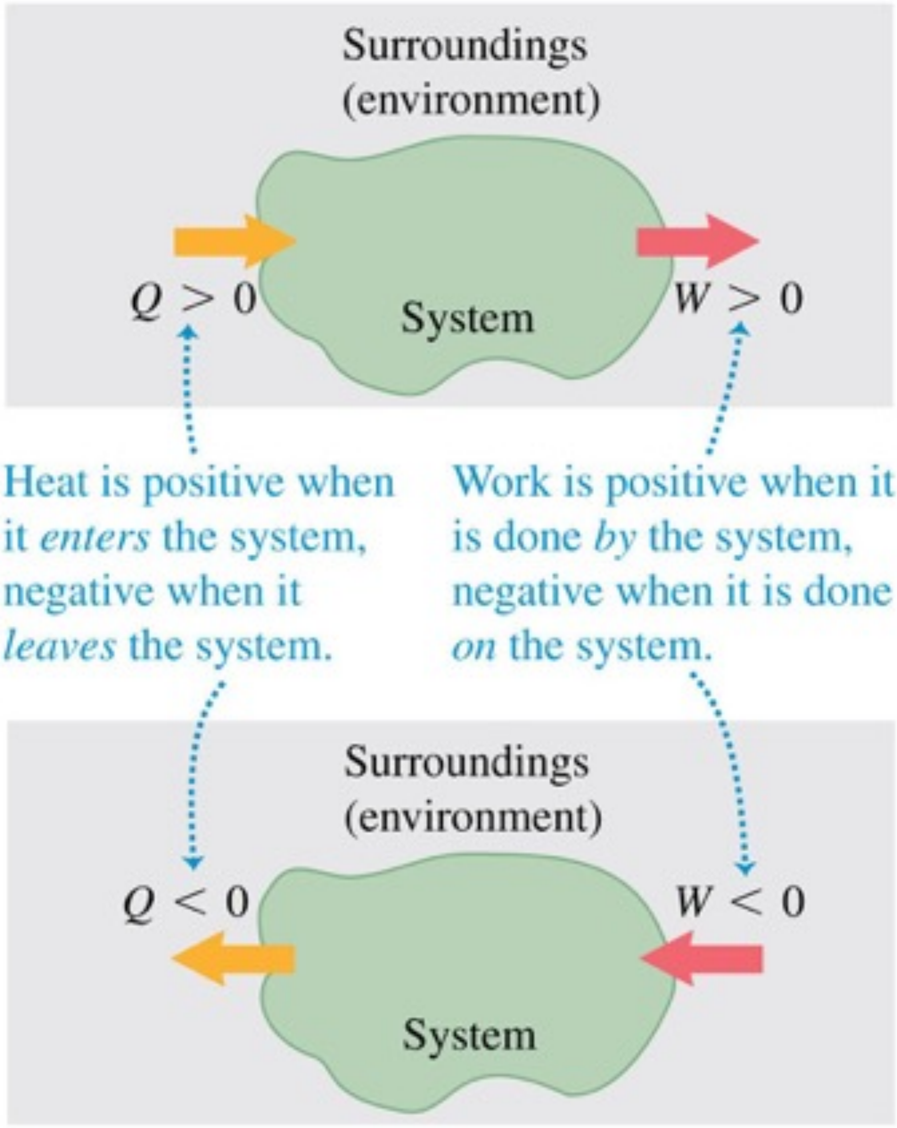
Lecture 5

PHYC 161 Fall 2016

Ch. 19 First Law of Thermodynamics

- In a *thermodynamic process*, changes occur in the state of the system.
- Careful of signs!
- Q is positive when heat flows *into* a system.
- W is the work done *by* the system, so it is positive for expansion.

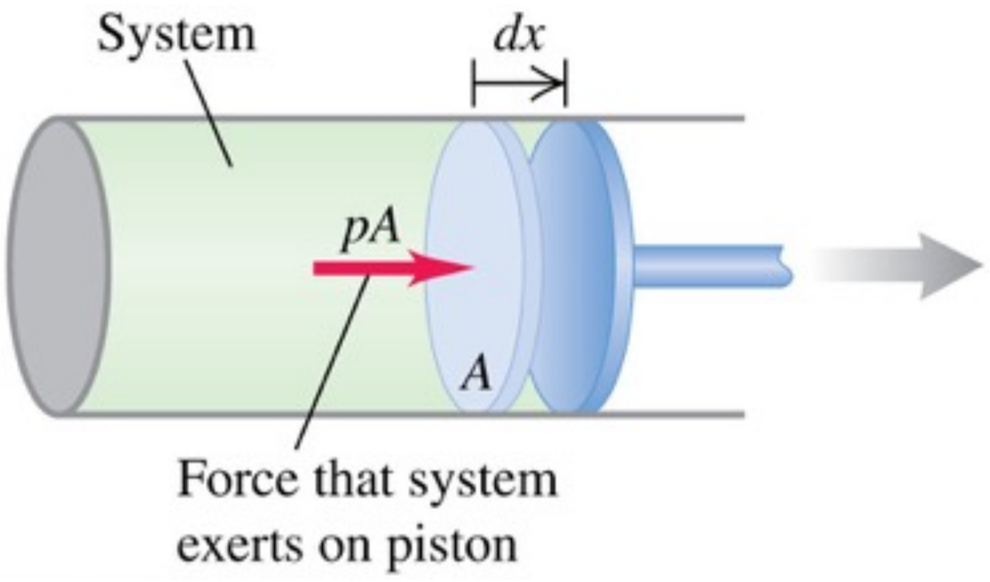


Heat is positive when it *enters* the system, negative when it *leaves* the system.

Work is positive when it is done *by* the system, negative when it is done *on* the system.

Work done during volume changes

- The infinitesimal work done by the system during the small expansion dx is $dW = pA\,dx$.



Force that system exerts on piston

- In a finite change of volume from V_1 to V_2:

Work done in a volume change

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

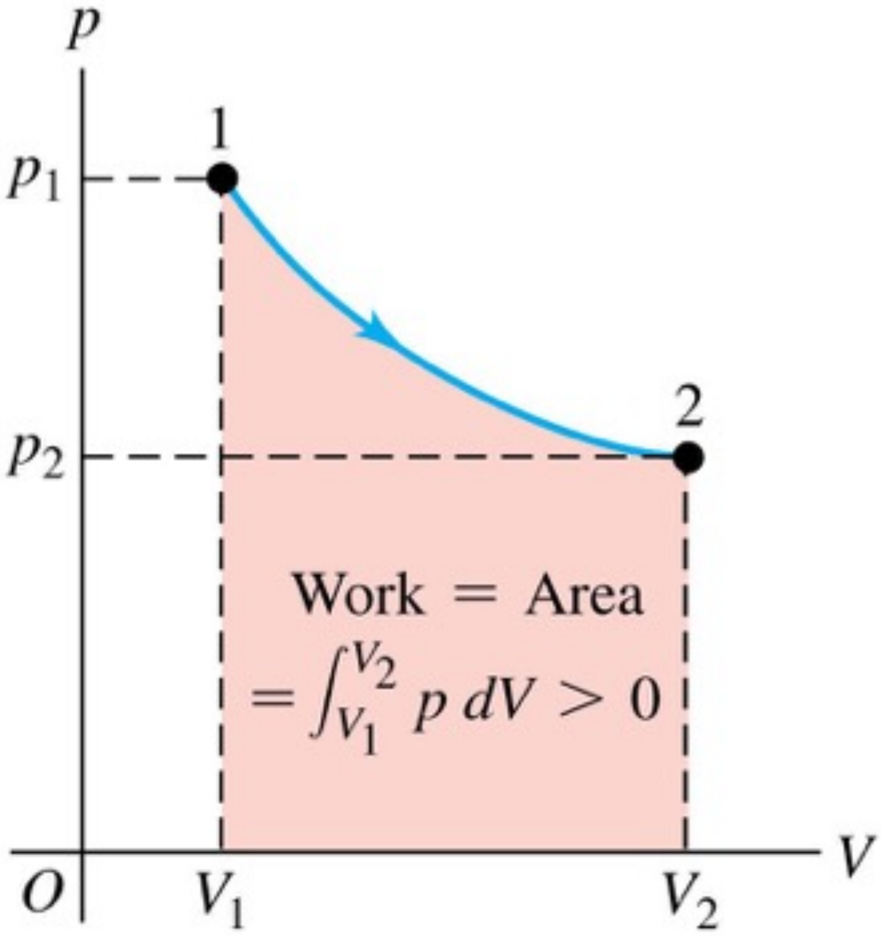
Upper limit = final volume

Integral of the pressure with respect to volume

Lower limit = initial volume

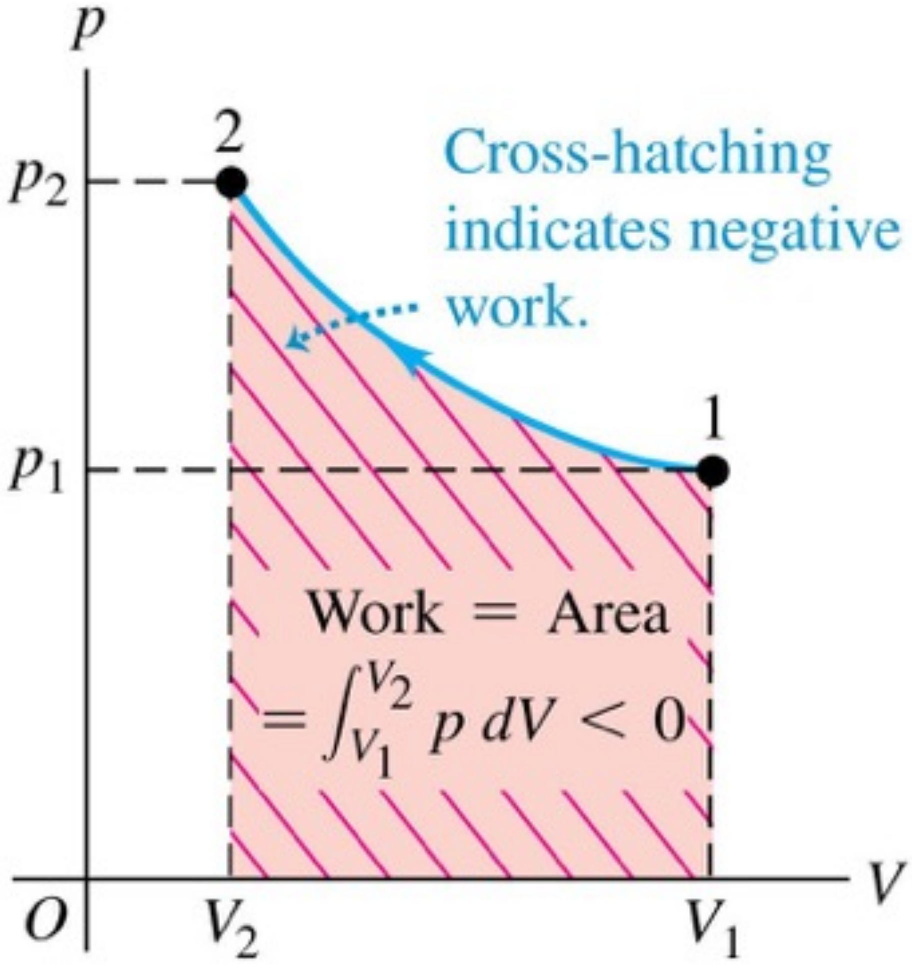
Work on a *pV*-diagram

- The work done equals the area under the curve on a *pV*-diagram.
- Shown in the graph is a system undergoing an **expansion** with varying pressure.



Work on a *pV*-diagram

- Shown in the graph is a system undergoing a **compression** with varying pressure.
- In this case the work is *negative*.



First law of thermodynamics

- The change in the internal energy U of a system is equal to the heat added minus the work done by the system:

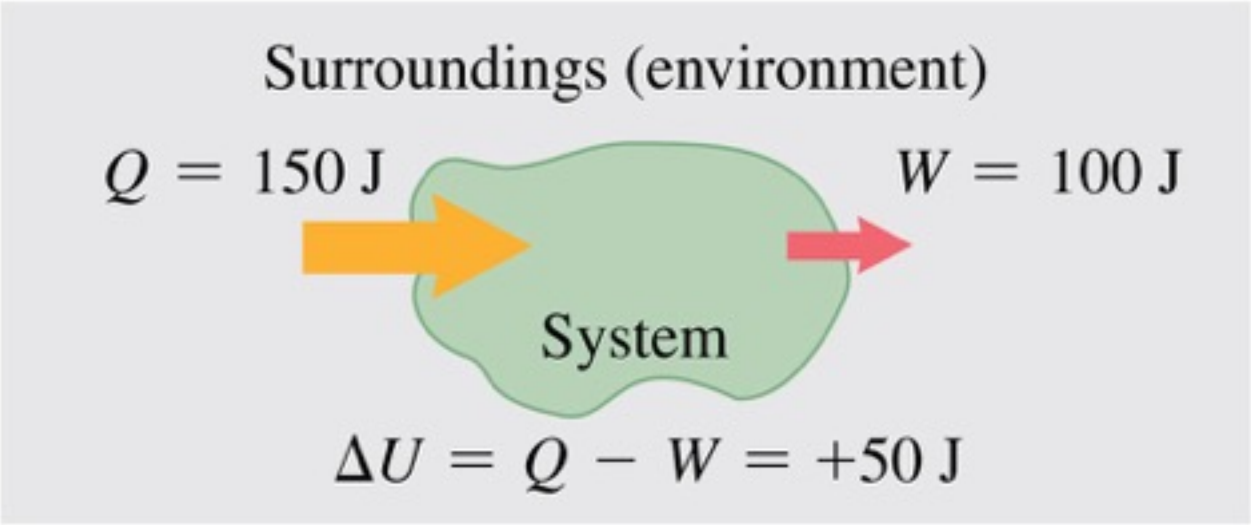
First law of thermodynamics:

$$\overbrace{\Delta U}^{\text{Internal energy change of thermodynamic system}} = \underset{\text{Heat added to system}}{Q} - \underset{\text{Work done by system}}{W}$$

- The first law of thermodynamics is just a generalization of the conservation of energy.
- Both Q and W depend on the path chosen between states, but ΔU is *independent of the path*.
- If the changes are infinitesimal, we write the first law as $dU = dQ - dW$.

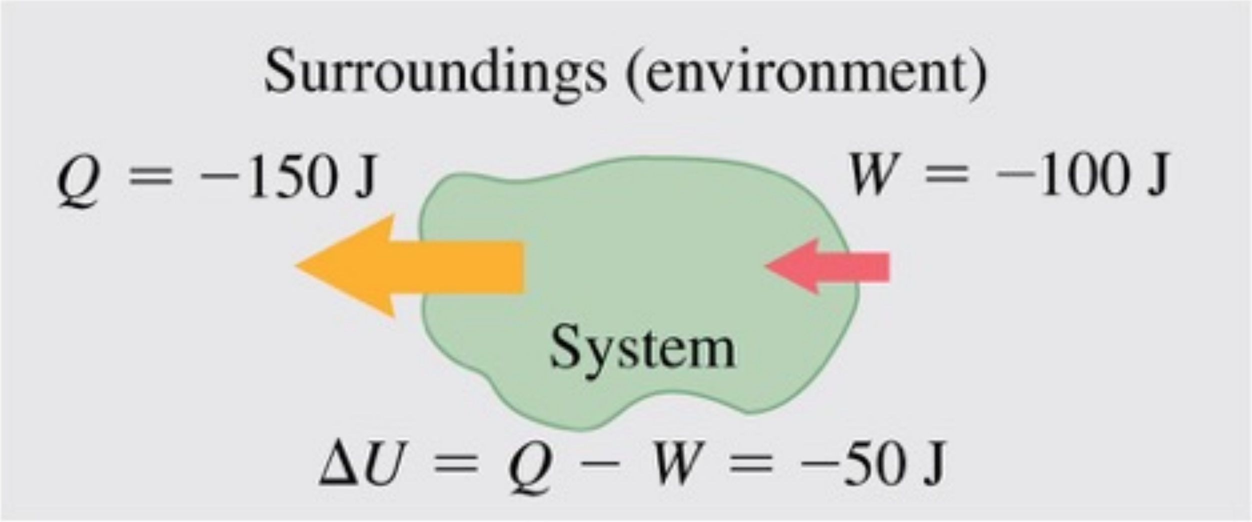
First law of thermodynamics

- In a thermodynamic process, the internal energy U of a system may *increase*.
- In the system shown below, more heat is added to the system than the system does work.
- So the internal energy of the system increases.



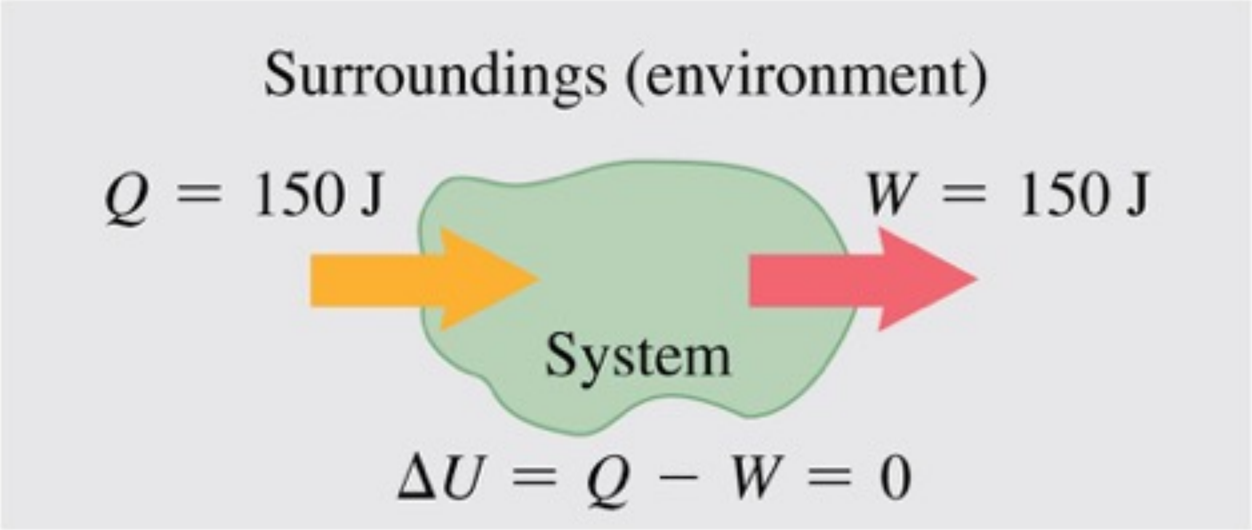
First law of thermodynamics

- In a thermodynamic process, the internal energy U of a system may *decrease*.
- In the system shown below, more heat flows out of the system than work is done.
- So the internal energy of the system decreases.



First law of thermodynamics

- In a thermodynamic process, the internal energy U of a system may *remain the same*.
- In the system shown below, the heat added to the system equals the work done by the system.
- So the internal energy of the system is unchanged.

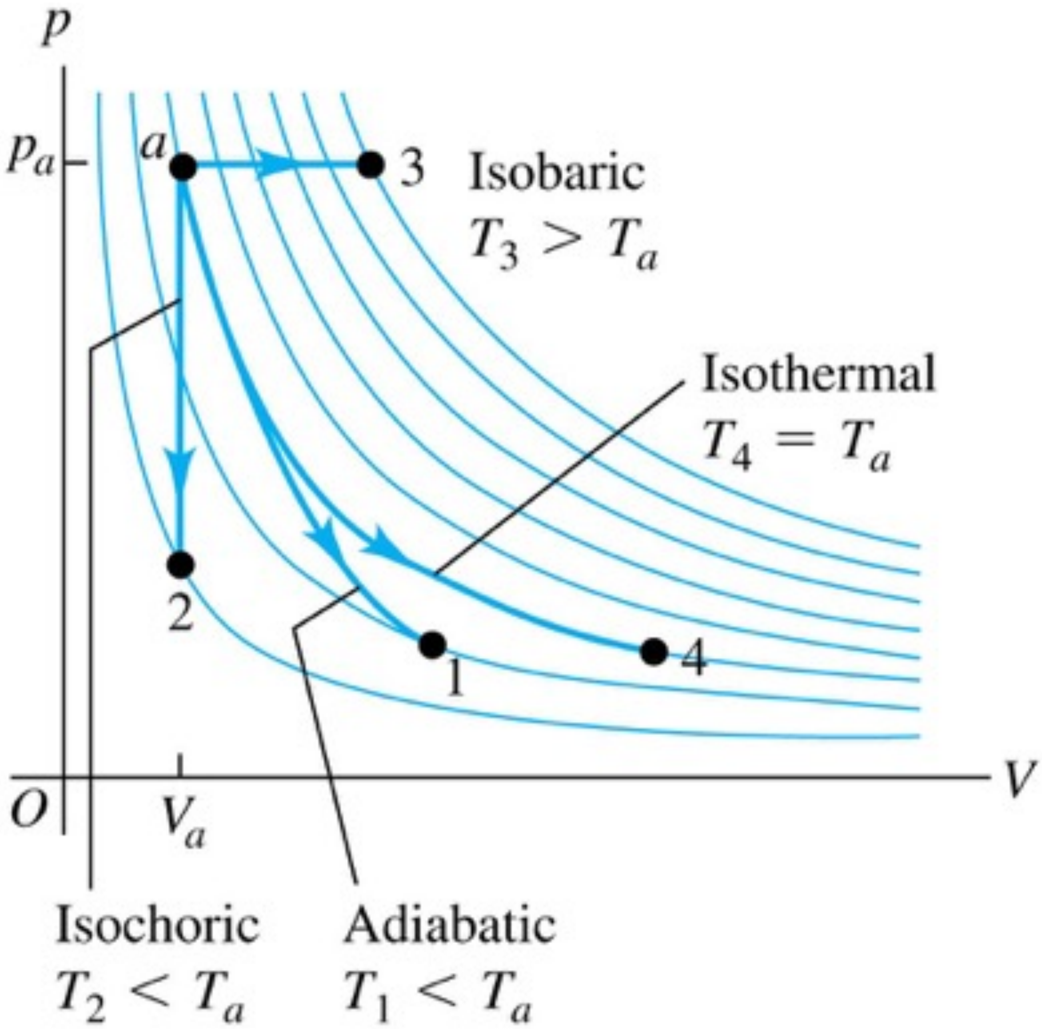


Four kinds of thermodynamic processes

- There are four specific kinds of thermodynamic processes that occur often in practical situations:
  - **Adiabatic**: No heat is transferred into or out of the system, so $Q = 0$. Also, $U_2 - U_1 = -W$.
  - **Isochoric**: The volume remains constant, so $W = 0$.
  - **Isobaric**: The pressure remains constant, so $W = p(V_2 - V_1)$.
  - **Isothermal**: The temperature remains constant.

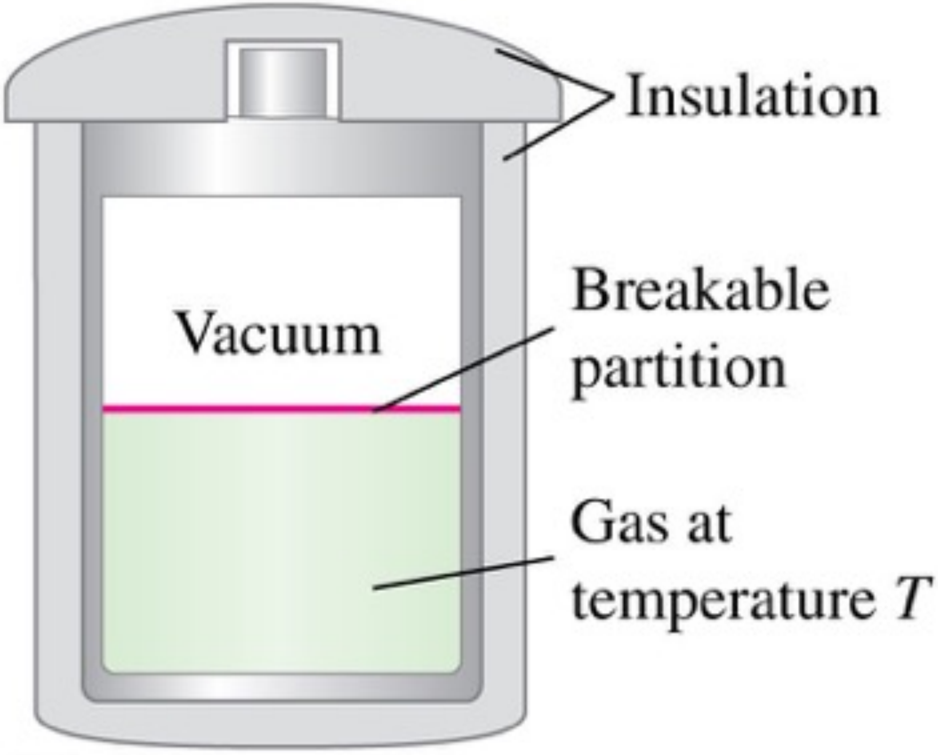
The four processes on a *pV*-diagram

- Shown are the paths on a *pV*-diagram for all four different processes for a constant amount of an ideal gas, all starting at state *a*.



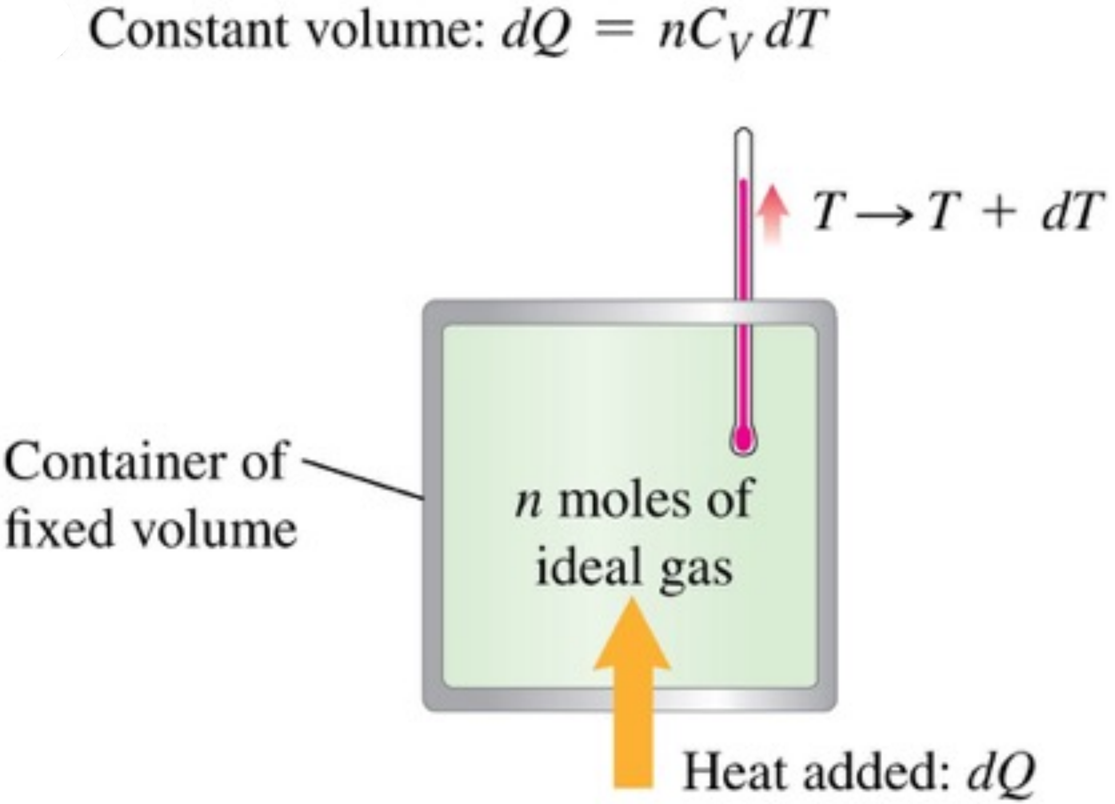
Internal energy of an ideal gas

- The internal energy of an ideal gas depends *only* on its *temperature*, not on its pressure or volume.
- The temperature of an ideal gas does *not* change during a free expansion.



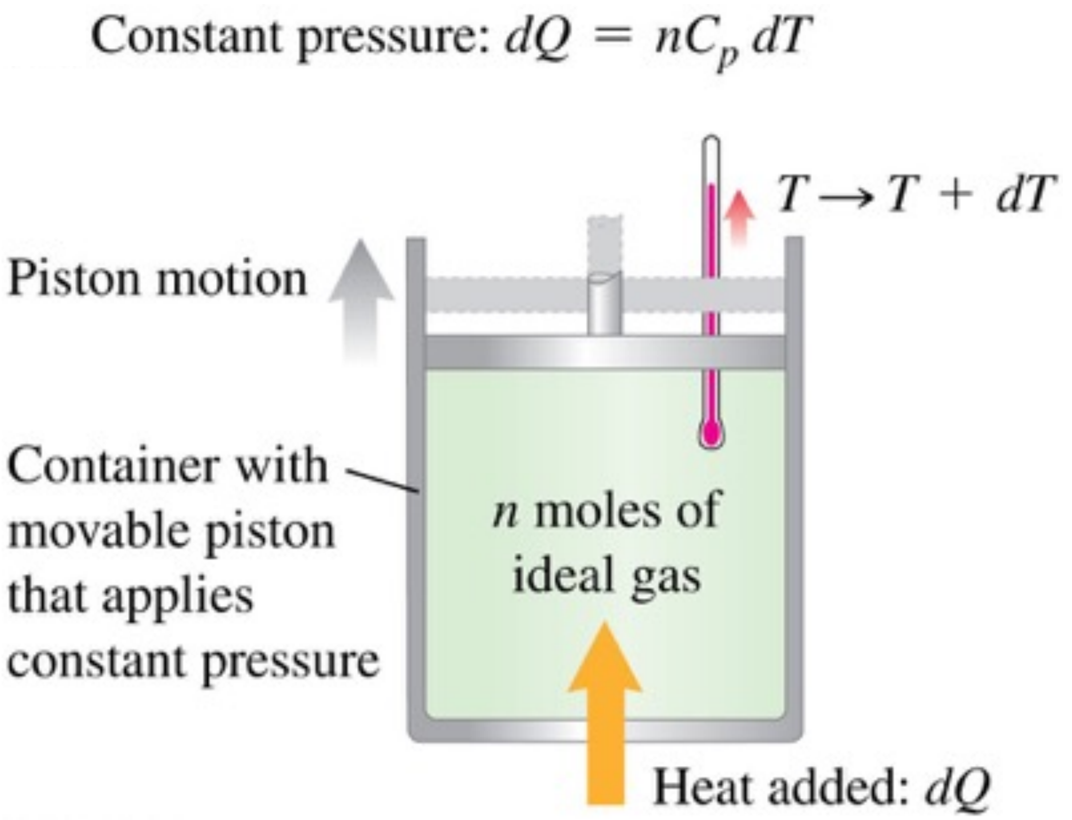
Heat capacities of an ideal gas

- C_V is the molar heat capacity at constant volume.
- To measure C_V, we raise the temperature of an ideal gas in a rigid container with constant volume, ignoring its thermal expansion.



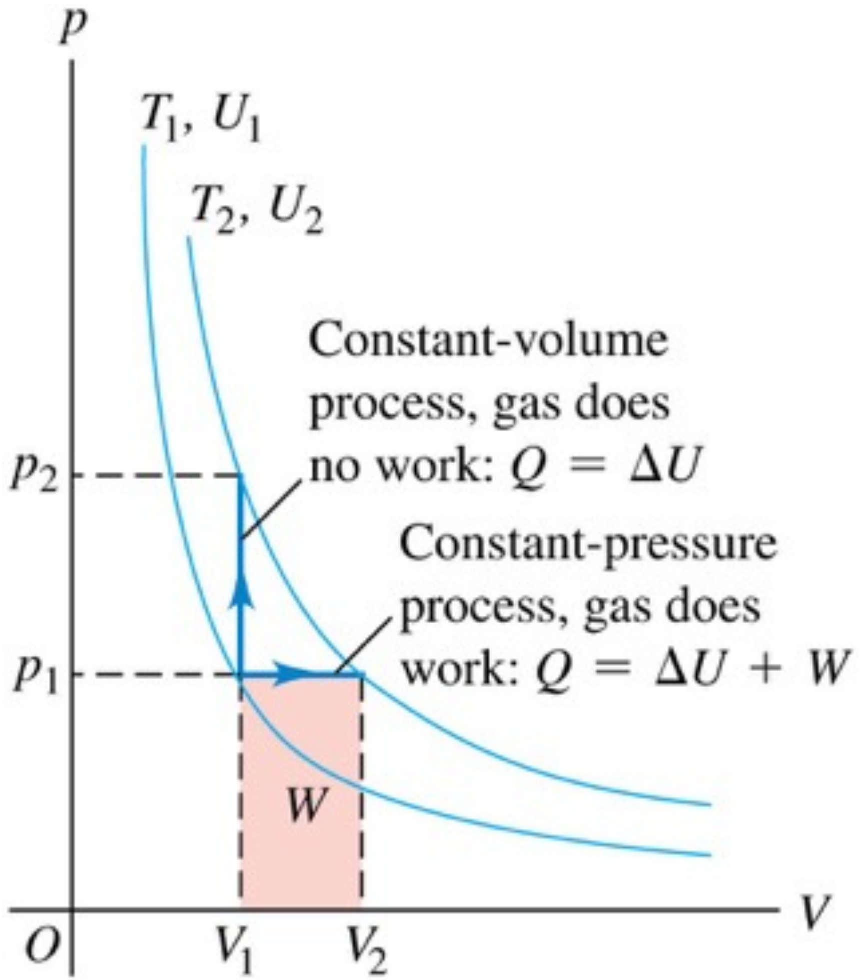
Heat capacities of an ideal gas

- C_p is the molar heat capacity at constant pressure.
- To measure C_p, we let the gas expand just enough to keep the pressure constant as the temperature rises.



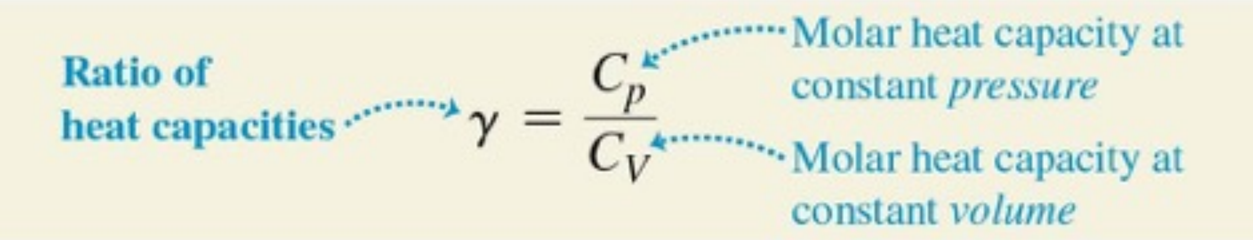
Relating C_p and C_V for an ideal gas

- To produce the same temperature change, more heat is required at constant pressure than at constant volume since ΔU is the same in both cases.
- This means that $C_p > C_V$.
- $C_p = C_V + R$.
- R is the gas constant $R = 8.314\ \text{J/mol} \cdot \text{K}$.



The ratio of heat capacities

- The *ratio of heat capacities* is:



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

- For monatomic ideal gases,

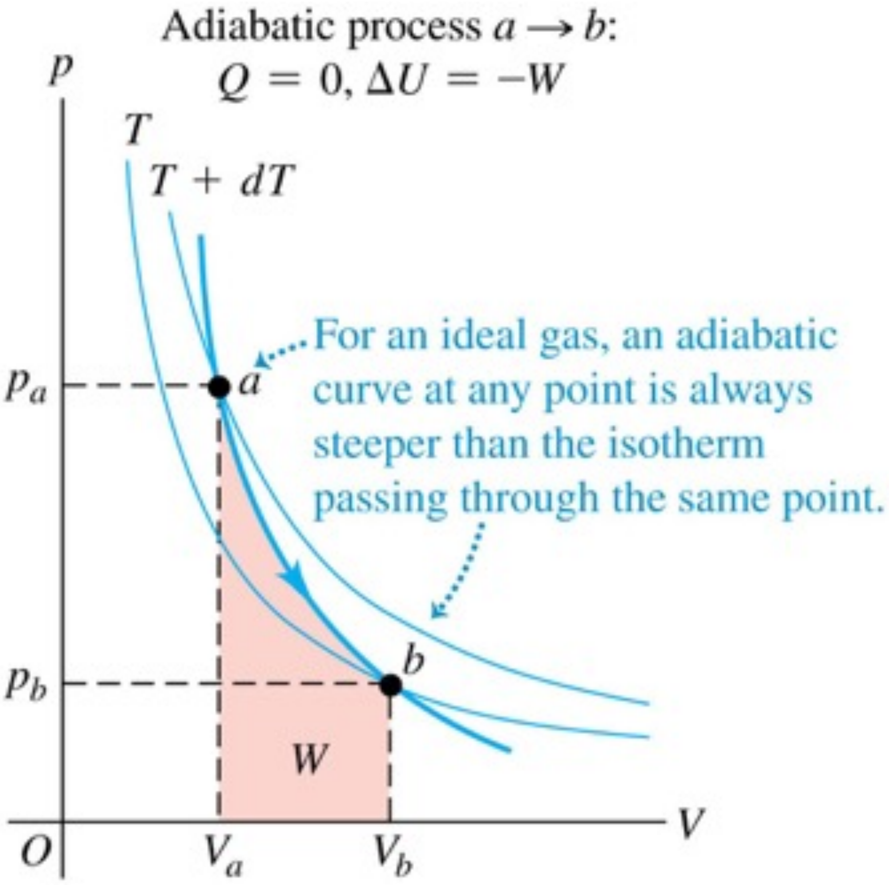
$$\gamma = 1.67.$$

- For diatomic ideal gases,

$$\gamma = 1.40.$$

Adiabatic processes for an ideal gas

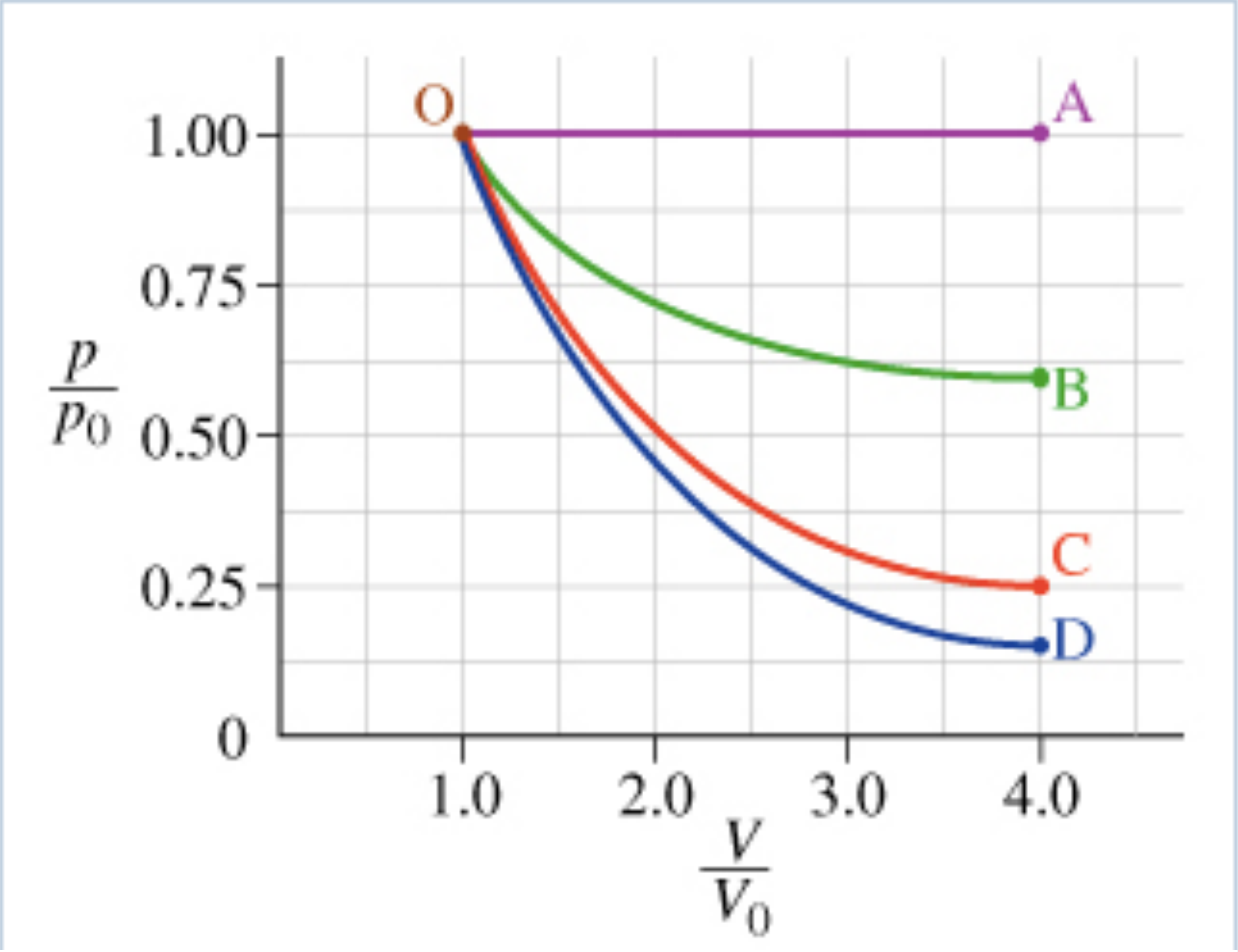
- In an adiabatic process, no heat is transferred in or out of the gas, so $Q = 0$.
- Shown is a pV-diagram for an adiabatic expansion.
- As the gas expands, it does positive work W on its environment, so its internal energy decreases, and its temperature drops.



For an ideal gas, an adiabatic curve at any point is always steeper than the isotherm passing through the same point.

- Note that an adiabatic curve at any point is always steeper than an isotherm at that point.

Expansion of a gas



- *Adiabiatic*: No heat is added or removed during the expansion.
- *Isobaric*: The pressure remains constant during the expansion.
- *Isothermal*: The temperature remains constant during the expansion.

Clicker question

- You have 10 moles of a monatomic gas, with an initial volume V_i. You then compress the gas to half the initial volume in two ways:
- A. ISOTHERMAL compression
- B. ADIABATIC compression

- Q: In which process, A or B, is the final pressure of the gas higher?