

Gas particles, pressure and heat conduction

AP Physics 2 (algebra-based) · Lesson

Quick answer: An ideal gas is a collection of tiny, randomly moving particles whose average kinetic energy is proportional to the kelvin temperature. Wall collisions create pressure, and the gas obeys $pV = nRT$. Heat conducts through solids at a rate $H = kA\Delta T/L$, so good insulators have a low thermal conductivity k .

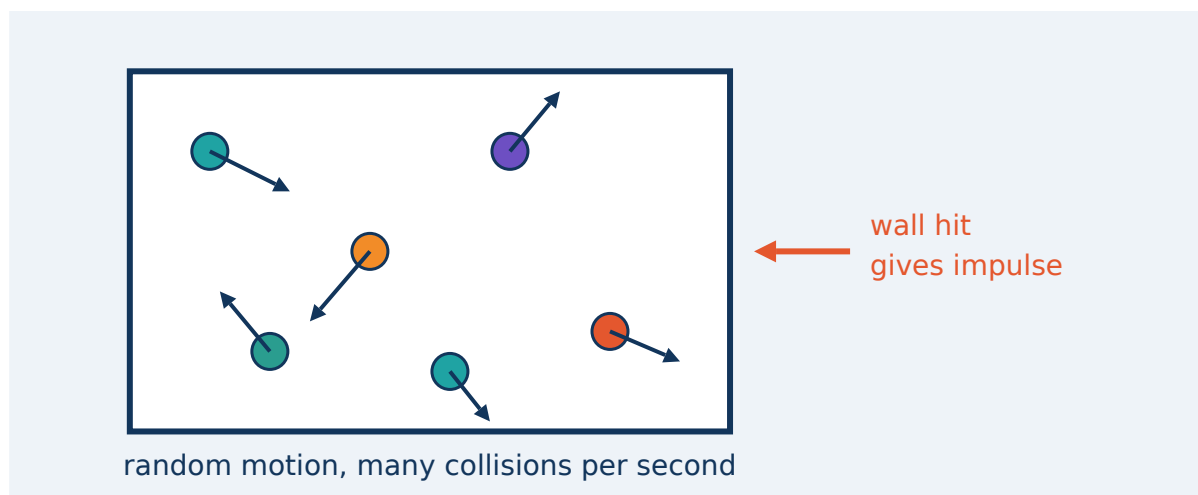
Level: AP Physics 2 (algebra-based) · **Curriculum:** AP P2 Unit 9

What does kinetic theory say about a gas?

Kinetic theory pictures a gas as a vast number of tiny particles that move randomly and almost never feel each other except in brief collisions. The particles are far apart compared with their own size, so a gas fills any container and is easy to compress. Collisions with the walls are elastic on average, which means the gas does not lose energy by simply sitting still.

Definition

An **ideal gas** is a model in which particles have negligible volume, exert no forces except during collisions, and collide elastically with each other and the walls. Real gases such as air at room conditions behave this way very closely.



Pressure is the average force per area from countless wall collisions.

Pressure appears because every collision with a wall delivers a small impulse. Trillions of impacts per second blend into a steady force on each square metre of wall. More collisions or harder collisions both raise the pressure.

How are temperature and molecular energy connected?

The absolute temperature measures the average translational kinetic energy of the particles. Doubling the kelvin temperature doubles the average energy per particle, whatever the gas.

Lighter particles reach the same energy by moving faster, so at a given temperature hydrogen moves much faster than oxygen.

Formula

$$K_{\text{avg}} = (3/2) k_B T \quad v_{\text{rms}} = \sqrt{(3k_B T/m)} = \sqrt{(3RT/M)}$$

K_{avg} is the average kinetic energy per particle (J), $k_B = 1.38 \times 10^{-23}$ J/K, T is the temperature in kelvin (K), m is the mass of one particle (kg), M is the molar mass (kg/mol) and $R = 8.31$ J/(mol·K).

Worked example

Find the root-mean-square speed of oxygen ($M = 0.032$ kg/mol) at 300 K.

$$v_{\text{rms}} = \sqrt{(3 \times 8.31 \times 300 / 0.032)} = \sqrt{(2.337 \times 10^5)} = \mathbf{483 \text{ m/s.}}$$

How do you use the ideal gas law?

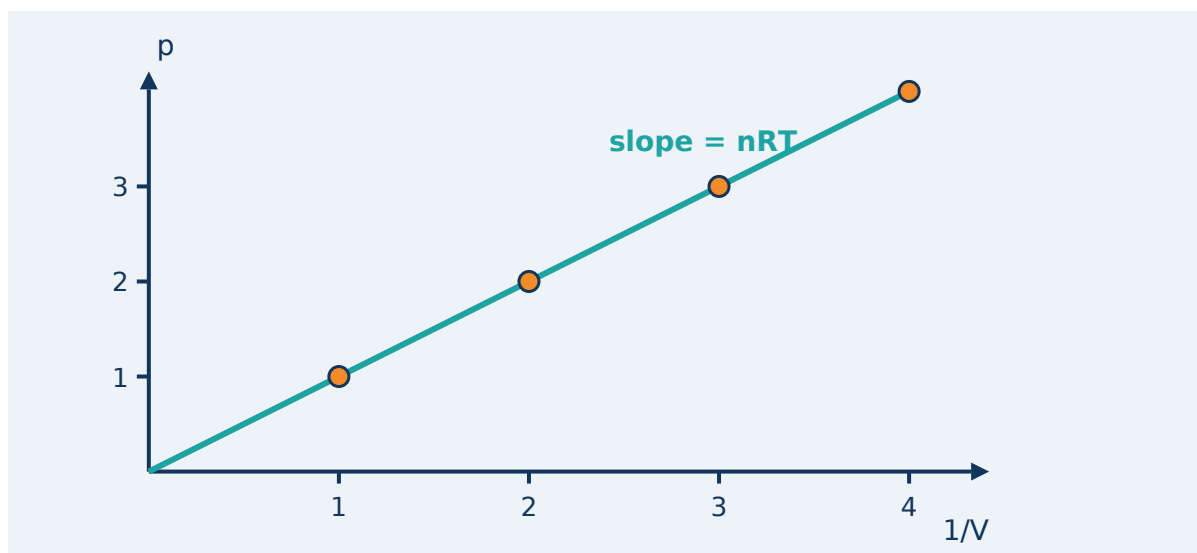
Formula

$$pV = nRT = Nk_B T$$

p is the absolute pressure (Pa), V is the volume (m^3), n is the amount of gas (mol), N is the number of particles, T is the temperature in kelvin (K). Convert litres with $1 \text{ L} = 1.0 \times 10^{-3} \text{ m}^3$.

The law links four variables, so fixing two of them leaves a simple relationship between the other two. The table lists the three cases that AP questions use most.

Fixed quantities	Relationship	Graph that is a straight line
n and T	$pV = \text{constant}$ (Boyle)	p against $1/V$ through the origin
n and V	$p/T = \text{constant}$	p against T (kelvin) through the origin
n and p	$V/T = \text{constant}$	V against T (kelvin) through the origin



At constant temperature and amount, p against $1/V$ is a straight line through the origin.

Worked example

Wanjiru in Nairobi seals 0.062 mol of air in a rigid 1.5 L bottle at 20 °C (293 K). Find the pressure, then the pressure after the bottle warms to 55 °C (328 K) in a car.

$p_1 = nRT/V = (0.062 \times 8.31 \times 293)/(1.5 \times 10^{-3}) = \mathbf{1.0 \times 10^5 \text{ Pa}}$. Volume and amount are fixed, so $p_2 = p_1 \times 328/293 = \mathbf{1.1 \times 10^5 \text{ Pa}}$.

Common mistake

Temperatures in the gas law must be in kelvin, and the pressure must be absolute. Using 25 instead of 298 for T , or a gauge pressure instead of an absolute one, gives results that are wrong by a large factor.

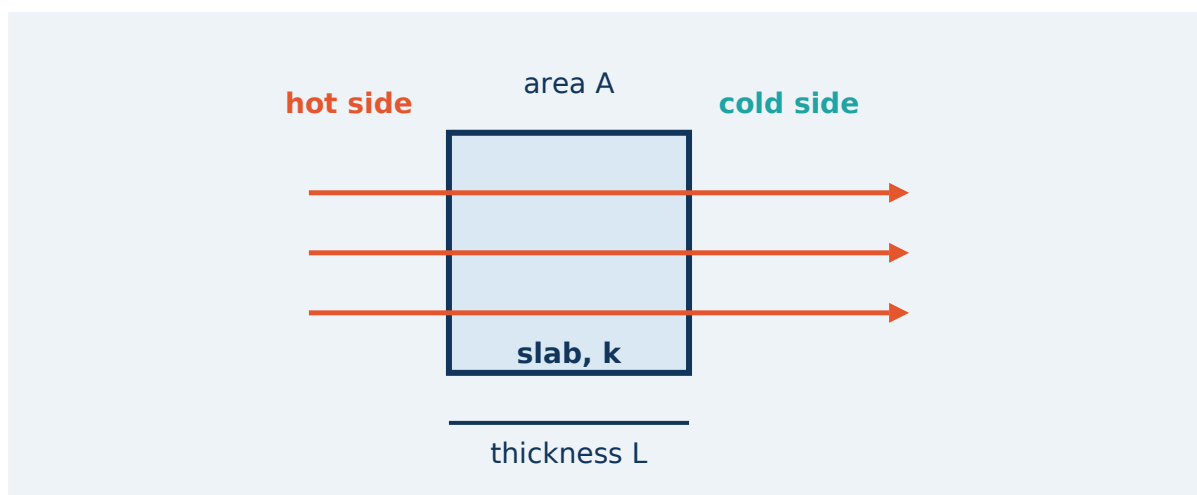
How does heat move through a solid by conduction?

In conduction, energy passes from fast-vibrating particles to their slower neighbours without any bulk movement of the material. Metals conduct best because free electrons carry energy quickly. Trapped air, as in foam or wool, conducts poorly and makes an excellent insulator.

Formula

$$H = Q/\Delta t = kA\Delta T/L$$

H is the rate of heat flow (W), k is the thermal conductivity (W/(m·K)), A is the cross-sectional area (m²), ΔT is the temperature difference across the material (K) and L is the thickness (m).



Heat flows from the hot face to the cold face; the rate depends on k , A , the temperature difference and L .

Material	k (W/(m·K))	Role
Copper	400	cooking pans, heat sinks
Aluminium	205	pans, radiators
Glass	0.80	windows

Material	k (W/(m·K))	Role
Wood	0.15	doors, handles
Polystyrene foam	0.033	cool boxes, insulation

Worked example

A foam cool box lid has $k = 0.033 \text{ W/(m·K)}$, area 0.30 m^2 and thickness 0.040 m . Inside it is 4°C and outside 30°C . Find the heat flow rate.

$H = k\Delta T/L = (0.033 \times 0.30 \times 26)/0.040 = \mathbf{6.4 \text{ W}}$. Over 2.0 hours this lets in $4.6 \times 10^4 \text{ J}$.

Lina's tip

For any gas question, write the known values in a column with units, convert to kelvin and cubic metres first, and only then pick the formula. Doubling or halving checks catch most slips.

How do AP questions combine these ideas?

A typical free-response question asks you to translate between words, equations and graphs. You may need to explain, in a short paragraph, why the pressure rises when a sealed container is heated: faster particles hit the walls more often and harder, and the pressure is proportional to the kelvin temperature. Another style asks you to design an experiment, naming the variable you change, the variable you measure and the quantities you hold fixed.

Quantities stay linked: if the volume doubles at constant temperature, each particle travels farther between wall hits, so collisions happen half as often and the pressure halves. Reasoning like this earns marks even before any numbers appear.

Key points to remember

- $pV = nRT = Nk_{\text{B}}T$, with T in kelvin and p absolute
- Average kinetic energy per particle: $K = (3/2) k_{\text{B}} T$, with $k_{\text{B}} = 1.38 \times 10^{-23} \text{ J/K}$
- $v_{\text{rms}} = \sqrt{3RT/M}$, so lighter gases move faster at the same temperature
- Conduction rate: $H = k\Delta T/L$ in watts
- At constant T and n , a graph of p against $1/V$ is a straight line through the origin

Gas particles, pressure and heat conduction: frequently asked questions

Why must temperature be in kelvin in the ideal gas law?

The law is a proportion between pressure, volume and the average kinetic energy of the particles. That energy is zero at 0 K , not at 0°C , so only the kelvin scale makes the proportions work.

Do heavier gas molecules have more kinetic energy?

No. At the same temperature all ideal gas particles have the same average translational kinetic energy, $(3/2) k_B T$. Heavier particles simply move more slowly.

What is the difference between k_B and R ?

$k_B = 1.38 \times 10^{-23} \text{ J/K}$ applies to a single particle, while $R = 8.31 \text{ J/(mol}\cdot\text{K)}$ applies to a mole. They are related by $R = N_A k_B$, where $N_A = 6.02 \times 10^{23}$ per mole.

Why do metals feel colder than wood at the same temperature?

Metal has a much larger thermal conductivity, so it draws heat from your hand faster. The faster loss of heat from your skin is what you sense as cold.

How do you find the number of particles in a gas sample?

Use $N = pV/(k_B T)$ with p in pascals, V in cubic metres and T in kelvin. You can also find $n = pV/(RT)$ first and multiply by 6.02×10^{23} .