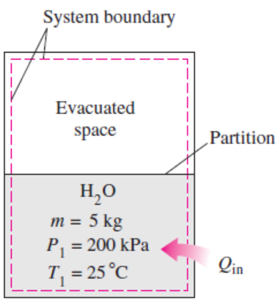


Example Cont.

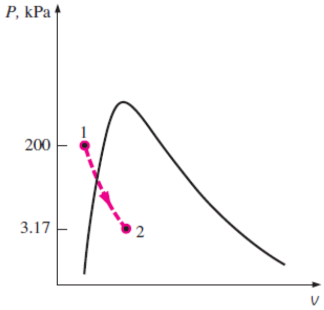
Example Cont.

Example

A rigid tank is divided into two equal parts by a partition. Initially, one side of the tank contains 5 kg of water at 200 kPa and 25°C, and the other side is evacuated. The partition is then removed, and the water expands into the entire tank. The water is allowed to exchange heat with its surroundings until the temperature in the tank returns to the initial value of 25°C. Determine (*a*) the volume of the tank, (*b*) the final pressure, and (*c*) the heat transfer for this process.



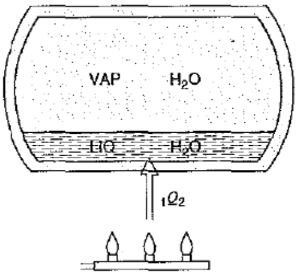
Example Cont.



Example

Example

A vessel having a volume of 5 m^3 contains 0.05 m^3 of saturated liquid water and 4.95 m^3 of saturated water vapor at 0.1 "MPa. Heat is transferred until the vessel is filled with saturated vapor. Determine the heat transfer for this process.

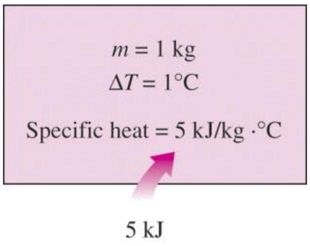


Example Cont.

Example Cont.

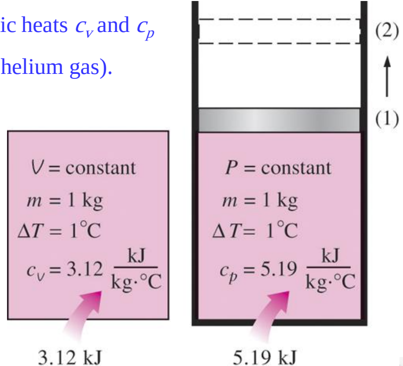
Specific Heat

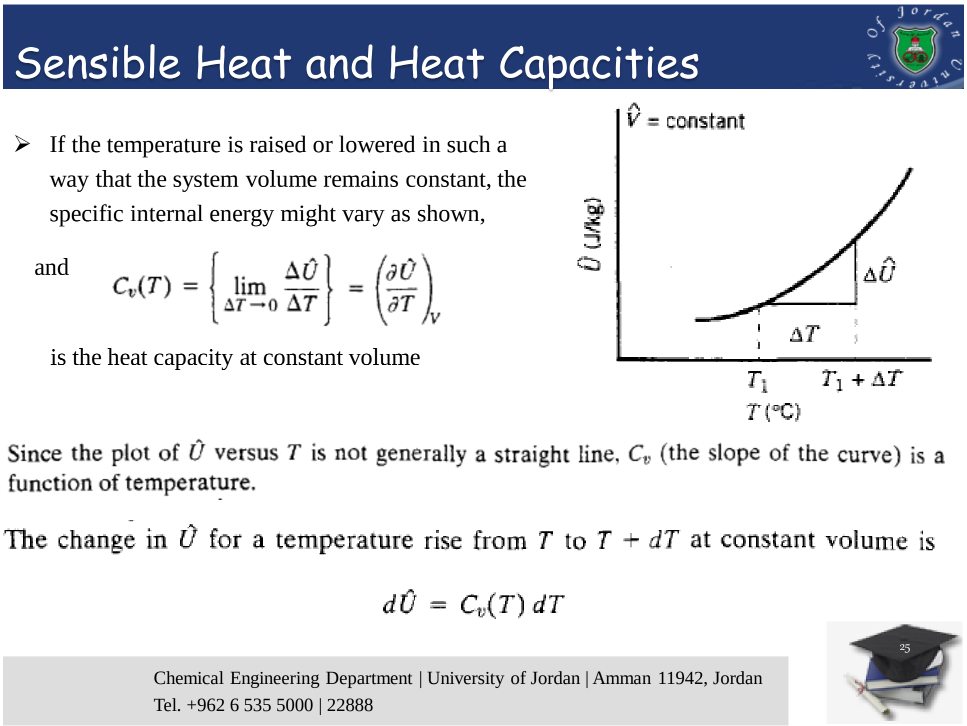
- **Specific heat at constant volume, c_v**: The energy required to raise the temperature of the unit mass of a substance by one degree as the volume is maintained constant.
- **Specific heat at constant pressure, c_p**: The energy required to raise the temperature of the unit mass of a substance by one degree as the pressure is maintained constant.



Specific heat is the energy required to raise the temperature of a unit mass of a substance by one degree in a specified way.

Constant-volume and constant-pressure specific heats c_v and c_p (values are for helium gas).





Sensible Heat and Heat Capacities

- If the temperature is raised or lowered in such a way that the system volume remains constant, the specific internal energy might vary as shown,

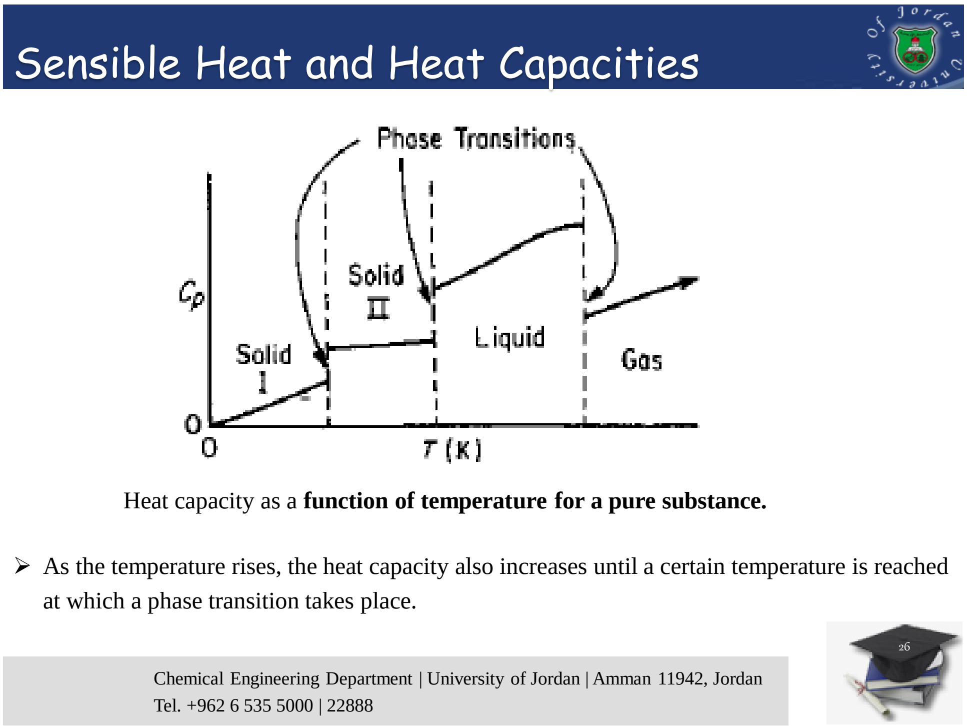
and $$C_v(T) = \left\{ \lim_{\Delta T \to 0} \frac{\Delta \hat{U}}{\Delta T} \right\} = \left(\frac{\partial \hat{U}}{\partial T} \right)_V$$

is the heat capacity at constant volume

Since the plot of $\hat{U}$ versus T is not generally a straight line, C_v (the slope of the curve) is a function of temperature.

The change in $\hat{U}$ for a temperature rise from T to $T + dT$ at constant volume is

$$d\hat{U} = C_v(T)\, dT$$



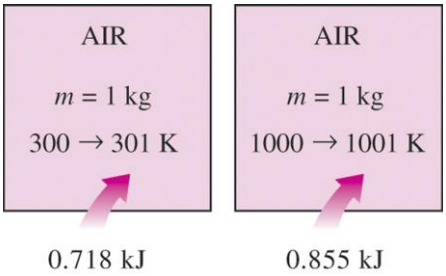
Sensible Heat and Heat Capacities

Heat capacity as a **function of temperature for a pure substance.**

- As the temperature rises, the heat capacity also increases until a certain temperature is reached at which a phase transition takes place.

Specific Heat

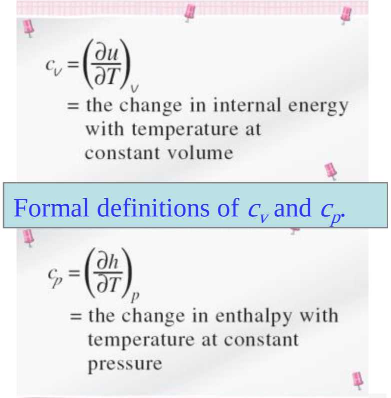
- The equations in the figure are valid for *any* substance undergoing *any* process.
- c_v and c_p are properties.
- c_v is related to the changes in *internal energy* and c_p to the changes in *enthalpy*.
- A common unit for specific heats is kJ/kg · °C or kJ/kg · K. **Are these units identical?**



The specific heat of a substance changes with temperature.

True or False?

c_p is always greater than c_v.



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

= the change in internal energy with temperature at constant volume

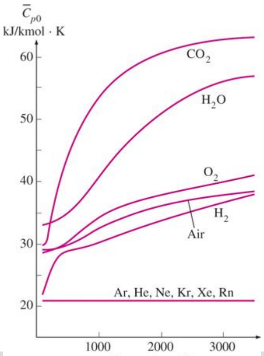
Formal definitions of c_v and c_p.

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

= the change in enthalpy with temperature at constant pressure

U, H and Specific Heat of Ideal Gas

- At low pressures, all real gases approach ideal-gas behavior, and therefore their specific heats depend on temperature only.
- The specific heats of real gases at low pressures are called *ideal-gas specific heats*, or *zero-pressure specific heats*, and are often denoted c_{p0} and c_{v0}.



- Ideal-gas constant-pressure specific heats for some gases (see Table A–2*c* for c_p equations).

- u and h data for a number of gases have been tabulated.
- These tables are obtained by choosing an arbitrary reference point and performing the integrations by treating state 1 as the reference state.

AIR

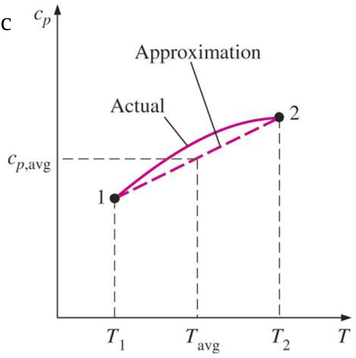
T, K	u, kJ/kg	h, kJ/kg
0	0	0
.	.	.
.	.	.
300	214.07	300.19
310	221.25	310.24
.	.	.
.	.	.

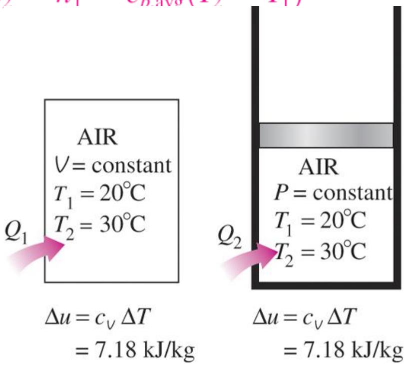
- In the preparation of ideal-gas tables, 0 K is chosen as the reference temperature.

U, H and Specific Heat of Ideal Gas

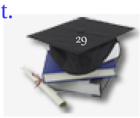
- Internal energy and enthalpy change when specific heat is taken constant at an average value

$$u_2 - u_1 = c_{v,\text{avg}}(T_2 - T_1)$$
$$h_2 - h_1 = c_{p,\text{avg}}(T_2 - T_1)$$
(kJ/kg)



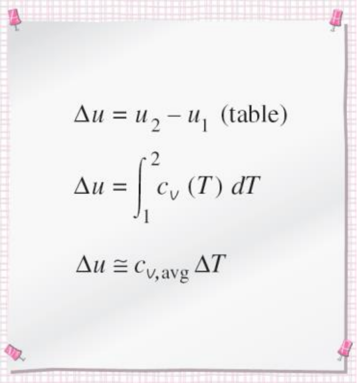


- For small temperature intervals, the specific heats may be assumed to vary linearly with temperature.
- The relation $\Delta u = c_v \Delta T$ is valid for *any* kind of process, constant-volume or not.



Three Ways of Calculating Δu and Δh

1. By using the tabulated *u* and *h* data. This is the easiest and **most accurate** way when tables are readily available.
2. By using the c_v or c_p relations (Table A-2c) as a function of temperature and performing the integrations. This is very inconvenient for hand calculations but quite desirable for computerized calculations. The results obtained are **very accurate**.
3. By using average specific heats. This is very simple and certainly very convenient when property tables are not available. The results obtained are **reasonably accurate** if the temperature interval is not very large.



$$\Delta u = u_2 - u_1 \ \text{(table)}$$
$$\Delta u = \int_1^2 c_v(T)\, dT$$
$$\Delta u \cong c_{v,\text{avg}} \Delta T$$

Three ways of calculating Δu.

- Where $C_{v,\text{avg}}$ is determined using c_v or c_p relations (Table A-2c) at the average temperature of $(T_1 + T_2)/2$

Specific Heat Relations of Ideal Gases

$$\left.\begin{aligned} h &= u + RT. \\ dh &= du + R\,dT \\ dh = c_p dT &\text{ and } du = c_v dT \end{aligned}\right\} \longrightarrow$$

The relationship between c_p, c_v and R

$$c_p = c_v + R \qquad (\text{kJ/kg} \cdot \text{K})$$

On a molar basis

$$\bar{c}_p = \bar{c}_v + R_u \qquad (\text{kJ/kmol} \cdot \text{K})$$

$$k = \frac{c_p}{c_v} \quad \text{Specific heat ratio} = 1 + \frac{R}{C_V}$$

AIR at 300 K

$$\left.\begin{aligned} c_v &= 0.718 \text{ kJ/kg} \cdot \text{K} \\ R &= 0.287 \text{ kJ/kg} \cdot \text{K} \end{aligned}\right\} c_p = 1.005 \text{ kJ/kg} \cdot \text{K}$$

or

$$\left.\begin{aligned} \bar{c}_v &= 20.80 \text{ kJ/kmol} \cdot \text{K} \\ R_u &= 8.314 \text{ kJ/kmol} \cdot \text{K} \end{aligned}\right\} \bar{c}_p = 29.114 \text{ kJ/kmol} \cdot \text{K}$$

- The c_p of an ideal gas can be determined from a knowledge of c_v and R.
- The specific ratio varies with temperature, but this variation is very mild.
- For monatomic gases (helium, argon, etc.), its value is essentially constant at 1.667.
- Many diatomic gases, including air, have a specific heat ratio of about 1.4 at room temperature.

Equations for Process Calculations: Ideal Gases

- For **an ideal gas** in any **mechanically reversible closed-system process (if $W_{\text{other}} = 0.0$)**

$$dQ - dW = C_V\,dT$$

Since $\quad dW = P\,dV \qquad\qquad dW = RT\frac{dV}{V}$

$$dQ = C_V\,dT + P\,dV$$

$$dQ = C_V\,dT + RT\frac{dV}{V}$$

Alternatively, let $V = RT/P$:

$$dQ = C_V\,dT + P\,d(RT/P) \;\Rightarrow\; dQ = C_V\,dT + P\left(\frac{R}{P}dT - \frac{RT}{P^2}dP\right)$$

$$\Rightarrow\; dQ = (C_v + R)dT - RT\frac{dP}{P}$$

Equations for Process Calculations: Ideal Gases

But $C_P = \frac{dH}{dT} = \frac{dU}{dT} + R = C_V + R$

$$dQ = C_P\,dT - RT\frac{dP}{P}$$

$$dW = RT\frac{dV}{V} \quad \longrightarrow \quad dW = -R\,dT + RT\frac{dP}{P}$$

, let $T = PV/R$:

$$dQ = C_V\,dT + P\,dV \quad \longrightarrow \quad dQ = C_V\left(\frac{V}{R}dP + \frac{P}{R}dV\right) + P\,dV$$

$$dQ = \frac{C_V}{R}V\,dP + \frac{C_P}{R}P\,dV$$

Isothermal Process

$$\Delta U = \Delta H = 0$$

$$Q = RT\ln\frac{V_2}{V_1} = -RT\ln\frac{P_2}{P_1}$$

$$W = -RT\ln\frac{V_2}{V_1} = RT\ln\frac{P_2}{P_1}$$

$Q = -W,$

$$Q = -W = RT\ln\frac{V_2}{V_1} = -RT\ln\frac{P_2}{P_1} \qquad (\text{const } T)$$

Isobaric Process

$$\Delta U = \int C_V \, dT \qquad \text{and} \qquad \Delta H = \int C_P \, dT$$

$$Q = \int C_P \, dT \qquad \text{and} \qquad W = -R(T_2 - T_1)$$

$$Q = \Delta H$$

$$Q = \Delta H = \int C_P \, dT \qquad (\text{const } P)$$

Isochoric (Constant- V) Process

$$\Delta U = \int C_V \, dT \qquad \text{and} \qquad \Delta H = \int C_P \, dT$$

$$Q = \int C_V \, dT \qquad \text{and} \qquad W = 0$$

$$Q = \Delta U = \int C_V \, dT \qquad (\text{const } V)$$

Adiabatic Process: Constant Heat Capacities

- An adiabatic process is one for which there is no heat transfer between the system and its surroundings

$$dQ = 0.$$

$$\frac{dT}{T} = -\frac{R}{C_V}\frac{dV}{V}$$

Integration with C_V constant then gives:

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{R/C_V}$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{R/C_P} \quad \text{and} \quad \frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^{C_P/C_V}$$

Adiabatic Process: Constant Heat Capacities

$$TV^{\gamma-1} = \text{constant}$$

$$TP^{(1-\gamma)/\gamma} = \text{constant}$$

$$PV^{\gamma} = \text{constant}$$

$$\gamma \equiv \frac{C_P}{C_V}$$

- Apply to an ideal gas with constant heat capacities undergoing a mechanically reversible adiabatic process

The work of an adiabatic process

$$dW = dU = C_V\,dT$$

$$W = \Delta U = C_V\,\Delta T$$

Adiabatic Process: Constant Heat Capacities

$$\gamma = \frac{C_P}{C_V} = \frac{C_V + R}{C_V} = 1 + \frac{R}{C_V}$$

Whence,

$$C_V = \frac{R}{\gamma - 1}$$

Therefore

$$W = C_V\,\Delta T = \frac{R\,\Delta T}{\gamma - 1}$$

Since $RT_1 = P_1V_1$ and $RT_2 = P_2V_2$, this expression may be written:

$$W = \frac{RT_2 - RT_1}{\gamma - 1} = \frac{P_2V_2 - P_1V_1}{\gamma - 1}$$

V_2 is usually not known, and is eliminated

$$W = \frac{P_1V_1}{\gamma - 1}\left[\left(\frac{P_2}{P_1}\right)^{(\gamma-1)/\gamma} - 1\right] = \frac{RT_1}{\gamma - 1}\left[\left(\frac{P_2}{P_1}\right)^{(\gamma-1)/\gamma} - 1\right]$$

Polytropic Process: Constant Heat Capacities

$$PV^{\delta} = \text{constant}$$

$$TV^{\delta-1} = \text{constant}$$

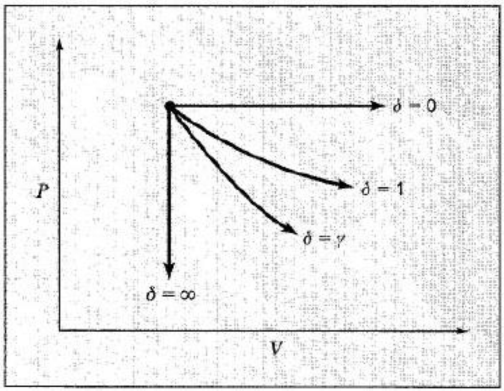
$$TP^{(1-\delta)/\delta} = \text{constant}$$

$$W = \frac{RT_1}{\delta - 1}\left[\left(\frac{P_2}{P_1}\right)^{(\delta-1)/\delta} - 1\right]$$

$$Q = \frac{(\delta - \gamma)RT_1}{(\delta - 1)(\gamma - 1)}\left[\left(\frac{P_2}{P_1}\right)^{(\delta-1)/\delta} - 1\right]$$

Polytropic Process

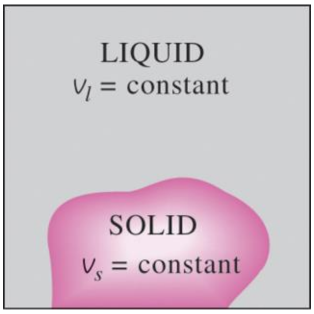
- Isobaric process (constant pressure process): δ = 0.
- Isothermal process:, δ = 1.
- Adiabatic process: δ = *γ*.
- Isochoric process: dV/dP = V/Pδ; for constant V, δ = $\pm\infty$



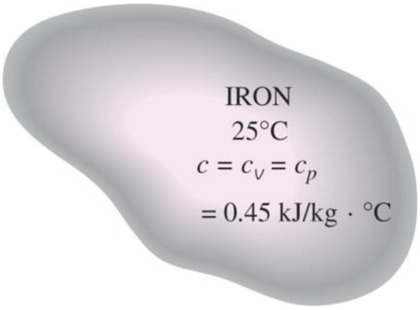
Paths of polytropic processes characterized by specific values of δ

U, H and Specific Heat of Solids and Liquids

- **Incompressible substance**: A substance whose specific volume (or density) is constant. Solids and liquids are incompressible substances.



The specific volumes of incompressible substances remain constant during a process.



The c_v and c_p values of incompressible substances are identical and are denoted by *c*.

U, H and Specific Heat of Solids and Liquids

$$du = c_v\, dT = c(T)\, dT \qquad \Delta u = u_2 - u_1 = \int_1^2 c(T)\, dT \qquad (\text{kJ/kg})$$

$$\Delta u \cong c_{\text{avg}}(T_2 - T_1) \qquad (\text{kJ/kg})$$

Enthalpy Changes

$$h = u + Pv \qquad dh = du + v\,dP + P\,\overset{\nearrow 0}{dv} = du + v\,dP$$

$$\Delta h = \Delta u + v\,\Delta P \cong c_{\text{avg}}\,\Delta T + v\,\Delta P \qquad (\text{kJ/kg})$$

For *solids*, the term $v\,\Delta P$ is insignificant and thus $\Delta h = \Delta u \cong c_{\text{avg}}\Delta T$. For *liquids*, two special cases are commonly encountered:

1. *Constant-pressure processes,* as in heaters ($\Delta P = 0$): $\Delta h = \Delta u \cong c_{\text{avg}}\Delta T$
2. *Constant-temperature processes,* as in pumps ($\Delta T = 0$): $\Delta h = v\,\Delta P$

$$h_{@\,P,T} \cong h_{f\,@\,T}$$

The enthalpy of a compressed liquid

- A more accurate relation than $h_{@P,T} \cong h_{f\,@\,T} + v_{f\,@\,T}(P - P_{\text{sat}\,@\,T})$

Approximations for liquids and solids

Using Saturated Liquid Data
('Compressed Liquid Rule')

$$v \approx v_f$$
$$h \approx h_f$$
$$u \approx u_f$$
$$s \approx s_f$$

- Using 'Incompressible Substance Model'

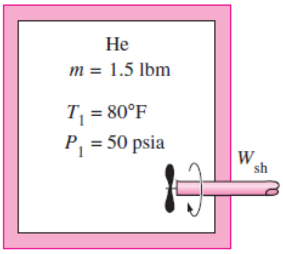
$$c_p = c_v = c$$
$$u_2 - u_1 = c(T_2 - T_1)$$
$$h_2 - h_1 = c(T_2 - T_1) + \underline{v(P_2 - P_1)}$$
$$h_2 - h_1 \approx c(T_2 - T_1)$$

- Generalized equations for the estimation of molar volumes of *saturated* liquids (Rackett equ.)

$$V^{\text{sat}} = V_c Z_c^{(1-T_r)^{0.2857}}$$

Example

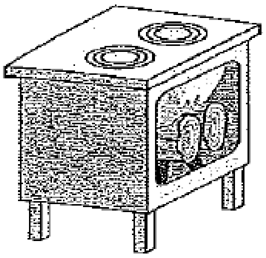
An insulated rigid tank initially contains 1.5 lbm of helium at 80°F and 50 psia. A paddle wheel with a power rating of 0.02 hp is operated within the tank for 30 min. Determine (*a*) the final temperature and (*b*) the final pressure of the helium gas.



Example Cont.

Example

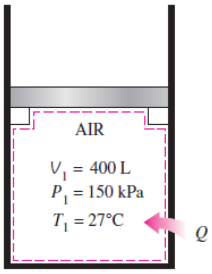
A 25-kg cast-iron wood-burning stove, contains 5 kg of soft pine wood and 1 kg of air. All the masses are at room temperature, 20°C, and pressure, 101 kPa. The wood now burns and heats all the mass uniformly, releasing 1500 watts. Neglect any air flow and changes in mass and heat losses. Find the rate of change of the temperature *(dT/dt}and* estimate the time it will take to reach a temperature of 75°C.



Example Cont.

Example

A piston–cylinder device initially contains air at 150 kPa and 27°C. At this state, the piston is resting on a pair of stops, and the enclosed volume is 400 L. The mass of the piston is such that a 350-kPa pressure is required to move it. The air is now heated until its volume has doubled. Determine (*a*) the final temperature, (*b*) the work done by the air, and (*c*) the total heat transferred to the air.



Example Cont.

Example Cont.