

Physics 1501

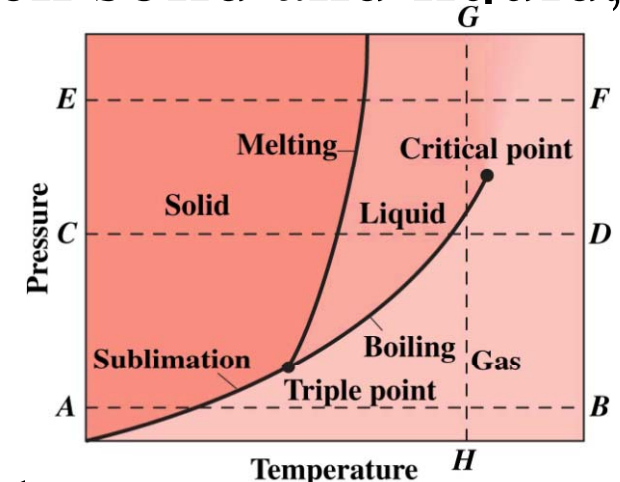
Fall 2008

**Mechanics, Thermodynamics,
Waves, Fluids**

Lecture 31: Heat and Work

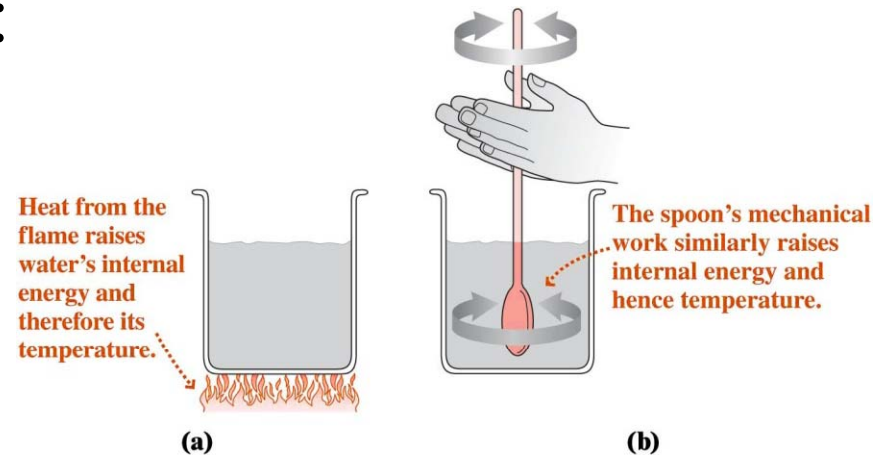
Recap:

- The **ideal gas law** relates pressure, temperature, and volume: $PV = NkT$.
 - The ideal gas law may also be written $pV = nRT$, where n is the number of moles of gas, and $R = 8.314 \text{ J/K}\cdot\text{mol}$.
 - Derivation of the ideal gas law from Newtonian mechanics shows that temperature measures the average kinetic energy of the gas molecules.
- **Phase changes** take substances between solid and liquid, liquid and gas, solid and gas.
 - Phase diagrams require energy, described by the heats of transformation.
 - The phase structure of a substance is described in its **phase diagram**.
- **Thermal expansion** occurs as most substances are heated.
 - An exception is water in the range from 0°C to 4°C .



The first law of thermodynamics

- Two ways to raise temperature:
 - Thermally: flow of heat
 - Energy flow resulting from a temperature difference
 - Mechanically: doing work
- End result is the same for the same energy input:
 - An increase ΔU in the system's **internal energy** U
- First law of thermodynamics
 - Change in internal energy of a system is the heat added *to* the system minus the work done *by* the system:



$$\Delta U = Q - W$$

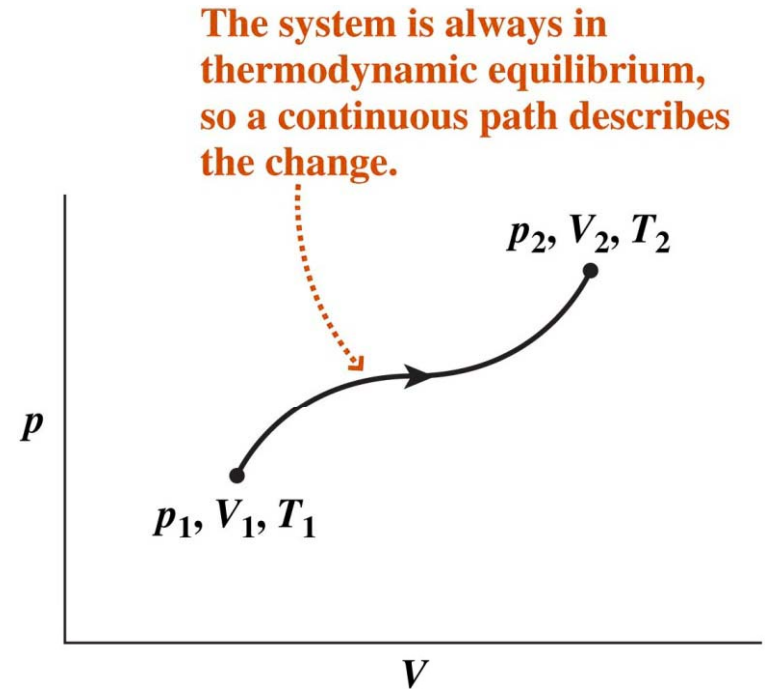
- Extends conservation of energy to include thermal processes

Reversible and irreversible processes

- Changing the state of a system can be done

- Reversibly

- In which case the system remains always in thermodynamic equilibrium and follows a path in its pressure-versus-volume (pV) diagram.
 - Any process carried out slowly enough is reversible.
 - It's possible to reverse the system's path in its pV diagram.



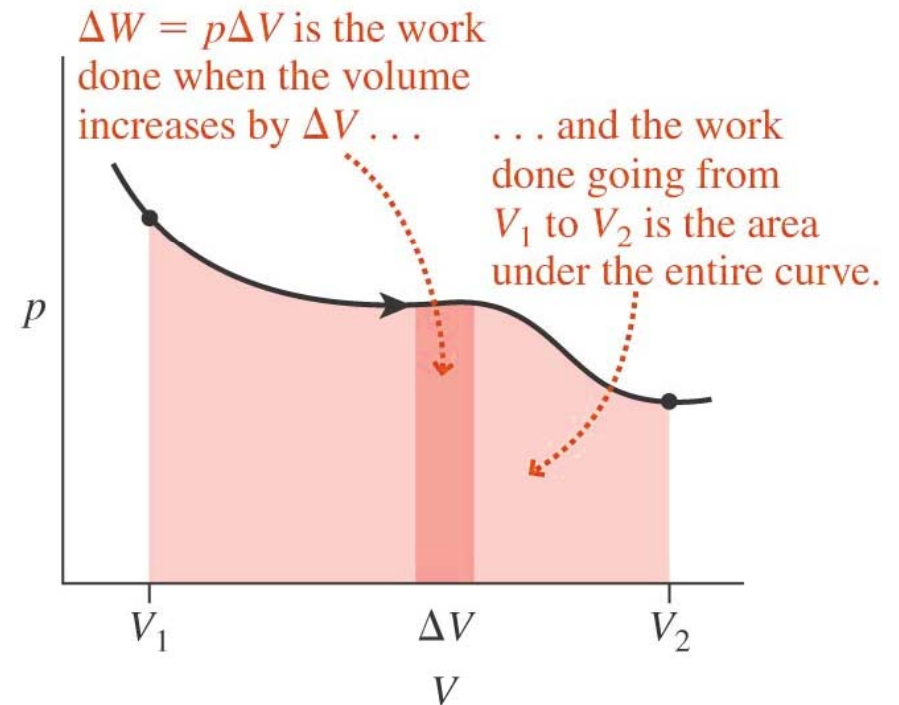
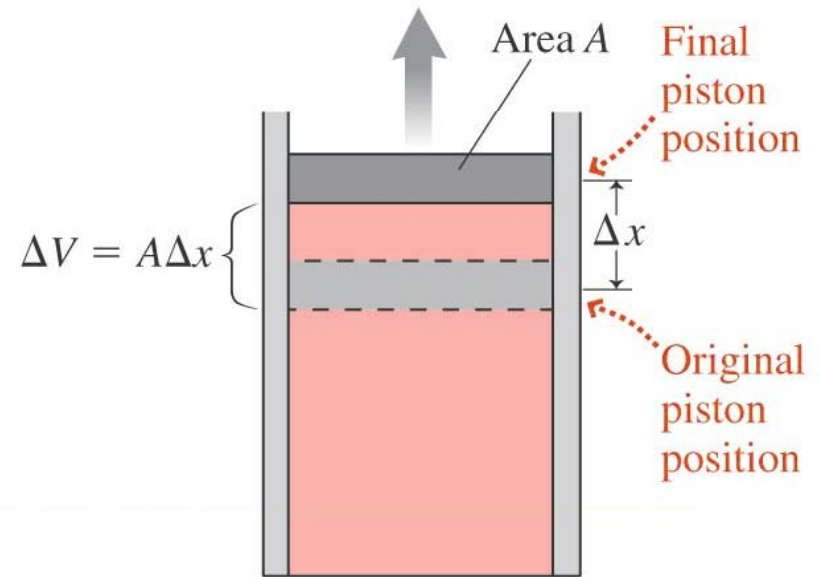
- Irreversibly

- In which case the system goes temporarily out of equilibrium, without well-defined values for temperature, pressure, and other quantities.
 - Although the system has no well-defined path in the pV diagram, it ends up in a definite state, back in equilibrium.

Doing work

- A piston-cylinder system is a useful device for describing the thermodynamic behavior of a gas.
 - The piston seals the cylinder, allowing the gas volume to change without any gas escaping.
 - Work can be done on or by the gas as the piston moves.
 - If the bottom is uninsulated, heat can flow in or out.
- The work done on or by the gas is the area under the pV curve:

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



question

- Two identical gas-cylinder systems are taken from the same initial temperature to the same final state, but by different processes. Which of the following are the same in both cases?
 - A. The internal energy
 - B. The heat added or removed
 - C. The work done on or by the gas

Isothermal processes and the ideal gas

- An **isothermal process** takes place at constant temperature.

- One way to achieve this is to keep the system in thermal contact with a heat reservoir—a much larger system held at constant temperature.

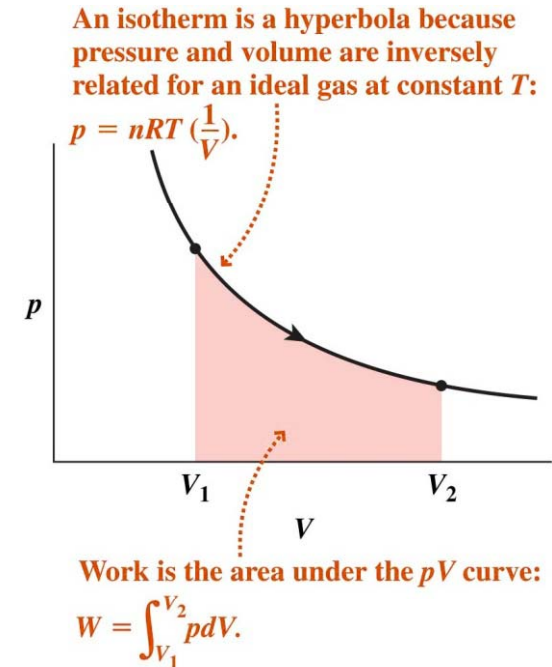
- The ideal gas law gives $P = nRT/V$.

- Then, with constant T , the work done is

$$W = \int_{V_1}^{V_2} p dV = nRT \int_{V_1}^{V_2} \frac{dV}{V} = nRT \ln(V_2/V_1)$$

- Since the temperature doesn't change, neither does the internal energy of an ideal gas. Therefore the first law gives

$$Q = W = nRT \ln(V_2/V_1)$$



Constant-volume processes

- In a constant-volume process, the heat added to the gas and the resulting temperature change are related by

$$Q = nC_V\Delta T$$

- Here C_V is the **molar specific heat at constant volume**.
 - Its units are J/K·mol.
- No work is done in a constant-volume process, so $W = 0$ and so the first law reads $\Delta U = Q$.
 - Therefore $\Delta U = nC_V\Delta T$.
 - For an ideal gas, internal energy depends on temperature alone, so this relationship $\Delta U = nC_V\Delta T$ between ΔU and ΔT holds for *any* process.

Isobaric processes

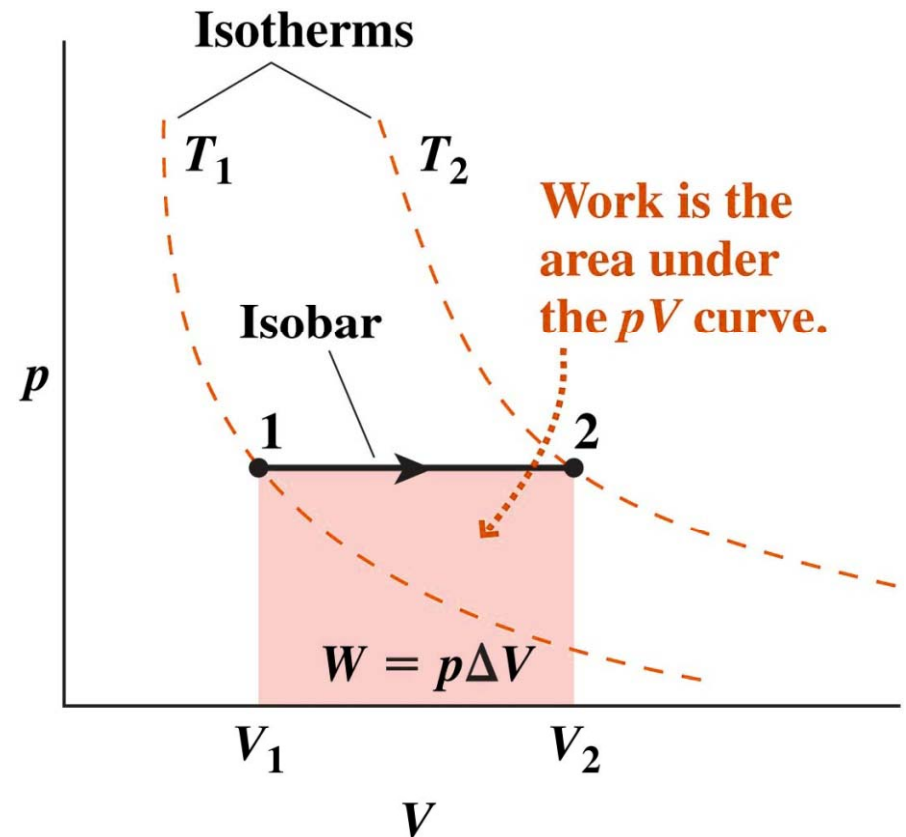
- An **isobaric process** takes place at constant pressure.
- Then the work done is $W = p \Delta V$.
- Adding heat to an ideal gas results both in a temperature change and in work being done.
 - Therefore it takes *more* heat to effect a given temperature change:

$$Q = nC_V\Delta T + p \Delta V$$

- The **molar specific heat at constant pressure**, C_p , expresses this extra work:

$$nC_p\Delta T = nC_V\Delta T + p \Delta V$$

- Here $C_p = C_V + R$.



Adiabatic processes

- In an **adiabatic process**, no heat flows into or out of the system.
 - Therefore $Q = 0$ and the first law reads $\Delta U = -W$.
 - Analysis of the adiabatic process for an ideal gas shows that

$$pV^\gamma = \text{constant}$$

where $\gamma = C_p/C_V$ is the ratio of specific heats of the gas.

- An adiabatic curve or **adiabat** is steeper than an isotherm because the gas does work.
 - It therefore loses internal energy and its temperature drops.

