

Heat, work and engines on PV diagrams

AP Physics 2 (algebra-based) · Worksheet answers

Each answer states the sign of Q and W, shows the substitution and gives the result with its unit in bold. Check your sign convention first, since that is the most common source of lost marks in thermodynamics.

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

Problem 1 Heat in, work out

1. $Q = +300 \text{ J}$ (heat enters). The gas does work on the surroundings, so $W = -120 \text{ J}$.
2. $\Delta U = Q + W = 300 + (-120) = \mathbf{+180 \text{ J}}$.

Problem 2 Constant pressure expansion

1. $\Delta V = 3.0 \text{ L} = 3.0 \times 10^{-3} \text{ m}^3$.
2. Work by the gas = $p\Delta V = 1.2 \times 10^5 \times 3.0 \times 10^{-3} = \mathbf{360 \text{ J}}$.
3. W on the gas = $\mathbf{-360 \text{ J}}$.

Problem 3 Compression on a graph

1. $V_i = 4.0 \text{ L}$ and $V_f = 1.5 \text{ L}$, so $\Delta V = -2.5 \text{ L} = -2.5 \times 10^{-3} \text{ m}^3$.
2. $W = -p\Delta V = -2.5 \times 10^5 \times (-2.5 \times 10^{-3}) = \mathbf{+625 \text{ J}}$.
3. W is positive, so energy **enters the gas** as work.

Problem 4 Engine efficiency

1. $e = W/Q_H = 500/2000 = \mathbf{0.25}$ (25%).
2. $Q_C = Q_H - W = 2000 - 500 = \mathbf{1500 \text{ J}}$.

Problem 5 Warming a monatomic gas

1. $\Delta U = (3/2)nR\Delta T$.
2. $\Delta U = 1.5 \times 0.20 \times 8.31 \times 50 = \mathbf{125 \text{ J}}$.
3. No. For an ideal gas, U depends only on T, so **ΔU is the same for any process with this ΔT** .

Problem 6 Rigid container

1. The volume is fixed, so $W = 0$.
2. $\Delta U = (3/2)nR\Delta T = 1.5 \times 0.50 \times 8.31 \times 120 = \mathbf{748 \text{ J}}$.
3. $Q = \Delta U - W = \mathbf{748 \text{ J}}$.

Problem 7 Slow squeeze in a water bath

1. The temperature is constant, so $\Delta U = 0$ for an ideal gas.
2. $Q = \Delta U - W = 0 - 350 = -350 \text{ J}$.
3. The 350 J leaves the gas as heat flowing into the water bath, so the gas does not warm up.

Problem 8 Quick pump stroke

1. $Q = 0$ (adiabatic).
2. $\Delta U = Q + W = 0 + 15 = +15 \text{ J}$.
3. $\Delta T = \Delta U / ((3/2)nR) = 15 / (1.5 \times 0.030 \times 8.31) = 40.1 \text{ K}$.

Problem 9 Triangular cycle

1. Triangle area = $\frac{1}{2} \times \text{base} \times \text{height} = \frac{1}{2} \times (3.0 \times 10^{-3} \text{ m}^3) \times (2.0 \times 10^5 \text{ Pa}) = 300 \text{ J}$.
2. The loop runs clockwise (A up to B, across to C, back to A), so the net work is done **by the gas**.
3. The gas returns to the same state, so $\Delta U = 0$.

Problem 10 Geothermal plant

1. $e = 1.8 \times 10^8 / 5.0 \times 10^8 = 0.36$ (36%).
2. $Q_c = 5.0 \times 10^8 - 1.8 \times 10^8 = 3.2 \times 10^8 \text{ J}$.
3. It is carried away by cooling water or air in the cooling towers.

Problem 11 Is this engine possible?

1. $e_{\max} = 1 - T_c/T_h = 1 - 300/550 = 0.455$.
2. 0.50 is larger than 0.455, so the claim is **impossible**.
3. It is an upper limit; real engines, with friction and heat leaks, always fall below it.

Problem 12 Entropy of heat flow

1. Hot block: $\Delta S = -600/400 = -1.50 \text{ J/K}$. Cold block: $\Delta S = +600/300 = +2.00 \text{ J/K}$.
2. Total = $+2.00 - 1.50 = +0.50 \text{ J/K}$.
3. The total is positive, which agrees with the second law: heat flows spontaneously from hot to cold.

Problem 13 Two expansions

1. Curve 1 is the isothermal expansion, because it is the less steep curve with pV constant, so T stays the same. Curve 2 falls faster, which means the gas cools as it expands.
2. The isothermal end state is at the starting temperature; the adiabatic end state is colder.
3. **The isothermal expansion does more work**, since the area under curve 1 is larger.

Heat entering during the isothermal expansion supplies the extra energy.

Problem 14 Spot the error

1. With W defined as work done on the gas, an expansion has negative W (-80 J), but the student used $+80$ J.
2. $\Delta U = 200 + (-80) = +120$ J.
3. 280 J would mean the gas gained energy from both the heat and the work, as if it had been compressed, which contradicts the expansion.

Problem 15 Constant pressure heating

1. $\Delta U = 1.5 \times 0.040 \times 8.31 \times 150 = 74.8$ J.
2. Work by the gas $= nR\Delta T = 0.040 \times 8.31 \times 150 = 49.9$ J.
3. $Q = \Delta U + \text{work by gas} = 74.8 + 49.9 = 124.7$ J. $Q/\Delta U = 1.67$, which is $5/3$.

Problem 16 Four-step engine cycle

1. Area $= (2.0 \times 10^5)(2.0 \times 10^{-3}) = 400$ J.
2. AB: $W = 0$, $\Delta U = 1.5(4.0 \times 10^5 - 2.0 \times 10^5)(1.0 \times 10^{-3}) = 300$ J, so $Q = 300$ J. BC: $\Delta U = 1.5 \times (12 \times 10^2 - 4 \times 10^2) = 1200$ J; the work by the gas is $4.0 \times 10^5 \times 2.0 \times 10^{-3} = 800$ J, so $Q = 2000$ J = **2000 J** (the pV values are 400 J at B and 1200 J at C).
3. $Q_H = 2300$ J, so $e = 400/2300 = 0.17$. pV at C is six times pV at A, so $e_{\text{Carnot}} = 1 - 1/6 = 0.833$. The cycle is far below the limit.

Problem 17 Adiabatic expansion

1. $Q = 0$ and $W = -150$ J (work done on the gas).
2. $\Delta U = Q + W = -150$ J. $\Delta T = \Delta U / ((3/2)nR) = -150 / (1.5 \times 0.10 \times 8.31) = -120$ K.
3. $T_f = 400 - 120 = 280$ K.

Problem 18 Ocean thermal engine

1. $e_{\text{max}} = 1 - 277/300 = 0.0767$.
2. $e = 0.60 \times 0.0767 = 0.0460$.
3. $P_{\text{in}} = P/e = 1.5 \times 10^6 / 0.0460 = 3.26 \times 10^7$ W. Rejected: $3.26 \times 10^7 - 1.5 \times 10^6 = 3.11 \times 10^7$ W.

Problem 19 Melting ice and entropy

1. $Q = mL = 0.200 \times 3.34 \times 10^5 = 6.68 \times 10^4$ J.
2. Ice: $\Delta S = Q/T = 6.68 \times 10^4 / 273 = +244.7$ J/K. Air: $\Delta S = -6.68 \times 10^4 / 293 = -228.0$ J/K.
3. Total $= 244.7 - 228.0 = +16.7$ J/K, which is positive, so the process is allowed.

Problem 20 Two inventor claims

1. The first law is satisfied (5.0 kJ in, 5.0 kJ out as work), but the sea water loses entropy $Q/T = -16.7 \text{ J/K}$ with no increase anywhere else, so the total entropy decreases. This violates the second law and the claim is **impossible**.
2. $e_{\max} = 1 - 300/400 = 0.25$, so $W_{\max} = 0.25 \times 1000 = \mathbf{250 \text{ J}}$.
3. The claimed 400 J is greater than 250 J, so claim 2 is **impossible**.