The First Law of Thermodynamics

Thermodynamic Work

- Consider a piston filled with a gas and sealed with a movable piston as shown below
- If the gas is compressed quasi-statically (slowly enough to allow the system to remain in thermal equilibrium at all times), the differential element of work dW done on the gas as the piston moves a distance dy is

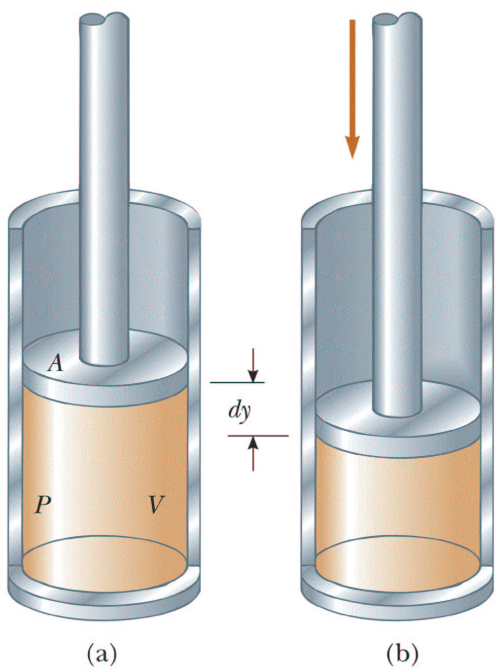
$$dW = \vec{F} \cdot d\vec{r} = \left(-F\hat{j}\right) \cdot \left(-dy\hat{j}\right) = Fdy = PAdy$$

  where P is the pressure of the gas and A is the area of the piston.

- Note that the volume of the cylinder decreases by an amount Ady, so we can write the differential change in the volume of the cylinder $-dV = Ady$, and the differential element of work done on the gas as

$$dW = -PdV$$

Serway/Jewett; Principles of Physics, 3/e
Figure 17.4



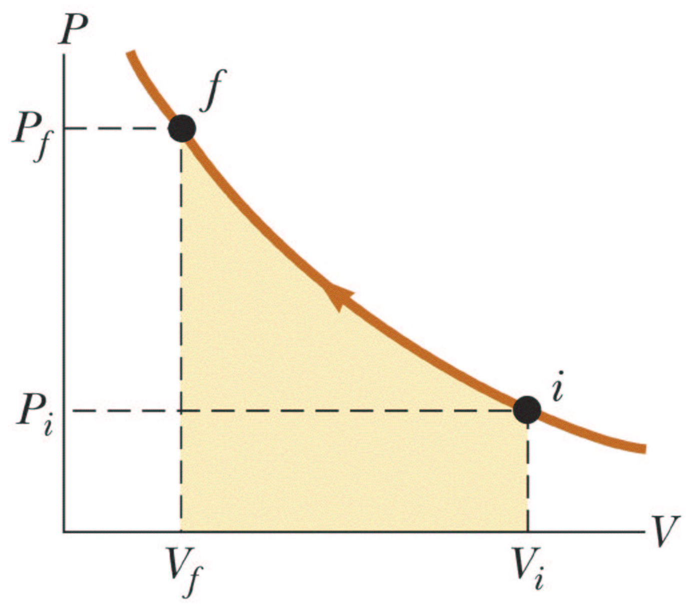
Thermodynamic Work II

- The total work done on the gas as its volume changes form V_i to V_f is

$$W = -\int_{V_i}^{V_f} P\,dV$$

- The work done on the gas is the negative of the area under the curve on a PV diagram

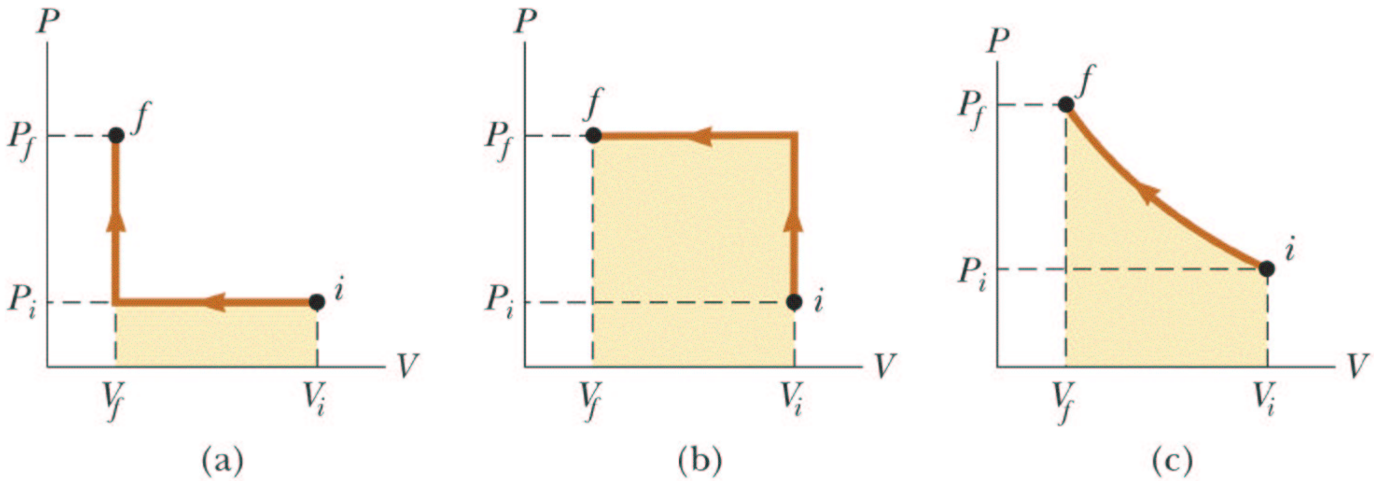
Serway/Jewett; Principles of Physics, 3/e
Figure 17.5



Path Dependence of Thermodynamic Work

- The work done on a gas as it is taken from an initial state to a final state depends on the path between these states

Serway/Jewett; Principles of Physics, 3/e
Figure 17.6



The First Law of Thermodynamics

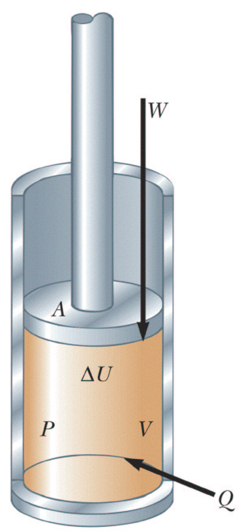
- The change in internal energy of a system is equal to the heat added to the system plus the work done on the system

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

- Statement of conservation of energy for thermodynamic systems
- Q and W separately depend on the path taken
- $\Delta E_{int} = Q + W$ does not depend on the path, but only on the initial and final states, so we call ΔE_{int} a *state variable*
- The first law can be expressed in differential form as

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

Serway/Jewett; Principles of Physics, 3/e
Figure 17.8



Example 1

Suppose 200 J of work are done on a system and 70 cal are extracted from the system. What is the change in internal energy of the system?

Example 2

A piston-cylinder arrangement contains 1.00 kg of liquid water which is converted to steam by boiling at standard atmospheric pressure. The volume changes from an initial value of $1.00 \times 10^{-3}\text{m}^3$ as a liquid to $1.671\ \text{m}^3$ as steam. (a) How much work is done on the system during the process? (b) How much energy is transferred as heat during the process? (c) What is the change in internal energy of the system during the process?

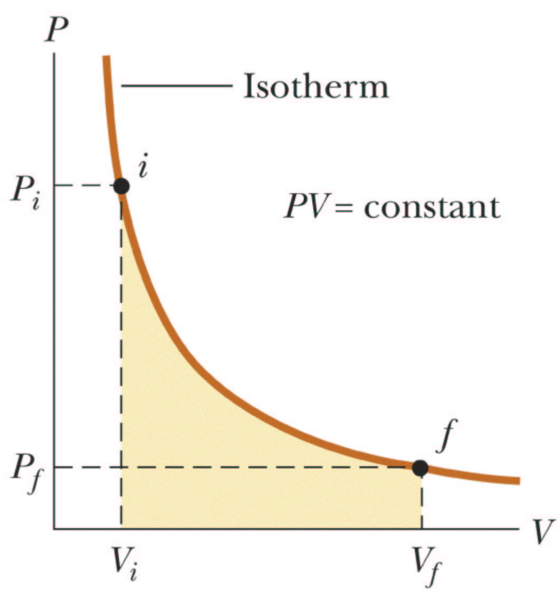
Applications of the First Law of Thermodynamics

- Cyclic process
  - Process that begins and ends at the same state
  - Since internal energy is a state variable $\Delta E_{int} = 0$
  - From the first law $Q = -W$
  - The net work done per cycle equals the area enclosed by the path representing the process on a PV diagram
- Adiabatic process
  - No heat enters or leaves the system $\Longrightarrow$ Q = 0
  - From the first law we have $\Delta E_{int} = W$
  - Free expansion is a unique adiabatic process in which $W = 0$ and therefore $\Delta E_{int} = 0$
- Isobaric process
  - Process that occurs at constant pressure
  - $W = -\int_{V_i}^{V_f} P\,dV = -P\int_{V_i}^{V_f} dV = -P\,(V_f - V_i)$
- Isovolumetric process
  - Process occurs at constant volume $\Longrightarrow W = 0$
  - From the first law we have $\Delta E_{int} = Q$

Applications of the First Law of Thermodynamics II

- Isothermal process
  - Process that occurs at constant temperature
  - Since the internal energy of an ideal gas is a function of temperature only, $\Delta E_{int} = 0$ for an ideal gas during an isothermal process
  - From the first law we have $Q = -W$
  - $W = -\int_{V_i}^{V_f} P\,dV = -nRT \int_{V_i}^{V_f} \frac{dV}{V} = -nRT\,\ln\left(\frac{V_f}{V_i}\right)$

Serway/Jewett; Principles of Physics, 3/e
Figure 17.9



Homework Set 5 - Due Mon. Jan. 19

- Read Sections 17..4 - 17.6
- Do problems 17.18, 17.22, 17.23, 17.27 & 17.28