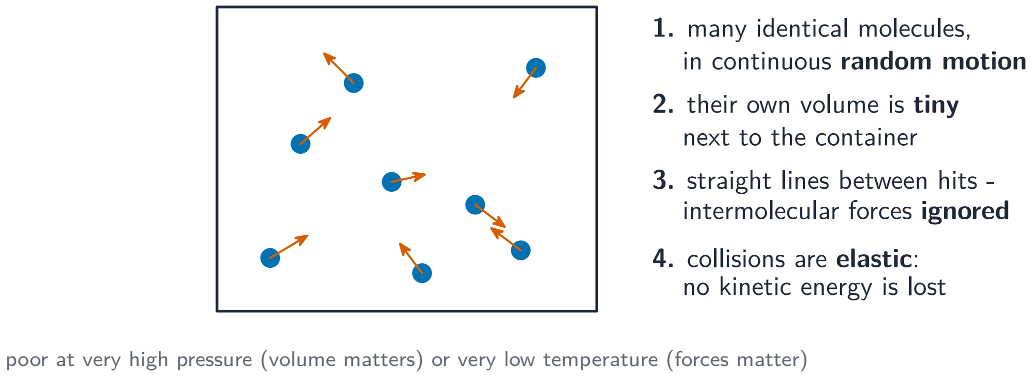
Thermodynamics

AP Physics 2

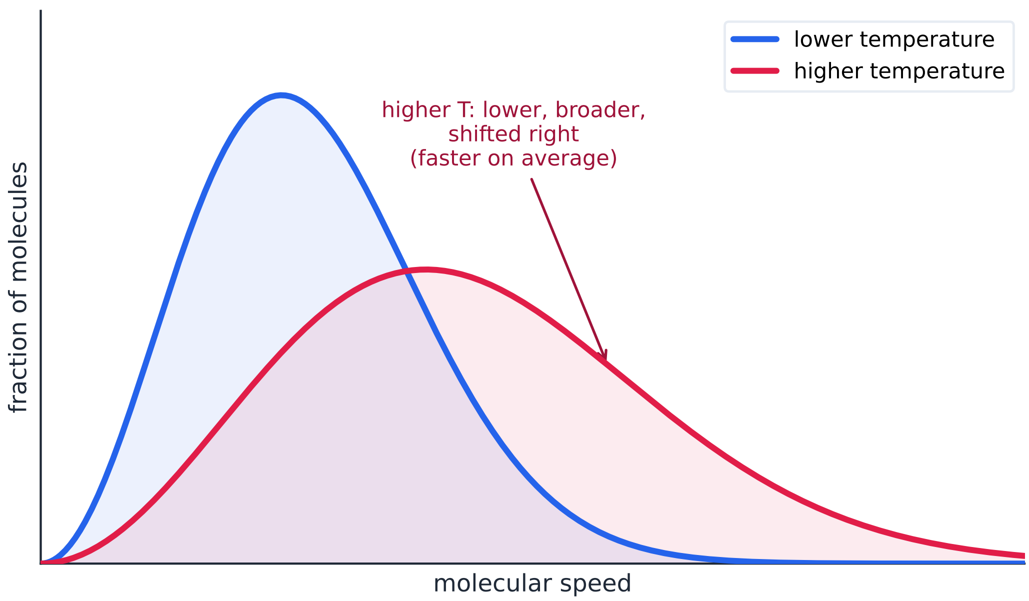
Kinetic Theory of Temperature and Pressure

Thermodynamics 热力学 studies heat and energy in large collections of particles. The **kinetic theory** 分子运动论 explains gas behavior from the random motion of its molecules:



The key assumptions of the kinetic theory of an ideal gas

- **Temperature** 温度 is a measure of the **average kinetic energy** of the molecules: $K_{\text{avg}} = \frac{3}{2}k_B T$ (with T in kelvin). Hotter means faster-moving molecules.
- **Pressure** 压强 comes from molecules colliding with the container walls –more frequent or harder collisions give more pressure.



The Maxwell-Boltzmann speed distribution shifts right and flattens at higher temperature

Worked example. Find the average kinetic energy of a gas molecule at 300 K, using

$k_B = 1.38 \times 10^{-23}$ J/K:

$$K_{\text{avg}} = \tfrac{3}{2} k_B T = 1.5 \times 1.38 \times 10^{-23} \times 300 = 6.2 \times 10^{-21} \text{ J}.$$

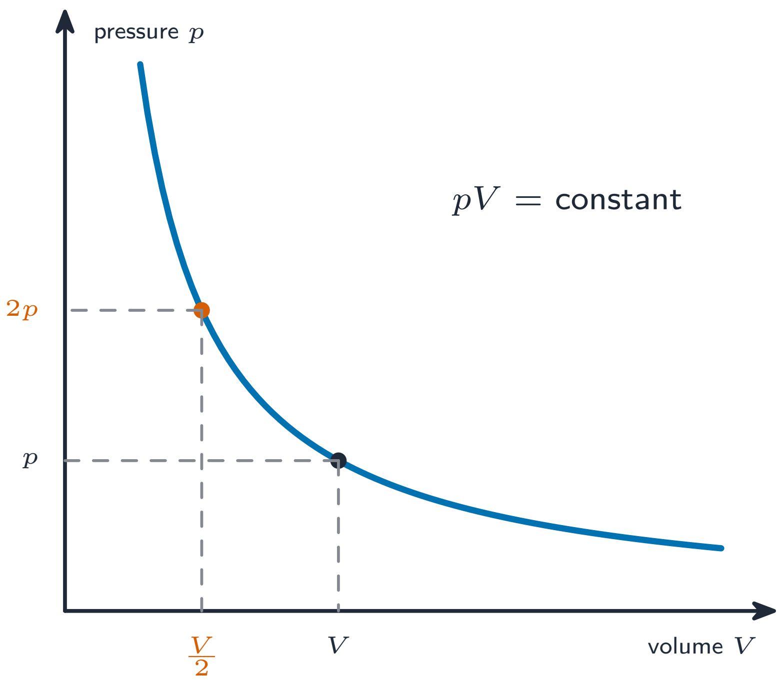
It depends only on temperature, not on the type of gas –at the same T, light and heavy molecules share the same average kinetic energy (so the light ones move faster).

The Ideal Gas Law

An **ideal gas** 理想气体 obeys

$$PV = nRT \qquad (\text{or } PV = N k_B T),$$

linking pressure P, volume V, amount (n moles or N molecules), and absolute temperature T. Use it to predict how a gas responds when you change one quantity and hold others fixed (e.g. heating at constant volume raises pressure).



Boyle's law: at constant temperature, pressure times volume is constant

Worked example. A sealed rigid container of gas is at 1.0×10^5 Pa and 300 K. It is heated to 450 K. Because the volume and amount are fixed, P/T is constant:

$$P_2 = P_1 \frac{T_2}{T_1} = 1.0 \times 10^5 \times \frac{450}{300} = 1.5 \times 10^5 \text{ Pa}.$$

Always convert temperatures to **kelvin** before using a gas law –using Celsius here would give nonsense.

Thermal Energy Transfer and Equilibrium

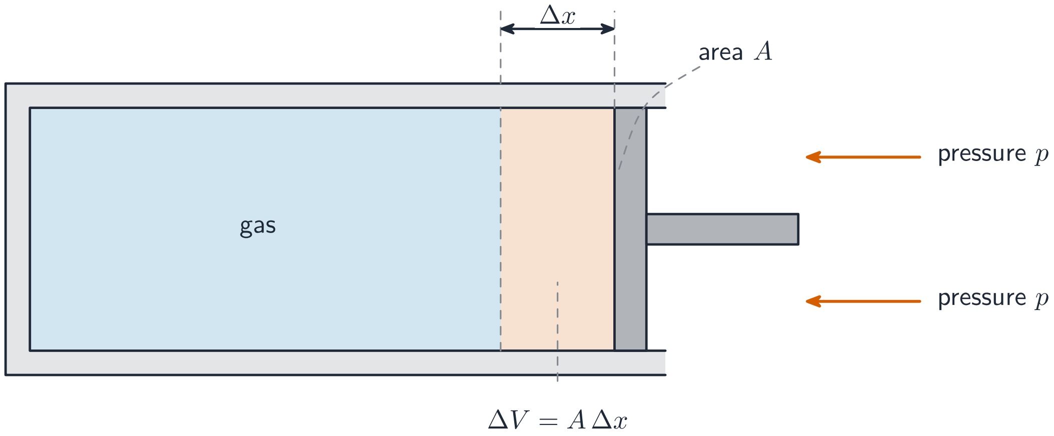
Heat 热量 Q is energy transferred because of a temperature difference; it flows from hot to cold. Two objects in contact reach **thermal equilibrium** 热平衡 when they share the same temperature, and net heat flow stops. The three transfer methods are **conduction** 传导, **convection** 对流, and **radiation** 辐射.

The First Law of Thermodynamics

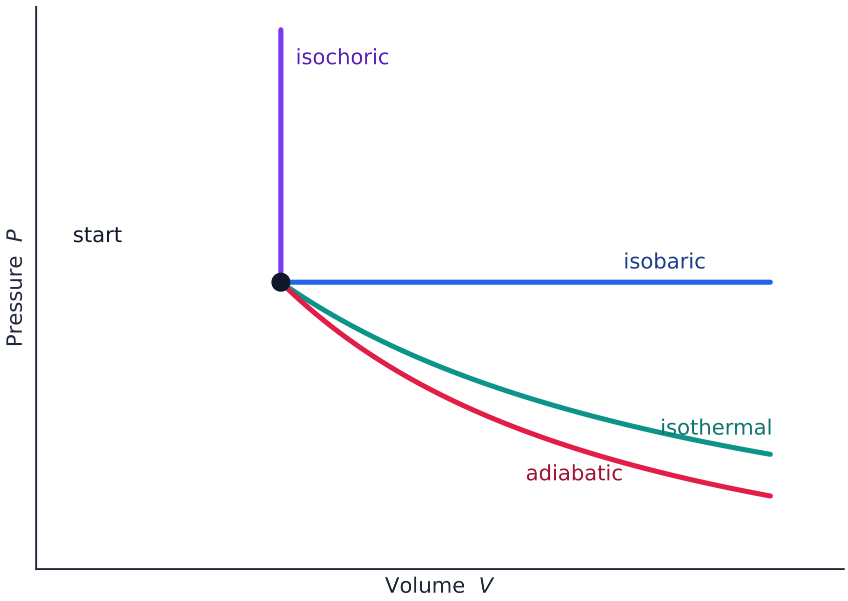
The **first law** 热力学第一定律 is conservation of energy for a gas:

$$\Delta U = Q + W,$$

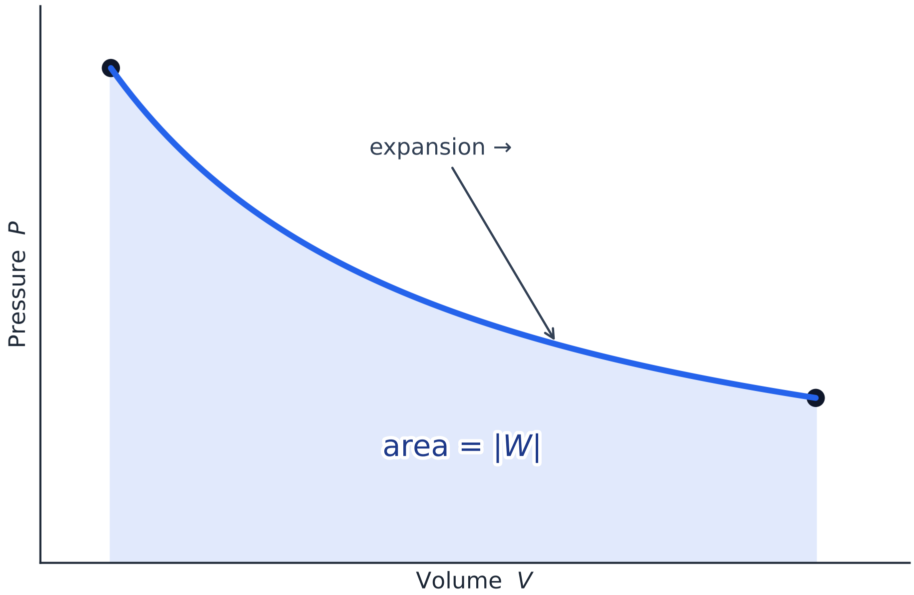
where ΔU is the change in **internal energy** 内能 (tied to temperature), Q is heat added **to** the gas, and W is work done **on** the gas. On a pressure–volume diagram, the work done **by** the gas is the area under the process curve. Watch signs: compressing a gas does positive work on it.



A gas pushing a piston out by a small distance does work equal to p times the volume change



The four thermodynamic processes drawn from a common starting state on a PV diagram



The work done during a volume change equals the area under the P-V curve

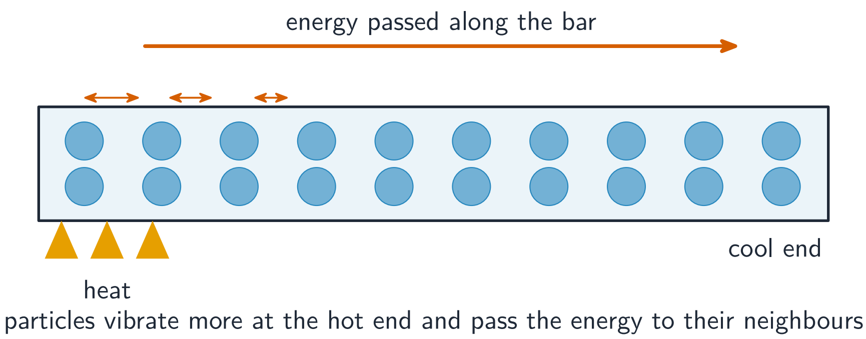
Worked example. A gas absorbs 500 J of heat and, as it expands, does 200 J of work **on its surroundings**. Find the change in its internal energy. Work done *on* the gas is $W = -200$ J (it does work, so it loses that energy):

$$\Delta U = Q + W = 500 + (-200) = 300 \text{ J}.$$

The internal energy rises by 300 J, so the gas ends up hotter. Getting the sign of W right is the whole game in first-law problems.

Specific Heat and Thermal Conductivity

- **Specific heat** 比热容 c is the heat needed to raise one kilogram by one degree: $Q = mc\,\Delta T$. A high specific heat (like water's) means a substance resists temperature change.
- **Thermal conductivity** 热导率 measures how fast heat conducts through a material; the rate of conduction rises with area and temperature difference and falls with thickness.



Conduction: vibrating particles pass energy along a metal bar

Worked example. How much heat raises the temperature of 2.0 kg of water from 20 °C to 80 °C? Water's specific heat is $c = 4200$ J/(kg °C):

$$Q = mc\,\Delta T = 2.0 \times 4200 \times (80 - 20) = 5.0 \times 10^5 \text{ J}.$$

Water's large specific heat is why it is used as a coolant and why coastal climates are mild.

Entropy and the Second Law of Thermodynamics

Entropy 熵 measures the disorder, or the number of ways to arrange, a system. The **second law** 热力学第二定律: the total entropy of an isolated system never decreases – energy naturally spreads out. This sets the **direction** of processes: heat flows hot→cold on its own, never the reverse, and no engine can convert heat entirely into work.

Exam tips

- Always convert temperatures to **kelvin** ($T_K = T_C + 273$) before using any gas law.
- In the first law $\Delta U = Q + W$, get the **sign of** W right: work done **on** the gas is positive; when the gas expands and does work on its surroundings, W is negative.
- **Temperature** measures the average kinetic energy of particles, so at the same T lighter molecules move faster.
- On a **PV diagram** the work done by the gas is the **area** under the process curve.
- Use $Q = mc\,\Delta T$ for temperature change; the **second law** fixes the direction —heat flows hot→cold and total entropy never decreases.