Homework: 10, 11, 15, 19, 21 (pages 500-501)

25, 29, 30, 32 (page 501)

10. An aluminum flagpole is 33m high. By how much does its length increase as the temperature increases by 15 C^0?

For a linear expansion:

$$\Delta L = L\alpha\Delta T = 33 \times 23 \times 10^{-6} \times 15 = 0.011\,(m)$$

$$\Delta L = 1.1\,\text{cm}$$

Note: $\alpha = 23 \times 10^{-6}/C^0$ is the coefficient of linear expansion of aluminum (see Table 18-2, page 483).

11. What is the volume of a lead ball at 30.0⁰C if the ball's volume at 60.0⁰C is 50.0 cm³?

For a volume expansion:

$$\Delta V = V\beta\Delta T = 50.0\times(3\times29\times10^{-6})(60.0-30.0) = 0.13(\text{cm}^3)$$

$$V_{30^0 C} = V - \Delta V = 50.0 - 0.13 = 49.87(\text{cm}^3)$$

15. A steel rod is 3.0 cm in diameter at 25.0⁰C. A brass ring has an interior diameter of 2.992 cm at 25.0⁰C. At what common temperature will the ring just slide onto the rod?

For a linear expansion of the steel rod:

$$D_{steel} = D_{steel,0} + D_{steel,0}\alpha_s \Delta T$$

For a linear expansion of the brass ring:

$$D_{brass} = D_{brass,0} + D_{brass,0}\alpha_b \Delta T$$

If the ring just slides onto the rod, so $D_{steel} = D_{brass}$

$$\Delta T = \frac{D_{steel,0} - D_{brass,0}}{D_{brass,0}\alpha_b - D_{steel,0}\alpha_s}$$

$$\Delta T = \frac{3.0 - 2.992}{2.992 \times 19 \times 10^{-6} - 3.0 \times 11 \times 10^{-6}} = 335.5^0$$

$$T = 25 + 335.5 = 360.5^0 C$$

19. A 1.28m-long vertical glass tube is half filled with a liquid at 20^0C. How much will the height of the liquid column change when the tube is heated to 30^0C? Take $\alpha_{glass}=1.0\times10^{-5}/K$ and $\beta_{liquid}=4.0\times10^{-5}/K$.

Here, we need to consider the cross-sectional area expansion of the glass and the volume expansion of the liquid:

$$\Delta A = A_0(2\alpha)\Delta T$$

$$\Delta V = V_0\beta\Delta T$$

$$h = \frac{V}{A} = \frac{V_0 + \Delta V}{A_0 + \Delta A} = \frac{V_0(1+\beta\Delta T)}{A_0(1+2\alpha\Delta T)} = h_0\frac{(1+\beta\Delta T)}{(1+2\alpha\Delta T)}$$

$$\Delta h = h - h_0 = h_0\left[\frac{(1+\beta\Delta T)}{(1+2\alpha\Delta T)}-1\right]$$

$$h_0 = \frac{1.28}{2} = 0.64 \text{ (m)}; \Delta T = 30^0C - 20^0C = 10^0$$

$$\boxed{\Delta h = 1.28\times10^{-4}\text{ (m)}}$$

21. As a result of a temperature rise of 32^0C, a bar with a crack as its center buckles upward. If the fixed distance L_0 is 3.77 m and the coefficient of linear expansion of the bar is $25 \times 10^{-6}/C^0$, find the rise x of the center.

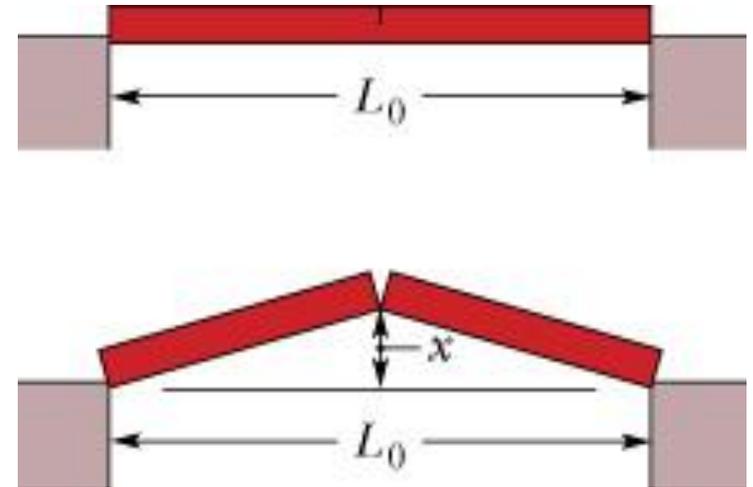For a linear expansion:

$$L - L_0 = L_0 \alpha \Delta T$$

$$x^2 = l^2 - l_0^2 = (l_0 + l_0 \alpha \Delta T)^2 - l_0^2$$

where $l = L/2$; $l_0 = L/2$

$$x^2 = l_0^2 (1 + \alpha \Delta T)^2 - l_0^2 \approx 2 l_0^2 \alpha \Delta T$$

(using the binomial theorem, see Appendix E)

$$x = l_0 \sqrt{2\alpha \Delta T} = \frac{3.77}{2} \sqrt{2 \times 25 \times 10^{-6} \times 32} = 75.4 \times 10^{-3} (m) = 75.4 (mm)$$

25. A certain diet doctor encourages people to diet by drinking ice water. His theory is that the body must burn off enough fat to raise the temperature of the water from 0.00⁰C to the body temperature of 37.0⁰C. How many liters of ice water would have to be consumed to burn off 454 g (about 1 lb) of fat, assuming that burning this much fat requires 3500 Cal be transferred to the ice water? Why is it not advisable to follow this diet? (One liter : 10³ cm³. The density of water is 1.00 g/cm³.)

1 food calorie = 1000 cal
The mass of water needs to drink:

$$m = \frac{Q}{c\Delta T} = \frac{3500 \times 1000\,(cal)}{1(cal/g.K) \times (37-0)^0 C} = 94.6 \times 10^3\,(g)$$

$$V = \frac{m}{\rho} = \frac{94.6 \times 10^3\,g}{1000\,g/liter} = 94.6\,(liters)$$

too much water to drink!!!

30. A 0.4 kg sample is placed in a cooling apparatus that removes energy as heat at a constant rate. The figure below gives T of the sample vs. time t; the sample freezes during the energy removal. The specific heat of the sample in its initial liquid phase is 3000 J/kg K^{-1}. What are (a) the sample's heat of fusion and (b) its specific heat in the frozen phase?

<u>Key issue:</u> The cooling apparatus removes energy as heat at a constant rate.
The rate of removed energy as heat (per minute):

$$R = \frac{Q_{cooling}}{t_{cooling}} = \frac{cm\Delta T}{t_{cooling}}$$

$$R = 900 \ (\text{J/min})$$
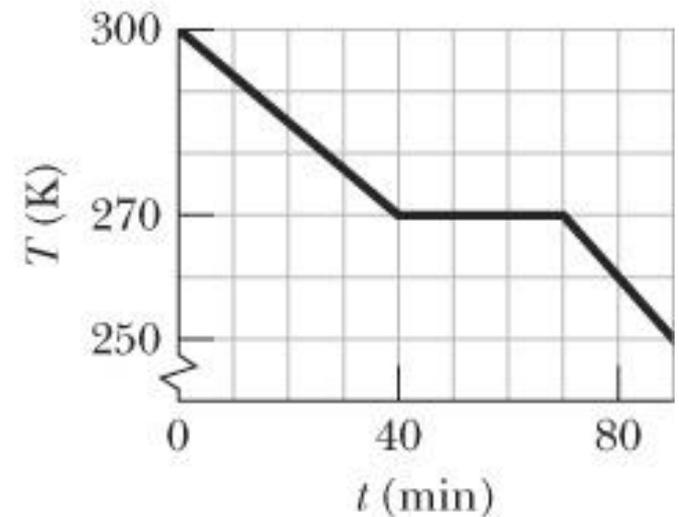
(a)

$$Q_{freezing} = 900 \ (\text{J/min}) \times 30 \ (\text{min}) = 27000 \ (\text{J}) \text{ or } 27 \ (\text{kJ})$$

$$Q_{freezing} = L_F m \Rightarrow L_F = 67.5 \ (\text{kJ/kg})$$

(b) $Q_{frozen} = cm\Delta T \Rightarrow c = \dfrac{Q_{frozen}}{m\Delta T} = \dfrac{R \times 20(\text{min})}{m \times 20(^0)} = 2250 \left(\dfrac{J}{kg.K} \right)$

32. The specific heat of a substance varies with temperature according to c=0.20+0.14T+0.023T², with T in ⁰C and c in cal/g K⁻¹. Find the energy required to raise the temperature of 1.0 g of this substance from 5⁰C to 15⁰C.

$$Q = cm\Delta T$$

In the case here:

$$c = c(T)$$

$$dQ = cmdT$$

$$Q_{total} = \int_{T_1}^{T_2} cmdT = m\int_{T_1}^{T_2} cdT = m\int_{T_1}^{T_2} (0.20 + 0.14T + 0.023T^2)dT$$

Chapter 2 Heat, Temperature and the First Law of Thermodynamics

2.4. Work and Heat in Thermodynamic Processes

We change a system, which is a gas confined to a cylinder with a movable piston, from an initial state p_i, V_i, T_i to a final state p_f, V_f, T_f:
- The procedure for changing the system from its initial state to its final one is called a thermodynamic process.
- During a thermodynamic process, energy as heat may be transferred into the system from a thermal reservoir (positive heat) or vice versa (negative heat). Work can also be done by the system by raising (positive work) or lowering the piston (negative work).
- The differential work dW done by the system for a differential displacement $d\vec{s}$:

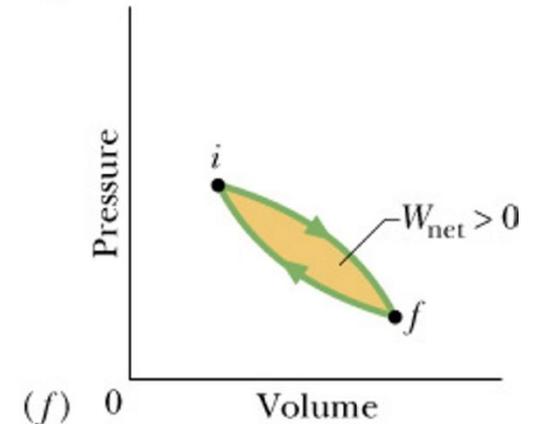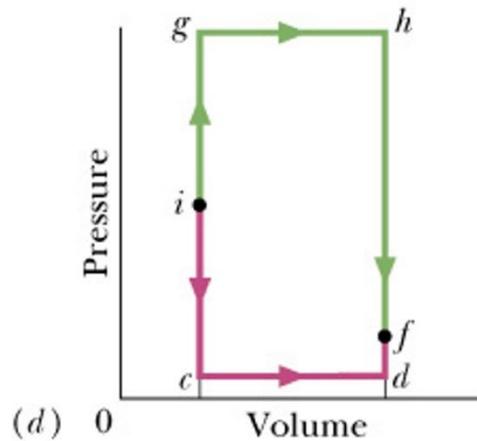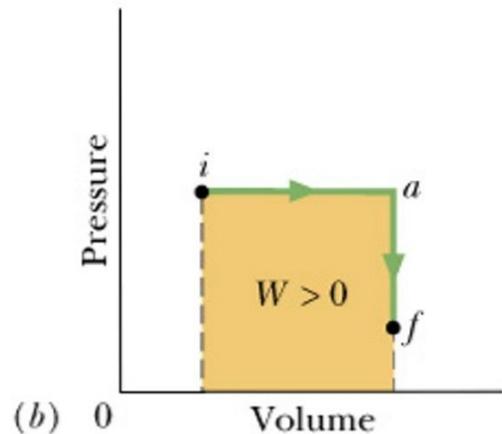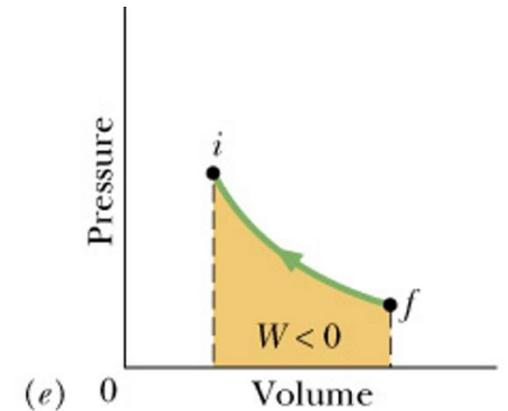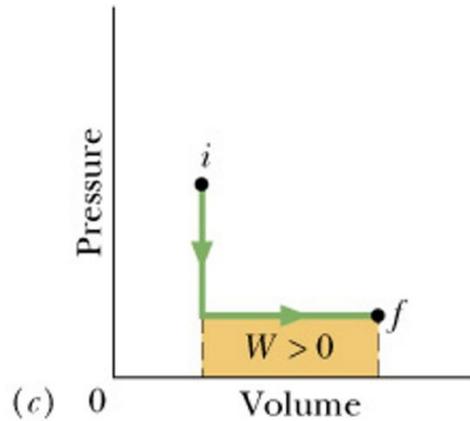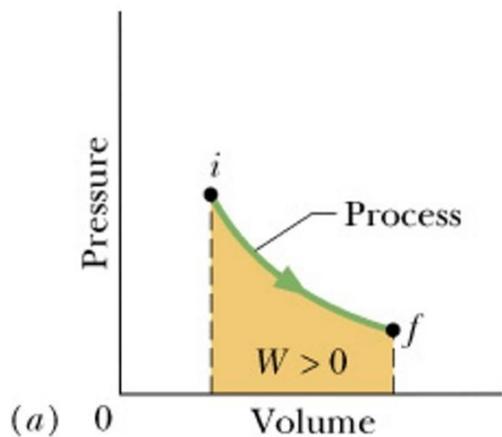$$dW = \vec{F}d\vec{s} = (pA)(ds) = p(Ads) = pdV$$

$\vec{F}$: the force exerted by the gas on the piston;
A: the cross-sectional area of the piston;
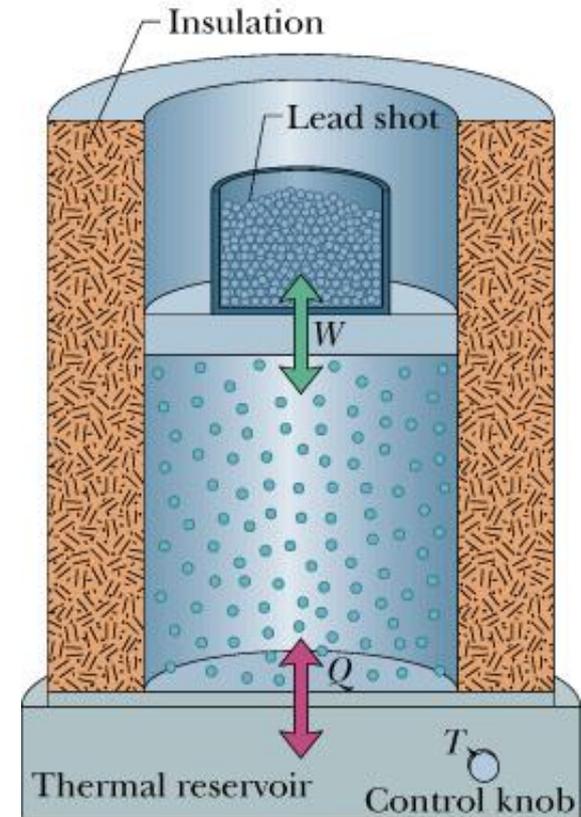
- **The total work done by the gas is:**

$$W = \int dW = \int_{V_i}^{V_f} p\, dV$$

- **Many ways to change the gas from state i to f:**

- **(f): The net work done by the gas for a complete cycle $W_{net} > 0$.**

Checkpoint 4: The p-V diagram here shows 6 curved paths (connected by vertical paths) that can be followed by a gas. Which two of the curved paths should be part of a closed cycle (those curved paths plus connecting vertical paths) if the net work done by the gas during the cycle is to be at its maximum positive value?
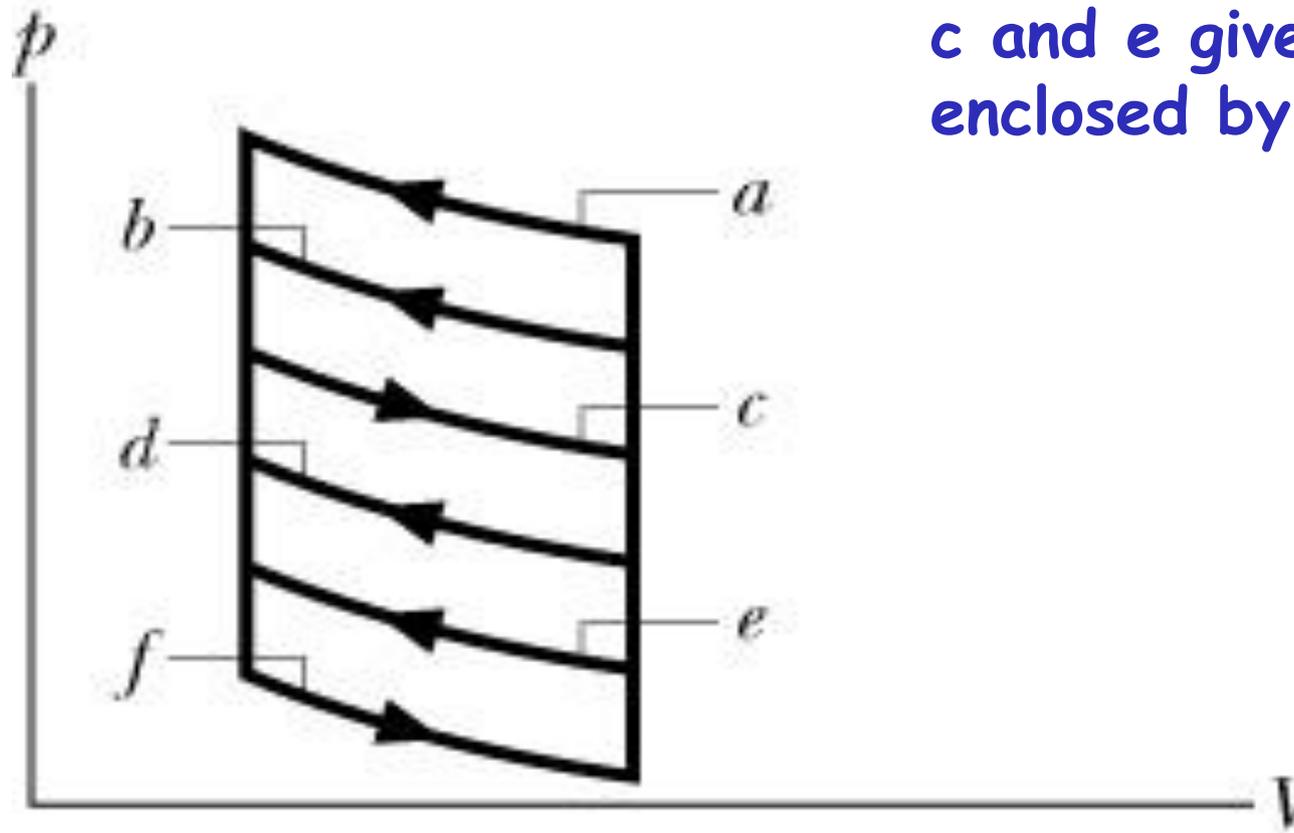
c and e gives a maximum area enclosed by a **clockwise** cycle

2.5. The First Law of Thermodynamics and Some Special Cases

• **The first law of thermodynamics:**
  - When a system changes from state i to state f:
    + The work W done by the system depends on the path taken.
    + The heat Q transferred by the system depends on the path taken.

 However, the difference Q-W does NOT depend on the path taken. It depends only on the initial and final states.
The quantity Q-W therefore represents a change in some intrinsic property of the system and this property is called the internal energy E_{int}.

$$\Delta E_{int} = E_{int,f} - E_{int,i} = Q - W$$

 For a differential change:

$$dE_{int} = dQ - dW$$

The internal energy E_{int} of a system tends to increase if energy is added as heat Q and tends to decrease if energy is lost as work done by the system.

Let W_{on} be the work done on the system:
$$W_{on} = -W$$
$$\Delta E_{int} = Q + W_{on}$$

Checkpoint 5: In the figure below, rank the paths according to (a) ΔE_{int}, (b) W done by the gas, (c) Q; greatest first.

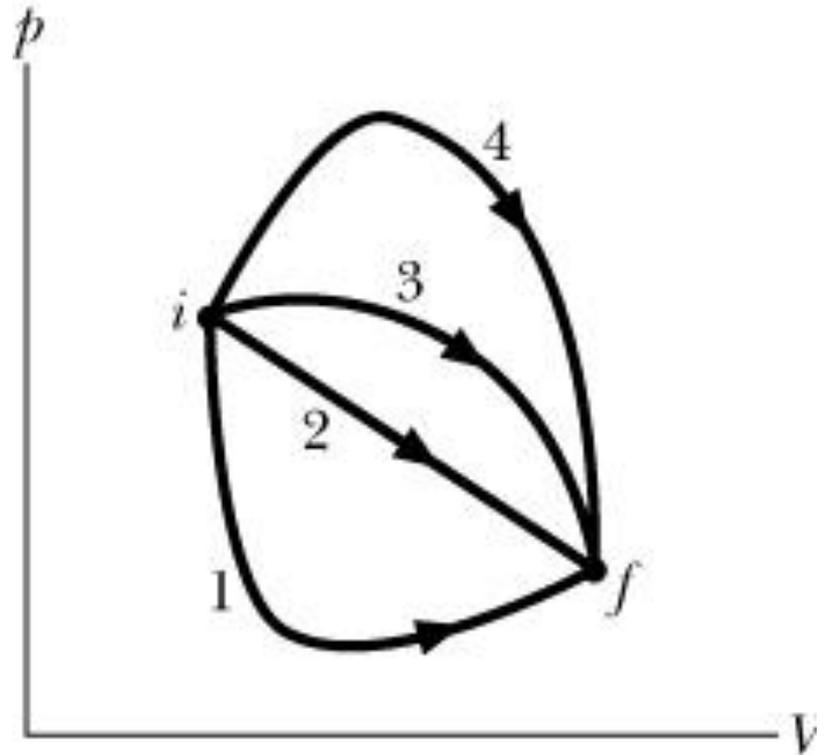$$\Delta E_{int} = Q - W$$

(a) all tie (only depending on i and f)
(b) 4-3-2-1
(c) Q = ΔE_{int} + W
so the ranking is 4-3-2-1

- **Some special cases:**

$$\Delta E_{int} = Q - W$$

1. Adiabatic processes: Q=0
(no transfer of energy as heat)
- A well-insulated system.
- Or a process occurs very rapidly.

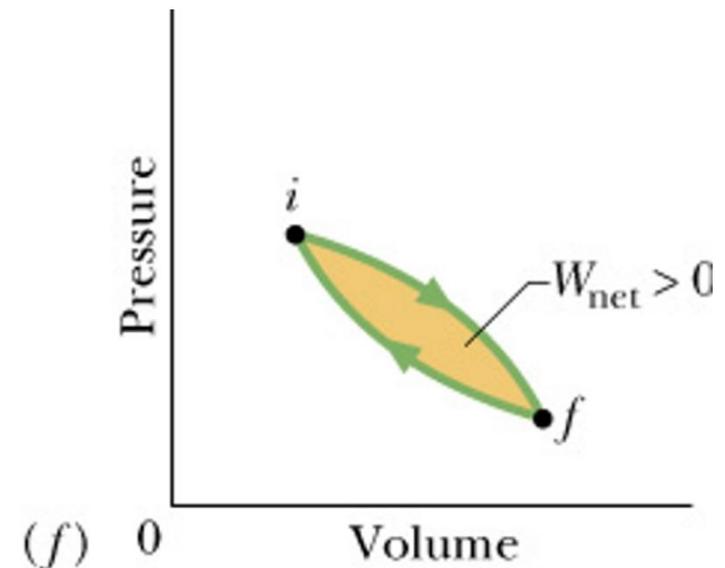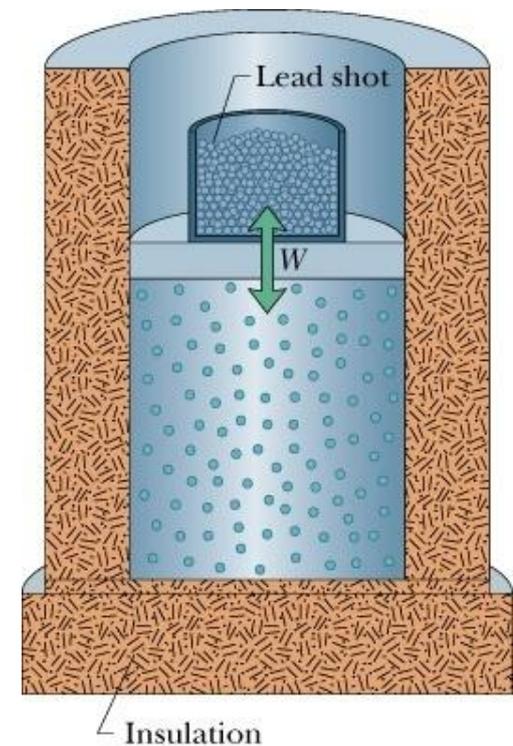$$\Delta E_{int} = -W$$

2. Constant-volume (isochoric) processes:
W=0 (no work done by the system)

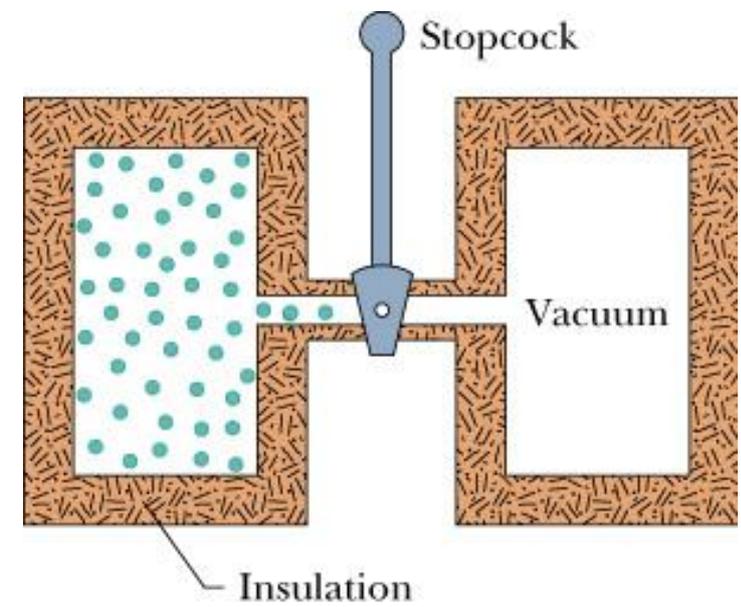$$\Delta E_{int} = Q$$

3. Cyclical processes: ΔE_{int}=0
In these processes, after some interchanges
of heat and work, the system is restored to
its initial state.

$$Q = W$$

Lead shot
W
Insulation

Pressure
i
$W_{net} > 0$
f
(f) 0   Volume

4. Free expansion: Q=W=0

$$\Delta E_{int} = 0$$

Stopcock

Vacuum

Insulation

Animation

Checkpoint 6: One complete cycle is shown (see figure). Are (a) ΔE_{int} for the gas and (b) the net energy transferred as heat Q positive, negative, or zero?

(a) zero
(b) the cycle direction is counterclockwise, so W < 0, thus Q < 0

Homework:

43, 44, 46, 47, 48, 49, 50 (pages 502, 503)