Teacher Guide — First Law of Thermodynamics Practice Problems

Answer Key and Worked Solutions

Section 1 — Recall and Identification

Problem 1.
Answer: B. $\Delta U = Q - W$

This is the standard statement of the first law as presented in the video. All other options rearrange the terms incorrectly.

Common error: Students confuse option A ($Q = \Delta U + W$, which is actually a valid rearrangement) with the canonical form — emphasize that the *canonical* form has ΔU isolated on the left.

Problem 2.
Answer: C. Positive

If $Q = +50\ \text{J}$ and $W = 0$:
$\Delta U = Q - W = 50 - 0 = +50\ \text{J}$

Common error: Students may think "no work" means no energy change — reinforce that heat alone can change internal energy.

Problem 3.
Answer: D. Isochoric (isovolumetric)

In an isochoric process, volume is constant ($\Delta V = 0$), so $W = P\Delta V = 0$.

Common error: Students often confuse "adiabatic" (no heat) with "no work." Stress that adiabatic means $Q = 0$, not $W = 0$.

Problem 4.
Answer: B. $\Delta U = -W$

For an adiabatic process, $Q = 0$, so:

$$\Delta U = Q - W = 0 - W = -W$$

Physically: the internal energy changes only due to work. If work is done **by** the system ($W > 0$), ΔU decreases.

Section 2 — Direct Application

Problem 5.

Given: $Q = +80\ \text{J}$ (absorbed), $W = +30\ \text{J}$ (done by system)

$$\Delta U = Q - W = 80 - 30 = \boxed{+50\ \text{J}}$$

Common error: Students forget that "does work on surroundings" means W is positive.

Problem 6.

Given: $Q = -50\ \text{J}$ (released), $W = +20\ \text{J}$ (done by surroundings... wait — re-read: "does 20 J of work on the surroundings" means done BY system)

$$\Delta U = Q - W = (-50) - (+20) = \boxed{-70\ \text{J}}$$

The internal energy decreases by 70 J.

Common error: Students may use $Q = +50$ — emphasize heat **released** is negative.

Problem 7.

(This is the video's sample problem.)

Given:

- Work done **on** the system by compression: $W = -100\ \text{J}$ (negative because work is done ON the system, not BY it)
- $\Delta U = +74\ \text{J}$

Rearrange: $Q = \Delta U + W$

$$Q = 74 + (-100) = \boxed{-26\ \text{J}}$$

26 J of heat was released (lost) by the system.

Teaching note: This is the exact example from the video. Students should recognize the sign flip — compression gives W a negative value in $\Delta U = Q - W$.

Common error: Using $W = +100$ and getting $Q = +174$ — must apply correct sign for work done ON the system.

Problem 8.

(From the supplemental example.)

Step 1 — Net heat:

$$Q = 40.00 - 25.00 = +15.00 \text{ J}$$

Step 2 — Net work:

- System does $+10.00$ J (positive, by system)
- Work done **on** system: -4.00 J

  $$W = 10.00 - 4.00 = +6.00 \text{ J}$$

Step 3:

$$\Delta U = Q - W = 15.00 - 6.00 = \boxed{+9.00 \text{ J}}$$

Common error: Adding the 4.00 J instead of subtracting.

Section 3 — Sign Convention Practice

Problem 9.

Given:

- Work done **on** the system (compression): $W = -60$ J
- Heat **released**: $Q = -15$ J

$$\Delta U = Q - W = (-15) - (-60) = -15 + 60 = \boxed{+45\text{ J}}$$

The internal energy increases by 45 J.

Common error: Students set $W = +60$ (forgetting it's done ON the system). Drill: "work done ON = negative W."

Problem 10.

Given: $W = +45$ J, $Q = +45$ J

$$\Delta U = Q - W = 45 - 45 = \boxed{0\ \text{J}}$$

This resembles an **isothermal process** (for an ideal gas, $\Delta U = 0$ and $Q = W$).

Problem 11.

Isochoric (constant volume): $W = 0$, $Q = +120\ \text{J}$

$$\Delta U = Q - W = 120 - 0 = \boxed{+120\ \text{J}}$$

$$W = \boxed{0\ \text{J}}$$

All heat absorbed goes directly into increasing internal energy.

Section 4 — Rearranging for Different Variables

Problem 12.

Given: $\Delta U = +35\ \text{J}$, $W = -18\ \text{J}$

Rearrange: $Q = \Delta U + W$

$$Q = 35 + (-18) = \boxed{+17\ \text{J}}$$

17 J of heat was absorbed by the system.

Common error: Forgetting to rearrange correctly; writing $Q = \Delta U - W$ instead of $Q = \Delta U + W$.

Problem 13.

Given: $Q = -90\ \text{J}$ (released), $\Delta U = -55\ \text{J}$

Rearrange: $W = Q - \Delta U$

$$W = (-90) - (-55) = -90 + 55 = \boxed{-35\ \text{J}}$$

W is negative, meaning **35 J of work was done ON the system**.

Common error: Arithmetic sign errors when subtracting negatives.

Problem 14.

Isothermal process, ideal gas: $\Delta U = 0$, $W = +200\text{ J}$

$$\Delta U = Q - W \Rightarrow 0 = Q - 200 \Rightarrow Q = \boxed{+200\text{ J}}$$

200 J of heat was absorbed by the system.

Section 5 — Multi-Step and Extended Problems

Problem 15.

Process 1: $Q_1 = +500\text{ J}$, $W_1 = +200\text{ J}$

$\Delta U_1 = 500 - 200 = \boxed{+300\text{ J}}$

Process 2: $Q_2 = -150\text{ J}$, $W_2 = -80\text{ J}$

$$\Delta U_2 = (-150) - (-80) = -150 + 80 = \boxed{-70\text{ J}}$$

Total:

$$\Delta U_{\text{total}} = 300 + (-70) = \boxed{+230\text{ J}}$$

Common error: Not tracking signs carefully across both steps.

Problem 16.

Adiabatic: $Q = 0$, work done ON the system: $W = -340\text{ J}$

$\Delta U = Q - W = 0 - (-340) = \boxed{+340\text{ J}}$

Internal energy increases by 340 J.

Teaching note: The simplified adiabatic form $\Delta U = -W$ gives the same result: $\Delta U = -(-340) = +340\text{ J}$.

Problem 17. *(Extends beyond video — metabolism context bridged in question stem)*

Given: $W = +420\text{ J}$ (work done BY body on environment), $Q = -230\text{ J}$ (heat released by body)

$\Delta U = Q - W = (-230) - (+420) = \boxed{-650\text{ J}}$

The body's internal energy is **decreasing** by 650 J — the body is drawing on stored energy (e.g., burning calories/fat).

Teaching note: Mark as extended beyond video. The same equation applies; the context is new.

Common error: Treating Q as positive because students think of metabolic heat as energy "generated."

Problem 18. *(Extends beyond video — cyclical process bridged in question stem)*

Part (a):
Cyclical process → $\Delta U = 0$, $Q = +1{,}200\ \text{J}$

$$0 = Q - W \Rightarrow W = Q = \boxed{+1{,}200\ \text{J}}$$

The system does 1,200 J of net work on the surroundings.

Part (b):
$Q = -400\ \text{J}$ (released), $\Delta U = 0$

$$W = Q = \boxed{-400\ \text{J}}$$

Negative W means **work was done ON the system** (net compression over the cycle).

Teaching note: Mark as extended beyond video.

Problem 19.
Process 1: $Q = +300\ \text{J}$, $\Delta U = +180\ \text{J}$

$$W = Q - \Delta U = 300 - 180 = \boxed{+120\ \text{J}}\ \text{(done by system)}$$

Process 2: $W = -50\ \text{J}$, $Q = -30\ \text{J}$

$$\Delta U_2 = Q - W = (-30) - (-50) = -30 + 50 = \boxed{+20\ \text{J}}$$

Cumulative ΔU:

$$\Delta U_{\text{total}} = 180 + 20 = \boxed{+200\ \text{J}}$$

Common error: Students may recalculate ΔU from scratch using cumulative Q and W without tracking individual steps — both methods should agree; verify by confirming $Q_{\text{total}} = 270\ \text{J}$, $W_{\text{total}} = 70\ \text{J}$, $\Delta U = 200\ \text{J}$.

Problem 20.

Part (a):

$$\Delta U = U_f - U_i = 1{,}720 - 1{,}500 = \boxed{+220\text{ J}}$$

Part (b):

Work done **on** the system: $W = -85\text{ J}$

$$Q = \Delta U + W = 220 + (-85) = \boxed{+135\text{ J}}$$

135 J of heat was absorbed by the system.

Common error: Using $W = +85$ and getting $Q = 305\text{ J}$ — must apply sign for work done ON the system.

Common Errors Summary

Error	How to Address
Treating work done ON the system as positive W	Remind: $W > 0$ means work done BY the system; compression → $W < 0$
Treating heat released as positive Q	Remind: $Q > 0$ = absorbed; $Q < 0$ = released
Forgetting to rearrange the formula	Practice all three forms: $\Delta U = Q - W$, $Q = \Delta U + W$, $W = Q - \Delta U$
Sign errors when subtracting negatives	Write out each substitution step before simplifying
Confusing adiabatic ($Q = 0$) and isochoric ($W = 0$)	Use mnemonic: **A**diabatic = no heat **A**dded; **I**sochoric = no volume change

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Exam Tips for Students

1. **Always write the formula first** before substituting — it prevents sign errors.
2. **Label signs explicitly** before computing: circle whether each quantity is positive or negative.
3. **Three rearrangements to memorize:**
   $$\Delta U = Q - W \quad Q = \Delta U + W \quad W = Q - \Delta U$$
4. For **special processes**, simplify first (e.g., $Q = 0$ for adiabatic, $W = 0$ for isochoric) — it reduces arithmetic errors.

5. **Check your answer's sign** — ask: "Does it make physical sense? If the system was compressed and released heat, should it gain or lose internal energy?"