

Chapter 3: Engineering Chemistry

Technical & Professional Knowledge for NICL AO (Scale I) 2026, Risk Engineer: Phase II (Main) exam.

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Chapter opener

What this chapter covers

This chapter starts with atoms, bonding, reactions and solutions. It then explains water chemistry, electrochemical cells, corrosion, fuels, polymers, lubricants, cement hydration and basic environmental chemistry. The aim is to recognise the chemical idea and apply a short rule with its conditions. Long derivations and plant-design calculations are outside this treatment. All 100 practice questions use the core material; Optional recall boxes extend a few ideas for a second reading.

Why chemistry basics matter to a risk engineer. Deposits, corrosion, combustion and chemical deterioration affect engineering materials and equipment. Understanding the chemical mechanism helps you distinguish what a treatment or protective measure actually does.

Learning objectives

After this chapter, you should be able to:

1. Distinguish atoms, ions, bonds and reaction types, read chemical formulas, and use concentration and the dilute-solution pH approximation.
2. Explain hardness, CaCO_3 -equivalent reporting, boiler-water troubles and the different purposes of water treatment.
3. Follow galvanic and electrolytic reactions, electrode signs and charge paths, and recognise basic battery chemistry.
4. Explain corrosion mechanisms and the principle behind zinc coating, tin coating and cathodic protection.
5. Distinguish fuel analysis, combustion, calorific-value conventions and petroleum and engine-fuel terms.
6. Relate polymer formation and chain structure to thermoplastic, thermoset, rubber and composite categories.
7. Explain lubricant regimes and distinguish viscosity index, flash point, fire point, autoignition and pour point.
8. Identify hydration products, pozzolanic reaction and the chemical consequences of carbonation and sulphate attack.
9. Distinguish BOD, COD and DO, acid-rain and greenhouse chemistry, and prevention from treatment.

Topic map

Unit	What you will learn	Practice questions
3.1 Chemical foundations, bonding and solutions	Particles, bonds, reactions, concentration, acids and pH	Q1–Q12, Q91–Q94
3.2 Water chemistry, hardness and treatment	Hardness, equivalent reporting, boiler troubles, treatment jobs	Q13–Q26, Q95–Q96

Unit	What you will learn	Practice questions
3.3 Electrochemistry, electrolysis and batteries	Charge carriers, cells, electrode signs, deposition and batteries	Q27–Q38, Q97–Q98
3.4 Corrosion and its prevention	Local cells, passivation, coatings and cathodic protection	Q39–Q50
3.5 Fuels, combustion and calorific value	Coal analysis, heat release, air supply and petroleum fractions	Q51–Q62, Q99–Q100
3.6 Polymers, elastomers and composites	Polymerisation, chain structures, rubber, blends and composites	Q63–Q72
3.7 Lubricants and lubricant properties	Fluid films, surface films, oil properties, grease and additives	Q73–Q79
3.8 Cement hydration and chemical deterioration	Hydrates, alkalinity, pozzolans, carbonation and chemical attack	Q80–Q84
3.9 Environmental chemistry and pollution prevention	Oxygen tests, air chemistry and prevention at source	Q85–Q90

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:** every number in this chapter's examples and numericals is chosen for mental arithmetic.

Source: the NICL recruitment notice dated 07/10/2026, as transcribed for this book.

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 a unit and its worked examples, try that unit's questions and check the key; use the revision kit before attempting all 100. Leave the Optional boxes for a second reading. When revising, connect each name to its job: the salt bridge carries ions, a softener addresses hardness, and an inhibitor must suit the material and environment.

Conventions used in this chapter

- **Units:** SI throughout, with g and mg for small masses and L and mL for solution volumes. A litre is 1,000 mL. Concentrations in mol/L use final solution volume; mg/L and mass-based ppm are distinguished. The numerical questions give the rounded chemical constants they need.
- **Symbols that differ from earlier chapters:** M is molar mass, not bending moment; V is solution volume where stated, while V after a potential value is the volt. Q is electric charge in 3.3, not a flow rate or question number. F is the Faraday constant in 3.3, not a mechanical force. E° denotes a standard electrode or cell potential. Z is atomic number in 3.1 and electrochemical equivalent in the Optional box of 3.3. Each relevant unit defines its symbols locally.
- **Chemical notation:** subscripts count atoms, superscripts show charge, and a coefficient multiplies the entire formula. State symbols are (s) solid, (l) liquid, (g) gas and (aq) dissolved in water. H^+ is the usual short notation for aqueous hydrogen ions; H_3O^+ emphasises their association with water.
- **Abbreviations:** EDTA ethylenediaminetetraacetic acid; RO reverse osmosis; HHV higher heating value, also called gross calorific value (GCV); LHV lower heating value, also called net calorific value (NCV); LPG liquefied petroleum gas; CNG compressed natural gas; PE polyethylene; PVC polyvinyl chloride; PTFE polytetrafluoroethylene; SI spark-ignition; CI compression-ignition; VI viscosity index; C-S-H calcium silicate hydrate; BOD biochemical oxygen demand; COD chemical oxygen demand; DO dissolved oxygen.
- **Boundaries:** Chapter 2 retains cement compounds, construction practice, cover and the fire triangle. Chapter 5 treats thermodynamics, alloys, heat treatment and mechanical systems; Chapter 6 treats energy-generation systems. Semiconductor doping belongs to Chapter 4 and physical-property calculations to Chapter 7.

3.1 Chemical foundations, bonding and solutions

In a nutshell. Chemistry follows particles as they combine, exchange electrons or disperse in a mixture. A formula describes composition; a balanced equation describes a change. Concentration and pH describe different aspects of a solution, so begin by identifying exactly what each quantity measures.

Symbol	Meaning here	Typical unit or use
Z	Atomic number	Number of protons
A	Mass number of an isotope	Protons plus neutrons
n	Amount of substance	mol
m	Mass	g, when M is in g/mol
M	Molar mass	g/mol
c	Molarity	mol/L
V	Final solution volume	L, when c is in mol/L

3.1.1 Atoms, ions and valence electrons

An **atom** has a small nucleus containing positively charged protons and uncharged neutrons. Negatively charged electrons occupy the surrounding space. A neutral atom has equal numbers of protons and electrons. The **atomic number, Z**, is its proton count and identifies the element. Changing that count changes the element.

The **mass number, A**, counts the protons and neutrons in one atom of a specified isotope. Thus neutron count = $A - Z$. Mass number is a whole-number particle count. It is different from the average atomic mass listed in a periodic table, which reflects the isotopes present in the sample and their abundances.

Isotopes are atoms of the same element with different neutron counts. Their proton counts agree, so their atomic numbers agree. Their mass numbers differ. An isotope is not an ion: isotope formation concerns the nucleus, whereas ordinary ion formation concerns electrons.

An **ion** is an atom or group of atoms with a net electric charge. Removing electrons from a neutral atom leaves a positive **cation**; adding electrons gives a negative **anion**. Na^+ is a sodium cation and Cl^- a chloride anion. Ca^{2+} has two fewer electrons than the corresponding neutral calcium atom. The positive charge does not mean that two protons have been added.

For the main-group atoms used here, such as sodium and chlorine, **valence electrons** are the outer-shell electrons involved in bonding. Sodium can lose its one outer-shell electron; chlorine can gain an electron into its outer shell. This main-group outer-shell description should not be extended into a universal rule for transition metals, whose bonding can involve d electrons as well.