

Gas particles, pressure and heat conduction

AP Physics 2 (algebra-based) · Worksheet answers

Each answer shows the formula, the substitution and the result with its unit in bold. Compare your reasoning as well as your final number, because AP scoring rewards the physics argument.

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

Problem 1 Kelvin readings

Use $T(K) = T(^{\circ}C) + 273$.

- $12 + 273 = \mathbf{285\ K}$.
- $400 - 273 = \mathbf{127\ ^{\circ}C}$.
- Absolute zero is 0 K, so $\mathbf{-273\ ^{\circ}C}$.

Problem 2 Counting molecules

- $N = nN_A = 0.25 \times 6.02 \times 10^{23} = \mathbf{1.5 \times 10^{23}\ molecules}$.
- $m = nM = 0.25 \times 28 = \mathbf{7.0\ g}$.

Problem 3 A bicycle pump

- $4.0\ cm^2 = 4.0 \times 10^{-4}\ m^2$.
- $p = F/A = 120 / 4.0 \times 10^{-4} = \mathbf{3.0 \times 10^5\ Pa}$.
- In a smaller volume each particle reaches the walls more often, so there are more collisions per second and a larger average force per unit area. **Higher pressure comes from more frequent collisions.**

Problem 4 Energy of one particle

- $27 + 273 = 300\ K$.
- $K = (3/2)k_B T = 1.5 \times 1.38 \times 10^{-23} \times 300 = \mathbf{6.21 \times 10^{-21}\ J}$.
- $327\ ^{\circ}C = 600\ K$, so $K = 1.24 \times 10^{-20}\ J$. The kelvin temperature doubled, so **the average energy doubled (ratio 2.00)**.

Problem 5 Heat through a window

- $4.0\ mm = 4.0 \times 10^{-3}\ m$.
- $H = kA\Delta T/L = 0.80 \times 1.5 \times 12 / 4.0 \times 10^{-3} = \mathbf{3600\ W}$ (3.6 kW).
- H is inversely proportional to L, so the rate **halves to 1.8 kW**.

Problem 6 Pressure from a particle count

1. $1.5 \text{ L} = 1.5 \times 10^{-3} \text{ m}^3$.
2. $p = (3.0 \times 10^{22} \times 1.38 \times 10^{-23} \times 310)/(1.5 \times 10^{-3}) = \mathbf{8.6 \times 10^4 \text{ Pa}}$.
3. This is 85% of atmospheric pressure, so the flask is slightly below atmospheric pressure.

Problem 7 Weather balloon

1. Fixed n gives $p_1 V_1/T_1 = p_2 V_2/T_2$.
2. $V_2 = V_1(p_1/p_2)(T_2/T_1) = 2.0 \times (1.01 \times 10^5/2.6 \times 10^4) \times (223/288) = \mathbf{6.0 \text{ m}^3}$.
3. The pressure falls by a factor of about 3.9 while the temperature falls only by a factor of 1.3, so the pressure effect dominates and the gas expands.

Problem 8 Speed of nitrogen

1. $v_{\text{rms}} = \sqrt{3RT/M} = \sqrt{3 \times 8.31 \times 293/0.028} = \mathbf{511 \text{ m/s}}$.
2. $m = 0.028/6.02 \times 10^{23} = 4.65 \times 10^{-26} \text{ kg}$.
3. $\sqrt{3 \times 1.38 \times 10^{-23} \times 293/4.65 \times 10^{-26}} = 511 \text{ m/s}$, which agrees with part 1 **within rounding**.

Problem 9 Doubling the speed

1. At 1000 K: $\sqrt{3 \times 8.31 \times 1000/0.028} = 944 \text{ m/s}$. At 250 K: 472 m/s.
2. $944/472 = \mathbf{2.00}$.
3. $v_{\text{rms}} \propto \sqrt{T}$, so doubling the speed needs **four times the kelvin temperature**.

Problem 10 Graph of p against $1/V$

1. A straight line through the origin; the slope equals nRT , which is $pV = 60.0 \text{ J}$.
2. $n = pV/(RT) = 60.0/(8.31 \times 295) = \mathbf{0.0245 \text{ mol}}$.
3. $p = 60.0/1.20 \times 10^{-3} = \mathbf{5.0 \times 10^4 \text{ Pa}}$.

Problem 11 Heat through a brick wall

1. $\Delta T = 21 - 5 = 16 \text{ K}$.
2. $H = 0.72 \times 12 \times 16/0.22 = \mathbf{628 \text{ W}}$.
3. $Q = H\Delta t = 628.4 \times 3600 = \mathbf{2.3 \times 10^6 \text{ J}}$.

Problem 12 Pan bases compared

1. Aluminium: $205 \times 0.030 \times 4.0/0.0030 = \mathbf{8200 \text{ W}}$. Steel: $16 \times 0.030 \times 4.0/0.0030 = \mathbf{640 \text{ W}}$.
2. Ratio = $205/16 = \mathbf{12.8}$.
3. Copper conducts heat sideways quickly, spreading the heat from the burner across the base so there are no hot spots.

Problem 13 Sealed can on a stove

1. Heating raises the kelvin temperature, so the particles' average kinetic energy and their speeds increase.
2. Faster particles strike the walls more often and with larger impulses, so the average force per unit area grows. With V and n fixed, $p \propto T$.
3. **The pressure difference across the wall grows until the wall can no longer resist it**, although the number of particles is unchanged.

Problem 14 Helium against air

1. From $pV = nRT$ with $n = m/M$: $pV = (m/M)RT$, so $\rho = m/V = pM/(RT)$.
2. Helium: 0.166 kg/m^3 . Air: 1.20 kg/m^3 .
3. Net lift $= (\rho_{\text{air}} - \rho_{\text{He}}) \times 1.0 \times 9.81 = (1.203 - 0.166) \times 9.81 = \mathbf{10.2 \text{ N}}$.

Problem 15 Spot the error

1. T was not converted to kelvin (25°C is 298 K), and V was not converted to m^3 ($3.0 \text{ L} = 3.0 \times 10^{-3} \text{ m}^3$).
2. $p = (0.15 \times 8.31 \times 298)/(3.0 \times 10^{-3}) = \mathbf{1.2 \times 10^5 \text{ Pa}}$.
3. 10.4 Pa is about one ten-thousandth of atmospheric pressure, which is absurd for a closed container with 0.15 mol of gas.

Problem 16 A heated jar lid

1. $p_2 = p_1 T_2/T_1 = 1.00 \times 10^5 \times 453/293 = \mathbf{1.55 \times 10^5 \text{ Pa}}$.
2. $F = (p_2 - p_0)A = (5.46 \times 10^4) \times 5.0 \times 10^{-3} = \mathbf{273 \text{ N}}$.
3. Since 273 N exceeds 200 N , the lid is pushed off (or the seal fails).

Problem 17 Bubble from a lake bed

1. $p = p_0 + \rho gh = 1.01 \times 10^5 + 1000 \times 9.81 \times 12 = \mathbf{2.19 \times 10^5 \text{ Pa}}$.
2. $V_2 = V_1(p_1/p_2)(T_2/T_1) = 1.0 \times (2.19 \times 10^5/1.01 \times 10^5)(295/280) = \mathbf{2.3 \text{ cm}^3}$.
3. The pressure ratio is 2.17 but the temperature ratio is only 1.05 , so the pressure change dominates.

Problem 18 Two layers in series

1. Wood: $0.020/(0.15 \times 2.0) = 0.0667 \text{ K/W}$. Foam: $0.040/(0.030 \times 2.0) = 0.667 \text{ K/W}$.
2. The temperature differences add: $\Delta T_{\text{total}} = H(R_W + R_F)$, so $H = 30/0.7333 = \mathbf{41 \text{ W}}$.
3. ΔT across wood $= HR_W = 40.91 \times 0.06667 = 2.73 \text{ K}$, so the interface is at $25 - 2.73 = \mathbf{22.3^\circ\text{C}}$. Almost the entire drop occurs across the foam.

Problem 19 Heavier means faster?

1. Both have $K = (3/2)k_B T = 6.21 \times 10^{-21} \text{ J}$, so **the energies are equal**.
2. Ratio = $\sqrt{M_{N_2}/M_{O_2}} = \sqrt{28/32} = \mathbf{0.935}$.
3. At the same temperature all ideal gas particles have the same average translational kinetic energy. Because $K = \frac{1}{2}mv^2$, the heavier oxygen molecules must move more slowly, about 6.5% slower than nitrogen. The claim fails on both counts.

Problem 20 Design an experiment on conduction

1. Independent: rod length L . Dependent: rate of heat flow H , found from the temperature rise of a water bath per second. Controlled: rod material, cross-sectional area, and the temperatures at the two ends.
2. Use rods of identical material and diameter in several lengths. Keep one end in a beaker of boiling water and the other in a known mass of cold water with a thermometer, insulate the sides, and record the temperature rise over a fixed time for each length, then repeat each reading.
3. Plot H against $1/L$. Because $H = kA\Delta T/L$, **the graph should be a straight line through the origin with slope $kA\Delta T$** .