EC-008 · MODULE 8 OF 22

Opens the Electrochemistry set

Atoms, Ions, and Bonding: The Chemistry Behind Corrosion

Survey-level chemistry. Atoms, ions, bonds, the ions a CP tech meets, and pH at a working level.

EXTERNAL CORROSION TRACK · FOUNDATION TIER · ELECTROCHEMISTRY & THE GALVANIC SERIES · ~30 MINUTES

BY THE END OF THIS MODULE

You'll be able to —

- Describe an atom in three sentences: nucleus, electrons in shells, and why outer electrons drive corrosion.
- Read the canonical corrosion reaction `Fe → Fe²⁺ + 2e⁻` symbol-by-symbol.
- Distinguish cations from anions and identify the common CP-environment ions on sight (Cl^-, SO_4^{2-}, HCO_3^-, Ca^{2+}, Mg^{2+}, H^+, OH^-).
- Name the three kinds of bonding (metallic, ionic, covalent) and connect each to the role it plays in a corrosion picture.
- Read pH at a working level: the logarithmic scale, the four zones for carbon steel, and the amphoteric exception.

SOIL CORROSIVITY REPORT — NEW INSTALL ALONG COUNTY ROAD

Five numbers that will drive 40 years of behavior

SITE: County Rd 27 / Sta 412+50	
pH	5.6
Resistivity	2,800 Ω·cm
Chloride (Cl^-)	210 ppm
Sulfate (SO_4^{2-})	95 ppm
Sulfide	not detected

A lab somewhere ran chemistry on a soil sample. These five numbers are the result. Coatings, CP design, inspection cadence — all decided from this.

YOU DON'T HAVE TO BE A CHEMIST TO READ IT

But you have to know what the report says

Why does pH 5.6 matter? Why is 210 ppm chloride a flag? What is happening at the atomic level in the soil that makes those numbers mean anything?

EC-008 is the chemistry primer. The minimum picture of atoms, ions, and bonds that lets the soil report — and every other piece of chemistry language a CP tech meets in this field — click into place. We stay at survey level. The goal isn't to make a chemist; it's to put the foundation under everything that comes after.

Three building blocks (atoms, ions, bonds),
one short list of ions (the ones a CP tech meets),
and pH at a working level.

That's the working level.

And one canonical reaction that holds it all together —

$$Fe \rightarrow Fe^{2+} + 2e^{-}$$

MODULE ROADMAP

Five sections, in order

01

Why metals corrode

The energy story behind every CP system in service.

02

Atoms + ions

The bare-minimum atomic picture. $Fe \rightarrow Fe^{2+} + 2e^-$ on sight.

03

Bonding

Metallic, ionic, covalent — what each one lets move.

04

The ions you'll meet

Cl^-, SO_4^{2-}, HCO_3^-, Ca^{2+}, H^+, OH^-.

05

pH at working level

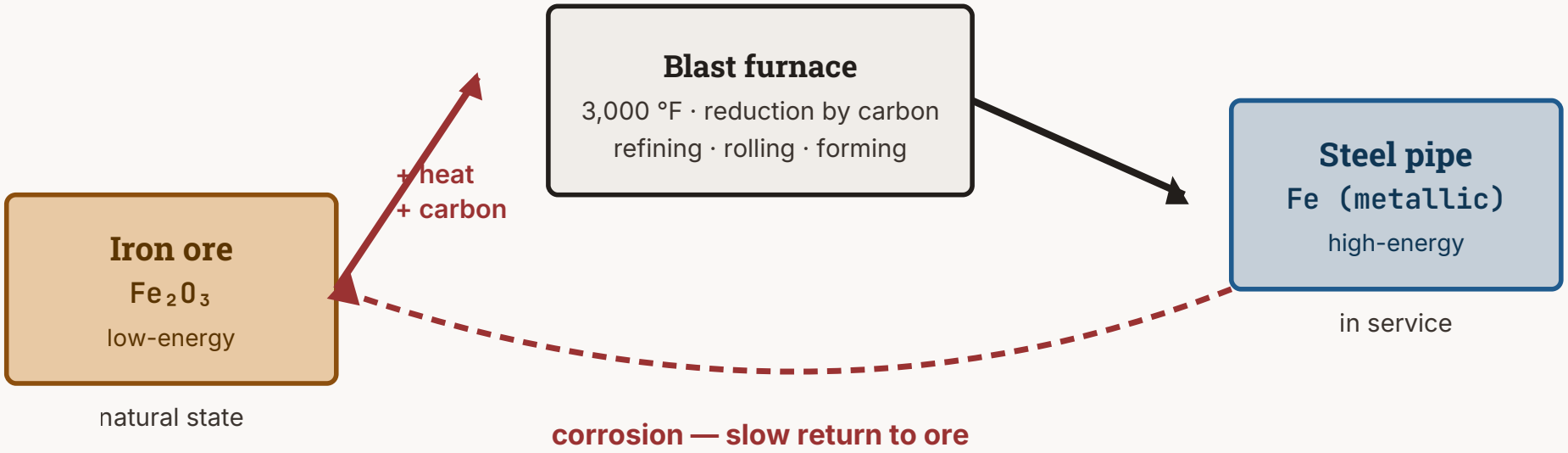
The scale, the four zones, the amphoteric exception.

SECTION 01 · THE ENERGY STORY

Why metals corrode at all

FROM ORE TO STEEL AND BACK AGAIN

Corrosion is metal returning to ore



Iron ore (Fe_2O_3) sits at a low-energy natural state. The blast furnace forces it into a high-energy metallic form. The metal is always trying to give that energy back — that's corrosion.

THE DRIVING FORCE ISN'T GOING AWAY

Every CP system in service is a countermeasure

> Corrosion is steel going home.
> The whole CP industry exists to slow that down.

Every coating, every sacrificial anode, every impressed-current rectifier, every inhibitor is engineered against the same fundamental driving force: the metal's natural tendency to return to a stable chemical compound. The driving force doesn't go away. The job is to keep that process from happening on a useful timescale.

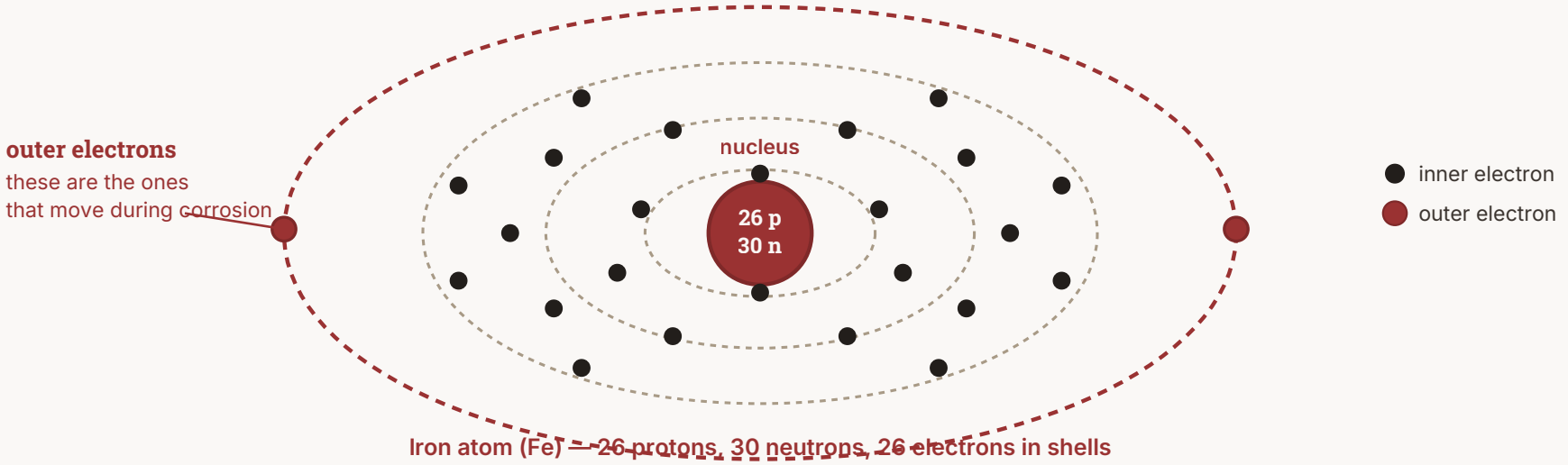
The next question is the one this module answers: **what is actually going on at the atomic level when steel corrodes?**

SECTION 02A · ATOMS

The bare-minimum atomic picture

THREE THINGS TO KNOW

Nucleus, electrons, shells



A heavy nucleus (protons + neutrons) and a cloud of electrons arranged in shells around it. In a neutral atom, electron count exactly balances proton count.

THE ATOMIC FINGERPRINT

Iron has 26 protons. Always.

The number of protons in the nucleus is what makes an element an element. Iron has 26 — every iron atom on the planet, in every pipeline, in every block of ore in the ground.

CP METAL

Iron — 26 p

Carbon steel pipelines. The reaction $Fe \rightarrow Fe^{2+}$ is the one we live with.

CP METAL

Copper — 29 p

Test leads, grounding, bond wires. More noble than iron — corrodes less readily.

CP METAL

Zinc — 30 p

Sacrificial anode metal. Loses electrons more readily than iron — gives itself up to protect steel.

Magnesium (12 p), aluminum (13 p), carbon (6 p), hydrogen (1 p), oxygen (8 p), sulfur (16 p), chlorine (17 p) — the proton count is what the element **is**.

THE ONES THAT DRIVE CORROSION

Outer-shell electrons are the ones that move

Inner electrons stay tightly bound to the nucleus. **Outer electrons** — the ones in the outermost shell — are loosely held, especially in metals. They're the ones that get stripped off or shared in chemical reactions.

> **That is the entire chemistry of corrosion in one sentence:** a metal atom at the surface of a structure loses its outer electrons to something in the environment, and what's left is a positive ion that floats away into the electrolyte.

Different metals hold their outer electrons with different strengths. Magnesium and zinc let theirs go readily (good sacrificial anodes). Iron is in the middle (carbon steel corrodes, but at workable rates). Copper holds its outer electrons more tightly (corrodes less). Gold holds them very tightly indeed (a gold ring buried in soil comes back looking the same).

> **Pointer ahead.** The quantitative ranking of how easily different metals give up their outer electrons is the galvanic series — covered as a table of measured numbers in EC-011.

SECTION 02B · IONS

What's left when electrons move

TWO KINDS OF IONS; ONLY THE SIGN DIFFERS

An ion is just a charged atom

+

Cation

Positively charged ion. Atom **lost** one or more electrons.

Example: Fe^{2+} · Ca^{2+} · H^{+}

-

Anion

Negatively charged ion. Atom **gained** one or more electrons.

Example: Cl^{-} · SO_4^{2-} · OH^{-}

> **Memory hook.** Cation has a "t" that looks like a plus sign — ca**+**ion is positive. Anion is negative. Both are ions; the only difference is the sign.

HOW CHARGES GET WRITTEN

Read the superscript

Cation examples (lost electrons)

- Fe^{2+} — iron, lost 2 electrons (ferrous ion)
- Fe^{3+} — iron, lost 3 electrons (ferric ion)
- Ca^{2+} — calcium, lost 2 electrons
- H^{+} — hydrogen, lost 1 electron
- Na^{+} — sodium, lost 1 electron

Anion examples (gained electrons)

- Cl^{-} — chloride, gained 1 electron
- OH^{-} — hydroxide, gained 1 electron
- SO_4^{2-} — sulfate, gained 2 electrons
- HCO_3^{-} — bicarbonate, gained 1 electron
- S^{2-} — sulfide, gained 2 electrons

The number tells you how many electrons moved; the sign tells you which way.

WORTH THE TIME TO WALK

The reaction every CP tech should know

$$Fe \rightarrow Fe^{2+} + 2e^{-}$$

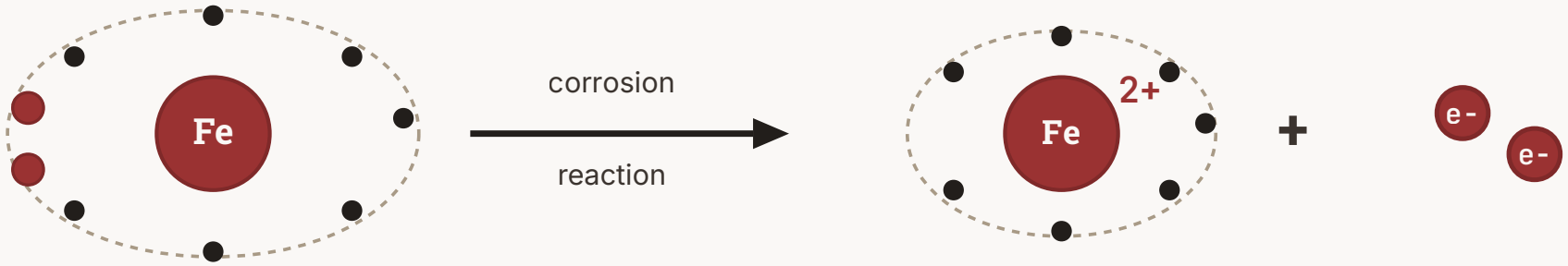
Iron atom on the left. Ferrous ion (positive 2) plus two free electrons on the right. The chemistry of carbon-steel corrosion, in one line.

> **This same reaction appears in every module that follows in the set:** in EC-009 as the anodic half of the corrosion cell, in EC-010 as the canonical oxidation half-reaction, in EC-012 as the basis for Faraday's-Law mass-loss calculations. Land it here so it doesn't have to be re-taught.

SYMBOL-BY-SYMBOL

What happens at the atomic level

$$Fe \rightarrow Fe^{2+} + 2e^-$$



Iron atom (neutral)
Fe · 26 p+ / 26 e-

Ferrous ion (positive 2)
Fe^{2+} · 26 p+ / 24 e-

Two electrons
stay in the metal

Left side: one iron atom (Fe), neutral, 26 protons and 26 electrons. Right side: a ferrous ion (Fe^{2+}) with 26 protons and 24 electrons, plus two electrons released into the metal. Charge balances: +2 + (−2) = 0.

SECTION 03 · BONDING

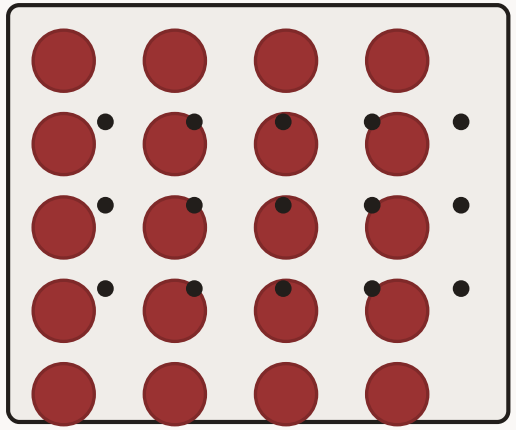
How atoms hold together (and why it matters in the field)

SURVEY LEVEL

Metallic, ionic, covalent

Metallic bonding

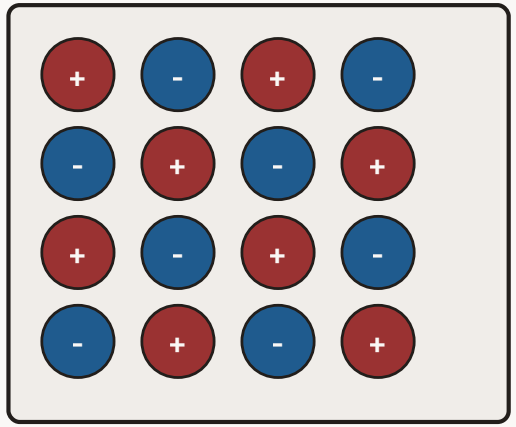
electrons free to move



steel · copper · zinc

Ionic bonding

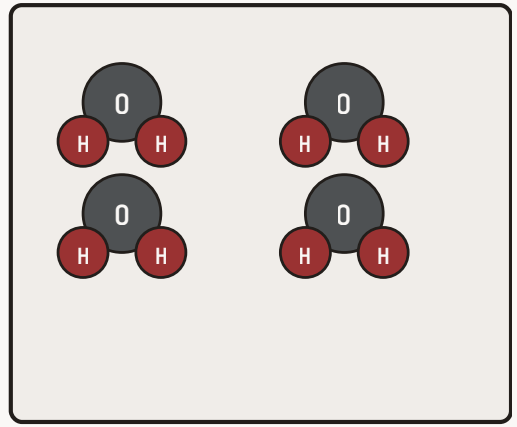
dissolves into ions in water



$NaCl$ · $CaCO_3$ · $MgSO_4$

Covalent bonding

shared electron pairs



H_2O · plastic · epoxy

Three patterns of how atoms stick together. Each one behaves differently with respect to electrons and ions — which is exactly why each one plays a different role in the corrosion picture.

WHAT EACH KIND OF BONDING LETS MOVE — OR BLOCKS

The chemistry under the obvious

STEEL

Metallic

Atoms share their outer electrons as a pool. Electrons are **free to move** through the metal.

The pipeline = the electron path.

SALTS IN MOIST SOIL

Ionic (dissolved)

Water pulls cations and anions apart from the dry lattice; **ions move through the water**.

Moist soil = the electrolyte.

COATINGS, PLASTICS

Covalent

Atoms share electron pairs; no free electrons, no dissolved ions. **Blocks both paths.**

Coating = the insulator.

Metallic lets electrons move. Ionic-in-water lets ions move. Covalent blocks both.
That's why CP works — and why coatings work.

SECTION 04 · COMMON CP IONS

The ions a CP tech actually meets

CL⁻ — THE MOST COMMON AGGRESSIVE ANION

Penetrates passive films · drives pitting

Where it shows up

- Marine environments and brackish groundwater
- Road-salt runoff (highway corridors)
- Produced water from oil-and-gas operations
- Industrial chloride spills and process leaks

Why it's aggressive

Cl^- is small enough to slip through tiny defects in passive oxide films and through holidays in coatings. It concentrates at those locations and drives **localized pitting** — concentrated metal loss, not uniform thinning.

Soil reports above roughly 100–200 ppm Cl^- deserve a closer look.

Recognition cue. Pitting corrosion in soil + a chloride number above the flag line on the soil report → chloride is probably driving it.

SO_4^{2-} AND HCO_3^-

The MIC feedstock and the natural-water buffer

Sulfate (SO_4^{2-}) — MIC feedstock

Common in agricultural and industrial soils. Doesn't attack passive films directly — but it's what **sulfate-reducing bacteria (SRB)** consume in oxygen-starved conditions.

The byproduct SRB generates is hydrogen sulfide (H_2S) — the rotten-egg gas — which drives microbiologically influenced corrosion (MIC).

High sulfate + low oxygen + the right bacteria = MIC warning.

Bicarbonate (HCO_3^-) — the buffer

Most natural groundwater contains dissolved bicarbonate. Acts as a **buffer** that holds the water's pH steady in the 7–8 range.

If something acidic enters, bicarbonate neutralizes. If something alkaline enters, it compensates the other way.

A generally good sign on a corrosivity report — usually the reason local groundwater is benign.

THE HARDNESS IONS AND THE PH-SETTING IONS

Scale-formers and the pH duo

Ca^{2+} and Mg^{2+} — scale-formers

The "hardness" ions in hard water and hard-soil environments. They tend to deposit at the cathode of a corrosion cell — the area being protected — forming calcium-carbonate or magnesium-carbonate scale.

Thin scale layers actually help — extra barrier between metal and electrolyte. Thick scale becomes its own maintenance problem.

H^+ and OH^- — set pH itself

The most important pair of ions in corrosion chemistry. Their balance defines whether a solution is acidic (excess H^+) or alkaline (excess OH^-).

Next section covers them in depth.

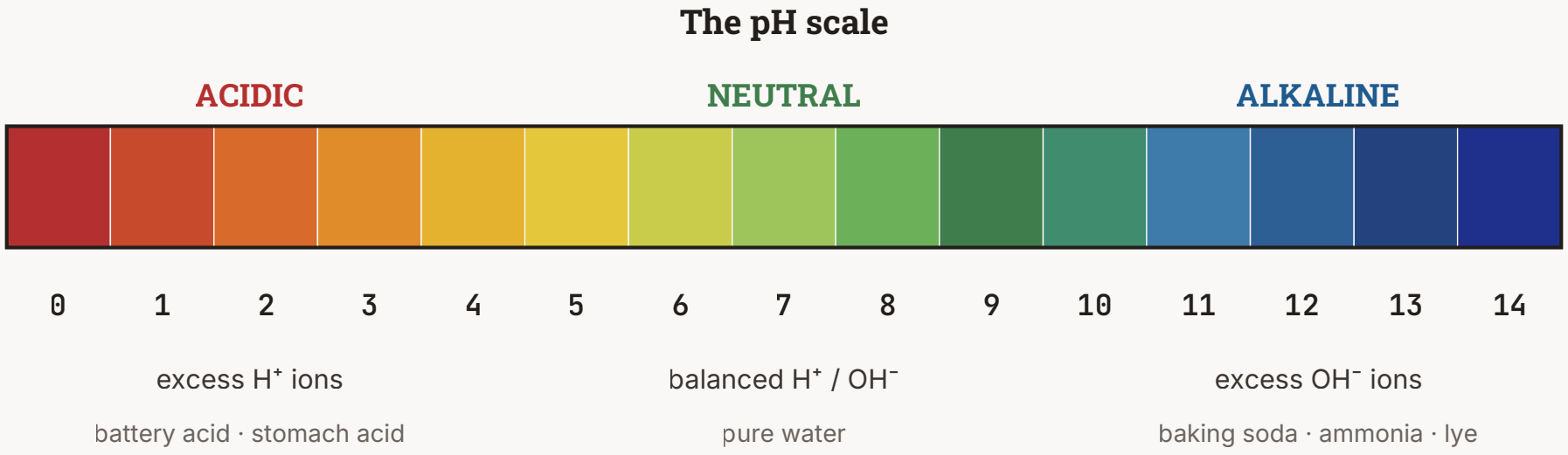
Pointer ahead. Soil chemistry as a complete driving system — resistivity, oxygen, drainage, MIC, interactions among all the ions above — is its own module in EC-019. EC-008 names the players; EC-019 puts them on the field together.

SECTION 05 · PH

pH at a working level

0 TO 14 · 7 IS NEUTRAL

pH is just "how much H^+ is in the water"



Lots of H^+ → acidic (low pH). Very little H^+ → alkaline (high pH). Pure water sits dead-center at 7. The number is a measure of H^+ concentration — but reported on a **logarithmic** scale.

THE MOST-MISUNDERSTOOD POINT ABOUT PH

Each step is ×10

A drop from pH 7 to pH 6 is ten times more H^+.
From pH 7 to pH 4 is a thousand times more H^+.

What this means in the field

Don't read the gap from pH 7 to pH 5 as a small change. It is a **100-fold** change in the variable that drives a major piece of corrosion chemistry.

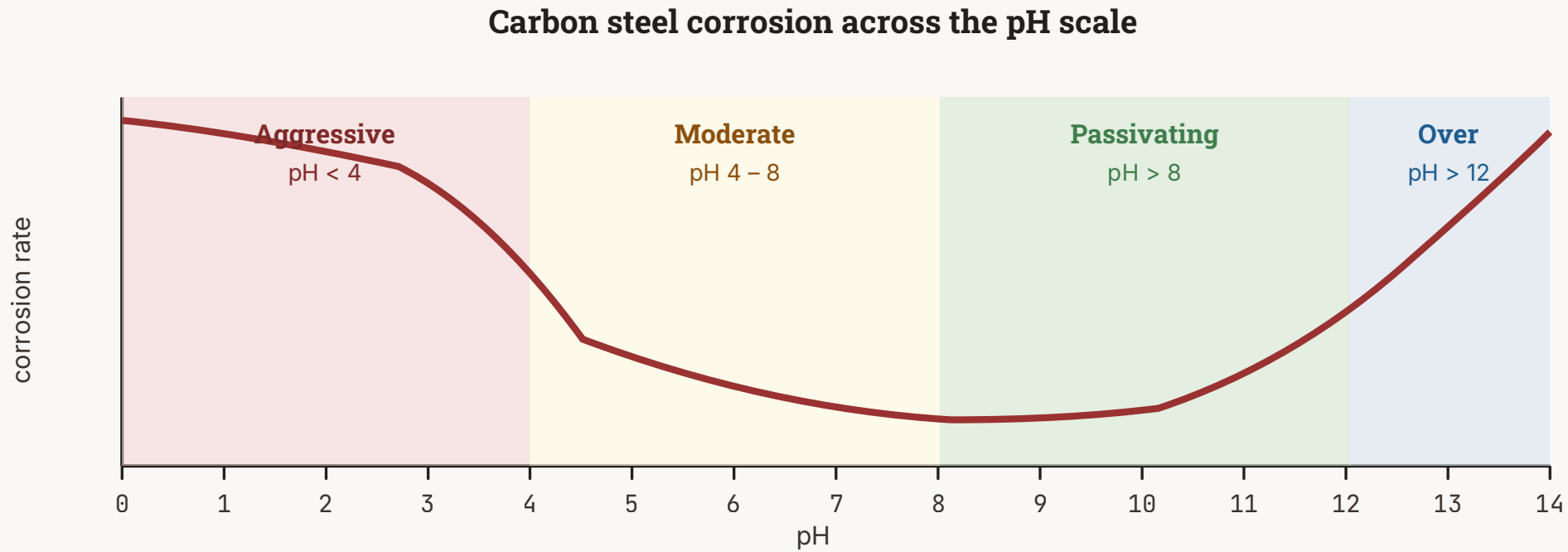
A pH 4 soil isn't "twice as acidic" as a pH 8 soil. It's **10,000 times** more H^+.

Quick reference

- pH 7 → reference (neutral)
- pH 6 → 10× more H^+
- pH 5 → 100× more H^+
- pH 4 → 1,000× more H^+
- pH 3 → 10,000× more H^+

WORKING-LEVEL MENTAL MODEL

Aggressive · Moderate · Passivating · Overprotection



Below pH 4 — aggressively corrosive (H^+ reaction at metal surface unrestricted). **pH 4–8** — moderate (most natural soils + waters). **Above pH 8** — oxide film stabilizes, corrosion slows. **Above pH 12** — CP-overprotection territory (rare in natural soils).

ALUMINUM AND ZINC DON'T BEHAVE LIKE STEEL

Some metals corrode at both ends of the pH scale

Carbon steel mostly likes pH between 4 and 12. A few metals corrode in **both** strong acid and strong alkali — the textbook word is amphoteric. Aluminum and zinc are the two a CP tech is most likely to meet.

> **Why it matters in the field.** A strongly alkaline soil (pH 11+) protects steel through passivation but destroys aluminum. If a buried aluminum component sits in that environment, it needs its own corrosion-control consideration — separate from the steel pipeline's CP system.

> **Recognition rule.** Strongly alkaline soil + aluminum (or zinc) hardware nearby → raise the flag. The fix lives with the CP designer; the recognition lives with the working tech.

DECODED WITH THE CHEMISTRY FROM THIS MODULE

Five numbers, read by a working tech

pH 5.6	Mildly acidic. About 25× more H^+ than neutral. On the acidic side of the moderate band — the steel will corrode at a meaningful rate if left to do so.
Resistivity 2,800 Ω·cm	Moderately aggressive ion content — more ions in the soil = better electrolyte = more aggressive environment.
Chloride 210 ppm	Above the rough 100–200 ppm flag line. Pitting risk; expect coating performance to degrade over time.
Sulfate 95 ppm	Moderate. Not the dominant concern on its own, but watch for low-oxygen + bacteria → MIC down the road.
Sulfide not detected	Good. No active SRB byproduct in this sample. Worth periodic re-testing.

None of that requires inventing chemistry. The lab generates the numbers; this module gives you the picture behind them.

ELECTROCHEMISTRY & THE GALVANIC SERIES — THE ROAD AHEAD

Where the chemistry foundation goes

EC-008 is module 1 of 7 in this set. The atoms, ions, bonds, and pH picture you just walked is the floor under every module that follows.

- **EC-009 — The Corrosion Cell.** Assembles the anode, cathode, electrolyte, and metallic path. $Fe \rightarrow Fe^{2+} + 2e^-$ becomes the anodic half.
- **EC-010 — Oxidation & Reduction.** Paired half-reactions at the anode and cathode together.
- **EC-011 — Galvanic Series.** Quantitative ranking of how readily metals lose electrons.
- **EC-012 — Faraday's Law.** Calculating mass loss from corrosion current.
- **EC-013 — Environmental Effects.** How temperature, oxygen, moisture, and pH change rates.
- **EC-014 — Polarization.** How the system shifts under load — closes the set.

UP NEXT

EC-009 — The Corrosion Cell

Metallic path + electrolyte + anode + cathode. EC-008's pieces, assembled into the system that drives corrosion on every buried structure.