



Designation: G 3 – 89 (Reapproved 1999)

Standard Practice for Conventions Applicable to Electrochemical Measurements in Corrosion Testing¹

This standard is issued under the fixed designation G 3; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice is intended to provide conventions for reporting and displaying electrochemical corrosion data. Conventions for potential, current density, electrochemical impedance and admittance, as well as conventions for graphical presentation of such data are included.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:

IEEE/ASTM SI 10 Standard for Use of the International System of Units (SI) (the Modern Metric System)²

3. Significance and Use

3.1 This practice provides guidance for reporting, displaying, and plotting electrochemical corrosion data and includes recommendations on signs and conventions. Use of this practice will result in the reporting of electrochemical corrosion data in a standard format, facilitating comparison between data developed at different laboratories or at different times. The recommendations outlined in this standard may be utilized when recording and reporting corrosion data obtained from electrochemical tests such as potentiostatic and potentiodynamic polarization, polarization resistance, electrochemical impedance and admittance measurements, galvanic corrosion, and open circuit potential measurements.

4. Sign Convention for Electrode Potential

4.1 The Stockholm sign invariant convention is recommended for use in reporting the results of specimen potential measurements in corrosion testing. In this convention, the positive direction of electrode potential implies an increasingly

oxidizing condition at the electrode in question. The positive direction has also been denoted as the noble direction because the corrosion potentials of most noble metals, such as gold, are more positive than the nonpassive base metals. On the other hand, the negative direction, often called the active direction, is associated with reduction and consequently the corrosion potentials of active metals, such as magnesium. This convention was adopted unanimously by the 1953 International Union of Pure and Applied Chemistry as the standard for electrode potential (1).³

4.2 In the context of a specimen electrode of unknown potential in an aqueous electrolyte, consider the circuit shown in Fig. 1 with a reference electrode connected to the ground terminal of an electrometer. If the electrometer reads on scale when the polarity switch is negative, the specimen electrode potential is negative (relative to the reference electrode). Conversely, if the electrometer reads on scale when polarity is positive, the specimen potential is positive. On the other hand, if the specimen electrode is connected to the ground terminal, the potential will be positive if the meter is on scale when the polarity switch is negative, and vice versa.

NOTE 1—In cases where the polarity of a measuring instrument is in doubt, a simple verification test can be performed as follows: connect the measuring instrument to a dry cell with the lead previously on the reference electrode to the negative battery terminal and the lead previously on the specimen electrode to the positive battery terminal. Set the range switch to accommodate the dry cell voltage. The meter deflection will now show the direction of positive potential.

Also, the corrosion potential of magnesium or zinc should be negative in a 1 N NaCl solution if measured against a saturated standard calomel electrode (SCE).

5. Sign Convention for Electrode Potential Temperature Coefficients

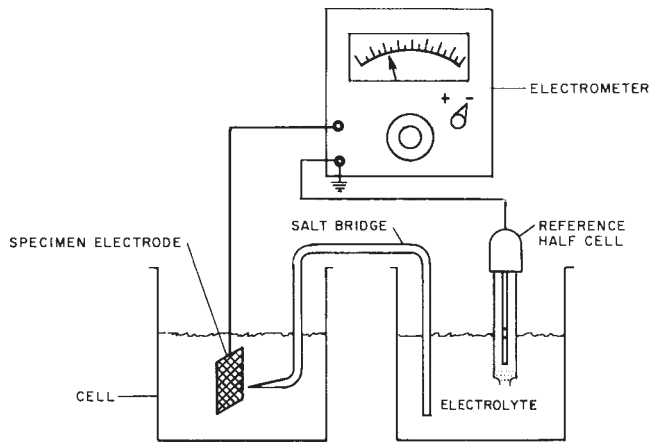
5.1 There are two types of temperature coefficients of electrode potential: isothermal temperature coefficients and the thermal coefficients. The sign convention recommended for both types of temperature coefficients is that the temperature coefficient is positive when an increase in temperature produces an increase (that is, it becomes more positive) in the

¹ This practice is under the jurisdiction of ASTM Committee G-1 on Corrosion of Metals and is the direct responsibility of Subcommittee G01.11 on Electrochemical Measurements in Corrosion Testing.

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² *Annual Book of ASTM Standards*, Vol 14.02 (excerpts in Vol 03.02).

³ The boldface numbers in parentheses refer to the list of references at the end of this practice.



NOTE 1—The electrode potential of specimen is negative as shown.
FIG. 1 Schematic Diagram of an Apparatus to Measure Electrode Potential of a Specimen

electrode potential. Likewise, the second temperature coefficient is positive when an increase in temperature produces an increase (that is, it becomes more positive) in the first temperature coefficient.

6. Sign Convention for Current and Current Density

6.1 The sign convention in which anodic currents and current densities are considered positive and cathodic currents and current densities are negative is recommended. When the potential is plotted against the logarithm of the current density, only the absolute values of the current density can be plotted. In such plots, the values which are cathodic should be clearly differentiated from the anodic values if both are present.

7. Conventions for Displaying Polarization Data

7.1 *Sign Conventions*—The standard mathematical practice for plotting graphs is recommended for displaying electrochemical corrosion data. In this practice, positive values are plotted above the origin on the ordinate axis and to the right of the origin on the abscissa axis. In logarithmic plots, the abscissa value increases from left to right and the ordinate value increases from bottom to top.

7.2 *Current Density-Potential Plots*—A uniform convention is recommended for plotting current density-potential data, namely, plot current density along the abscissa and potential along the ordinate. In current density potential plots, the current density may be plotted on linear or logarithmic axes. In general, logarithmic plots are better suited to incorporation of wide ranges of current density data and for demonstrating Tafel relationships. Linear plots are recommended for studies in which the current density or potential range is small, or in cases where the region in which the current density changes from anodic to cathodic is important. Linear plots are also used for the determination of the polarization resistance R_p , which is defined as the slope of a potential-current density plot at the corrosion potential E_{corr} . The relationship between the polarization resistance R_p and the corrosion current density i_{corr} is as follows (2, 3):

$$\left[\frac{d(\Delta E)}{di} \right]_{\Delta E = 0} = R_p = \frac{b_a b_c}{2.303(b_a + b_c) i_{corr}} \quad (1)$$

where:

- b_a = anodic Tafel slope,
- b_c = cathodic Tafel slope, and
- ΔE = the difference $E - E_{corr}$, where E is the specimen potential.

Fig. 2 is a plot of polarization, $E - E_{corr}$, versus current density i (solid line) from which the polarization resistance R_p has been determined as the slope of the curve at the corrosion potential E_{corr} .

7.3 *Potential Reference Points*—In plots where electrode potentials are displayed, some indication of the conversion of the values displayed to both the standard hydrogen electrode scale (SHE) and the saturated calomel electrode scale (SCE) is recommended if they are known. For example, when electrode potential is plotted as the ordinate, then the SCE scale could be shown at the extreme left of the plot and the SHE scale shown at the extreme right. An alternative, in cases where the reference electrode was not either SCE or SHE, would be to show on the potential axis the potentials of these electrodes against the reference used. In cases where these points are not shown on the plot, an algebraic conversion could be indicated. For example, in the case of a silver-silver chloride reference electrode (1 M KCl), the conversion could be shown in the title box as:

$$\begin{aligned} \text{SCE} &= E - 0.006 \text{ V} \\ \text{SHE} &= E + 0.235 \text{ V} \end{aligned} \quad (2)$$

where E represents electrode potential measured against the silver-silver chloride standard (1 M KCl).

NOTE 2—A table of potentials for various common reference electrodes is presented in Appendix X2.

7.4 *Units*—The recommended unit of potential is the volt. In cases where only small potential ranges are covered, millivolts or microvolts may be used. The SI units for current density are ampere per square metre or milliamperes per square centimetre (Practice E 380). Still in use are units expressed in amperes per square centimetre, and microamperes per square centimetre.

7.5 *Sample Polarization Curves*—Sample polarization plots employing these recommended practices are shown in Figs. 2-6. Fig. 3 and Fig. 4 are hypothetical curves showing active and active-passive anode behavior, respectively. Fig. 5 and Fig. 6 are actual polarization data for Type 430 stainless steel (UNS 43000) (4) and two aluminum samples (5). Fig. 3 and Fig. 4 are exhibited to illustrate graphically the location of various points used in discussion of electrochemical methods of corrosion testing. The purpose of Fig. 5 and Fig. 6 is to show how various types of electrode behavior can be plotted in accordance with the proposed conventions.

8. Conventions for Displaying Electrochemical Impedance Data

8.1 Three graphical formats in common use for reporting electrochemical impedance data are the Nyquist, Bode, and Admittance formats. These formats are discussed for a simple electrode system modelled by an equivalent electrical circuit as shown in Fig. 7. In the convention utilized the impedance is defined as:

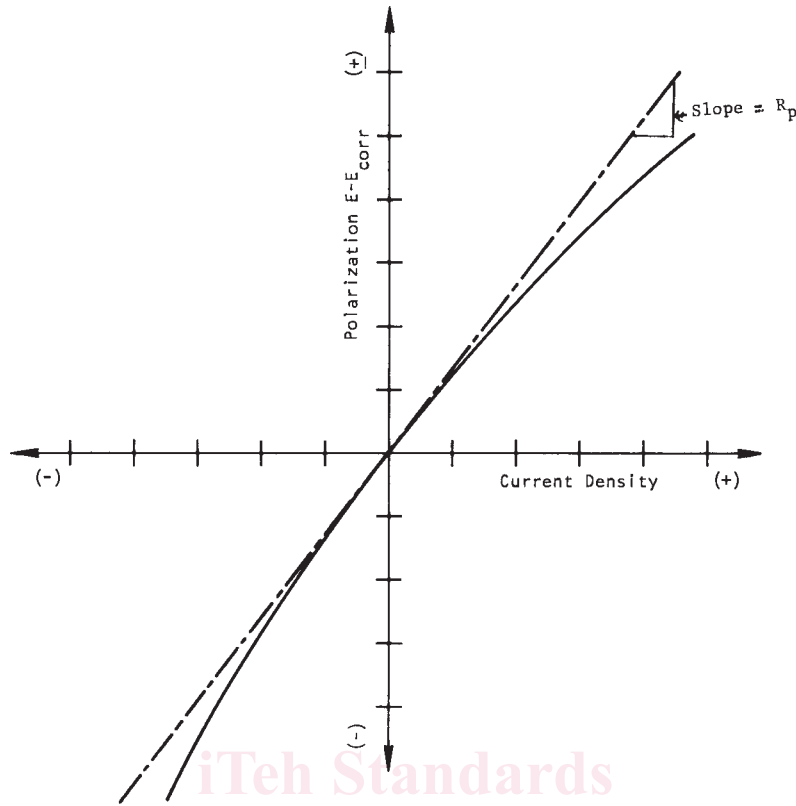


FIG. 2 Hypothetical Linear Polarization Plot

$$Z = Z' + jZ'' \quad (3)$$

where:

- Z = real or in-phase component of impedance,
- Z' = the imaginary or out-of-phase component of impedance, and
- $j^2 = -1$.

The impedance magnitude or modulus is defined as $|Z|^2 = (Z')^2 + (Z'')^2$. For the equivalent electrical circuit shown in Fig. 7, the imaginary component of impedance

$$Z'' = \frac{-1}{2\pi fC} \quad (4)$$

where:

- f = frequency in cycles per second (or hertz, Hz, where one Hz is equal to 2π radians/s, and $w = 2\pi f$, where the units for w are radians/s), and
- C = capacitance in farads.

The phase angle, θ is defined as:

$$\theta = \arctan (Z'' / Z') \quad (5)$$

The admittance, Y , is defined as

$$1/Z = Y = Y' + jY'' \quad (6)$$

where:

- Y' = real or in-phase component of admittance, and
- Y'' = the imaginary of out-of-phase component of admittance.

8.2 Nyquist Format (Complex Plane, or Cole-Cole):

8.2.1 The real component of impedance is plotted on the abscissa and the negative of the imaginary component is

plotted on the ordinate. In this practice positive values of the real component of impedance are plotted to the right of the origin parallel to the x axis (abscissa). Negative values of the imaginary component of impedance are plotted vertically from the origin parallel to the y axis (ordinate).

8.2.2 Fig. 8 shows a Nyquist plot for the equivalent circuit of Fig. 7. The frequency dependence of the data is not shown explicitly on this type of plot. However, the frequency corresponding to selected data points may be directly annotated on the Nyquist plot. The magnitude of the appropriate impedance components increases when moving away from the origin of the corresponding axes. Higher frequency data points are typically located towards the origin of the plot while lower frequency points correspond to the increasing magnitude of the impedance components.

8.2.3 Recommended units for both axes are $\text{ohm}\cdot\text{cm}^2$. The units $\text{ohm}\cdot\text{cm}^2$ are obtained by multiplying the measured resistance or impedance by the exposed specimen area. For a resistor and capacitor, or dummy cell equivalent circuit, the assumed area is 1 cm^2 . Regarding the impedance data shown in Fig. 8 for the circuit of Fig. 7, the distance from the origin to the first (high frequency) intercept with the abscissa corresponds to R_s . The distance between the first intercept and the second (low frequency) intercept with the abscissa corresponds to R_p .

8.3 Bode Format:

8.3.1 Electrochemical impedance data may be reported as two types of Bode plots. In the first case, the base ten logarithm of the impedance magnitude or Modulus, $|Z|$, is plotted on the

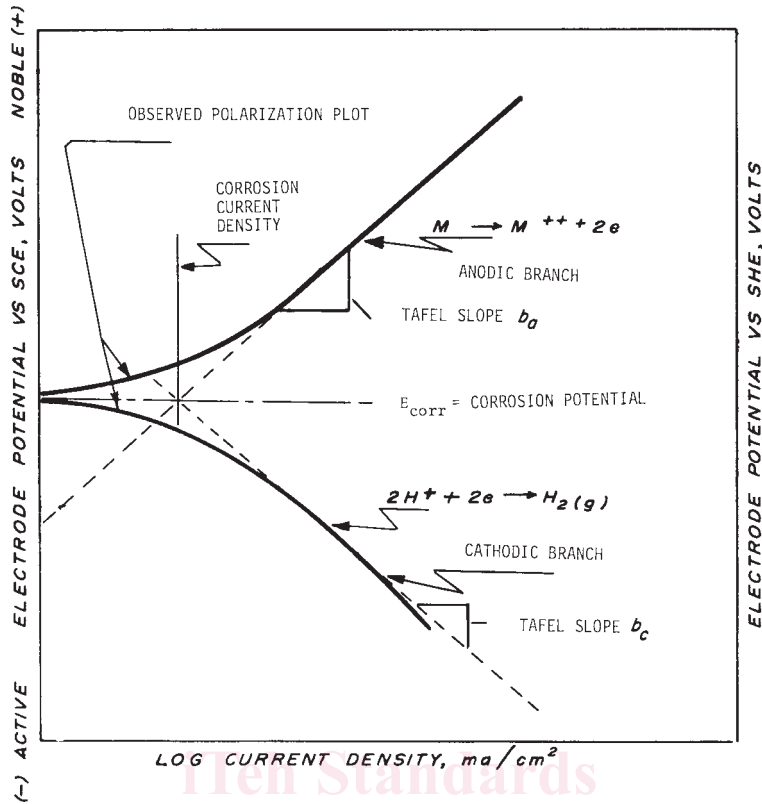


FIG. 3 Hypothetical Cathodic and Anodic Polarization Diagram

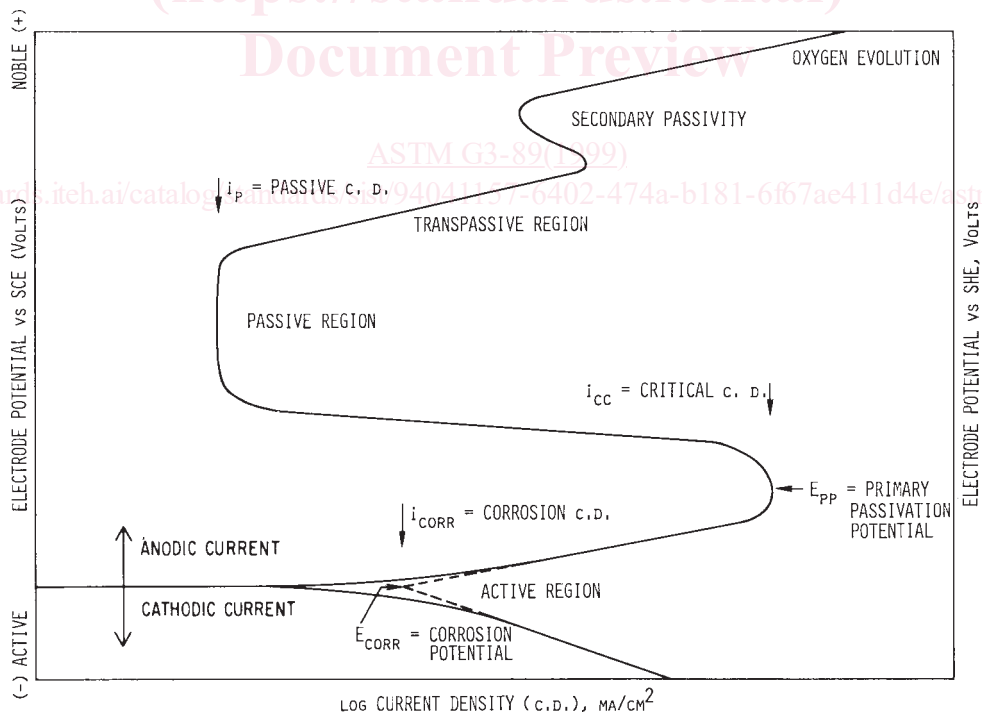


FIG. 4 Hypothetical Cathodic and Anodic Polarization Plots for a Passive Anode

ordinate and the base ten logarithm of the frequency is plotted on the abscissa. In this practice increasing frequency values are plotted to the right of the origin parallel to the x axis (abscissa) and increasing values of impedance magnitude are plotted vertically from the origin parallel to the y axis (ordinate). The

origin itself is chosen at appropriate nonzero values of impedance magnitude and frequency.

8.3.2 Fig. 9 shows a typical plot for the simple electrical circuit model of Fig. 7. The magnitude of the high frequency impedance where the impedance magnitude is independent of