EC-009 · MODULE 2 OF 7

# The Electrochemical Cell

Anodes, cathodes, electrolytes - the machine behind every corroded pipe. The second module of the Electrochemistry & the Galvanic Series set.

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

BY THE END OF THIS MODULE

# You'll be able to -

- Name the four parts of a corrosion cell and explain why removing any one stops the corrosion.
- State where the metal loss happens - the anode - and why the cathode is protected.
- Read the anodic reaction and the two cathodic reactions, and tell which one runs in a given environment.
- Explain the corrosion cell as "a battery you didn't want."
- Recognize corrosion cells at every scale, including differential-aeration cells - the most common natural driver.
- Explain the anode-to-cathode area ratio and why a small coating defect is bad news.
- Size up soil resistivity as the electrolyte's headline property.

AT THE BOTTOM OF A BELL HOLE

# Two joints of the same pipe. One pitted, one clean.

An excavator has a length of old, bare steel line uncovered. Two joints - same vintage, same steel, same trench - and they don't match. One is clean gray metal. A few feet down, the surface is rough with rust and broken up by pits, one deep enough to put on the report.

Same pipe. Same soil, near enough. So why is one spot quietly eating itself while the other one is fine?

**The bad spot and the good spot are wired together into a circuit. Metal leaves one and not the other because the two ends are doing two different jobs.**

**That circuit is the corrosion cell - and this module assembles it.**

FIVE SECTIONS, IN ORDER

# How we'll build the cell

01
### The four-part cell
Anode, cathode, electrolyte, metallic path.

02
### Where the metal goes
The anodic and cathodic reactions.

03
### A battery you didn't want
The analogy that demystifies it.

04
### Cells at every scale
Micro, macro, differential aeration.

05
### Electrolyte & the field
Resistivity, area ratio, finding cells.

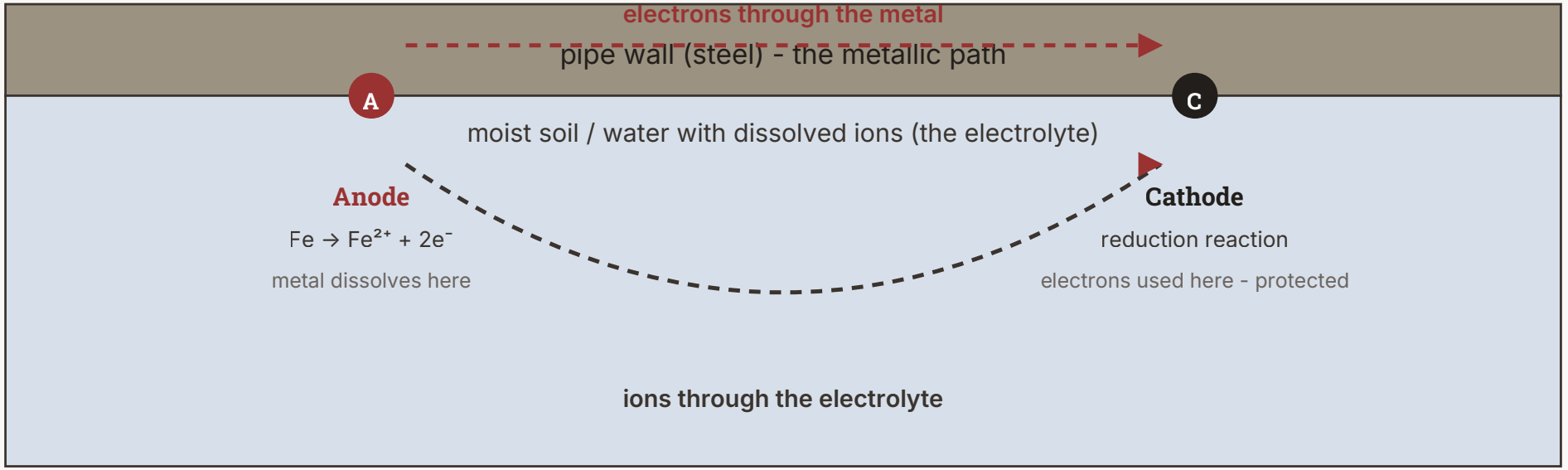
SECTION 1 · THE FOUR-PART CELL

# Anode, cathode, electrolyte, path

FOUR PARTS WORKING TOGETHER

# The corrosion cell

## The corrosion cell at the pipe wall




**Take any one of the four pieces away and the cell stops.**

ALL FOUR. NONE OPTIONAL.

# Take one away, the corrosion stops

- **Anode** - where iron dissolves ($Fe \rightarrow Fe^{2+} + 2e^-$). The metal that's leaving.
- **Cathode** - where the freed electrons get used in a reduction reaction. No metal lost; it's protected.
- **Electrolyte** - the wet, ion-filled medium: moist soil, water, concrete pore fluid. How charge moves outside the metal.
- **Metallic path** - the pipe itself (the electron path), tying anode to cathode.

Anode, cathode, electrolyte, metallic path. Remove any one and corrosion stops - the most useful diagnostic idea you own.

THE TWO ELECTRODES

# One gives up metal. One is protected.

### Anode

Where the metal goes. Iron atoms give up electrons and leave the surface as ions: $Fe \rightarrow Fe^{2+} + 2e^-$. Always the corroding end.

### Cathode

Where the freed electrons are consumed by a reduction reaction. No metal leaves. The cathode is effectively protected - the seed of cathodic protection.

Same piece of steel can host both, a few feet - or a few grains - apart.

THE TWO CONDUCTORS

# Ions move one way, electrons the other

### Electrolyte

The wet, ion-filled medium both electrodes sit in - moist soil for a buried line. Ions drift through it to balance the charge.

### Metallic path

The metal connection - almost always the pipe itself, one continuous piece carrying electrons from anode to cathode.

**The split:** electrons travel through the metal, ions travel through the electrolyte. They trade at the anode and cathode. That hand-off is the whole engine.

SECTION 2 · WHERE THE METAL GOES

# The reactions that move the metal

THE RULE THAT MATTERS MOST

# The metal always leaves from the anode

Always. The cathode loses nothing. If you remember one sentence from this module, make it that one - it tells you which end you want your pipeline on.

> **Why the cathode is protected:** its reaction consumes electrons and tends to make the surface more alkaline - conditions that don't dissolve iron. Flood a surface with enough electrons and it stops corroding. That one fact is the whole idea behind cathodic protection.

ONE ANODIC, TWO CATHODIC

# The reactions that run the cell

ANODIC · THE METAL LEAVES

### Iron dissolves

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

CATHODIC · AERATED, NEUTRAL

### Oxygen reduction

$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$

CATHODIC · ACIDIC / NO OXYGEN

### Hydrogen evolution

$2H^+ + 2e^- \rightarrow H_2$

Iron dissolves at the anode and releases electrons. They travel through the steel to the cathode, where one of the two reductions uses them up.

THE ENVIRONMENT PICKS THE WINNER

# Which one runs where

### Oxygen reduction

Runs when oxygen reaches the metal and the environment is roughly neutral to alkaline. The everyday case for most buried pipe.

### Hydrogen evolution

Runs when it's acidic - $H^+$ everywhere - or when oxygen has been shut out so oxygen reduction can't. Pits, under deposits, tight crevices, low-pH soils.

Two questions to ask any site: is there oxygen at the metal, and is it acidic?

**Electrons through the metal. Ions through the electrolyte. The reactions trade them at the anode and the cathode.**

**Four parts, two reactions, one continuous loop of current - and the current is your pipe.**

SECTION 3 · A BATTERY YOU DIDN'T WANT

# Same machine. Wrong direction.

YOU ALREADY KNOW THIS MACHINE

# A corrosion cell is a battery

### A flashlight battery

An active metal that gives up electrons (anode), a material that takes them (cathode), a paste that carries ions (electrolyte), a wire (the path). Current flows and does useful work.

### A corrosion cell

The same four parts - but the current is metal leaving your pipeline. You didn't ask for this battery, and it runs itself down by dissolving your structure.

Corrosion is a battery you didn't want.

THE CELL, TURNED AGAINST ITSELF

# This is what cathodic protection inverts

The anode and cathode sit at slightly different potentials - that difference is the push that drives the cell.

> Cathodic protection flips it: supply electrons from an outside source so the **whole structure becomes a cathode**, and the corrosion moves to an anode you chose. Every coating, isolation joint, and CP system in the rest of your training is a way of breaking this cell.

SECTION 4 · CELLS AT EVERY SCALE

# Microscopic to miles long

ON A SINGLE PIECE OF STEEL

# Tiny cells, side by side

Look closely and a steel surface isn't uniform - grain boundaries, weld zones, mill scale, inclusions. Each can sit at a slightly different potential than the metal beside it.

The result is a carpet of microscopic anodes and cathodes on the same surface, each running a tiny corrosion cell. A patch of bright steel scraped next to mill scale goes anodic - the bright spot corrodes. This is the engine behind general surface rust.

BETWEEN WHOLE REGIONS OF A STRUCTURE

# Same physics, stretched across feet or miles

CELL

### Coating holiday

A small bare anode against a large coated cathode. The corrosion funnels onto the holiday.

CELL

### New pup in an old line

Bright new steel welded into old, scaled pipe goes anodic - the new joint corrodes first, while the old line is protected.

CELL

### Dissimilar soils

A line crossing from sandy ridge into wet clay forms a cell between the two soils, current running through the ground.

THE MOST COMMON NATURAL DRIVER UNDERGROUND

# The low-oxygen spot corrodes

Read it twice - it runs against intuition. Where oxygen is plentiful, the metal holds the cathodic, protected role. Where oxygen is scarce, the metal takes the anodic role and gives up metal.

Under a paved road, under a deposit or disbonded coating, deep in wet clay, at the bottom of a trench - the starved spot goes anodic.

> **Back to the bell hole:** the pitted joint most likely sat where oxygen was scarcer and went anodic to the better-aerated joint nearby. The clean joint wasn't lucky - it was the cathode, protected at the pitted joint's expense.

SECTION 5 · ELECTROLYTE, AREA RATIO & THE FIELD

# Resistivity, ratios, and reading a dig

WHY A SMALL BARE SPOT IS BAD NEWS

# Small anode, large cathode

The bigger the cathode, the more total corrosion current the cell can drive - and all of it has to come off the anode. A small anode concentrates that loss into a small spot, fast and deep.

> On a well-coated line, a tiny holiday can corrode faster than bare pipe - the whole coated surface funnels its corrosion onto that one spot. A defect about 0.1% of the surface sits at roughly a 1,000:1 cathode-to-anode ratio.

A small coating defect matters far more than its size suggests.

THE ELECTROLYTE'S HEADLINE PROPERTY

# How easily the ground carries current

Lower resistivity means ions move easily, more corrosion current, faster loss. As a rough field guideline:

- **Below ~1,000 Ω·cm** - severely corrosive.
- **~1,000 to 3,000 Ω·cm** - quite corrosive.
- **~3,000 to 10,000 Ω·cm** - moderate.
- **Above ~10,000 Ω·cm** - mild.

> **One number, two meanings.** For a bare pipe, low resistivity means faster corrosion. For a CP system you want to run, low resistivity is welcome - it spreads protective current more easily. Same number; what changes is whose current you mean.

READING A DIG BACKWARD FROM THE EVIDENCE

# Tell the anode from the cathode

### Anodic spots

Active metal loss - pitting, localized thinning, crusty mounds of rust. Where the metal is leaving.

### Cathodic spots

Little metal loss. In many soils a chalky calcium / magnesium scale; the metal underneath comes out comparatively clean.

You don't always have to dig - a pipe-to-soil potential survey maps where the structure reads more active (anodic) along the line. How that's run is a later module.

THE FOUR-PART RULE, PUT TO WORK

# Break one part, stop the cell

- **Coatings** - shrink the exposed metal area.
- **Isolation fittings** - cut the metallic path between dissimilar sections.
- **Cathodic protection** - flood the structure with electrons so the whole thing acts as a cathode.
- **Keeping it dry** - remove the electrolyte where you can (more an internal-corrosion lever than an external one).

> Every corrosion-control method you will learn is an attack on one of the four parts of the cell. Name the part you're breaking and you understand the method.

BOOKEND

# Now you can read the dig

Walk back to those two joints. You can answer "why here, not there" now: a corrosion cell - most likely differential aeration - with the pitted joint as the anode and the clean joint as the protected cathode.

**That's the whole job in miniature - find the cells before they find the leaks.**

WHAT TO WALK AWAY WITH

# The cell, in six lines

- **Four parts:** anode, cathode, electrolyte, metallic path. Remove any one and corrosion stops.
- **The metal always leaves the anode.** The cathode loses nothing - it's protected.
- **Electrons move through the metal; ions through the electrolyte.** Anode: Fe → $Fe^{2+}$ + $2e^{-}$. Cathode: oxygen reduction (aerated / neutral) or hydrogen evolution (acidic / oxygen-starved).
- **A corrosion cell is a battery you didn't want** - the current is metal leaving your structure.
- **Cells form at every scale** - micro spots, coating holidays, soil-to-soil. Differential aeration (the low-oxygen spot goes anodic) is the most common natural driver.
- **Small anode + large cathode = concentrated loss.** A tiny coating defect matters more than its size suggests.

WHY THIS MODULE SITS WHERE IT DOES

# Cathodic protection is the corrosion cell, turned against itself

Coatings shrink the anode. Isolation cuts the path. CP floods the structure with electrons so it all becomes a cathode.

You can't understand the cure until you understand this cell. That's why EC-009 is the conceptual prerequisite for the entire cathodic-protection curriculum that follows.

WHERE THE ELECTROCHEMISTRY SET GOES

# Each module is a closer look at this machine

- **EC-010** - oxidation and reduction as a matched pair - the anodic and cathodic reactions, always running together.
- **EC-011** - the galvanic series - which metals go anodic to which, and by how much.
- **EC-012** - corrosion rate - how fast metal actually leaves for a given current.
- **EC-013** - reference electrodes - the tools that measure the cell's potentials.
- **EC-014** - polarization - how the cell shifts under load.

FURTHER READING + THE NEXT MODULE

# Sources used + where this goes

- **Electrochemical Basics (Part 2)** - Field Notes from RCS
- **Corrosion Basics: An Introduction**
- **Peabody's Control of Pipeline Corrosion**
- **Cathodic Protection Training Materials** (CP-1 / CP-2)
- **AUCSC Short Course Materials**
- **NACE SP0169** - External Corrosion Control, Underground/ Submerged Piping
- **NACE SP0285** - UST Systems by Cathodic Protection
- **ASTM G57** - Field Measurement of Soil Resistivity

UP NEXT

## EC-010 - Oxidation and Reduction

The anodic and cathodic reactions you just named, treated as a matched pair - oxidation and reduction always running together, and what controls each side.