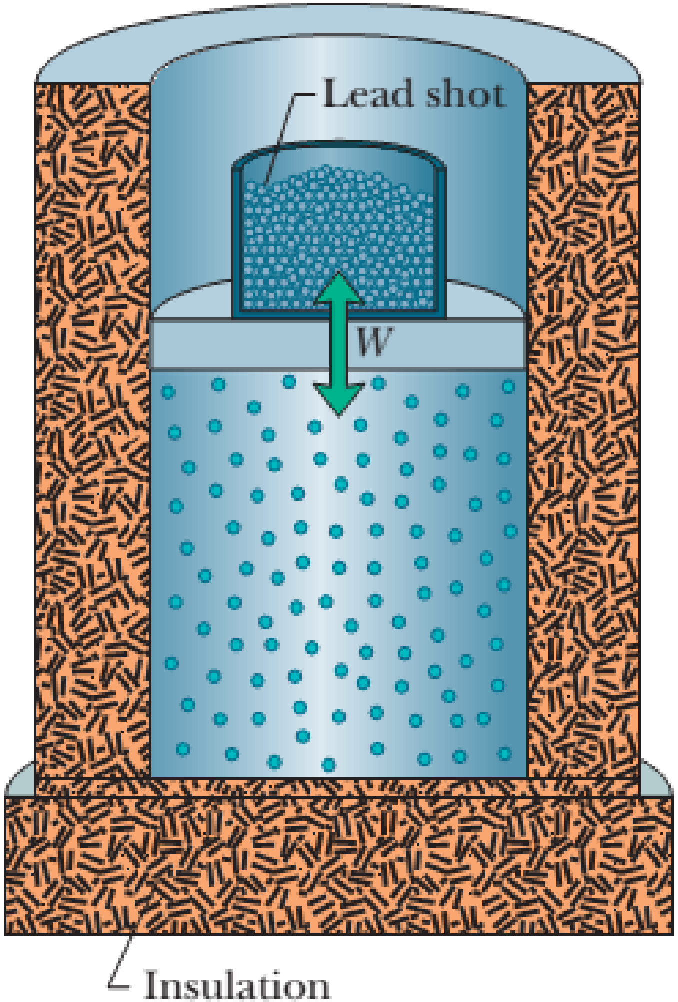
Lecture 4
Chapter 18: Temperature, heat and the first law of thermodynamics

15.5 Some Special Cases of the First Law of Thermodynamics



Adiabatic processes

An adiabatic process is one that occurs so rapidly or occurs in a system that is so well insulated that no transfer of energy as heat occurs between the system and its environment .

$Q = 0$

1st law of thermodynamics for ADIABATIC PROCESS,

$$\Delta E_{int} = Q - W = 0 - W$$

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

- This tells us that if work is done by the system (that is, if W is positive), the internal energy of the system decreases by the amount of work. $\Delta E_{int} = -(+W) = -W$

- Conversely, if work is done on the system (that is, if W is negative), the internal energy of the system increases by that amount. $\Delta E_{int} = -(-W) = +W$

Constant-volume processes

If the volume of a system is held constant, that system can do no work.

$W = p\Delta V = p(V\text{-}V) = p(0) = 0$

1st law of thermodynamics for CONSTANT-VOLUME PROCESS

$$\Delta E_{int} = Q - W = Q - 0$$

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

- Thus, if heat is absorbed by a system (that is, if Q is positive), the internal energy of the system increases.

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

- Conversely, if heat is lost during the process (that is, if Q is negative), the internal energy of the system decreases.

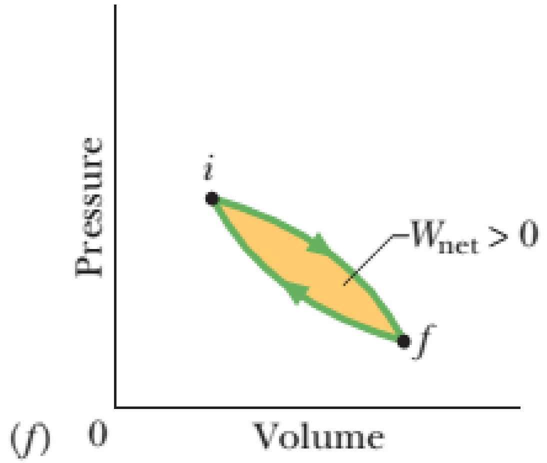
$$\Delta E_{int} = -Q$$

Cyclical processes

There are processes in which, after certain interchanges of heat and work, the system is restored to its initial state. In that case, no intrinsic property of the system—including its internal energy—can possibly change.

$\Delta E_{int} = E_f - E_i = E_f - E_f = 0$

$[E_i = E_f]$



1st law of thermodynamics for cyclical process

ΔE_{int} = Q – W

0 = Q - W

Q = W

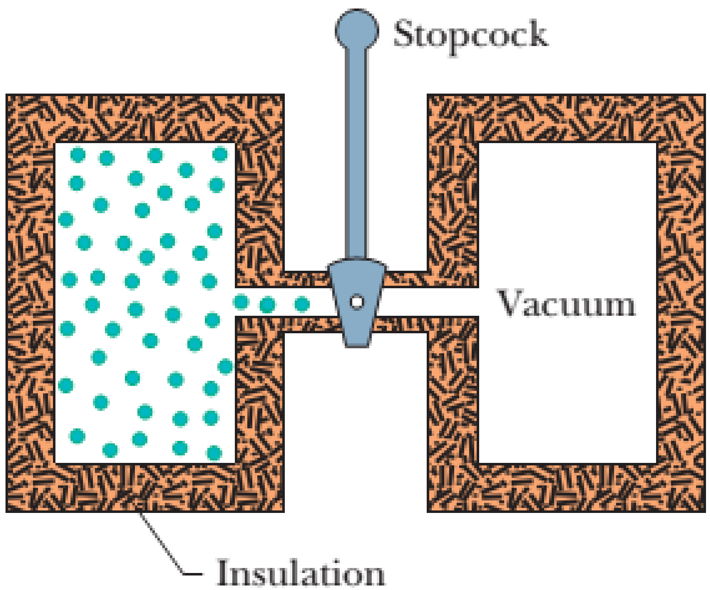
Thus, the net work done during the process must exactly equal the net amount of energy transferred as heat; the store of internal energy of the system remains unchanged.

4. **Free expansions:** These are adiabatic processes in which no transfer of heat occurs between the system and its environment and no work is done on or by the system .

$Q = W = 0$

1st law of thermodynamics, $\Delta E_{int} = Q - W = 0 - 0 = 0$

$\Delta E_{int} = 0$ (free expansion).



46. Suppose 200 J of work is done on a system and 70.0 cal is extracted from the system as heat. In the sense of the first law of thermodynamics, what are the values (including algebraic signs) of (a) W, (b) Q, and (c) ΔE_{int} .

Solution:

(a) The work done is negative since work done on the system.

$$W = - 200 \text{ J}$$

(b) Energy is extracted from the system,

$Q = - 70 \text{ cal} = - 70(4.2) \text{ J} = - 294 \text{ J}$ [1 cal = 4.2 J]

(c) Internal energy change,

$\Delta E\_int = Q - W = (- 294) - (- 200) = - 294 + 200 = - 94 \text{ J}$

48. As a gas is held within a closed chamber, it passes through the cycle shown in Fig. Determine the energy transferred by the system as heat during constant-pressure process CA if the energy added as heat Q_{AB} during constant-volume process AB is 20.0 J, no energy is transferred as heat during adiabatic process BC, and the net work done during the cycle is 15.0 J.

Given: Q_{CA}=?, Q_{AB}= +20 J, Q_{BC}=0, W = +15 J

$First\ law\ of\ thermodynamics, \Delta E_{int}$= Q – W

For a cyclical process,

ΔE_{int}= E – E = 0

0 = Q – W

Q = W

$Q_{AB} + Q_{BC} + Q_{CA} = W$

$+20 + 0 + Q_{CA} = +15$

Q_{CA} = - 5 J

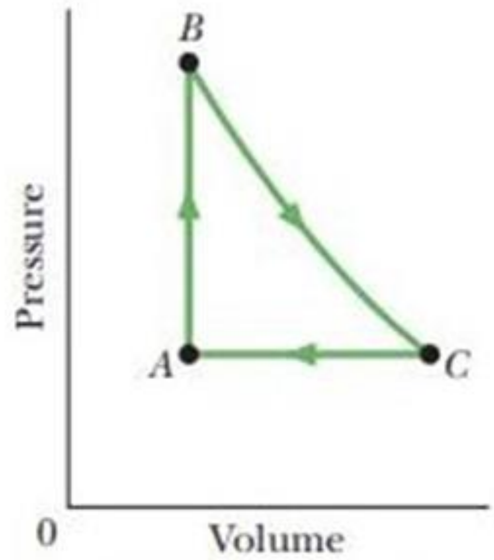


Figure 18-41 Problem 48.

Sample Problem 18.05: First law of thermodynamics: work, heat, internal energy change

Let 1.00 kg of liquid water at 100^0C be converted to steam at 100^0C by boiling at standard atmospheric pressure (which is 1.00 atm or 1.01×10^5 Pa) in the arrangement of Fig. 18-17. The volume of that water changes from an initial value of 1.00×10^{-3} m^3 as a liquid to 1.671 m^3 as steam.

(a) How much work is done by the system during this process?

(b) How much energy is transferred as heat during the process?

(c) What is the change in the system's internal energy during the process?

$$W = \int_{V_i}^{V_f} p\, dV = p \int_{V_i}^{V_f} dV = p(V_f - V_i)$$

$$= (1.01 \times 10^5\ \text{Pa})(1.671\ \text{m}^3 - 1.00 \times 10^{-3}\ \text{m}^3)$$

$$= 1.69 \times 10^5\ \text{J} = 169\ \text{kJ}. \qquad \text{(Answer)}$$

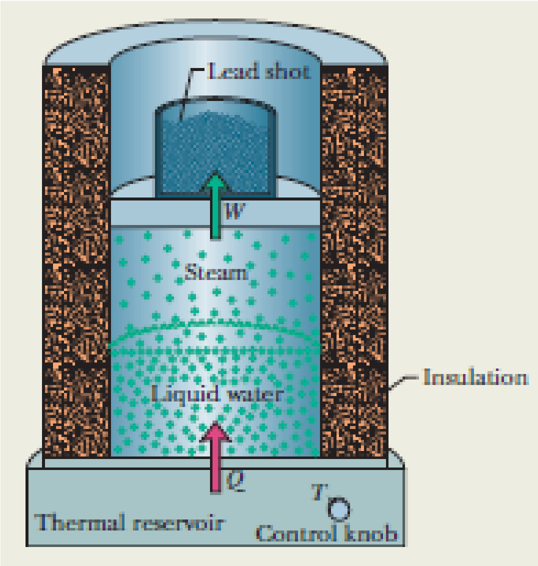


Figure 18-17 Water boiling at constant pressure. Energy is transferred from the thermal reservoir as heat until the liquid water has changed completely into steam. Work is done by the expanding gas as it lifts the loaded piston.