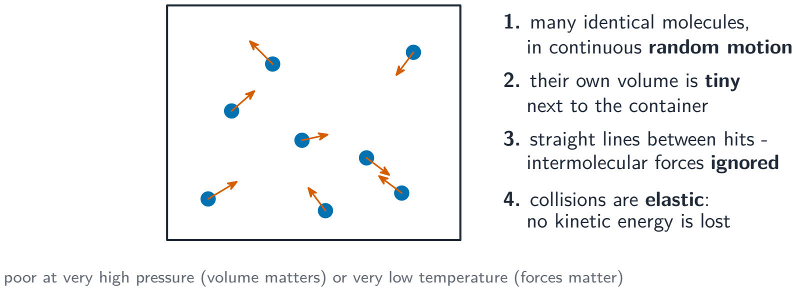
Thermodynamics

AP Physics 2

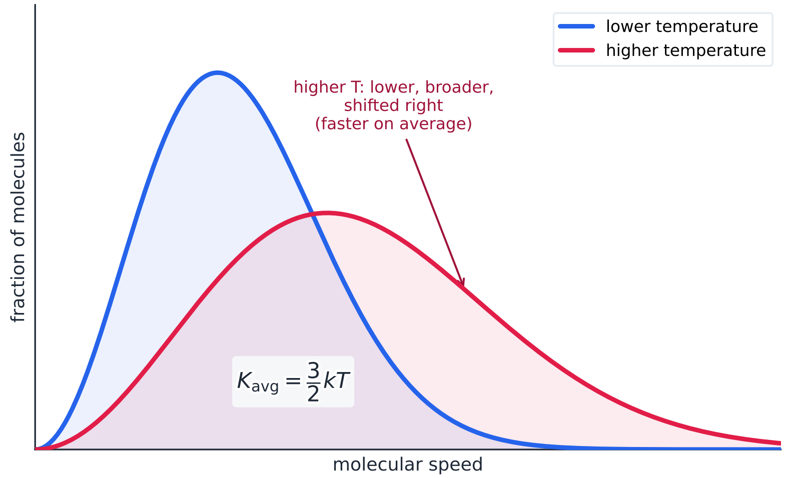
Kinetic Theory of Temperature and Pressure

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:

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

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).

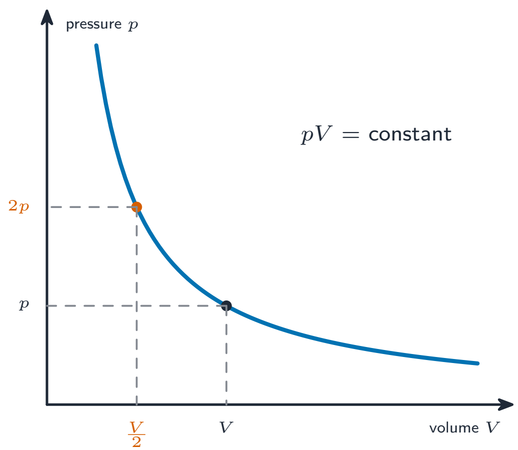
The Ideal Gas Law

An iceberg: heat, density and phase changes connect thermodynamics to fluids and buoyancy

An **ideal gas** 理想气体 obeys

$$PV = nRT \qquad (\text{or } PV = Nk_BT),$$

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.

Heating the gas inside a balloon lowers its density, so the balloon rises — the ideal gas law in action

Thermal Energy Transfer and Equilibrium

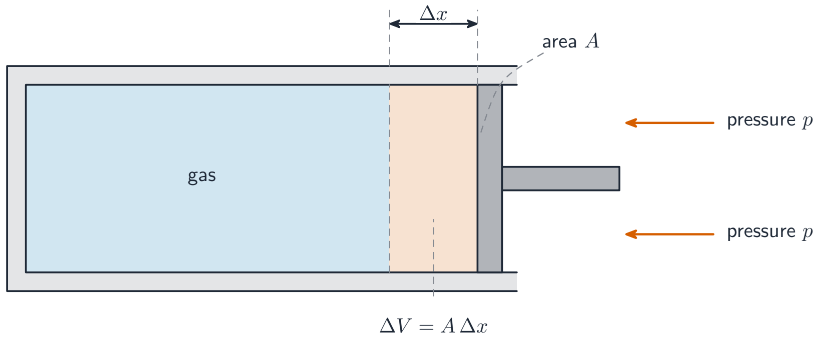
Heat 热量 Q is energy transferred because of a temperature difference; it flows from hot to cold. Two objects in contact reach **thermal equilibrium** 热平衡 when they share the same temperature, and net heat flow stops. The three transfer methods are **conduction** 传导, **convection** 对流, and **radiation**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

The First Law of Thermodynamics

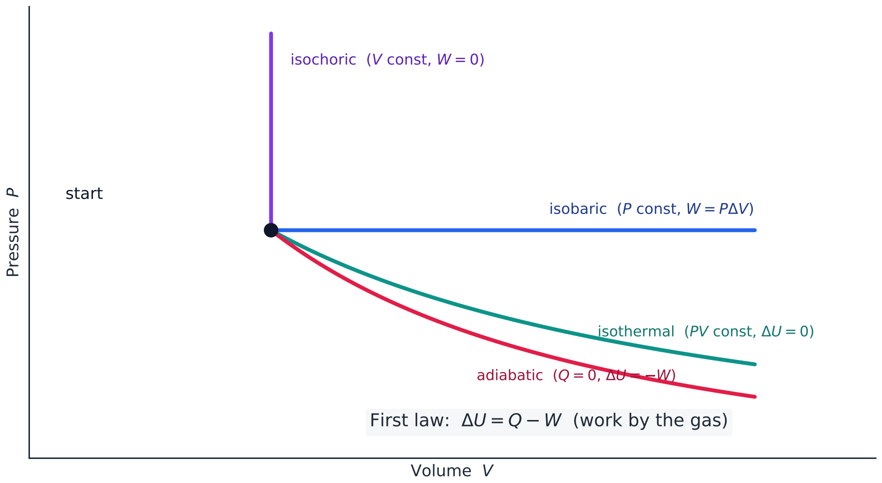
The **first law** 热力学第一定律 is conservation of energy for a gas:

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

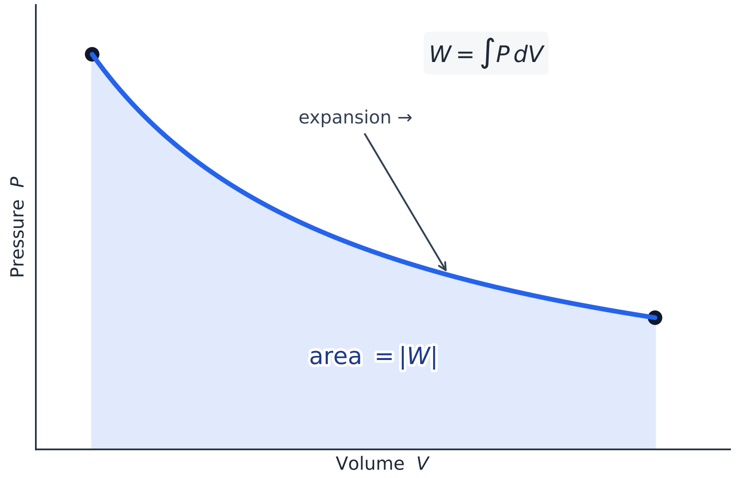
where ΔU is the change in **internal energy** 内能 (tied to temperature), Q is heat added **to** the gas, and W is work done **on** the gas. On a pressure–volume diagram, the work done **by** the gas is the area under the process curve. Watch signs: compressing a gas does positive work on it.



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

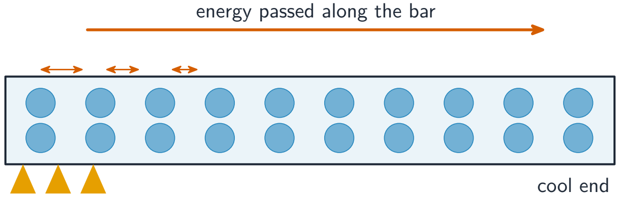
Worked example. A gas absorbs 500 J of heat and, as it expands, does 200 J of work **on its surroundings**. Find the change in its internal energy. Work done *on* the gas is $W = -200$ J (it does work, so it loses that energy):

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

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.