Chapter 19: The First Law of Thermodynamics

- What is a “system”? What is “status” of a system? What is a “process”?
- How the energy conservation works for a system?
- How to calculate the “work” done by a system to the environment?
- How many kinds of processes are there?
- How much is C_p of an ideal gas system?

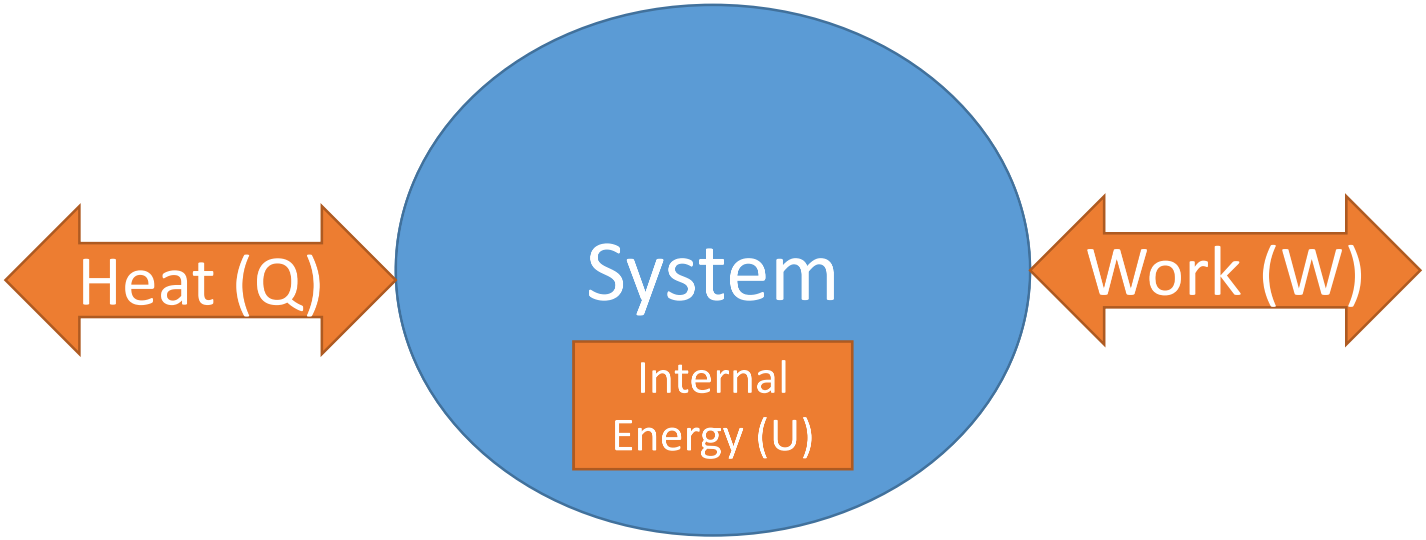
What is a “system”? What is “status” of a system? What is a “process”?

- What is a “system”?
  - A (closed) system is any collection of objects that is convenient to regard as a unit for analysis, and that may have the potential to exchange energy (either by heat or work) with its surroundings.

- What is a “status” of a system?
  - A status is to describe the states of a system. It does not show information of the history of the system, rather it only describe its thermodynamic states (e.g. temperature, volume, pressure, number of molecules etc.)

- What is a “process”?
  - A process is to describe how the system evolve from one status (initial state) to the other status (final state). Different process could have different evolution of internal energy, heat and work done by the system.

How does the energy conservation work for a system?



Use the system as the "viewer"

+Q means "add heat in" **(IN)**

+U means "increase internal energy"

+W means "do work to the environment" **(OUT)**

Energy Conservation Law

Your total asset has $x_{morning}$ amount of money in the morning, you make y amount today, and spend z amount of money. What is your total asset in the end of today, x_{night}?

$$x_{night} = x_{morning} + y - z$$

A system has an initial total internal energy U_i, it absorb heat Q, and did a work W to the environment. What is the final total internal energy, U_f, of the system?

$$U_f = U_i + Q - W$$

The First Law of Thermodynamics

$$\Delta U = U_f - U_i = Q - W$$

For a process

$$dU = dQ - dW$$

For a infinitesimal process

The First Law of Thermodynamics is actually an "**Energy Conservation Law**"

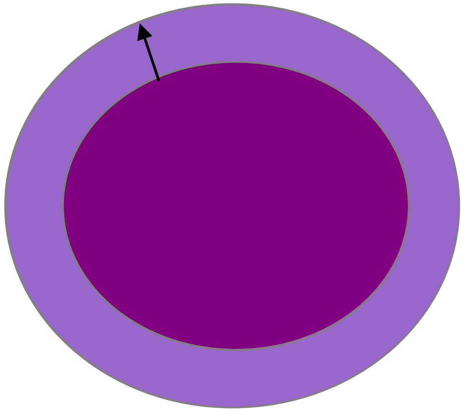
Note: This law **doesn't have assumption of "ideal gas**". Which means it works for all kinds of systems.

How to calculate the "work" done by a system to the environment?

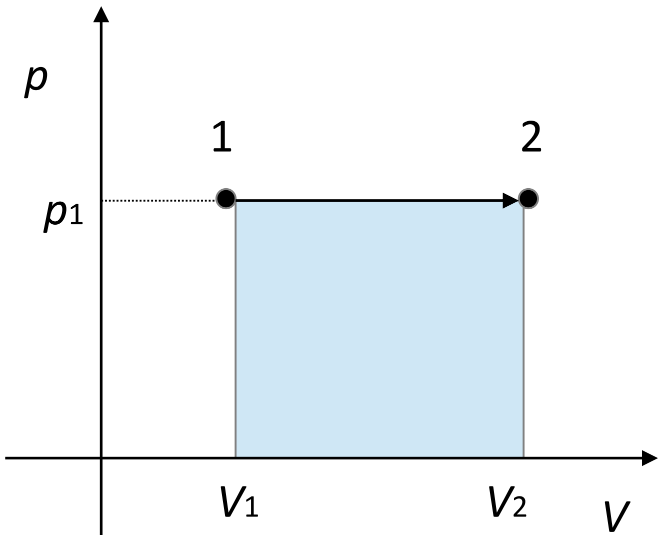
Definition of "Work" $W = \vec{F} \cdot \vec{s}$

$$dW = p \cdot dA \cdot s = p \cdot dV$$

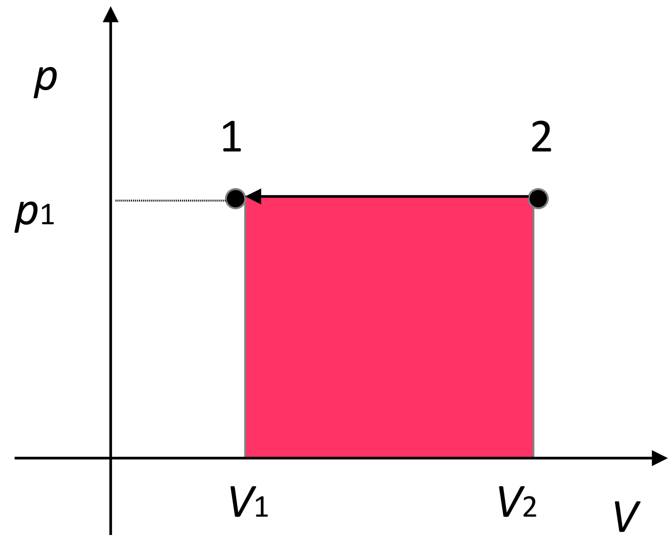
$$W = \int_{V_1}^{V_2} p \cdot dV$$



Examples for calculation work done by the system

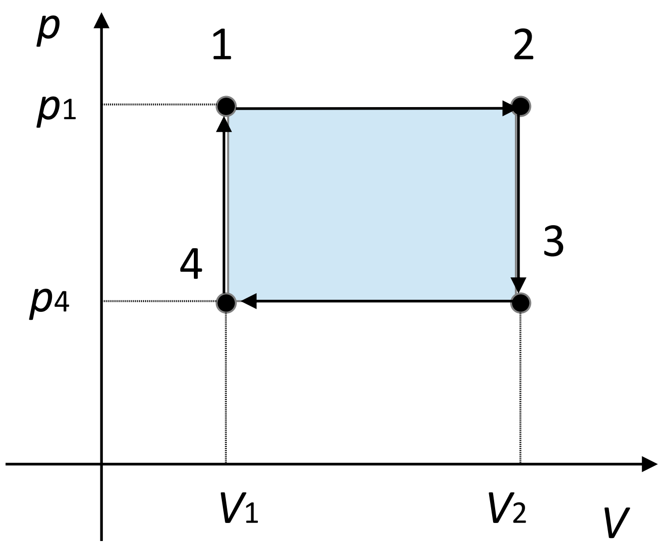


$W = p\,(V_2 - V_1) > 0$

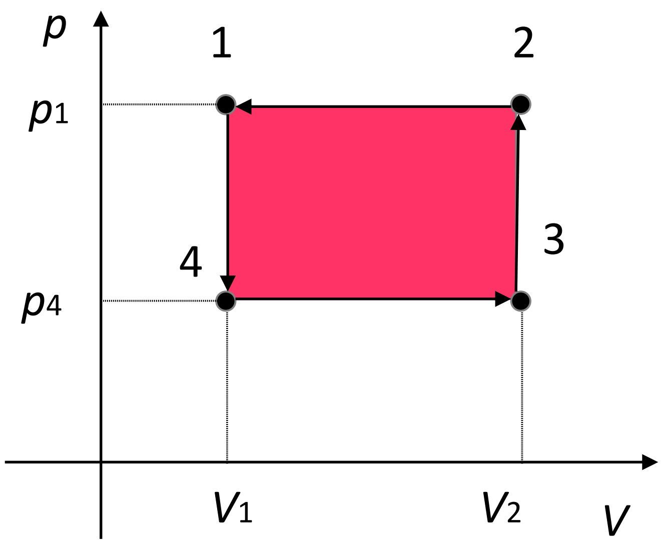


$W = p\,(V_1 - V_2) < 0$

Examples for calculation work done by the system



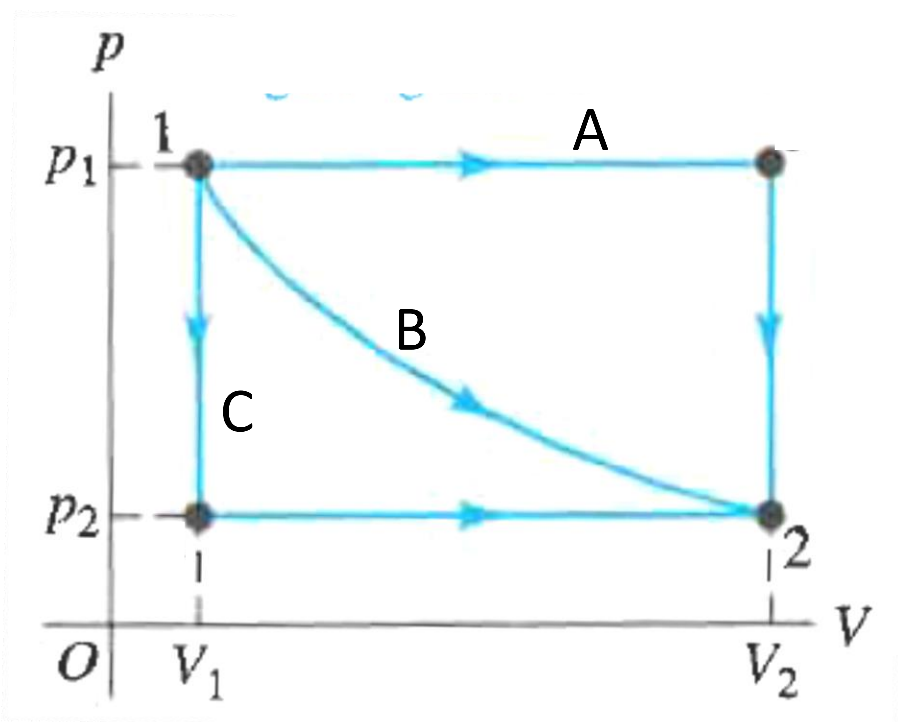
$W = p_1 (V_2 - V_1) + p_4 (V_1 - V_2) > 0$



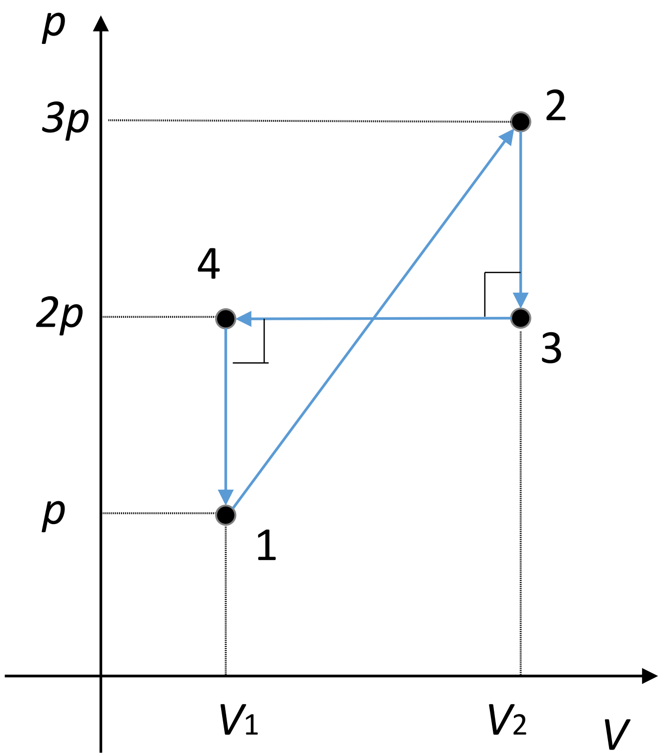
$W = p_4 (V_2 - V_1) + p_1 (V_1 - V_2) > 0$

Quiz

For a system, if you want to change the status of the system from point 1 to 2, which path will do least work to the environment? Which path will require least heat input?



Quiz: How much heat?



1➔2➔3➔4➔1

How much heat is added to the system after the processes described?

How many kinds of processes are there?

- Isochoric Process (constant volume, $\Delta V = 0$)
- Isobaric Process (constant pressure, $\Delta p = 0$)
- Isothermal Process (constant temperature, $\Delta T = 0$)
- Adiabatic Process (no heat exchange, $Q = 0$)

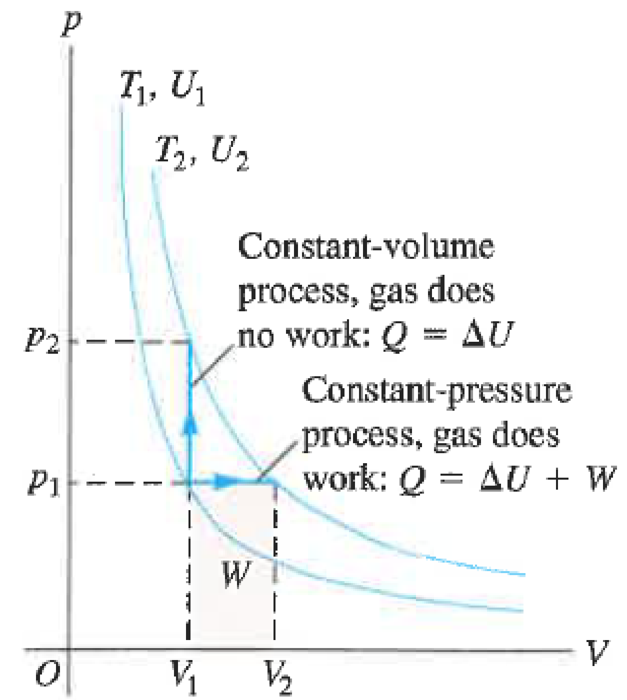
Isochoric Process (constant volume, $\Delta V = 0$)

First Law of Thermodynamics $\Delta U = Q - W$

Isochoric Process (constant volume, $\Delta V = 0$)

$$W = \int_{V_1}^{V_2} p dV = 0$$

$$\Delta U = Q$$



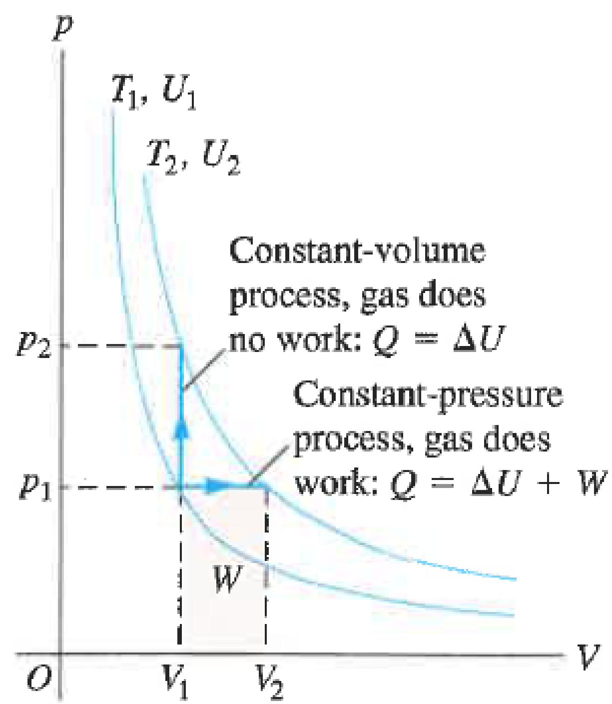
Isobaric Process (constant pressure, $\Delta p = 0$)

First Law of Thermodynamics $\Delta U = Q - W$

Isobaric Process (constant pressure, $\Delta p = 0$)

$$W = \int_{V_1}^{V_2} p dV = p(V_2 - V_1)$$

$$\Delta U = Q - p(V_2 - V_1)$$



Isothermal Process (constant temperature, $\Delta T = 0$)

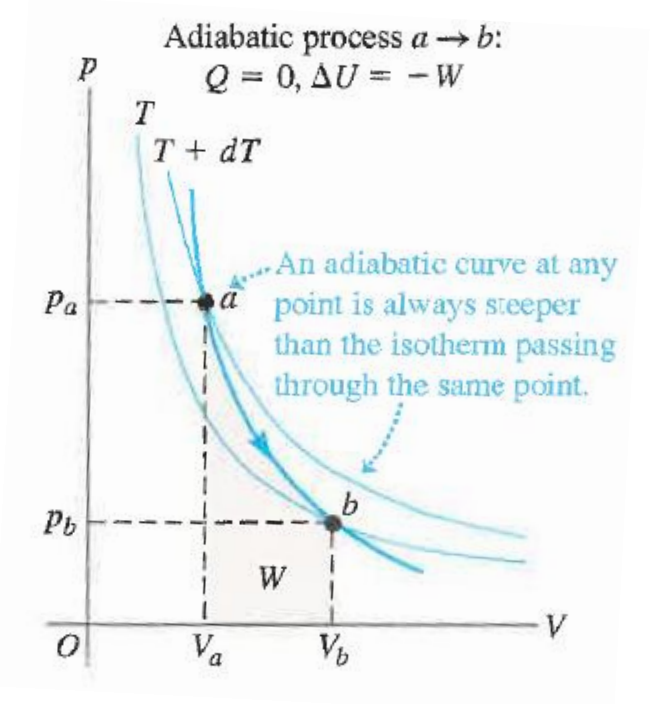
First Law of Thermodynamics $$\Delta U = Q - W$$

Isothermal Process (constant temperature, $\Delta T = 0$)

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

$$\Delta U = \frac{3}{2}nR\Delta T = 0$$

$$Q = W$$

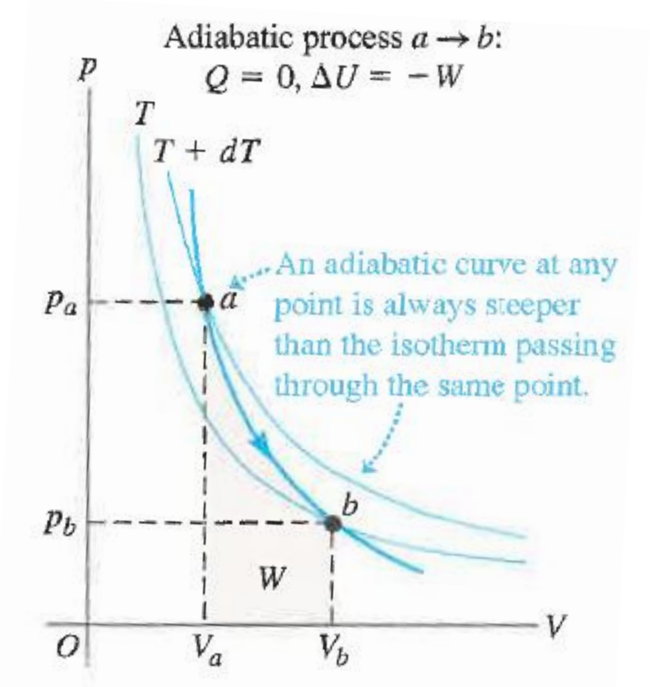


Adiabatic Process (no heat exchange, $Q = 0$)

First Law of Thermodynamics $\Delta U = Q - W$

Adiabatic Process (no heat exchange, $Q = 0$)

$$\Delta U = -W = -\int_{V_1}^{V_2} p dV$$



Adiabatic Process (no heat exchange, $Q = 0$)

There is a special Equation of state for Adiabatic process:

$$\Delta U = -W$$

$$nC_V dT = -pdV$$

$$C_V dT = -\frac{RT}{V} dV$$

$$\frac{dT}{T} + \frac{R}{C_V}\frac{dV}{V} = 0$$

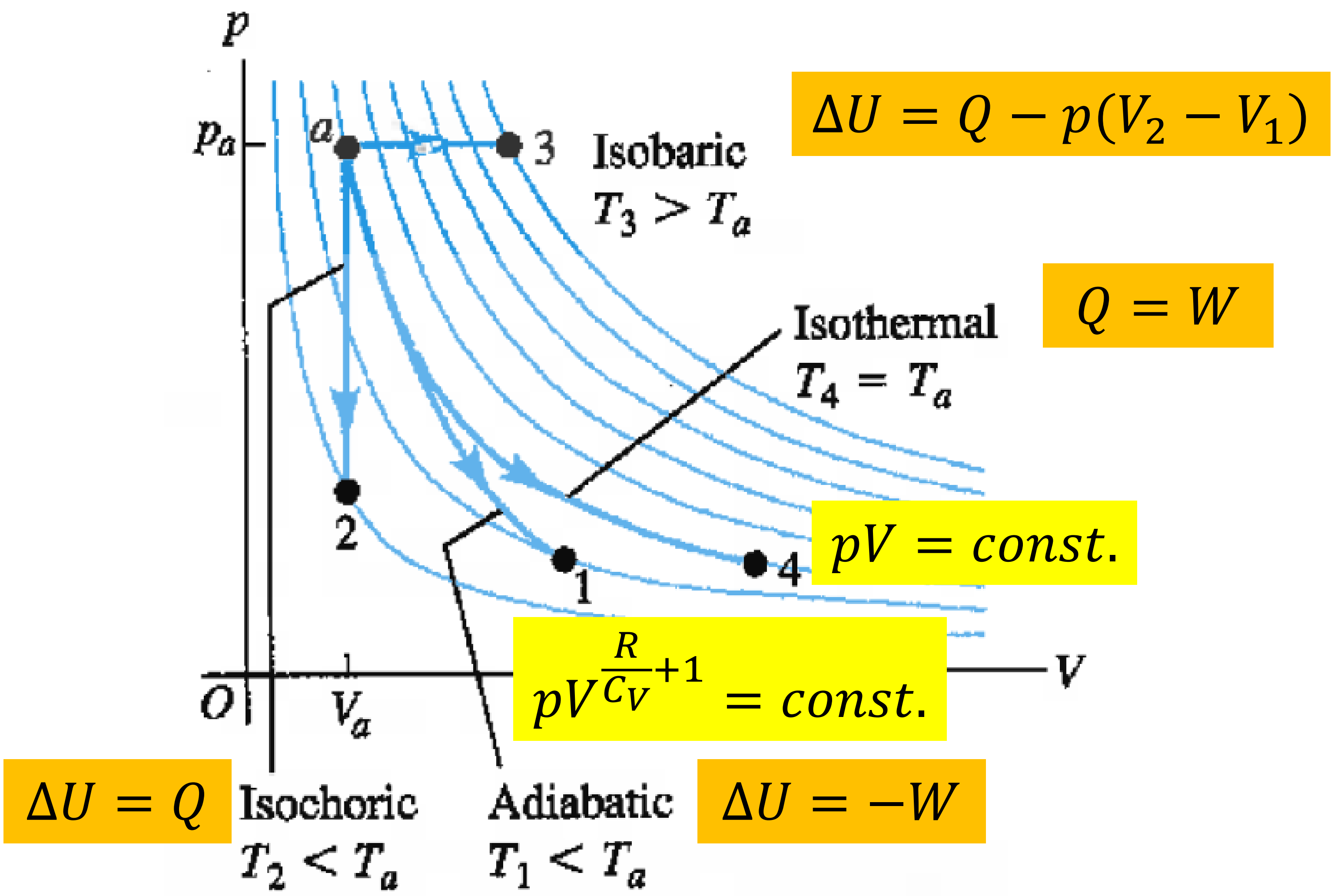
$$lnT + \frac{R}{C_V} lnV = const.$$

$$TV^{\frac{R}{C_V}} = const.$$

$$\frac{pV}{nR} V^{\frac{R}{C_V}} = const.$$

$$pV^{\frac{R}{C_V}+1} = const.$$

p-V Diagram of the 4 Processes



How much is C_p of an ideal gas system?

In Chapter 18, change of temperature means change of internal energy

$$\Delta U = nC_V \Delta T$$

Isobaric Process (constant pressure, $\Delta p = 0$)

$$\Delta U = Q - W$$

$$Q = nC_p \Delta T$$

$$W = p(V_2 - V_1) = nR(T_2 - T_1) = nR\Delta T$$

$$pV = nRT$$

$$\Delta U = nC_p \Delta T - nR\Delta T = (C_p - R)n\Delta T$$

Combine results from Isochoric and Isobaric Processes

$$\Delta U = nC_V \Delta T = (C_p - R)n\Delta T$$

$$C_p = C_V + R$$

Ratio of Heat Capacities

$$\gamma = \frac{C_p}{C_V}$$

For monatomic ideal gas

$$C_V = \frac{3}{2}R \qquad C_p = \frac{5}{2}R$$

$$\gamma = \frac{5}{3} = 1.67$$

For most diatomic ideal gas

$$C_V = \frac{5}{2}R \qquad C_p = \frac{7}{2}R$$

$$\gamma = \frac{7}{5} = 1.4$$

See table 19.1 on page 638