EC-014 - MODULE 7 OF 7

Polarization Fundamentals Types and Effects

A potential is not a fixed property of a pipeline. It is where the steel sits, given the current that is flowing — and this module is about what happens in between.

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

BY THE END OF THIS MODULE

You'll be able to -

- Define **polarization** as the shift in a metal's potential caused by current passing through its surface, and say what it costs and how long it takes.
- Separate **real polarization from resistance drop**, and explain why one decays over days while the other vanishes in a second.
- Read the **potential-versus-current picture** the trade argues from: which way each line runs, what the crossing means, and why the bottom axis is compressed.
- Convert a polarization shift into a corrosion-rate cut: **decades = shift ÷ 100 mV**, then **10 ^ decades**.
- Name the **three real kinds** - activation, concentration, environmental - and recognize the delivery limit from the truck.
- Name the **four ground conditions** that move current demand between one survey and the next, and the ceiling on the other end.

MODULE ROADMAP

Five sections, in order

01
Two speeds
What left in one second, and what took five days.

02
What it is
Potential moving in response to current.

03
The picture
Two lines, one crossing, a compressed axis.

04
The hundred
Where the criterion comes from, and the arithmetic.

05
Kinds and knobs
Three real ones, one impostor, four conditions.

YOUR FIRST ANNUAL SURVEY IS TWO DAYS BEHIND YOU, AND IT WENT FINE

Twenty-some stations, a pair of numbers each, nothing to flag

The rectifier is cycling on an interrupter — three seconds on, one second off — so every station gives you two readings instead of one.

CURRENT FLOWING

On-potential, about -1.28 V

Station after station, the pair holds. The numbers look like a protected line, and they look like they belong together.

THE ONE-SECOND GAP

Instant-off, about -0.98 V

Your notebook sits right on top of four years of records from the tech who retired last spring. Nothing to flag.

THE RECTIFIER GOES OFF SO A CREW CAN TIE NEW PIPING IN

You pull one reading on the way out, and it fits neither number

The project manager wants the unit at the compressor station de-energized while the work goes on. Standard request, easy yes. Your meter is already on the seat, so you read the test station just outside the fence before you leave.

> **It comes back -0.91 V.** That is not the on-potential you wrote down two days ago, and it is not the instant-off either. It is *past* the instant-off — seventy millivolts less negative than the number you recorded in the interrupter gap, at this same station.

You check the leads and the cell. The number is real. Nothing about the pipe has changed except that the current stopped. A tech with twenty years on you does not sound surprised: *it's depolarizing — go read it again tomorrow.*

SO YOU KEEP READING IT

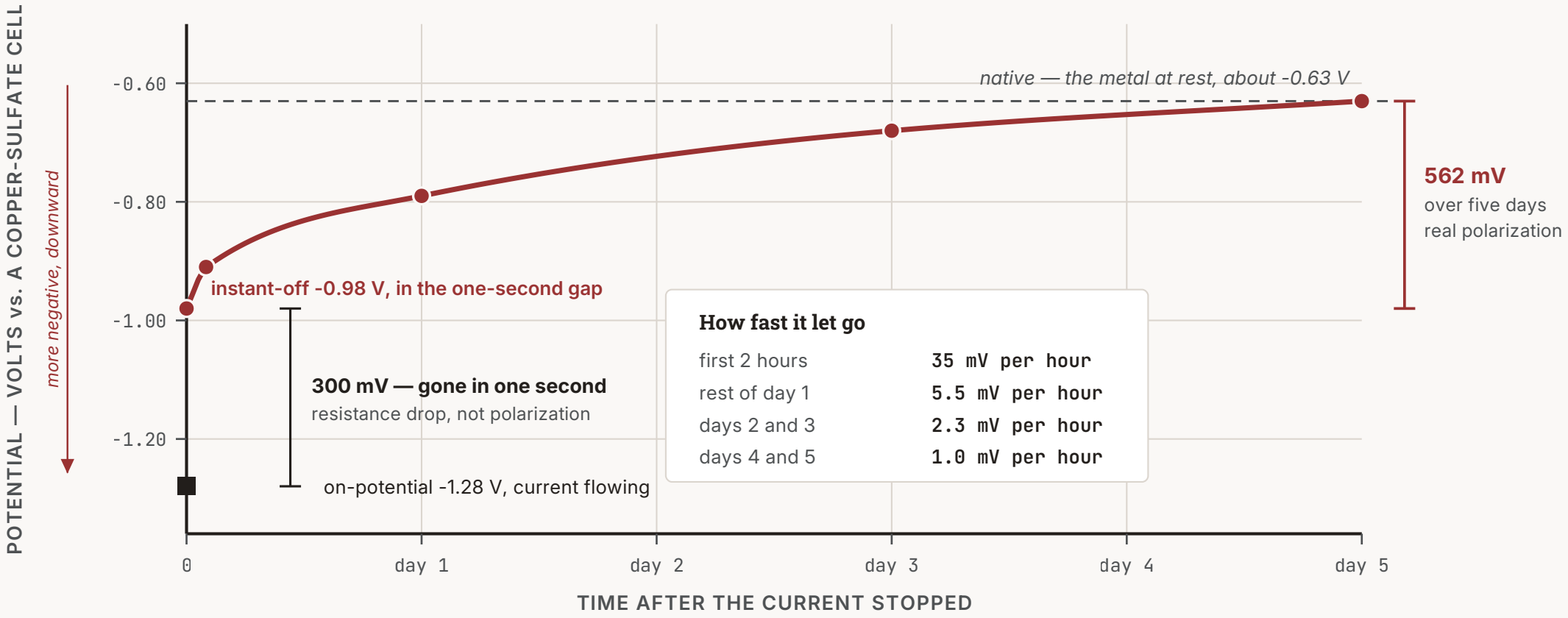
The number keeps moving, and then it very nearly stops

When you read it	Potential	What you are looking at
Survey day, current flowing	-1.28 V	*on-potential*
Survey day, one-second gap	-0.98 V	*instant-off*
Two hours after shutdown	-0.91 V	*already past the instant-off*
One day	-0.79 V	*still moving, more slowly*
Three days	-0.68 V	*slower again*
Five days	-0.63 V	**very nearly stopped - the metal at rest**

Nothing broke. Nothing leaked. You watched a number you thought was a property of the pipe turn out to be a property of the **current**.

THE SHAPE IS THE TEACHING POINT, NOT THE ENDPOINTS

Fast at first, then slower, then almost nothing



It behaved like something draining, not something switching.

SECTION 1 - THE SPLIT

Two things left, at two different speeds

LINE THE NUMBERS UP AND THEY SPLIT CLEANLY IN HALF

Three hundred millivolts in one second. Three hundred fifty more in five days.

-1.28 V TO -0.98 V

300 mV

Gone inside one second

It vanished inside a single one-second window of the interrupter cycle — gone before your meter could finish settling.

That amount never had anything to do with the condition of the steel.

-0.98 V TO -0.63 V

350 mV

Gone over five days

And it did not bleed off evenly: about 35 mV an hour over the first two hours, 5.5 an hour through the rest of day one, then 2.3, then 1.0.

That is the fingerprint of chemistry, not wiring.

One was electrical and instant.
One was chemical and slow.

Telling them apart is the difference between a number that describes your pipe and a number that describes your wiring.

SECTION 2 - THE DEFINITION

What polarization actually is

START WITH STEEL THAT NOBODY IS DOING ANYTHING TO

A metal left alone settles where it wants to sit

AT REST

The native potential

Put bare steel in soil and walk away. It settles somewhere around **-0.55 to -0.65 V** vs. a copper-sulfate cell for ordinary carbon steel, depending on the ground.

The trade calls that its native or free-corroding potential. It is the number your station drifted back toward over five days.

UNDER CURRENT

The potential moves

Now push current onto it. The potential shifts away from that resting number, and it stays shifted for as long as the current keeps flowing.

That movement is **polarization**. It is not a substance and not a setting. It is a displacement.

THE CAREFUL WORDING, AFTER YOU HAVE ALREADY WATCHED IT HAPPEN

How far you have shoved a metal off the potential it would sit at on its own

> **Peabody's Control of Pipeline Corrosion** defines polarization as “the deviation (change) in potential of an electrode as a result of the passage of current.”

That sentence packs a great deal into very few words, and it is a hard one to absorb before you have watched it happen. After five days of watching a station drift from -0.98 back to -0.63 volts, it is just a careful way of saying what you already saw: **current moved the number, and when the current stopped, the number went home.**

TWO CONSEQUENCES, AND BOTH OF THEM SHOW UP IN THE FIELD

It costs current to create, and it takes time to build

IT COSTS CURRENT

Farther costs more

The farther you want to move a structure's potential, the more current you have to push through its surface. Polarization is bought, not switched on.

IT TAKES TIME

The surface has to change first

The chemistry at the steel has to shift before the potential settles. That is why your station needed five days to let go of it — and why a freshly energized system does not reach its final number the same afternoon.

That second point is the one that catches new techs. **A rectifier is not a dimmer switch on a light.** It is closer to a thermostat — you turn it up, and the room takes its time. How long it takes depends on what you are protecting: a large or poorly coated structure can need days or weeks, a small well-coated one far less.

SECTION 3 - THE PICTURE

The picture the whole trade argues from

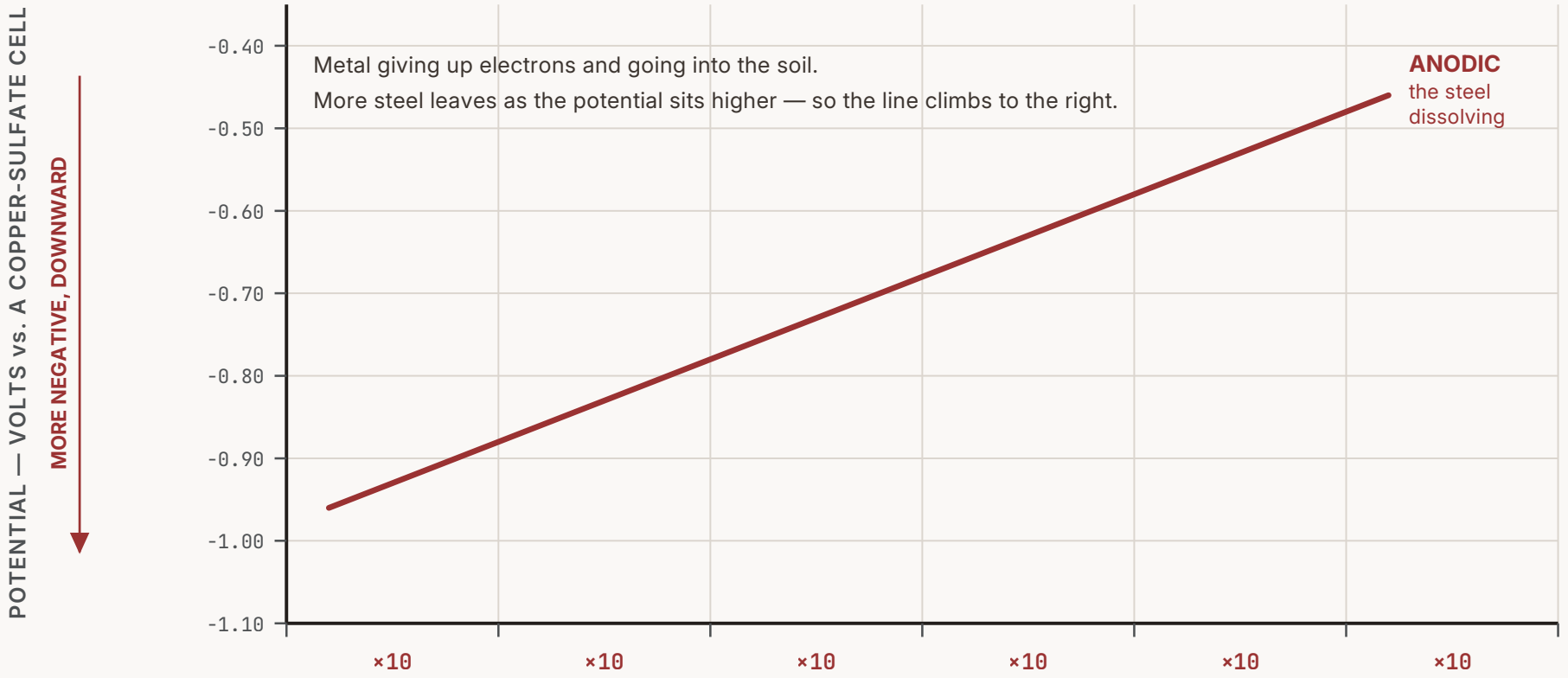
READ THE DIRECTION FIRST - THIS AXIS IS FLIPPED FROM YOUR SURVEY PLOTS

Potential down the side, current across the bottom

Potential runs positive at the top, negative at the bottom — flipped from your survey plots. *Every Evans diagram is drawn this way. Each step right is ten times more current.*

LINE ONE - THE CORROSION SIDE

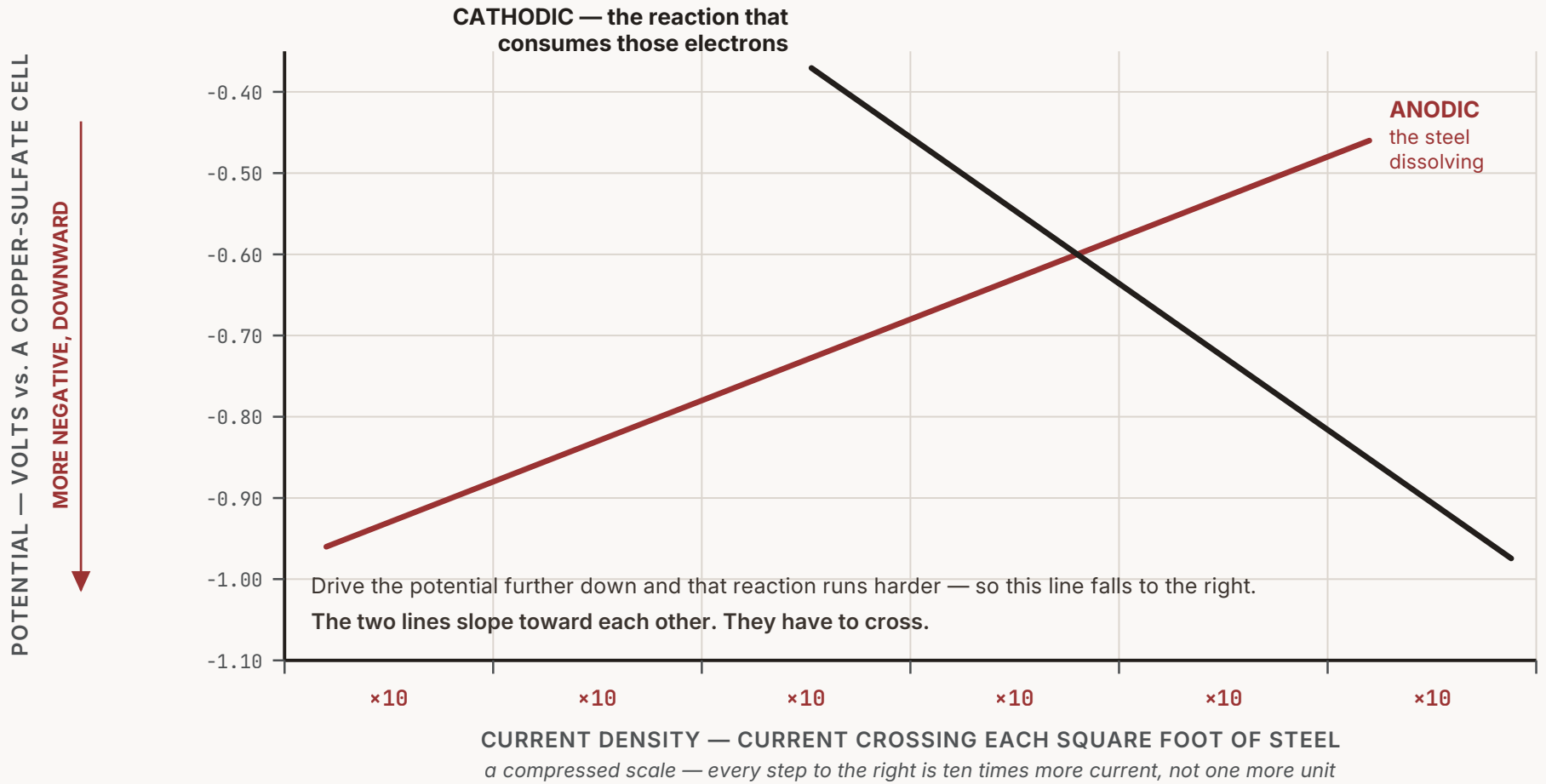
The first line: the metal dissolving



Steel giving up electrons and going into the soil. Nothing here is a measurement you take — it is the behavior of the metal.

LINE TWO - THE REACTION THAT TAKES THE ELECTRONS

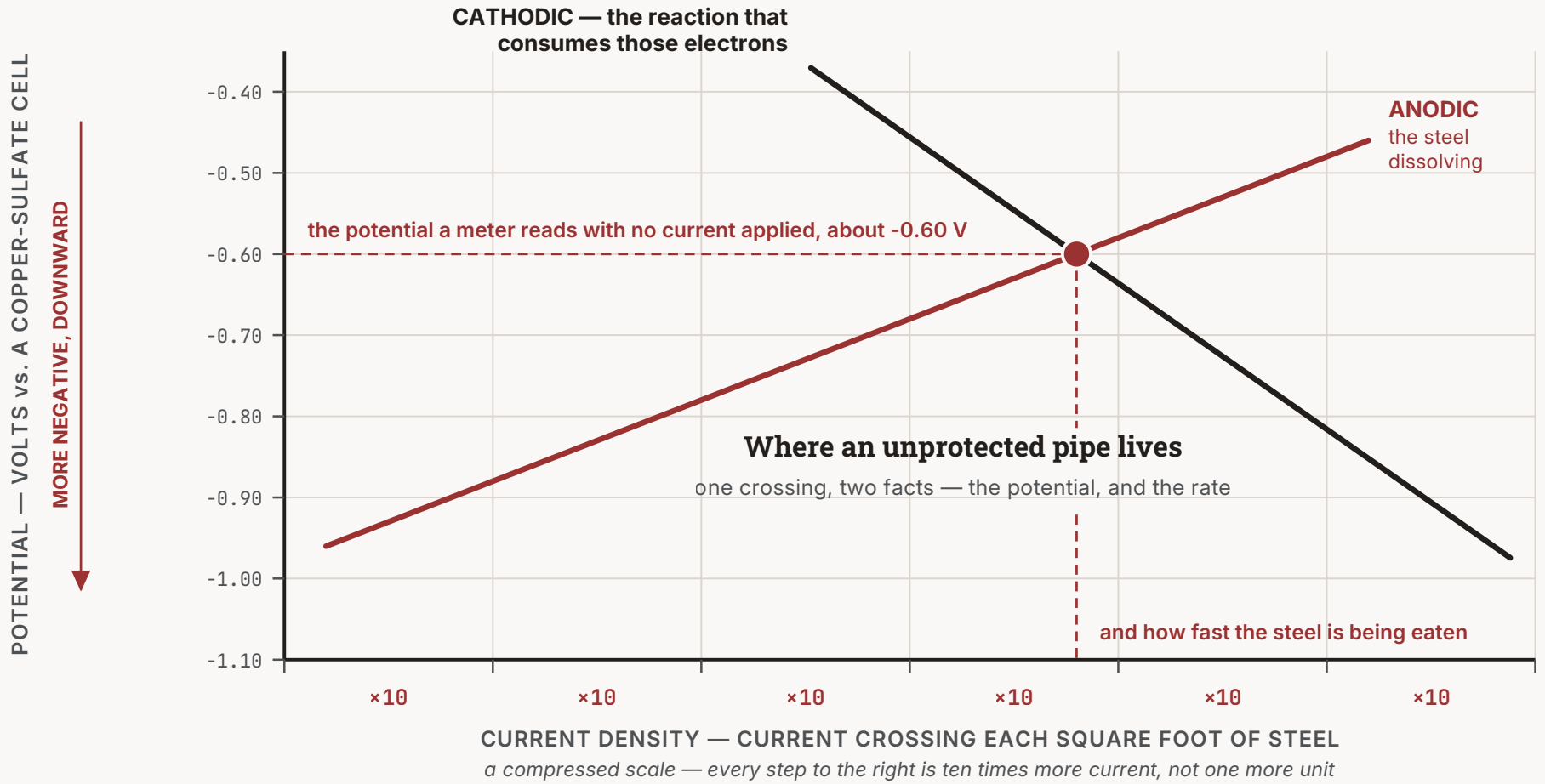
The second line: something has to consume them



Electrons leaving the steel have to go somewhere. In buried pipe that is most often oxygen being reduced at the surface.

WHERE THE TWO LINES CROSS

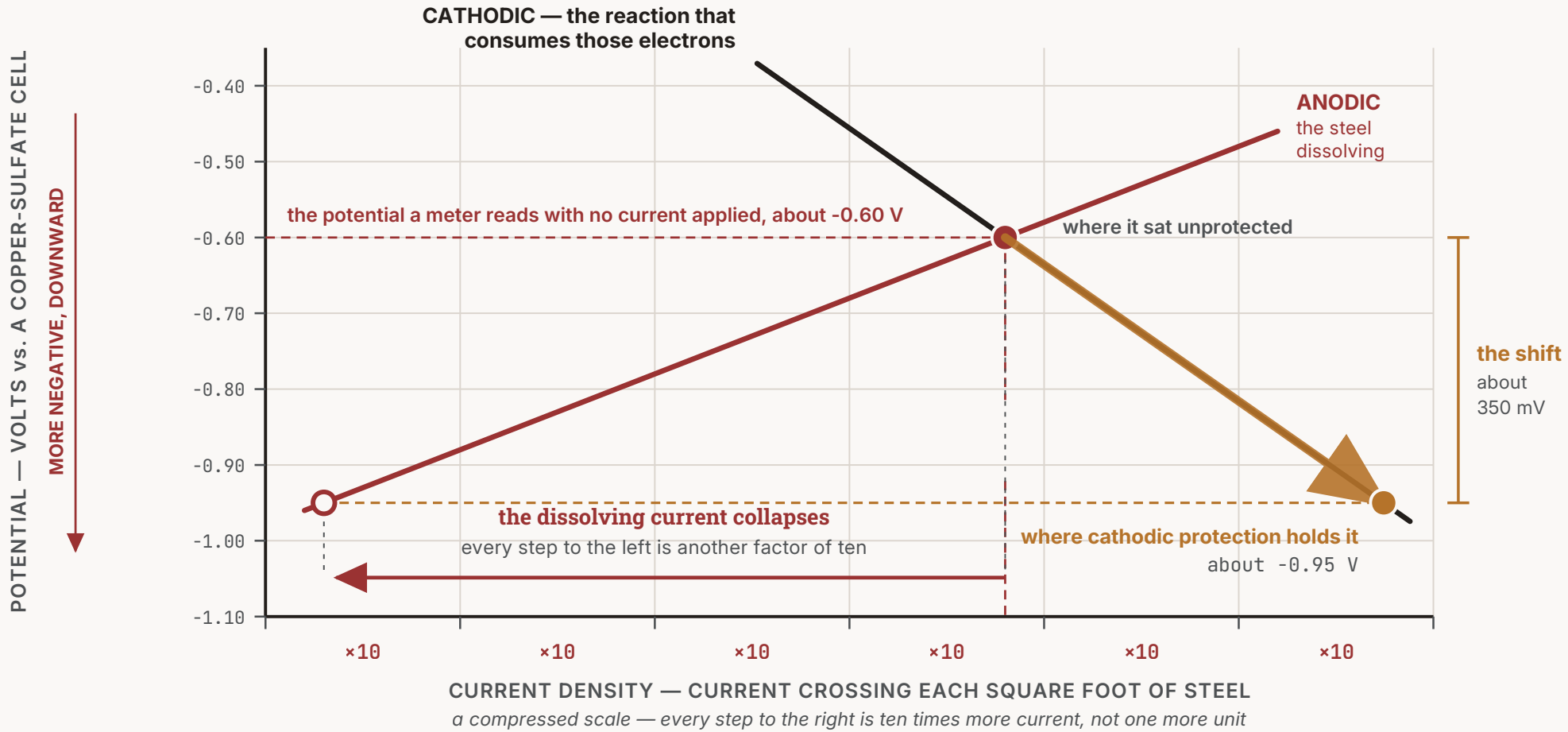
The crossing is where an unprotected pipe actually lives



Both facts come out of one intersection: the potential you would measure, and the rate the steel is going away.

CATHODIC PROTECTION REFUSES TO LET THE METAL SIT AT THE CROSSING

Supply electrons from somewhere else, and the operating point slides down



An anode bed or a rectifier drags the potential below the crossing — and the dissolving current slides left with it, a factor of ten per step.

THE BOTTOM AXIS IS THE WHOLE REASON ANY OF THIS IS PRACTICAL

Corrosion rate does not fall in proportion - it falls by factors of ten

> If corrosion rate fell off in proportion to potential, protecting a pipeline would take impossible current. It falls off by **factors of ten** instead, which is why a few hundred millivolts and a modest rectifier can shut down a line that would otherwise rust through.

You will never be asked to construct that graph on a job. You need to know it exists, which way the two lines run, and why the compressed axis makes small potential shifts pay off large. That last part is where the next section starts.

SECTION 4 - THE CRITERION, AND THE ARITHMETIC

Why the number is a hundred millivolts

IT GETS QUOTED LIKE A SPEED LIMIT - HANDED DOWN, OBEYED, RARELY EXPLAINED

It is not arbitrary. It falls straight out of that graph.

For carbon steel in ordinary soil, the corrosion side of that drawing has a measured steepness.

> The potential has to move roughly **one hundred millivolts** for the corrosion rate to change by a **factor of ten**.

That figure is not something you calculate on a job. It is a property of steel, measured in laboratories, and it is stable enough that the industry built a criterion on it.

THE ONE PIECE OF ARITHMETIC WORTH CARRYING OUT OF THIS MODULE

Shift, to decades, to a rate cut

POLARIZATION SHIFT, CONVERTED TO A CORROSION-RATE CUT

```
decades = shift (mV) ÷ 100 mV per decade
corrosion rate is cut by 10 ^ decades
```

Steel moves about one decade - one factor of ten - per hundred millivolts of shift.

A hundred millivolts is one decade. One decade is a factor of ten. So the 100 mV criterion is not saying “a hundred millivolts is a safe number.” It is saying: **move the steel a hundred millivolts and you have cut what it loses to about a tenth of what it was losing.** That is the practical line between a pipe actively corroding and a pipe essentially not.

THE STATION YOU JUST WATCHED DEPOLARIZE

What was that system actually buying?

With the rectifier on the interrupter, the station read **-0.98 V** instant-off. After five days with the current off, it settled at **-0.63 V**.

> STEP 1 - THE SHIFT
>
> `shift = 0.98 V - 0.63 V = 0.35 V = 350 mV`
>
> *The polarized potential, minus the potential the metal returns to on its own.*

Three hundred fifty millivolts of real polarization — the part that took five days to drain, not the part that vanished in a second.

350 MILLIVOLTS, CONVERTED

Three and a half decades

STEP 2 - CONVERT TO DECADES

```
decades = 350 mV ÷ 100 mV per decade = 3.5
```

STEP 3 - CONVERT TO A RATE CUT

```
10 ^ 3.5 = about 3,000
```

Roughly three thousand times less metal loss than the bare, unprotected condition.

That system was not scraping past the criterion. It was three and a half times past it — and the five-day drift you stumbled into was the proof.

A DIFFERENT LINE, AT A STATION NEAR THE FAR END OF THE PROTECTED LENGTH

Native -0.61 V. Polarized, current interrupted, -0.73 V.

STEP 1 - THE SHIFT

`shift = 0.73 V - 0.61 V = 0.12 V = 120 mV`

STEP 2 - CONVERT TO DECADES

`decades = 120 mV ÷ 100 mV per decade = 1.2`

STEP 3 - CONVERT TO A RATE CUT

`10 ^ 1.2 = about 16`

Sixteen times less metal loss - real protection, but a thinner margin.

BOTH OF THEM CLEAR THE MARK. THEY ARE NOT THE SAME STATION.

Sixteen times is not three thousand times

The station	Shift	Decades	Metal loss cut by
The one you watched depolarize	350 mV	3.5	about 3,000 ×
The one near the far end	120 mV	1.2	about 16 ×

Two stations, the same criterion, and almost two hundred times the difference in margin. A number that passes and a number that is comfortable are not the same number.

> The criterion is a floor, not a target. The arithmetic behind it is what tells a protected station apart from one that is a dry summer away from not being.

SECTION 5 - THE KINDS, AND THE IMPOSTOR

Three kinds that are real, and one that is not

KIND ONE OF THREE - THE REACTION ITSELF IS SLUGGISH

Activation polarization

THE MECHANISM

The reaction has a hump to get over

Electrons crossing between the metal and the things in the soil have to clear an energy hump before anything happens.

Pushing that reaction faster costs potential — so driving more current means shifting further.

WHERE IT DOMINATES

Plenty of reactant, modest current

A wet, active soil with no shortage of anything to react with, and a system running at ordinary output.

Nothing is running short here. The limit is the reaction's own speed.

KIND TWO OF THREE - THE REACTION RUNS OUT OF SOMETHING TO REACT WITH

Concentration polarization

THE MECHANISM

Limited by delivery, not by steel

In buried pipe the usual bottleneck is oxygen: the surface consumes it faster than fresh oxygen can work its way in through the soil.

The reaction is no longer limited by the metal at all.

THE SIGNATURE FROM THE TRUCK

More output stops buying more shift

Turn a rectifier up and the potentials move. Turn it up again and they move less. A third time and they barely move at all — while the anode bed works harder and the power bill climbs.

> When more output stops producing more shift, the honest first question is not “what broke?” It is **“have I hit the delivery limit?”** Techs have chased shorted casings and bad connections for days over a system that was simply out of oxygen to reduce.

KIND THREE OF THREE - THE CURRENT CHANGES THE CHEMISTRY, AND THE CHANGED CHEMISTRY HELPS

Environmental polarization

Cathodic reactions leave the film right against the steel more alkaline than the bulk soil around it — and that alkaline film is a less hospitable place for corrosion to proceed.

> The protection you paid for with current partly maintains itself through the environment it creates. That is also why a system running for months holds its numbers better than one energized last week — the surface has had time to build the conditions that help it.

AND THEN THERE IS THE THREE HUNDRED MILLIVOLTS THAT DISAPPEARED IN ONE SECOND

Resistance drop is not polarization at all

Current flows from an anode bed, through soil, onto your pipe. That soil has resistance. Current through resistance produces a voltage, and your reference cell sits out in that soil reading it along with everything else. **Every on-potential you take with the current flowing carries that amount baked in.**

Nothing about the steel has changed. It is a measurement artifact, and it disappears the instant the current does — which is exactly why interrupters exist, and why the pair of numbers you take at a station is worth more than either number alone.

It is not real polarization, but it looks exactly like it on a meter. A confident on-potential can make an under-protected pipe look comfortably protected, and the pipe will not argue with you.

SAME STATION, SAME SETTING, A DIFFERENT ANSWER - AND MOST OF THE TIME NOTHING IS WRONG

Four ground conditions move current demand, and all four move with the weather

OXYGEN

The master depolarizer

More oxygen at the steel means the cathodic reaction runs harder and current demand goes up. Dry, sandy, well-aerated ground is thirstier than saturated clay for exactly this reason.

TEMPERATURE

Warm speeds reactions up

A line that holds its numbers in February can slip in August without a single component changing anywhere on the system.

MOISTURE AND MOVEMENT

Water carries in, and sweeps away

Water brings reactants in and sweeps products away, which erases concentration polarization and raises demand. A creek crossing does not behave like a hilltop.

SOIL CHEMISTRY

Acidity picks the reaction

Acidity changes which reaction dominates at the surface, and different reactions polarize differently.

When a station that read comfortably last fall reads marginal in July, the useful reaction is not to go hunting for a fault. **Ask what changed in the ground.**

RECOGNIZE IT - THE DEPTH BELONGS TO LATER MODULES

More is not automatically better

Push a structure far past what protection requires and you start trading one problem for another.

AT THE COATING

Coating disbondment

Drive it hard enough and conditions at the coating-to-steel interface can lift the coating away from the pipe — which creates the shielded spots nobody wants.

AT THE STEEL

Hydrogen at the surface

Heavy over-polarization generates hydrogen right at the steel surface, and that brings its own set of problems for the metal.

The goal is enough polarization, held steadily — not the most a rectifier can produce.

EVERYTHING ABOVE COLLAPSES INTO A FEW HABITS AT THE BOX

What to write down, and what not to panic about

WRITE IT DOWN

Record which number is which

A single potential with no note about whether current was flowing is half a measurement. Six months from now neither you nor the person auditing the file can reconstruct it.

DON'T PANIC

A moving number is not a fault

A potential that drifts after the current stops is polarization doing what it does. Fast decay in the first hours, then slower and slower, is the ordinary shape.

READ THE SPEED

A quick decay says something

Something that falls back to native almost immediately never held much polarization to begin with. The speed of the drift is information, not noise.

GIVE IT TIME

A new system has not finished

Reading a just-energized system the same afternoon and calling it underperforming is a mistake made every season.

THE CONSTRUCTION IS FINISHED AND THE RECTIFIER GOES BACK ON

You already know the station will not snap back to -0.98 V

RETURNS INSTANTLY

The resistance drop

That part is electrical, and it never left the steel to begin with. Close the breaker and it is back in your reading the same second.

HAS TO BE REBUILT

The polarization

It rebuilds the same way it drained, only backwards — fast at first, then slower, over hours and days, until the surface chemistry settles where it was before.

> Read that station on the way out and you get an honest number for that afternoon and a misleading one for the line. **Read it next week and you have your survey back.**

WHAT TO WALK AWAY WITH

Seven things worth carrying

- **Polarization is potential moving in response to current** - how far a metal has been shoved off the potential it would sit at on its own. It costs current to create and it takes time to build or drain.
- **Two things ride on an on-potential** - real polarization, which decays over hours and days, and resistance drop, which vanishes the instant the current stops. Only one of them describes your steel.
- **The picture is two lines and a crossing** - the metal dissolving, the reaction consuming the electrons, and a bottom axis where every step is ten times more current. Protection drags the operating point below the crossing.
- **Steel moves about one decade per hundred millivolts** - shift the potential 100 mV and the corrosion rate falls by roughly a factor of ten. That is where the 100 mV criterion comes from; it is a floor, not a target.
- **Do the arithmetic:** decades = shift ÷ 100 mV, rate cut = 10 ^ decades. A 350 mV shift is 3.5 decades, about 3,000 times less loss. A 120 mV shift clears the same criterion at about 16 times - both pass, one has far more margin.
- **Three real kinds, one impostor** - activation (sluggish reaction), concentration (reactant delivery runs out), environmental (the current improves the surface chemistry). Resistance drop is a measurement artifact. When more current stops buying more shift, suspect the delivery limit before you suspect a fault.
- **Oxygen, temperature, moisture, and soil chemistry** move current demand season to season - and over-polarizing past what protection requires trades corrosion for coating and hydrogen problems.

FURTHER READING

References & further reading

- **Evan's Diagram** - Field Notes from RCS article on the potential-versus-current picture, the kinds of polarization, and how cathodic protection shifts the operating point.
- **Examples of Depolarizers** - Field Notes from RCS article on oxygen and the other agents that keep cathodic reactions running.
- **Influencing Factors: Temperature, Oxygen & Relative Movement** - Field Notes from RCS article on the environmental conditions that change current demand.
- **Peabody's Control of Pipeline Corrosion** - long-standing field reference on polarization behavior and cathodic protection criteria.
- **Corrosion Basics: An Introduction** - foundational text on the electrochemistry and kinetics behind polarization.
- **NACE SP0169** - Control of External Corrosion on Underground or Submerged Metallic Piping Systems; the source of the polarization-shift criterion.
- **NACE TM0497** - Measurement Techniques Related to Criteria for Cathodic Protection; on-potential versus instant-off measurement practice.

THIS SET CLOSES HERE

EC-014 completes Electrochemistry & the Galvanic Series

Seven modules ago this started with atoms and bonding, and ran through the corrosion cell, oxidation and reduction, the galvanic series, the arithmetic of metal loss, and the reference cell that measures all of it. From here the work turns outward - the forms corrosion takes in the ground, and the surveys that find it.