Thermodynamics — Practice Problems & Exam Prep (Sampler)

Core concepts: Laws of thermodynamics, properties of pure substances, ideal gases, cycles (Carnot, Otto, Diesel, Rankine, Brayton), entropy, enthalpy, exergy, psychrometrics, heat engines, refrigerators, PV/T diagrams, phase change, and energy balances.

- - 20 worked essay/problem-style questions with concise solutions
- - 20 multiple-choice questions with clear explanations
- - Useful for engineering students and professionals preparing for exams or interviews

Disclaimer: Use as a study aid. Validate formulas and constants against course materials and standards.

Part I — Worked Problems & Model Answers (20)

1. First Law – Closed System Energy Balance

A piston–cylinder device contains 2.0 kg of an ideal gas. It is heated at constant volume raising temperature from 300 K to 600 K. If $c_v = 0.718$ kJ/kg·K, calculate the heat added and change in internal energy.

Solution / Key idea: $\Delta U = m \cdot c_v \cdot \Delta T = 2 \cdot 0.718 \cdot (600-300) = 2 \cdot 0.718 \cdot 300 = 430.8$ kJ. For constant volume, $Q = \Delta U = 430.8$ kJ.

2. Isentropic Compression

Air (ideal gas, k=1.4) is compressed isentropically from 100 kPa, 300 K to 800 kPa. Find final temperature.

Solution / Key idea: $T_2 = T_1 \cdot (P_2/P_1)^{(k-1)/k} = 300 \cdot (800/100)^{0.4/1.4} = 300 \cdot 8^{0.2857} \approx 300 \cdot 1.993 \approx 598$ K.

3. Carnot Efficiency

A heat engine operates between 500 K and 300 K. Determine the maximum (Carnot) efficiency.

Solution / Key idea: $\eta_{Carnot} = 1 - T_c/T_h = 1 - 300/500 = 0.4 = 40\%$.

4. Rankine Cycle – Work Output

A simple Rankine cycle with boiler pressure 8 MPa and condenser at 10 kPa. Using idealized saturated steam tables, estimate qualitative where most work comes from and how to increase efficiency.

Solution / Key idea: Most turbine work comes during expansion from high pressure to intermediate; to increase efficiency: raise boiler pressure/temperature (superheat), use reheat and regeneration (feedwater heaters) to reduce irreversibility.

5. Entropy Change — Phase Change

Calculate entropy change when 1 kg of water at 100°C (saturated liquid) is vaporized at 1 atm. Use latent heat ≈ 2257 kJ/kg.

Solution / Key idea: $\Delta s = L_{vap} / T = 2257 / (373.15) \approx 6.05$ kJ/kg·K.

6. Psychrometrics — Humid Air

Air at 30°C dry-bulb and 50% RH. Find approximate dew point or explain how you'd compute humidity ratio.

Solution / Key idea: Use saturation pressure tables: $p_{sat}(30°C) \approx 4.24$ kPa; partial pressure = $0.5 \cdot 4.24 = 2.12$ kPa; find dew point where $p_{sat}(T_{dp}) = 2.12 \rightarrow \sim 19°C$. Humidity ratio $w = 0.622 \cdot p_v/(p_{atm} - p_v)$.

7. Brayton Cycle — Specific Work

Ideal Brayton cycle with pressure ratio 10, inlet 288 K. Describe how pressure ratio affects work and efficiency.

Solution / Key idea: Higher pressure ratio increases thermal efficiency up to an optimum (material/real constraints). Specific work increases with pressure ratio but compressor work increases; optimum depends on component efficiencies and maximum temperature.

8. Gibbs Free Energy

Why is ΔG important for chemical reactions and phase stability at constant T,P?

Solution / Key idea: $\Delta G < 0$ spontaneous; $\Delta G = \Delta H - T\Delta S$; minima of G determine equilibrium phases; useful for reaction feasibility and phase diagrams.

9. Exergy — Useful Work

Explain exergy and how it's different from energy.

Solution / Key idea: Exergy is the maximum useful work extractable relative to environment; energy is conserved but exergy is destroyed by irreversibility. Exergy analysis locates losses and opportunities for improvement.

10. Throttling Process (Joule–Thomson)

A gas throttles through a valve with no work and no heat; explain temperature change and Joule–Thomson coefficient.

Solution / Key idea: Throttling: $h_1 = h_2$. Temperature change depends on Joule–Thomson coefficient $\mu_{JT} = (\partial T/\partial P)_H$. For real gases at moderate temps, cooling may occur; ideal gases show no JT effect.

11. Vapor Compression Refrigeration – COP

Given evaporator at −5°C and condenser at 35°C, qualitatively describe COP dependence on temperatures.

Solution / Key idea: COP decreases as temperature lift ($T_{cond} - T_{evap}$) increases. Lower evaporator temp or higher condenser temp reduces COP; use subcooling and superheat control to optimize.

12. Ideal Gas Mixes — Dalton's Law

How to compute partial pressures and mean molar mass for a mixture of gases?

Solution / Key idea: Use Dalton: $p_i = y_i \cdot p_{total}$. Mean molar mass = $\Sigma\, y_i \cdot M_i$. Use ideal gas relations per component if needed.

13. Heat Exchanger – LMTD vs NTU

When to use LMTD or NTU method for heat exchanger sizing?

Solution / Key idea: Use LMTD when terminal temperatures known and exchanger type fixed; use NTU when outlet temps unknown or for performance analysis; NTU handles effectiveness directly.

14. Otto vs Diesel Cycle Efficiency

Compare Otto and Diesel cycles for same compression ratio; why Diesel may have lower/higher efficiency?

Solution / Key idea: For same compression ratio, Otto is typically more efficient; Diesel efficiency depends on cutoff ratio; Diesel may be favored for practical higher compression ratios and fuel types.

15. Real Gas Behavior — Compressibility

When ideal gas breaks down and how to correct?

Solution / Key idea: At high pressure/low temp, ideal gas fails. Use compressibility factor Z or real gas EOS (Van der Waals, Redlich-Kwong) to correct pV behavior.

16. Heat Transfer Coupling

In a combustion chamber, how do conduction, convection, and radiation contribute?

Solution / Key idea: All three present: convection from gases to walls, conduction within walls, radiation significant at high temps; design needs consider combined resistance and fouling factors.

17. Polytropic Processes

Define polytropic process and give engineering examples.

Solution / Key idea: Polytropic: $pV^n = \text{const}$. $n=1$ is isothermal, $n=\gamma$ is adiabatic (reversible). Real compressors often follow polytropic behavior due to heat transfer and inefficiencies.

18. Steam Tables Use

Explain when to use saturated vs superheated steam tables and key properties to read.

Solution / Key idea: Saturated tables for mixture/boiling conditions (quality, h_f, h_g), superheated tables for $T > T_{sat}$ at given p (use for turbine inlet superheat). Key properties: h, s, v, x.

19. Mixing & Energy Balance

Mix two streams of water at different temperatures — how to compute final temp?

Solution / Key idea: Use energy balance: $m_1 \cdot c_p \cdot (T_1 - T_f) = m_2 \cdot c_p \cdot (T_f - T_2)$ solve for T_f (neglect loss to env).

20. Closed vs Open Systems

Contrast energy balance forms for closed and open (control volume) systems.

Solution / Key idea: Closed: $\Delta E = Q - W$ (no mass flow). Open: steady-flow E balance: $\dot{m}(h + V^2/2 + gz) + \dot{Q} = \dot{W} + \dot{m}(h + \ldots)$ across in/out; include enthalpy and flow terms.

Part II — Multiple-Choice Questions with Explanations (20)

MCQ 1. Which law states energy is conserved in thermodynamic processes?

A) Zeroth Law
B) First Law
C) Second Law
D) Third Law

Explanation: First Law of Thermodynamics: energy conservation ($\Delta E = Q - W$).

MCQ 2. Entropy of an isolated system tends to:

A) Decrease
B) Stay constant
C) Increase or stay constant
D) Vanish

Explanation: Second law: entropy increases for irreversible processes; constant for reversible.

MCQ 3. Carnot cycle efficiency depends on:

A) Pressure only
B) Temperature of heat reservoirs
C) Working fluid only
D) Volume

Explanation: $\eta = 1 - T_c/T_h$ depends on reservoir temperatures.

MCQ 4. Saturated liquid quality x is:

A) Mass fraction of liquid
B) Mass fraction of vapor
C) Pressure
D) Temperature

Explanation: Quality is mass fraction of vapor in a saturated mixture.

MCQ 5. Ideal gas internal energy depends on:

A) Pressure only
B) Temperature only
C) Volume only

D) Both P and V independently

Explanation: For ideal gas, u = u(T) depends only on temperature.

MCQ 6. Which process has PV^γ = const?

A) Isothermal

B) Polytropic with n=1

C) Isentropic (reversible adiabatic)

D) Throttling

Explanation: Isentropic reversible ideal gas: PV^γ = constant.

MCQ 7. Joule–Thomson throttling keeps which property constant?

A) Temperature

B) Entropy

C) Enthalpy

D) Pressure

Explanation: Throttling: h1 = h2 (enthalpy constant).

MCQ 8. Which cycle best models steam power plants?

A) Otto

B) Brayton

C) Rankine

D) Carnot

Explanation: Rankine cycle models steam power plants.

MCQ 9. In psychrometrics, relative humidity is:

A) Mass ratio of vapor to dry air

B) Partial pressure ratio of vapor to saturation pressure

C) Total pressure

D) Absolute humidity

Explanation: RH = p_v / p_sat(T) (ratio of partial to saturation pressure).

MCQ 10. Which method is better when outlet temps unknown for HX?

A) LMTD

B) NTU
C) Empirical only
D) Graphical only

Explanation: NTU method handles unknown outlet temps via effectiveness.

MCQ 11. COP of a refrigerator is:

A) Q_out/W
B) Q_in/W (heat removed from cold)
C) W/Q_in
D) W/Q_out

Explanation: COP = Q_L / W (heat removed from refrigerated space divided by work).

MCQ 12. Compressibility factor Z = 1 indicates:

A) Real gas
B) Ideal gas behavior
C) Condensation
D) Phase change

Explanation: $Z \approx 1$ approximates ideal gas behavior.

MCQ 13. Gibbs free energy useful for:

A) Open systems only
B) Predicting spontaneity at constant T&P
C) Calculating PV work only
D) Measuring entropy directly

Explanation: $\Delta G < 0$ indicates spontaneous processes at constant T and P.

MCQ 14. Which increases Rankine efficiency?

A) Lower boiler temp
B) Reheat and regeneration
C) Increase condenser pressure
D) Remove superheat

Explanation: Reheat and regeneration improve Rankine efficiency.

MCQ 15. For ideal gas, Cp − Cv equals:

- A) 0
- B) R (gas constant)
- C) Cp*Cv
- D) γ

Explanation: Cp − Cv = R for ideal gas.

MCQ 16. Phase diagram critical point marks:

- A) Triple point
- B) End of distinct liquid■vapor boundary
- C) Absolute zero
- D) Saturation line start

Explanation: Critical point is where liquid and vapor become indistinguishable.

MCQ 17. Entropy units are:

- A) kJ/kg
- B) kJ/kg·K
- C) kPa
- D) J

Explanation: Entropy commonly in kJ/kg·K.

MCQ 18. Polytropic index n=1 corresponds to:

- A) Adiabatic
- B) Isothermal
- C) Isentropic
- D) Throttling

Explanation: n=1 → isothermal process (pV^1=const).

MCQ 19. Exergy destruction is zero for:

- A) Irreversible process
- B) Reversible process
- C) Real engine
- D) Throttling

Explanation: Reversible processes have zero exergy destruction.

MCQ 20. Which is an extensive property?

- A) Temperature
- B) Pressure
- C) Entropy
- D) Mass

Explanation: Mass is extensive (depends on system size).

About This Study Guide

This sampler mirrors the full Thermodynamics problem pack: worked problems, conceptual drills, cycle comparisons, and MCQs with clear rationales. Use it for exam prep, coursework revision, or interview preparation.

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