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PART A — Questions 1, 2 & 3

ME 2222 Thermodynamics · First Law, SFEE & Second Law

Course	ME 2222 – Thermodynamics
Total Marks	40
Duration	~80 minutes
Questions	3

PART OVERVIEW

Part A of the ME 2222 Thermodynamics examination focuses on the foundational laws of thermodynamics and their direct engineering applications. Students will demonstrate their understanding of energy conservation, steady-flow systems, and the Second Law concept of entropy. The three questions progressively build from conceptual definitions through mathematical derivations to quantitative problem solving, reflecting the analytical depth expected at this level of mechanical engineering study. Part A carries a total of 40 marks and students are expected to complete it within approximately 80 minutes, leaving clear, well-structured workings for each calculation.

QUESTION-BY-QUESTION BREAKDOWN

Question 1 — First Law of Thermodynamics

20 marks

Overview

This is the highest-weighted question in Part A and spans conceptual understanding through to full derivation and numerical problem solving. It opens with four short-answer definitions covering the core vocabulary of thermodynamics, then moves into a formal derivation of the First Law for a closed system, a straightforward numerical application involving an air motor, and finally a challenging polytropic process derivation followed by a complete numerical solution for an ethane compression problem.

What will be tested:

- (a) Definitions of System types, Equilibrium State, Process, and Reversibility — students must provide concise, accurate descriptions with relevant examples for each concept. [8 marks]
- (b) Statement and derivation of the First Law for a closed system — the equation for change in internal energy ($U_2 - U_1$) must be derived with clearly stated assumptions. [2 marks]
- (c) Numerical application for an air motor — given specific internal energies at start and end of expansion and the work done, students compute the direction and magnitude of heat transfer. [3 marks]
- (d) Polytropic process heat transfer derivation — prove $Q_{12} = -[(n-\gamma)/(\gamma-1)]W_{12}$, then apply it to a 1 kg ethane polytropic compression ($PV^{1.3} = \text{const}$) from 1.10 bar / 27°C to 6.60 bar. [7 marks]

SKILLS ASSESSED

- ✓ Define and distinguish thermodynamic systems
- ✓ Apply the First Law to closed systems
- ✓ Derive polytropic process relationships
- ✓ Use ideal gas law with specific heat ratios
- ✓ Perform unit-consistent numerical calculations

PREPARATION TIPS

- ★ Memorise $Q_{12} = -[(n-\gamma)/(\gamma-1)]W_{12}$ and know how to derive it
- ★ For part (c) keep sign conventions consistent throughout
- ★ Calculate $R = R_u / M$ for ethane before starting part (d)
- ★ State every assumption (ideal gas, perfect gas) explicitly

Question 2 — Steady Flow Energy Equation (SFEE)

10 marks

Overview

Question 2 tests students' ability to move from closed to open systems. The first part requires a full derivation of the Steady Flow Energy Equation from first principles, identifying every energy term — enthalpy, kinetic energy, potential energy, heat transfer, and shaft work. The second part is a two-stage numerical problem set in an air compressor: students must apply the SFEE to find the shaft work input, then use the continuity equation and ideal gas relationships to determine the ratio of inlet to outlet pipe diameters.

What will be tested:

(a) Derive the Steady Flow Energy Equation from the energy balance of an open system control volume, defining all terms with usual notation. [4 marks]

(b(i)) Given inlet/outlet conditions (velocity, pressure, specific volume) and the cooling rate of 58 kW for an air compressor passing 0.5 kg/s, compute the rate of shaft work input in kW using the SFEE. [4 marks]

(b(ii)) Using the continuity equation (mass flow rate = AV/v), determine the ratio of the inlet pipe diameter to the outlet pipe diameter. [2 marks]

SKILLS ASSESSED

- ✓ Derive the SFEE from energy conservation principles
- ✓ Identify and substitute all SFEE terms correctly
- ✓ Apply the continuity equation for steady flow
- ✓ Convert between specific volume and cross-sectional area

PREPARATION TIPS

- ★ Include ALL terms (KE, PE, enthalpy, Q, W_s) in your SFEE derivation
- ★ Keep units in kJ/s (kW) from the start to avoid conversion errors
- ★ For (b)(ii) recall $A = \dot{m} \times v / V$ and relate diameter via $A = \pi d^2/4$
- ★ Check whether potential energy terms can be neglected and state why

Question 3 — Second Law of Thermodynamics & Entropy

10 marks

Overview

Question 3 introduces the Second Law and the concept of entropy. Students first state the two classical formulations of the Second Law — the Kelvin–Planck statement (no engine can convert heat entirely to work) and the Clausius statement (heat cannot flow spontaneously from cold to hot). They then derive the entropy change formula for an isothermal process from the Clausius inequality, and finally apply these ideas to a real numerical problem involving isothermal reversible compression of nitrogen, including p–v and T–s diagram sketches.

What will be tested:

- (a) State and clearly explain both the Kelvin–Planck and the Clausius statements of the Second Law; describe their physical significance and equivalence. [4 marks]
- (b) Starting from the Clausius inequality, derive the expression for entropy change in an isothermal (constant-temperature) reversible process. [2 marks]
- (c) For 0.03 m³ of nitrogen at 1.05 bar and 15°C compressed isothermally and reversibly to 4.2 bar: calculate entropy change, heat flow, and work done; sketch p–v and T–s diagrams. [4 marks]

SKILLS ASSESSED

- ✓ State and interpret the two Second Law formulations
- ✓ Derive entropy change from the Clausius inequality
- ✓ Apply isothermal work and heat relationships for perfect gases
- ✓ Sketch accurate thermodynamic process diagrams

PREPARATION TIPS

- ★ Learn the exact wording of both Kelvin–Planck and Clausius statements
- ★ For isothermal compression: $W = mRT \ln(P1/P2)$ and $\Delta S = Q/T$
- ★ Calculate mass of nitrogen using $PV = mRT$ before anything else
- ★ On T–s diagram: isothermal = horizontal line; label direction of process

MARKS SUMMARY

Question	Topic	Marks
Q1	First Law of Thermodynamics	20
Q2	Steady Flow Energy Equation (SFEE)	10
Q3	Second Law of Thermodynamics & Entropy	10
TOTAL		40