THERMO DAY 1: KINETIC THEORY OF TEMPERATURE & PRESSURE

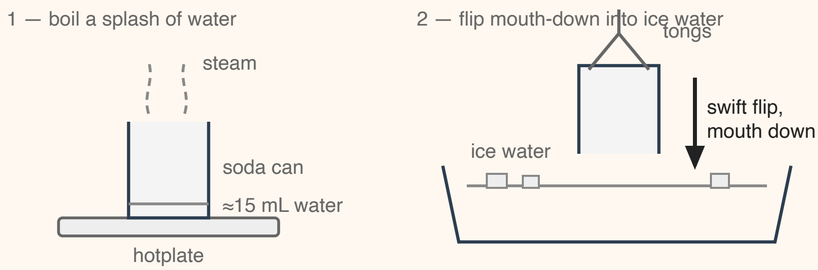
UNIT PREVIEW

AP Physics 1 tracked energy in visible systems such as carts, springs, and pucks. AP Physics 2 opens the box: ordinary samples contain roughly 10^{23} particles, and thermodynamics connects their microscopic behavior to gas laws, engines, and the direction of macroscopic processes.

Today: how particle motion and collisions determine two measurable state variables, **temperature** and **pressure**.

WARMUP **The Crushed Can — predict first**

Your teacher boils a splash of water inside an open soda can until steam jets from the mouth, then grabs the can with tongs and flips it **mouth-down into ice water** in one fast motion.



The apparatus. Commit to a prediction before the teacher flips the can.

Prediction — circle one. The instant the can's mouth hits the ice water:

(A) nothing much happens — aluminum is stiff **(B)** ice water rises slowly up into the can **(C)** the can is crushed, almost instantly

In one line, why did you pick your prediction?

____

THE SYSTEM, THE BOUNDARY, THE SURROUNDINGS

NAME THE SYSTEM FIRST

In AP 1, no energy equation got written until you drew a dashed line and named the system ("cart + Earth; friction crosses the boundary"). Thermodynamics keeps that habit, with official names:

System — the stuff you are tracking. **Boundary** — the surface where the tracking stops. **Surroundings** — everything outside the boundary.

Every equation in Unit 9 is bookkeeping across a named boundary. Start naming now.

QUICK **Name the Parts of the Can Demo**

Fill each blank from the bank: *ice bath + room air* · *the gas sealed inside the can* · *can wall + the water surface at the mouth*

System = ______________________ Boundary = ______________________

Surroundings = ______________________

THE KINETIC MODEL OF MATTER

THE MODEL

A gas consists of many particles in **continuous, random motion**. Between collisions, each particle travels in a straight line. One breath of air holds about 10^{22} molecules, each undergoing roughly a billion collisions per second. Temperature and pressure describe the collective behavior of those particles.

TEMPERATURE TRACKS AVERAGE TRANSLATIONAL KINETIC ENERGY

$$KE_{avg} = \frac{3}{2} k_B T$$

k_B = 1.38×10^{-23} J/K (Boltzmann's constant — the exchange rate between kelvin and joules)
T = temperature, in **kelvin** (K)

KE_{avg} = average *translational* kinetic energy of ONE typical particle (J) — the energy of flying from place to place

Temperature is a state variable, not an energy. In this ideal-gas model, it is directly proportional to the **average translational kinetic energy per particle**. Molecular speeds also increase with temperature, but as $v_{rms} \propto \sqrt{T}$.

Use kelvin in kinetic-theory equations: $T_K = T_{^\circ C} + 273$. In the classical ideal-gas model, average translational kinetic energy approaches zero as T approaches 0 K (–273°C). By contrast, 0°C marks the freezing point of water, not the absence of molecular motion.

WE DO — Average KE at Room Temperature

The classroom air sits at 20°C. Find the average translational kinetic energy of one air molecule.

Step 1 — convert: $T = 20^\circ\mathrm{C} + 273 =$ __________ K

Step 2 — compute, carrying units: $KE_{avg} = \frac{3}{2} k_B T = \frac{3}{2}(1.38 \times 10^{-23}\ \mathrm{J/K})($______ $\mathrm{K}) =$ ___________ J

YOU DO — Average KE in a Bread Oven

The air inside a bread oven holds at 77°C. Find the average translational kinetic energy of one air molecule. Convert to kelvin first; carry units through the computation.

QUICK — Kelvin Round-Trip

(a) Your body: 37°C = __________ K **(b)** Nitrogen boils at 77 K = __________ °C **(c)** An Arctic morning: –40°C = __________ K

PRESSURE FROM COLLISIONS WITH CONTAINER WALLS

PRESSURE ARISES FROM COLLISIONS

Gas particles repeatedly collide with the container walls. Each collision transfers a small impulse (AP 1: impulse = Δp); the combined momentum transfer produces a steady force. **Pressure is force per area** (N/m²). Pressure increases when particles transfer more momentum per collision or collide with the wall more frequently.

WE DO **One Kick on the Wall**

A nitrogen molecule ($m = 4.65 \times 10^{-26}$ kg) flies straight at the can wall at 500 m/s and rebounds straight back at 500 m/s. Take "toward the wall" as positive.

(a) The molecule's momentum change: $\Delta p = m(v_f - v_i) =$ __________ kg·m/s

(b) What impulse does the molecule give the wall — magnitude and direction?

Scale the collisions up: room air produces ≈3×10²³ collisions on every square centimeter each second. Impulse per collision × collision rate gives a force of order 10^5 N on every square meter, consistent with atmospheric pressure.

Back to the can: boiling drove out most of the air and filled the can with steam. The ice bath cools the remaining gas, and much of the steam condenses to liquid. Both changes reduce the pressure inside the can, while the room's air pressure remains nearly unchanged.

Circle one: after the ice bath, the greater pressure on the can wall is the **inside / outside** pressure. The resulting net force points toward the lower-pressure side.

WE DO **Two Gases, One Temperature**

A sealed flask of room-temperature air also holds a puff of helium. Helium atom: $m_{He} = 6.64 \times 10^{-27}$ kg. Nitrogen molecule: $m_{N_2} = 4.65 \times 10^{-26}$ kg. Both gases share one temperature.

(a) Circle: the larger average translational KE belongs to **helium / nitrogen / neither — the averages are equal**.

(b) Which particle typically moves faster? Defend your pick from $KE = \frac{1}{2}mv^2$ in one line.

(c) Numeracy check: $m_{N_2}/m_{He} =$ __________ (≈ how many times heavier nitrogen is)

HEAT IS NOT TEMPERATURE

THREE WORDS, THREE JOBS

Temperature (K): the state variable that *tracks* average translational KE per particle ($KE_{avg} = \frac{3}{2}k_B T$). A drop and a bathtub of 40°C water read the **same temperature**.

Thermal (internal) energy (J): the *total* of every particle's microscopic kinetic AND potential energy. Today's ideal gas has zero potential share — translational KE is the whole total; in liquids like coffee, molecular PE is a big share. Same temperature, ~10^6× the molecules: the bathtub holds ~10^6× the drop's energy.

Heat, Q (J): energy *in transit* across a boundary, driven by a temperature difference. Objects hold thermal energy, never heat — an account holds a *balance*; a *deposit* exists only while money moves.

PRACTICE

1 Freezer Physics

A kitchen freezer holds its air at –18°C. **(a)** Convert: T = __________ K **(b)** Find KE_{avg} for one air molecule (carry units).

2 Reading the Thermometer Backward

Inside a sealed lab oven, the average translational KE of the air molecules is 8.28×10^{-21} J. **(a)** Find the oven's temperature in kelvin (carry units). **(b)** Convert the oven's temperature to °C.

TOOL BOX — RMS SPEED

$v_{rms} = \sqrt{3k_BT/m}$ — the speed of a particle carrying exactly the average KE (set $\frac{1}{2}mv^2 = \frac{3}{2}k_BT$, solve for v). Where the $\frac{3}{2}k_BT$ comes from: tomorrow.

3 Liquid-Nitrogen Cold

Nitrogen molecules: $m = 4.65 \times 10^{-26}$ kg. Find v_{rms} **(a)** in this room at 293 K, and **(b)** at 77 K, just above where nitrogen turns to liquid. Carry units both times.

(c) T fell by a factor of 3.8; v_{rms} fell by only __________ $\rightarrow$ $v_{rms} \propto$ __________.

4 Fix the Claim

A student says: *"My hot coffee has more heat in it than your iced coffee."* Rewrite the student's claim in 2–3 sentences so that **temperature**, **thermal energy**, and **heat** are each used correctly. (Assume equal amounts of the same coffee.)

5 Two Gases, by the Numbers

A sealed flask at 350 K holds both helium ($m_{He} = 6.64 \times 10^{-27}$ kg) and nitrogen ($m_{N_2} = 4.65 \times 10^{-26}$ kg). **(a)** The ratio KE_{He}/KE_{N_2} = __________ **(b)** Starting from $\frac{1}{2}m_{He}v_{He}^2 = \frac{1}{2}m_{N_2}v_{N_2}^2$, find v_{He}/v_{N_2} (3 sig figs).