

Chapter 5: Basics of Mechanical Engineering

NICL AO 2026 Risk Engineer: Technical & Professional Knowledge

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Chapter opener

What this chapter covers

This chapter moves from thermodynamic systems, laws, ideal gases and heat capacities to heat engines and piston-engine operation. Heat transfer leads into alloys and heat treatment, then machine elements, pumps, hydraulic turbines, refrigeration and air conditioning. The Core starts from scratch; Optional recall boxes are for a second reading. All 100 questions test the Core.

Why mechanical basics matter to a risk engineer. A machine's purpose, transfers and operating conditions help explain its technical description. A clear boundary and balance distinguish heat, stored energy and power.

Learning objectives

After this chapter, you should be able to:

1. Classify systems and transfers, explain the laws and use consistent signs.
2. Apply ideal-gas and heat-capacity relationships with their conditions.
3. Distinguish Carnot/Otto/Diesel cycles, SI/CI and two-/four-stroke operation.
4. Identify heat-transfer modes and apply their qualified laws.
5. Recognise alloy families and qualified carbon-steel treatments.
6. Explain machine-element roles, idler directions and the differential.
7. Distinguish pumps, priming and hydraulic turbines.
8. Trace refrigeration, balance heat/work, interpret COP and conditional dehumidification.

Topic map

Unit	What you will learn	Practice questions
5.1 Thermodynamic systems and laws	Systems, properties, laws and energy signs	Q1–Q12, Q91
5.2 Ideal gases, heat capacities and processes	Ideal gases, heat capacities and process constraints	Q13–Q24, Q92, Q93, Q94, Q95
5.3 Heat engines, cycles and IC-engine operation	Heat engines, cycles and piston-engine operation	Q25–Q38, Q96, Q97
5.4 Heat-transfer modes and laws	Conduction, convection, radiation and insulation	Q39–Q50, Q98
5.5 Engineering alloys, steel making and heat treatment	Alloy families and qualified heat-treatment routes	Q51–Q62
5.6 Machine elements and power transmission	Machine-element roles, gear directions and differential	Q63–Q70

Unit	What you will learn	Practice questions
5.7 Pumps and hydraulic turbines	Pump mechanisms, priming and hydraulic turbines	Q71–Q80
5.8 Refrigeration and air conditioning	Refrigeration balances, COP and air treatment	Q81–Q90, Q99, Q100

Exam context

- **The section:** 50 questions, 50 marks, 35 minutes: an *average* of 42 seconds a question.
- **Marking:** +1 correct, –0.25 wrong, 0 blank.
- **No calculators:** the numerical data here are chosen for mental arithmetic.

Source: the NICL recruitment notice dated 07/10/2026, as transcribed for this book. The practice allocation below is a learning choice, not a forecast of topic weights.

Should you guess?

If p is your honest chance of being right, the expected mark from answering is

$$\text{Expected mark} = p - 0.25(1 - p) = 1.25p - 0.25$$

The break-even point is $p = 20\%$, a blind pick among five options, so a blind guess is worth zero *on average*. If the options you rule out really are wrong and the rest are equally likely, one option out gives +0.063 per guess, two out +0.167, three out +0.375. Ruling out the right answer by mistake reverses the gain.

How to use this chapter

Read each unit and work its examples before its questions. Diagnose errors with the end explanations, then revise before the numericals. Optional boxes can wait. Questions are figure-independent.

Conventions

- **Energy signs:** heat into a system is positive; work done by it is positive. For a closed system with negligible motion/height-energy changes, $\Delta U = Q - W$. Q and W are energy amounts; P denotes power. Unit 5.1 supplies the full symbol table.
- **Units:** SI; gas/cycle/radiation temperatures are supplied in kelvin. No scale conversion is tested. Stated material constants are teaching data, not universal values.
- **Reused symbols:** γ is the heat-capacity ratio, not Chapter 2's specific weight; ϵ is emissivity, not strain; σ_{SB} is the Stefan–Boltzmann constant, not stress. R is a gas-specific constant in 5.2 and R_{th} is thermal resistance in 5.4. Lower-case p is pressure, upper-case P power.
- **Abbreviations:** SI = spark ignition; CI = compression ignition; IC = internal combustion; COP = coefficient of performance; AC = air conditioning here. TDC/BDC mean top/bottom dead centre.

5.1 Thermodynamic systems and laws

In a nutshell. First choose what you are studying and draw its boundary. Then distinguish energy crossing that boundary from energy stored inside it. The laws tell us how to balance transfers and which transfer directions are possible.

5.1.1 Systems, boundaries and properties

A **system** is the matter or region selected for study; everything outside is its surroundings. Its **boundary** can be a real wall, an imaginary surface through a pipe, or a moving piston face. Choose the boundary before classifying transfers.

Gas beneath a sealed piston retains its mass; a running pump has liquid crossing its connections. Including a stirrer motor inside a tank's boundary changes which drive-energy transfer crosses that boundary.

A **closed system** exchanges no mass, but it may exchange energy. Its boundary can move. An **open system**, also called a control volume, permits mass to cross; energy can cross with that mass and also as heat or work. An **isolated system** exchanges neither mass nor energy. These words classify permitted exchanges, not whether the system has a fixed temperature.

Boundary choice	Mass can cross?	Energy can cross?	Recognition example
Closed	No	Yes, as heat or work	Gas beneath a sealed moving piston
Open	Yes	Yes, including with flowing mass	Pump with inlet and delivery connections
Isolated	No	No	Perfectly sealed boundary excluding heat and work

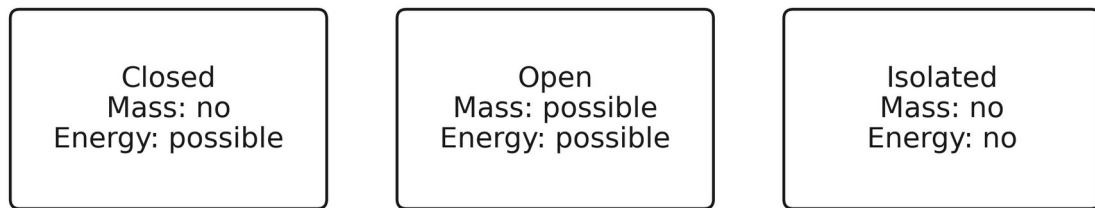
Table 5.1. Boundary classifications; the isolation example is an ideal limiting description.

Insulation excludes heat through the wall, but a powered shaft can still transfer work. Equal steady inflow and outflow do not close a control volume: fluid particles still cross its boundary.

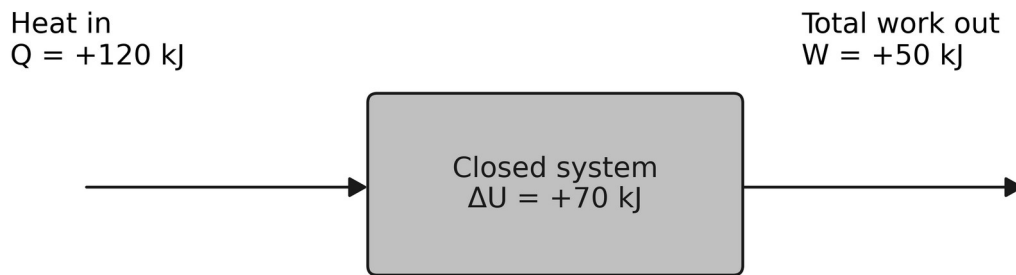
A **property** describes an equilibrium state: pressure, volume, temperature or internal energy. Its change depends on the end states. Heat and work are process transfers that can depend on the path; a gas stores internal energy rather than heat.

An **intensive property**, such as temperature or pressure, does not scale with the amount of uniform material at the same state. Extensive mass, volume and internal energy do. Dividing an extensive property by mass gives a specific property, such as $u = U/m$. Equal-temperature objects can have different total energies.

Boundaries and a separate closed-system balance



Boundary classification concerns crossings, not temperature.



$$\Delta U = Q - W; \text{negligible KE/PE changes. Schematic.}$$

Figure 5.1. Boundaries and signed balance. Mass and energy permissions are separate from the signed closed-system balance. Example 5.1 has 120 kJ heat in, 50 kJ work out and 70 kJ stored-energy increase; ΔU is not a third transfer arrow. Schematic.

5.1.2 Equilibrium and the zeroth law

Thermal equilibrium means equal temperatures and no net heat transfer between bodies; it does not require equal masses, pressures or capacities. With a heat-transfer path, a warmer and colder object tend towards this condition.

The **zeroth law** says that if A and B are each in thermal equilibrium with C, they are in equilibrium with each other. A thermometer provides this common temperature comparison. Chapter 7 owns calibration and scale conversions.

Thermal equilibrium is part of thermodynamic equilibrium; mechanical balance also matters. A piston accelerating under a pressure imbalance is not mechanically balanced. We use equilibrium end states so their properties are well defined.

5.1.3 Heat, work and the first law

Heat is energy transferred because of a temperature difference. **Work** transfers energy through other organised interactions, such as a piston, shaft or electrical input. Internal energy U is microscopic stored energy; bulk kinetic energy and elevation energy are accounted for separately.

Symbol	Meaning in this chapter	Units	Sign or distinction
Q	Heat transferred during the interval	J or kJ	Positive into the system
W	Total work transferred during the interval	J or kJ	Positive done by the system