Chapter 15

$Q \Rightarrow$ 

After this you can
- discuss the 1st law of thermodynamics
- discuss how a gas can do work or have work done to it
- determine the work done on a gas for constant pressure process
- discuss the graphical method of determining the work done on a gas
  when the pressure is ~~not con~~stant.

Zeroth Law → thermometers work!

First Law of Thermodynamics

Any change in energy of a system must come from outside the system.

Conservation of Energy

$$\Delta U = Q + W$$

ΔU ↑ internal energy

Q ↑ heat

W ↑ work

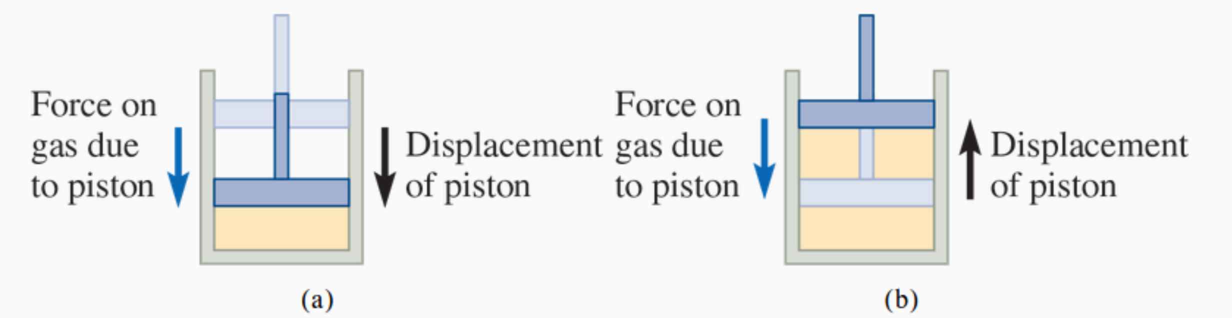


Figure 15.1 (a) When a gas is compressed, the work done on the gas by the piston is positive; the work done on the piston by the gas is negative. (b) When a gas expands, the work done on the gas by the piston is negative; the work done on the piston by the gas is positive.

Table 15.1 Sign Conventions for the First Law of Thermodynamics

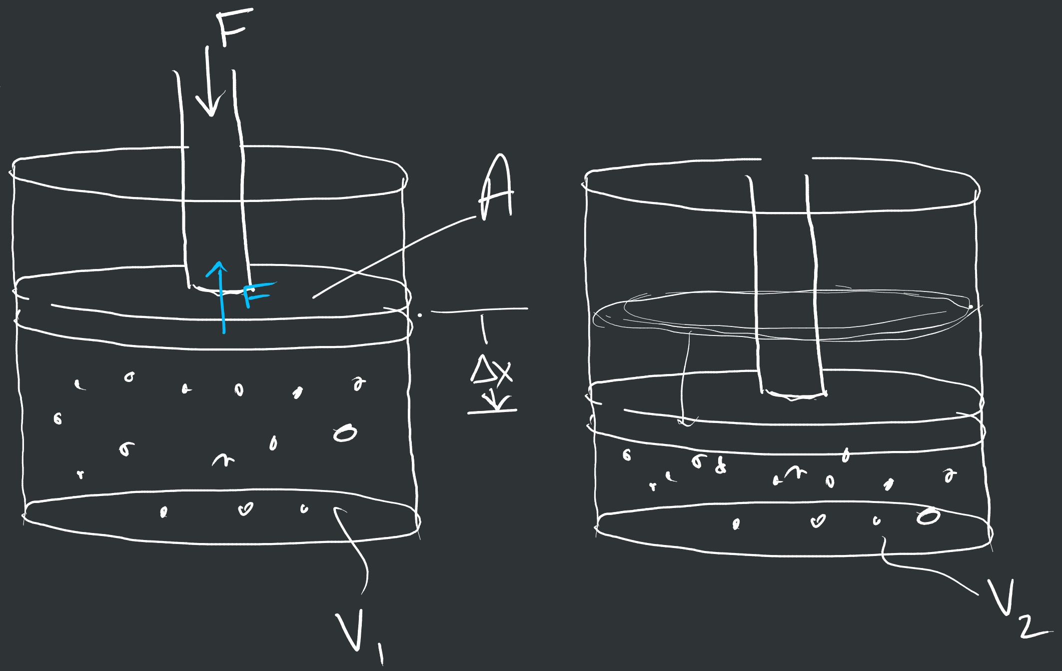
Quantity	Definition	Meaning of + Sign	Meaning of − Sign
Q	Heat flow into the system	Heat flows *into* the system	Heat flows *out of* the system
W	Work done *on* the system	Surroundings do *positive* work on the system	Surroundings do *negative* work on the system (system does positive work on the surroundings)
ΔU	Internal energy change	Internal energy *increases*	Internal energy *decreases*

Work = Force · displacement

$$W = F \cdot \Delta x$$

$$P = \frac{F}{A}$$

$$F = P \cdot A$$



$$W = P \cdot \underbrace{A \cdot \Delta x}$$

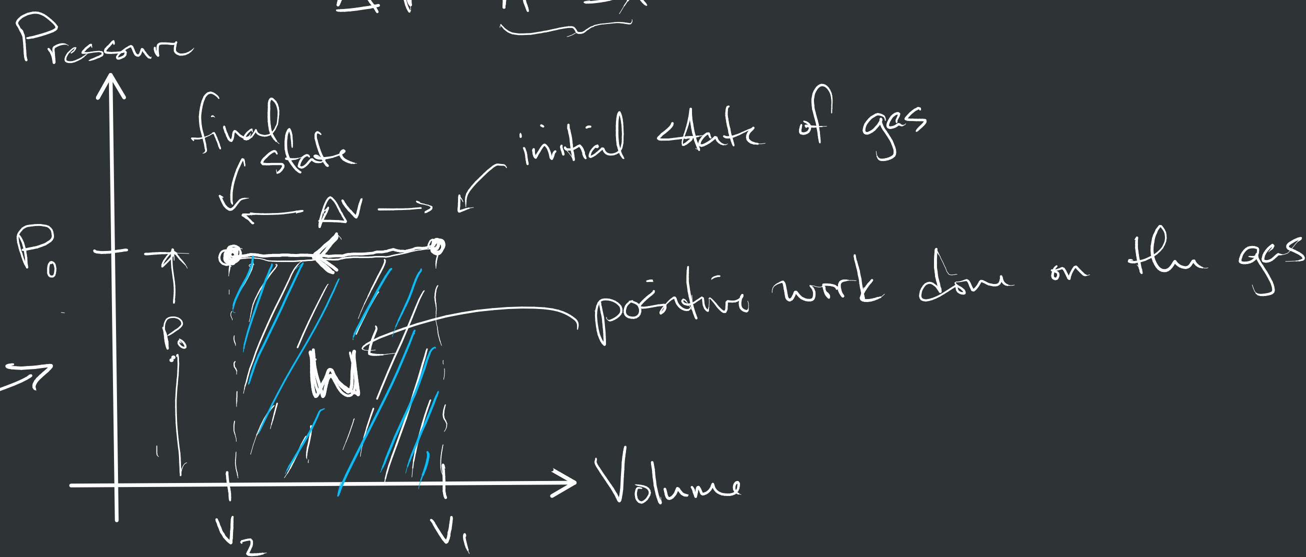
$$\Delta V = V_2 - V_1$$

$$\Delta V = \underbrace{A \cdot \Delta x}$$

$$\underbrace{W = -P\,\Delta V}$$

only applies to work done under constant pressure

"PV Diagram"



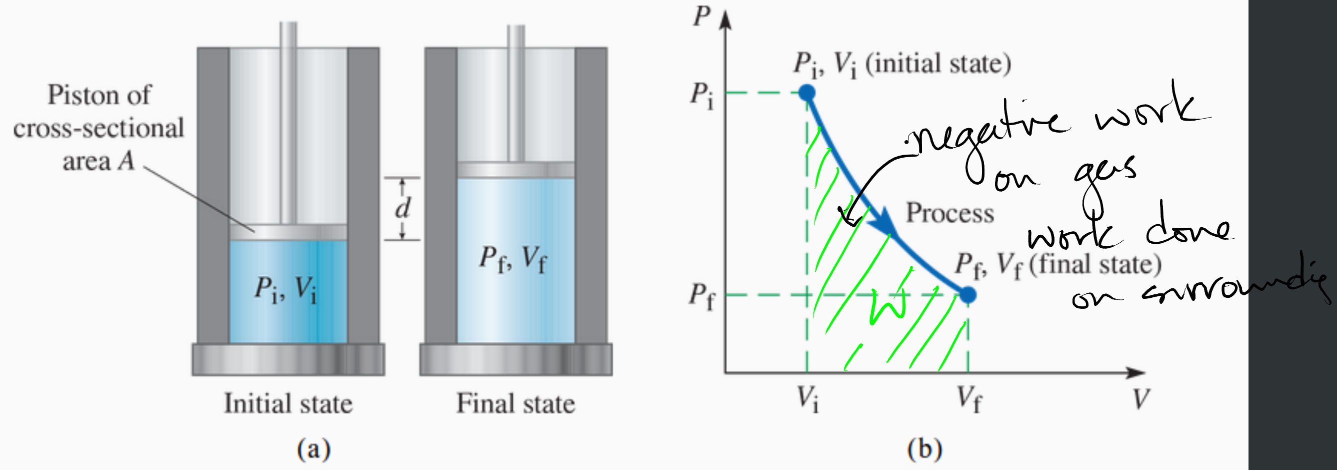


Figure 15.2 (a) Expansion of a gas from initial pressure P_i and volume V_i to final pressure P_f and volume V_f. During the expansion, *negative* work is done on the gas by the moving piston because the force exerted on the gas and the displacement are in opposite directions. (b) A *PV* diagram for the expansion shows the pressure and volume of the gas starting at the initial values P_i, V_i, and ending at the final values P_f, V_f.

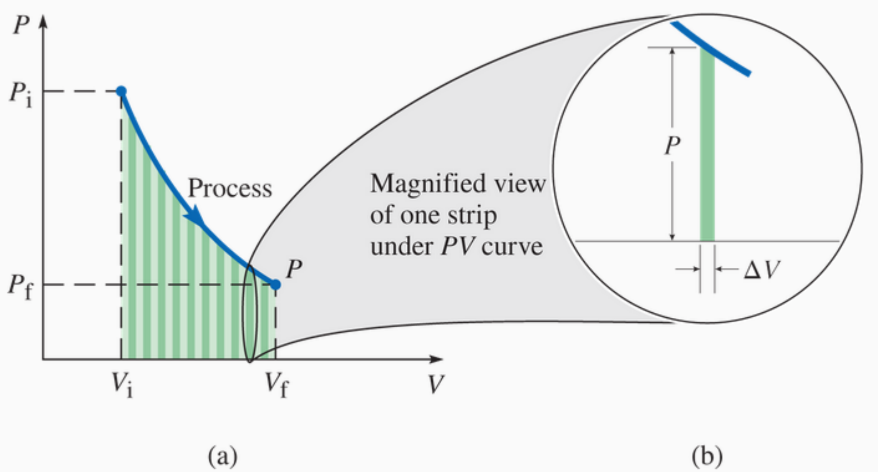
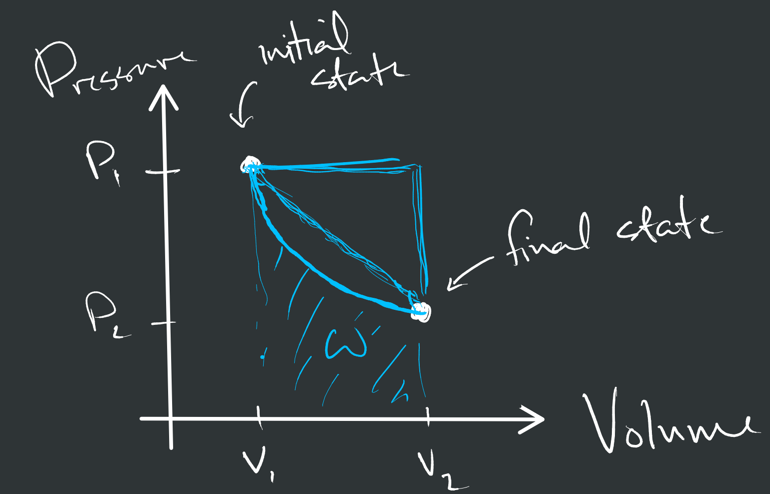


Figure 15.3 (a) The area under the *PV* curve is divided into many narrow strips of width ΔV and of varying heights P. The sum of the areas of the strips is the total area under the *PV* curve, which represents the magnitude of the work done on the gas. (b) An enlarged view of one strip under the curve. If the strip is very narrow, we can ignore the change in P and approximate its area as $P\triangle V$.

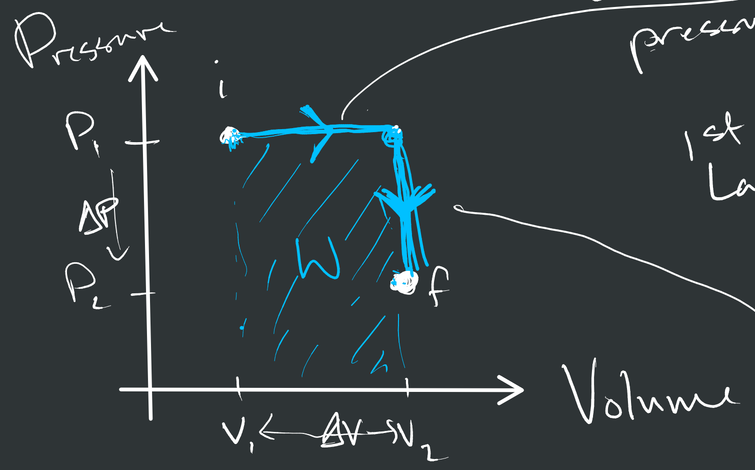
After this you can
- discuss several interesting thermodynamic process
- use the First Law of Thermo to calculate the relevant quanities

→ state is changing



Amount of work done depend on the path from one state to another state

pressure, volume, temperature



constant pressure → isobaric expansion $\Delta V > 0$

$$W = -p\Delta V$$

1st Law → $\Delta U = Q + W$

$$Q = \Delta U - W$$

$$Q = \frac{3}{2}p\Delta V + \frac{2}{2}p\Delta V$$

$$\boxed{Q = \frac{5}{2}p\Delta V}$$

(monatomic gas)

$$U = \frac{3}{2}Nk_BT$$

$$\Delta U = \frac{3}{2}Nk_B\Delta T$$

$$pV = Nk_BT$$

$$p\Delta V = Nk_B\Delta T$$

only valid for constant pressure

$$\Delta U = \frac{3}{2}p\Delta V$$

Constant volume

Isochoric process

$$W = -P\cancel{\Delta V}^{\,0}$$

$$W = 0$$

$$\Delta U = Q + \cancel{W}^{\,0}$$

$$\Delta U = Q$$

$$Q = \frac{3}{2}\Delta P \cdot V$$

$$U = \frac{3}{2} N k_B T$$

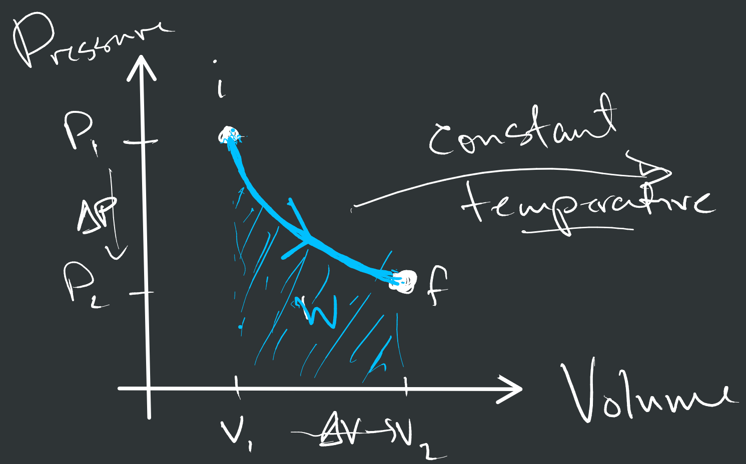
$$\Delta U = \frac{3}{2} N k_B \Delta T$$

$$PV = N k_B T$$

constant volume

$$\Delta P \cdot V = N k_B \Delta T$$

$$\Delta U = \frac{3}{2}\Delta P \cdot V$$



isothermal expansion

$$P \cdot V = N k_B T \quad \text{constant}$$

$$P = \frac{N k_B T}{V} \leftarrow \text{hyperbola}$$

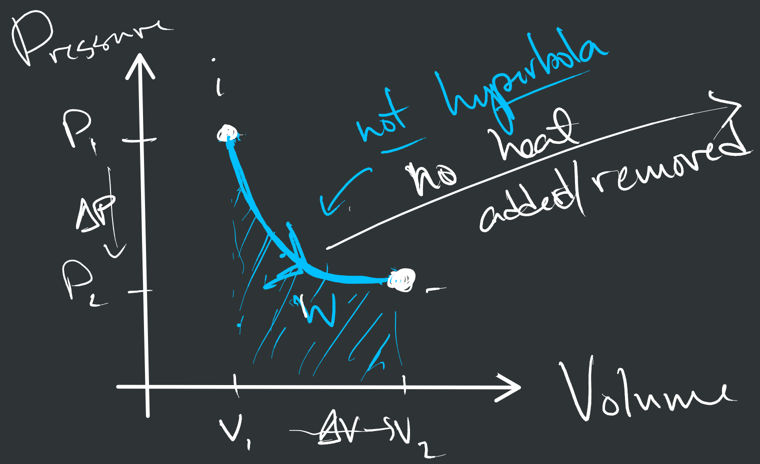
$$\Delta U = Q + W$$

$$\Delta U = \frac{3}{2} \cancel{N k_B \Delta T}^{\,0}$$

$$\Delta U = 0$$

$$0 = Q + W \Rightarrow \boxed{-W = Q}$$

$$W = N k_B T \ln\left(\frac{V_i}{V_f}\right)$$



adiabatic expansion (isentropic expansion)

→ 1. well insulated process

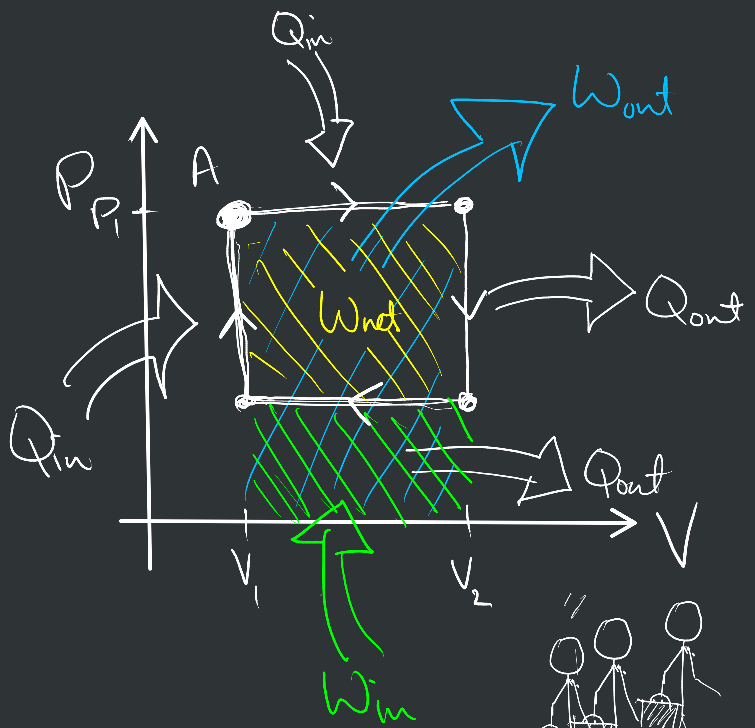
2. quick expansion

$$\dot{Q} = 0$$

$$\Delta U = \cancel{Q}^{0} + W$$

$$\Delta U = W$$

After this you can
- discuss the function of a heat engine
- apply the definition of efficiency to the context of an engine
- differentiate between the function of an engine ~~and a heat pump~~



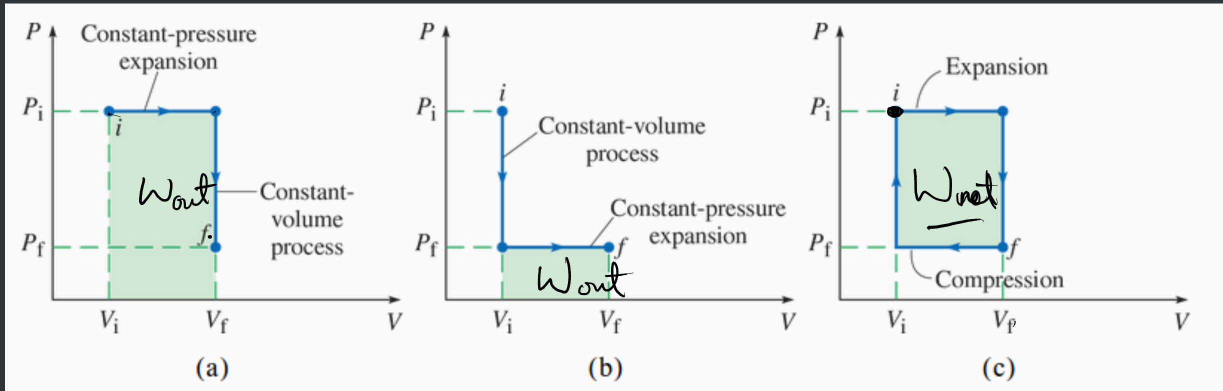
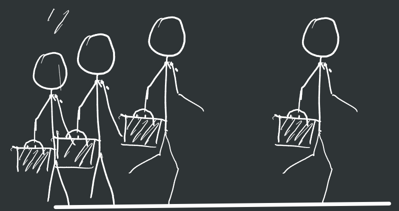
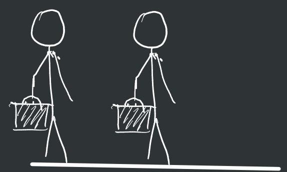
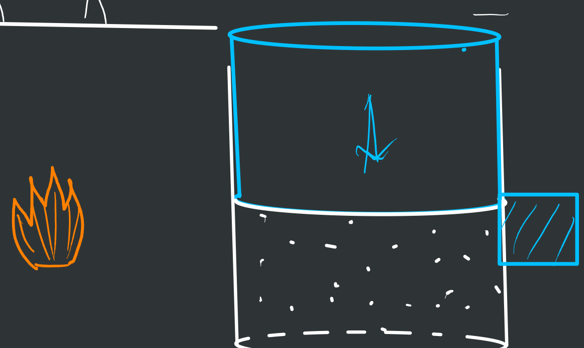


Figure 15.4 (a) and (b) Two paths between the same initial and final states as the process shown in Fig. 15.3. The magnitude of the work done on the gas is equal to the area under the graph, and is negative because the volume increases. For (a), $W = -P_i(V_f - V_i)$, and for (b), $W = -P_f(V_f - V_i)$. Note that the work done depends on the path taken between the initial and final states. (c) A closed cycle. The work done on the gas from i to f is $-P_i(V_f - V_i)$, as in (a). The work done from f back to i is $+P_f(V_f - V_i)$, the same magnitude as in (b) but opposite in sign because we have reversed the process (compression instead of expansion). The net work done during the cycle is the sum of these: $W_{net} = -P_i(V_f - V_i) + P_f(V_f - V_i) = -(P_i - P_f)(V_f - V_i)$. The magnitude of W_{net} is the area of the shaded rectangle, and the sign is negative because the negative work done during expansion (i to f) is larger in magnitude than the positive work done during compression (f to i).







for a closed cycle

$$\Delta U = 0 = Q + W_{gas}$$

$$Q_{NET} = -W_{gas}$$

$$Q_{NET} = Q_{in} - Q_{out}$$

$$= Q_H - Q_C$$

$$Q_{in} - Q_{out} = \underbrace{-W_{gas}}_{-W_{gas} = W_{out}}$$

$$Q_{in} - Q_{out} = W_{out}$$

$$\boxed{Q_{in} = \underline{\underline{W_{out}}} + \underline{\underline{Q_{out}}}}$$

<u>input</u>

useful work

exhaust

book

$$Q_H = W_{NET} + Q_C$$

$$\text{efficiency} = \frac{\text{what you get}}{\text{what you pay for}} \times 100\%$$

$$= \frac{\text{useful work}}{\text{heat in}}$$

$$e = \frac{W_{out}}{Q_{in}} \times 100\% \;\rightsquigarrow\; e = \frac{W_{out}/t}{Q_{in}/t} = \frac{\text{Power out}}{\text{rate of heat input}}$$

mechanical power out

heat power in