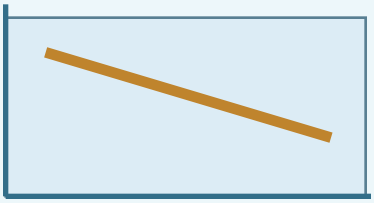
Thermodynamics · Student Workbook

One calculus-based course · Illustrated online text · Physical inquiry · Original problem bank



HEAT • WORK

Delta U = Q - Wby

Student: _____ Class: _____ Date: _____

How to use this workbook

Read the illustrated section on the website before completing each corresponding STRIDES note. Sketch a physical representation, derive the model, then use actual measurements in the physical lab. The online MCQ/FRQ bank has expandable solutions; do not open them until after a written attempt.

Learning targets

- Model thermal systems and sign conventions for heat and work.
- Connect ideal gas states with microscopic energy and temperature.
- Use calculus to calculate quasi-static boundary work from P-V functions.
- Solve phase-change and calorimetry balances with physical branch checks.
- Use logarithmic entropy relationships and propagated measurement uncertainty.

Suggested sequence

1. Notes and worked examples → 2. STRIDES and diagrams → 3. Physical lab → 4. Original MCQ/FRQ practice → 5. Reflection.

Thermodynamics | P-V Visual Revision

AP Physics C/ECE1401 | STUDENT | Five paths + cycle

S1 | Six graphs that must not look alike

Every path represents a different physical constraint. Pressure belongs on the vertical axis; volume belongs on the horizontal axis. Sketch the process and identify the state points before finding work.

1. Isobaric



P stays fixed.

W = P(Vf − Vi)

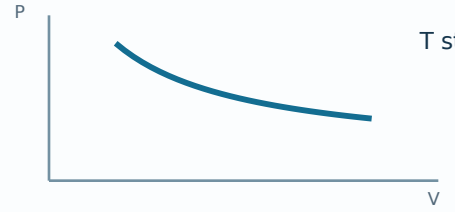
2. Isochoric



V stays fixed.

W = 0

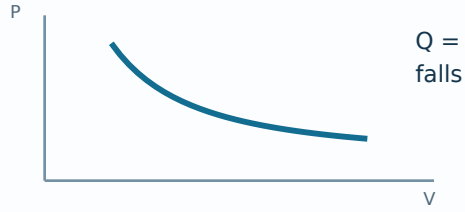
3. Isothermal



T stays fixed.

W = Pi Vi ln(Vf/Vi)

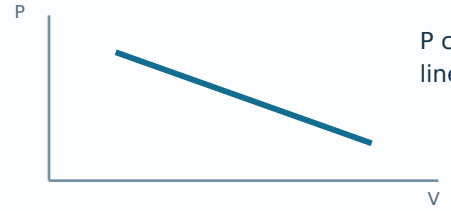
4. Reversible adiabatic



Q = 0. Curve falls faster.

P V^γ = constant

5. Linear pressure



P changes linearly with V.

W = ½(Pi+Pf) ΔV

6. Closed cycle



Final state equals initial.

ΔUcycle = 0

Sign convention: $W_{by} > 0$ on expansion, $W_{by} < 0$ on compression; $\Delta U = Q - W_{by}$. A cycle can have nonzero enclosed work even when $\Delta U_{cycle} = 0$.

S2 | One initial state, different paths

Take P_i = 180 kPa, V_i = 2.00 L, and n = 0.160 mol monatomic ideal gas. For expansion paths use V_f = 5.00 L. For the fixed-volume case use V_f = 2.00 L and P_f / P_i = 1.25. For the linear path use P_f / P_i = 0.75. 1 kPa·L = 1 J.

Process	Pf (kPa)	Vf (L)	Wby (J)	ΔU (J)	Q (J)	
Isobaric						
Isochoric						
Isothermal						
Adiabatic						
Linear						

Required work

1. For the isochoric case, explain why the pressure can change even when no boundary work is done.

2. Derive the isothermal integral W = ∫(PiVi / V) dV and interpret its sign.

3. For the reversible adiabatic case, derive Pf and integrate W using γ = 5/3.

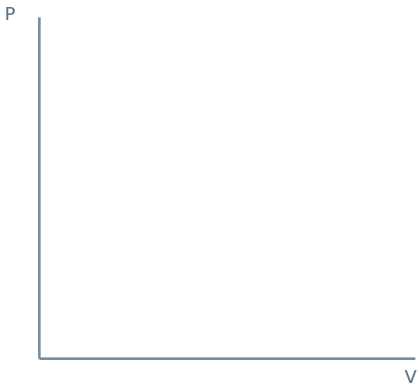
4. Rank the four expansion paths by work from the same initial state and final volume.

S3 | Match graph, process and first law

On each blank set of axes, draw labeled state points A and B. Show pressure versus volume, direction of the process, and the area representing work where appropriate.

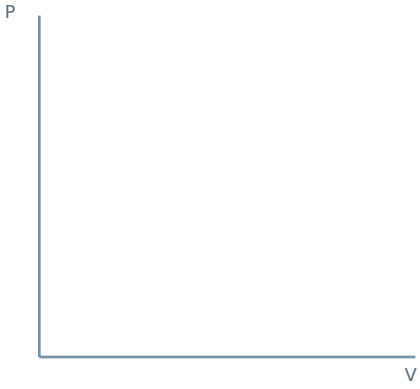
A. Isothermal vs adiabatic

From the same A, expand to the same final volume. Explain which has lower final pressure and greater Wby.



B. Compression

Show a constant-pressure compression from 5.0 L to 2.0 L, and explain why the signed work is negative.



Cycle synthesis: Sketch a clockwise rectangular cycle with points A, B, C and D on P–V axes. Explain why the gas returns to its original internal energy but may do positive net work over the cycle.

S4 | Connect the graph models to your lab

The online lab uses thermal mixing rather than a gas piston. The same practices apply: define a system, state assumptions, predict a measurable quantity, propagate uncertainty, and compare the observation with the model.

Cold-cup energy balance: $m_h c(T_h-T_f) = [m_c c+C_{cup}](T_f-T_c)$. Assumptions: constant specific heat, cup initially at T_c, negligible heat exchange with the room.

1. Predict the ideal mixing temperature without the cup heat capacity; list every measured input and unit.

2. Explain why a measured Tfinal below your ideal prediction could mean a positive cup heat capacity OR heat escaping to the room.

3. Sketch a graph of measured final temperature versus trial number. Are errors systematic, random, or both?

4. Write the first-order independent-input uncertainty equation for Tideal as a sum of squared partial-derivative terms.

5. Which improvement would most effectively separate cup heat capacity from heat lost to the room? Defend your choice.

T1 · Ideal gas and thermal systems

STRIDES: Subject / Topic / Rules / Illustrations / Definitions / Example / Steps.

Subject and topic: _____

Definitions and rules (use words and correct SI units):

Illustration: draw a labeled system, control volume, graph, or force diagram.

Example and solution steps: start with assumptions and derive the governing equation.

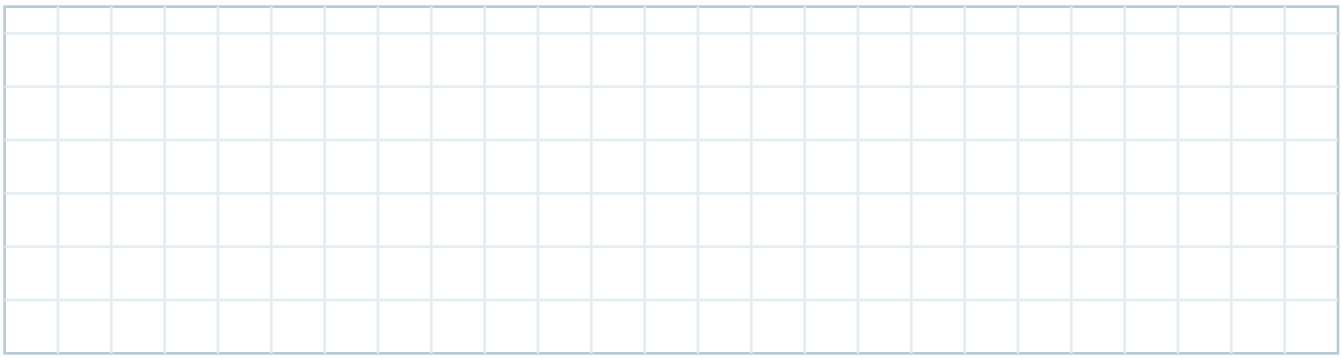
T2 · First law and sign conventions

STRIDES: Subject / Topic / Rules / Illustrations / Definitions / Example / Steps.

Subject and topic: _____

Definitions and rules (use words and correct SI units):

Illustration: draw a labeled system, control volume, graph, or force diagram.



Example and solution steps: start with assumptions and derive the governing equation.

T3 · P-V work and integration

STRIDES: Subject / Topic / Rules / Illustrations / Definitions / Example / Steps.

Subject and topic: _____

Definitions and rules (use words and correct SI units):

Illustration: draw a labeled system, control volume, graph, or force diagram.

Example and solution steps: start with assumptions and derive the governing equation.

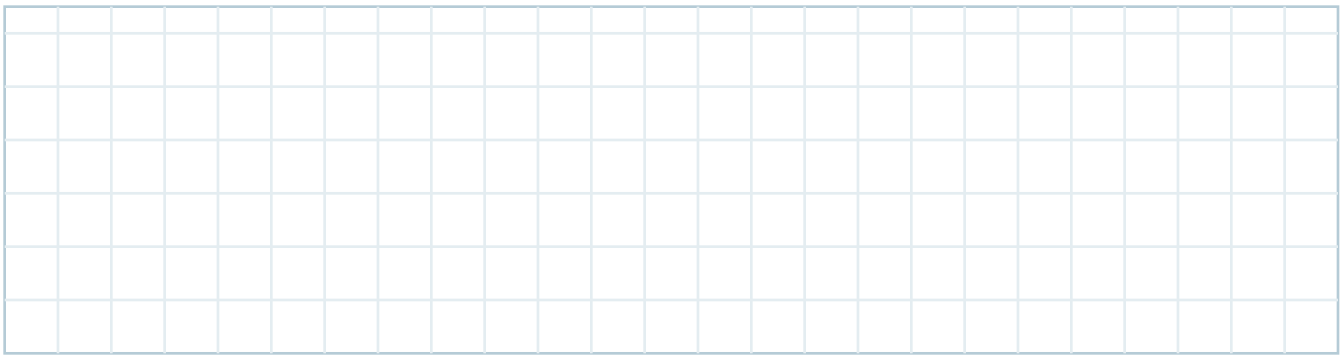
T4 · Calorimetry and equilibrium

STRIDES: Subject / Topic / Rules / Illustrations / Definitions / Example / Steps.

Subject and topic: _____

Definitions and rules (use words and correct SI units):

Illustration: draw a labeled system, control volume, graph, or force diagram.



Example and solution steps: start with assumptions and derive the governing equation.

T5 · Phase change

STRIDES: Subject / Topic / Rules / Illustrations / Definitions / Example / Steps.

Subject and topic: _____

Definitions and rules (use words and correct SI units):

Illustration: draw a labeled system, control volume, graph, or force diagram.

Example and solution steps: start with assumptions and derive the governing equation.

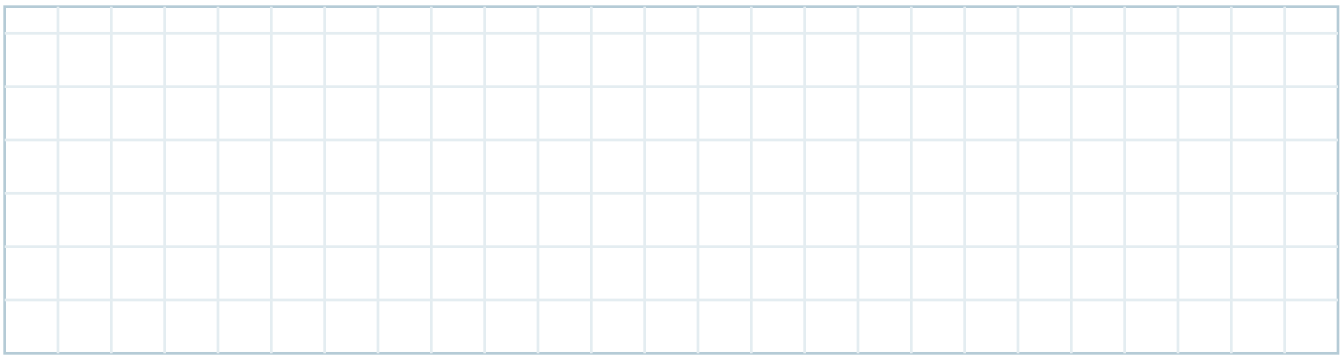
T6 · Entropy and heat transfer

STRIDES: Subject / Topic / Rules / Illustrations / Definitions / Example / Steps.

Subject and topic: _____

Definitions and rules (use words and correct SI units):

Illustration: draw a labeled system, control volume, graph, or force diagram.



Example and solution steps: start with assumptions and derive the governing equation.

Physical inquiry: Water mixing and calorimetry

Required apparatus: two cups, insulated cup and lid, measuring vessel or kitchen scale, basic thermometer, warm/cool water.

Safety: Warm tap water only, below about 50 C; no boiling water, open flames, or exposed heating elements.

Prediction: derive the governing physical expression and define all variables.

Sketch the apparatus and label reference heights, temperatures, masses, and controlled variables.

Procedure: write at least six reproducible steps, including repeated trials, instrument resolution, and control of changing conditions.

Measurements: repeat the mixture for three independent trials.

Trial	m_hot (kg)	T_hot (C)	m_cold (kg)	T_cold (C)	T_final (C)
1					
2					
3					

Fit / model reduction: predict T_final, calculate apparent cup heat capacity and compare trials

Propagation of uncertainty: show derivatives, instrument uncertainties, and a numerical result.

Interpretation: discuss random variation, systematic bias, assumptions, and a specific improvement.

Original independent practice: multiple choice

These questions are newly authored for this workbook. Solve before opening the website solution dropdowns. Circle one option and justify your model briefly.

T1. A fixed amount of ideal gas has temperature 300 K. At constant volume, heating to 450 K changes pressure by a factor of:

A) 0.67 B) 1.50 C) 2.00 D) 3.00

T2. A gas absorbs 600 J of heat and does 250 J of boundary work. Its internal energy changes by:

A) +850 J B) −350 J C) +350 J D) −850 J

T3. For expansion at constant 125 kPa from 1.5 L to 4.5 L, work by the gas is:

A) 375 J B) 125 J C) 3.75 J D) 375 kJ

T4. An ideal gas expands isothermally. Which statement is true?

A) ΔU increases B) Q is zero C) Wby must be zero D) Q=Wby

T5. At fixed amount of monatomic ideal gas, U is proportional to:

A) volume B) pressure alone C) absolute temperature D) container surface area

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T6. Equal masses of the same liquid at 20°C and 46°C mix in ideal insulation. The final temperature is:

A) 20°C B) 33°C C) 46°C D) 66°C

T7. During equilibrium melting of pure ice at atmospheric pressure, adding heat primarily changes:

A) temperature of both phases B) mass of liquid water C) pressure only D) specific heat capacity

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T8. An ideal linear thermal expansion model gives $\Delta L/L_0$ approximately equal to:

A) $\alpha\Delta T$ B) $\alpha/\Delta T$ C) $c\Delta T$ D) $1/\alpha$

Original extended-response practice

Write equations before substituting numbers. Show units, diagrams and a closing physical interpretation.

T13 · Two P–V paths

An ideal monatomic gas with n=0.160 mol starts at P=180 kPa and V=2.0 L and ends at V=5.0 L. Consider (i) constant-pressure expansion and (ii) isothermal expansion. For each (a) find work by gas, (b) find ΔU, (c) find Q. Explain why two final states are not identical.

Diagram / graph

T14 · Calorimeter calibration

A trial mixes 0.150 kg water at 43°C with 0.220 kg water at 21°C in a cup initially at 21°C. Final recorded temperature is 29.4°C. (a) Predict ideal Tf. (b) Estimate effective cup heat capacity assuming negligible external heat loss. (c) State two reasons the estimate might be biased.

Diagram / graph



Synthesis and laboratory reflection

1. Which assumption is most consequential in the main model, and how could you test it?

2. Which measurement dominates the propagated uncertainty? Provide numerical evidence.

3. Compare one experimental result with the mathematical prediction. Explain whether disagreement is significant relative to the uncertainty.

4. What would you change in a second iteration of the experiment?

Online supplements

Use the illustrated text, 16 original practice questions with expandable solutions, dynamic model, and web-based report at /physics/ece1401/thermodynamics/ .