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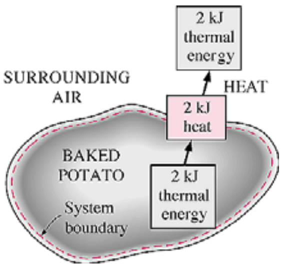
CHAPTER 3

The First Law of Thermodynamics: Closed Systems

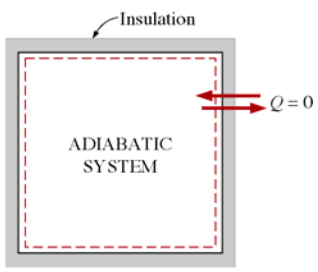
3-1

Heat Transfer

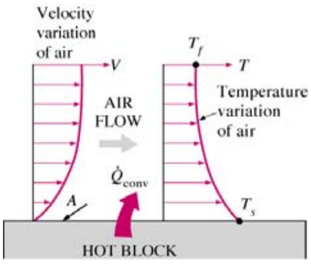


3-2

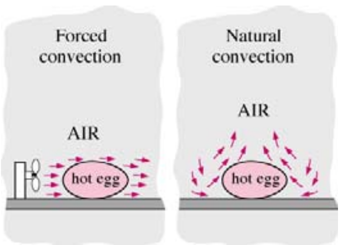
Adiabatic Process



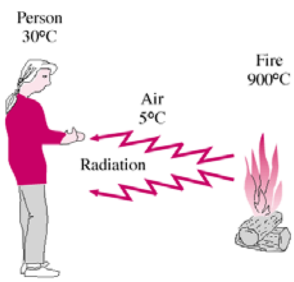
Convection: Heat Transfer



Convection: Cooling



Radiation



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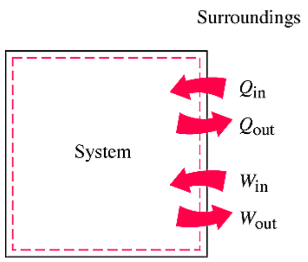
Heat and Work



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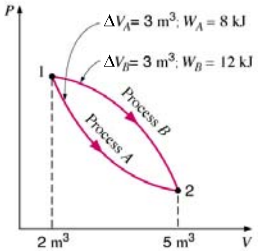
Path Functions



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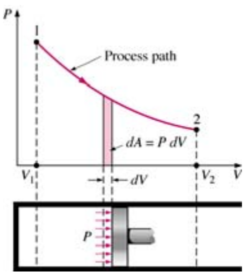
Boundary Work



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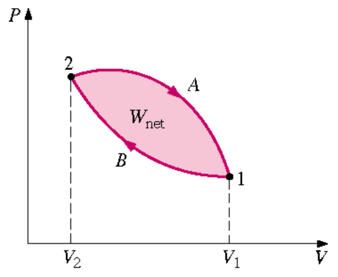
Net Work per Cycle



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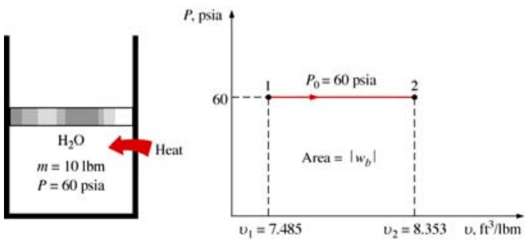
Schematic/Diagram for Ex. 3-8



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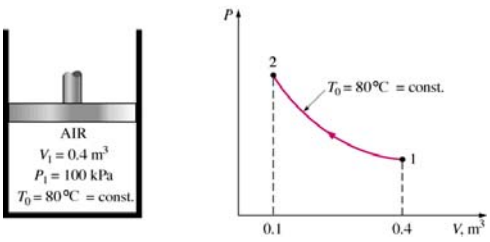
Schematic/Diagram for Ex. 3-9



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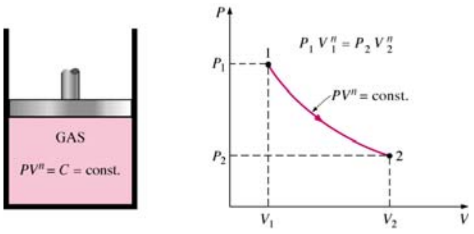
Schematic/Diagram for the Polytropic Process



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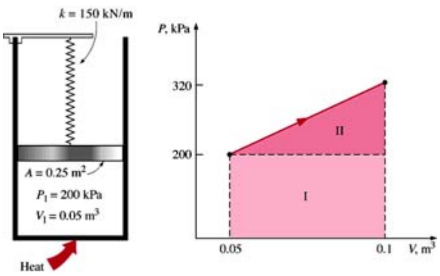
Schematic/Diagram for Ex. 3-13



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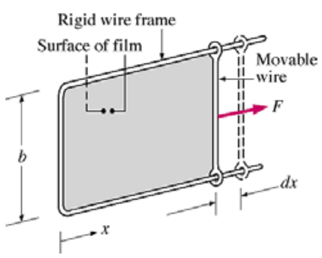
Stretching a Liquid Film



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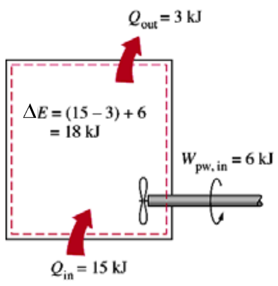
System Energy Change



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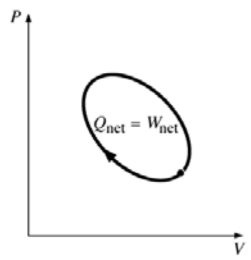
Energy Change for a Cycle



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Closed-Systems, First-Law

General $Q - W = \Delta E$

Stationary systems $Q - W = \Delta U$

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

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

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Formal Definitions of C_v and C_p

$$C_\upsilon = \left(\frac{\partial u}{\partial T}\right)_\upsilon$$

= the change in internal energy with temperature at constant volume

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

= the change in enthalpy with temperature at constant pressure

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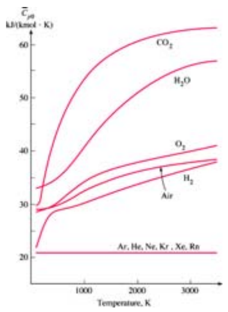
Specific Heats for Some Gases



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Three Ways to Calculate ²u

$$\Delta u = u_2 - u_1 \text{ (table)}$$

$$\Delta u = \int_1^2 C_\upsilon(T)\, dT$$

$$\Delta u \cong C_{\upsilon,\mathrm{av}}\, \Delta T$$

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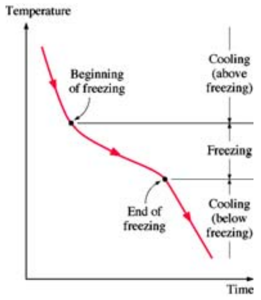
Typical Freezing Curve (food)



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Chapter Summary

- The first law of thermodynamics is essentially an expression of the conservation of energy principle. Energy can cross the boundaries of a closed system in the form of heat or work.
- If the energy transfer across the boundaries of a closed system is due
to a temperature difference, it is *heat*; otherwise, it is *work*.

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Chapter Summary

- Heat is transferred in three ways: *conduction*, *convection*, and *radiation*.
  - *Conduction* is the transfer of energy from the more energetic particles of a substance to the adjacent less energetic ones as a result of interactions between the particles.
  - *Convection* is the mode of energy transfer between a solid surface and the adjacent liquid or gas that is in motion, and it involves the combined effects of conduction and fluid motion.
  - *Radiation* is the energy emitted by matter in the form of electromagnetic waves (or photons) as a result of the changes in the electronic configurations of the atoms or molecules.

3-24

Chapter Summary

- The three modes of heat transfer are expressed as:

$$\dot{Q}_{cond} = -k_t A \frac{dT}{dt} \qquad \text{(W)}$$

$$\dot{Q}_{conv} = hA(T_s - T_f) \qquad \text{(W)}$$

$$\dot{Q}_{rad} = \varepsilon \sigma A(T_s^4 - T_{surr}^4) \qquad \text{(W)}$$

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Chapter Summary

- Various forms of work are expressed as follows:
  - ***Electrical work***: $W_e = VI\Delta t$ **(kJ)**
  - ***Boundary work***: $W_b = \int_1^2 PdV$ **(kJ)**
  - ***Gravitational work*** **(=DPE)**: $W_g = mg(z_2 - z_1)$ **(kJ)**
  - ***Acceleration work*** **(=DKE)**: $W_a = \frac{1}{2}m(\vec{V}_2^2 - \vec{V}_1^2)$ **(kJ)**
  - ***Shaft work***: $W_{sh} = 2\pi n \tau$ **(kJ)**
  - **Spring work:** $W_{spring} = \frac{1}{2}k(x_2^2 - x_1^2)$ **(kJ)**

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Chapter Summary

- For the ***ploytropic process (Pv^n*** = constant) of real gases, the boundary work can be expressed as:

$$W_b = \frac{P_2V_2 - P_1V_1}{1-n} \qquad (n \neq 1) \qquad (kJ)$$

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Chapter Summary

- The energy balance for *any system* undergoing *any process* can be expressed as:

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

Chapter Summary

- The energy balances for *any system* undergoing *any process* can be expressed in the *rate form* as:

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

Chapter Summary

- Taking heat transfer to the system and work done by the system to be positive quantities, the energy balance for a closed system can also be expressed as:

$$Q - W = \Delta U + \Delta KE + \Delta PE \qquad (kJ)$$

where:

$$W = W_{other} + W_b$$

$$\Delta U = m(u_2 - u_1)$$

$$\Delta KE = \frac{1}{2} m(\vec{V}_2^2 - \vec{V}_1^2)$$

$$\Delta PE = mg(z_2 - z_1)$$

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Chapter Summary

- For a *constant-pressure process*, $W_b + \Delta U = \Delta H$. Thus

$$Q - W_{other} = \Delta H + \Delta KE + \Delta PE \qquad (kJ)$$

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Chapter Summary

- The amount of energy needed to raise the temperature of a unit of mass of a substance by one degree is called the *specific heat at constant volume* C_v for a constant-volume process and the *specific heat at constant pressure* C_p for a constant pressure process. They are defined as:

$$C_v = \left(\frac{\partial u}{\partial T}\right)_v \quad and \quad C_p = \left(\frac{\partial h}{\partial T}\right)_p$$

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Chapter Summary

- For ideal gases *u*, *h*, C_v, and C_p are functions of temperature alone. The Δu and Δh of ideal gases can be expressed as:

$$\Delta u = u_2 - u_1 = \int_1^2 C_v(T)\,dT \cong C_{v,av}(T_2 - T_1)$$

$$\Delta h = h_2 - h_1 = \int_1^2 C_p(T)\,dT \cong C_{p,av}(T_2 - T_1)$$

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Chapter Summary

- For ideal gases C_v, and C_p are related by:

$$C_p = C_v + R \qquad [kJ/(kg \cdot K)]$$

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Chapter Summary

- The *specific heat ratio k* is defined as:

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

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Chapter Summary

- For *incompressible substances* (liquids and solids), both the constant-pressure and constant-volume specific heats are identical and denoted by C:

$$C_p = C_v = C \qquad [kJ/(kg \cdot K)]$$

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Chapter Summary

- The Δu and Δh of incompressible substances are given by

$$\Delta u = \int_1^2 C(T)\,dT \cong C_{av}(T_2 - T_1) \qquad (kJ/kg)$$

$$\Delta h = \Delta u + v\Delta P \qquad (kJ/kg)$$

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Chapter Summary

- The refrigeration and freezing of foods is a major application area of thermodynamics.