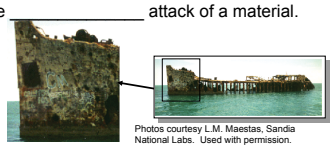
Chapter 17: Corrosion and Degradation of Materials

ISSUES TO ADDRESS...

- How does _____ occur?
- Which _____ are most likely to corrode?
- What _____ affect corrosion rate?
- How do we _____ corrosion?

THE COST OF CORROSION

- _____:
  -- the destructive _____ attack of a material.
  -- Al Capone's ship, Sapona, off the coast of Bimini.



Photos courtesy L.M. Maestas, Sandia National Labs. Used with permission.

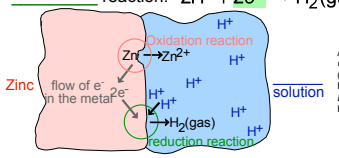
- Cost:
  -- 4 to 5% of the Gross National Product (GNP)*
  -- this amounts to just over _____**

* H.H. Uhlig and W.R. Revie, *Corrosion and Corrosion Control: An Introduction to Corrosion Science and Engineering*, 3rd ed., John Wiley and Sons, Inc., 1985.
**Economic Report of the President (1998).

ELECTROCHEMICAL CORROSION

Ex: consider the corrosion of zinc in an acid solution

- Two reactions are necessary:
  -- _____ reaction: $Zn \rightarrow Zn^{2+} + 2e^-$
  -- _____ reaction: $2H^+ + 2e^- \rightarrow H_2(gas)$

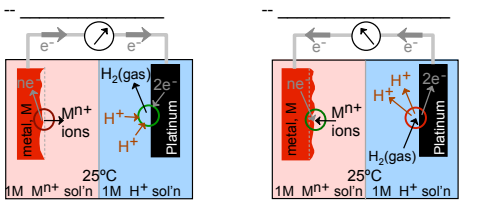


Adapted from Fig. 17.1, *Callister & Rethwisch 8e.* (Fig. 17.1 is from M.G. Fontana, *Corrosion Engineering*, 3rd ed., McGraw-Hill Book Company, 1986.)

- Other _____ reactions in solutions with dissolved oxygen:
  -- acidic solution
  -- neutral or basic solution
  _____ $O_2 + 2H_2O + 4e^- \rightarrow 4(OH)^-$

STANDARD HYDROGEN ELECTRODE

- Two outcomes:



-- Metal is the _____ (-)

$V^{o}_{metal} < 0$ (relative to Pt)

-- Metal is the _____ (+)

$V^{o}_{metal} > 0$ (relative to Pt)

Adapted from Fig. 17.2, *Callister & Rethwisch 8e.*

STANDARD EMF SERIES

- EMF series

metal	V^{o}_{metal}
Au	+1.420 V
Cu	+0.340
Pb	- 0.126
Sn	- 0.136
Ni	- 0.250
Co	- 0.277
Cd	- 0.403
Fe	- 0.440
Cr	- 0.744
Zn	- 0.763
Al	- 1.662
Mg	- 2.363
Na	- 2.714
K	- 2.924

more cathodic

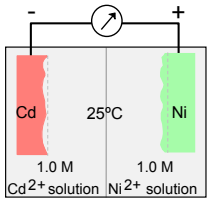
more anodic

ΔV^{o} = _____

Data based on Table 17.1, *Callister 8e.*

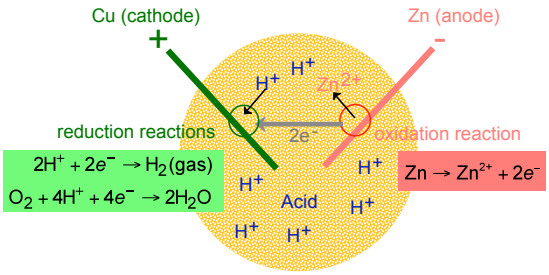
- Metal with _____ V^{o}_{metal} corrodes.
- Ex: Cd-Ni cell

$V^{o}_{Cd} < V^{o}_{Ni}$ ∴ Cd _____



Adapted from Fig. 17.2, *Callister & Rethwisch 8e.*

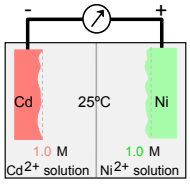
CORROSION IN A GRAPEFRUIT



EFFECT OF SOLUTION CONCENTRATION AND TEMPERATURE

- Ex: _____ cell with standard _____ solutions

$V^o_{Ni} - V^o_{Cd} = 0.153$ V

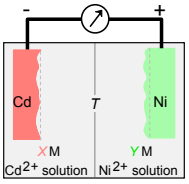


- Ex: Cd-Ni cell with _____ solutions

$$V_{Ni} - V_{Cd} = V^o_{Ni} - V^o_{Cd} - \frac{RT}{nF} \ln \frac{X}{Y}$$

n = #e^- per unit _____ reaction (= 2 here)

F = Faraday's constant = _____ C/mol.



- Reduce _____ by
  - -- increasing X
  - -- decreasing Y
  - -- increasing T

GALVANIC SERIES

- Ranking of the _____ of metals/alloys in seawater

more cathodic (inert)

Platinum
Gold
_____
Titanium
Silver
316 Stainless Steel (passive)
Nickel (passive)
Copper
Nickel (active)
Tin
Lead
316 Stainless Steel (active)
_____
Aluminum Alloys
Cadmium
Zinc
Magnesium

more anodic (active)

Based on Table 17.2, *Callister & Rethwisch 8e.* (Source of Table 17.2 is M.G. Fontana, *Corrosion Engineering*, 3rd ed., McGraw-Hill Book Company, 1986.)

FORMS OF CORROSION

Forms of corrosion

- Uniform Attack
  _____ & reduction reactions occur uniformly over surfaces.
- Selective Leaching
  Preferred _____ of one element/constituent [e.g., Zn from brass (Cu-Zn)].
- _____
  Corrosion along grain boundaries, often where precip. particles form.

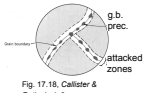


Fig. 17.18, *Callister & Rethwisch 8e.*

- _____ corrosion
  Corrosion at crack tips when a _____ stress is present.
- Galvanic
  _____ metals are physically joined in the presence of an _____. The more anodic metal corrodes.
- _____ attack
  Combined _____ attack and mechanical wear (e.g., pipe elbows).
- Pitting
  Downward propagation _____.

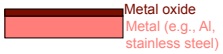
Fig. 17.17, *Callister & Rethwisch 8e.* (Fig. 17.17 from M.G. Fontana, *Corrosion Engineering*, 3rd ed., McGraw-Hill Book Company, 1986.)

- _____ Narrow and confined spaces.

Fig. 17.15, *Callister & Rethwisch 8e.* (Fig. 17.15 is courtesy LaQue Center for Corrosion Technology, Inc.)

CORROSION PREVENTION (i)

- _____
  -- Use metals that are relatively unreactive in the corrosion environment -- e.g., _____
  -- Use metals that _____
  - These metals form a thin, adhering oxide layer that slows corrosion.



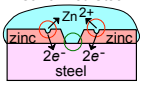
- Lower the _____ (reduces rates of oxidation and reduction)
- Apply _____ -- e.g., films and coatings

CORROSION PREVENTION (ii)

- Add _____ (substances added to solution that decrease its reactivity)
  -- Slow _____ reactions by removing reactants (e.g., remove O_2 gas by reacting it w/an inhibitor).
  -- Slow _____ reaction by attaching species to the surface.
- _____ (or sacrificial) protection
  -- Attach a more _____ material to the one to be protected.

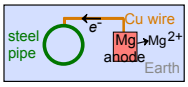
Adapted from Fig. 17.23, *Callister & Rethwisch 8e.*

Galvanized Steel



e.g., zinc-coated nail

Using a sacrificial anode



e.g., Mg Anode

Adapted from Fig. 17.22(a), *Callister & Rethwisch 8e.*

SUMMARY

- Metallic corrosion involves electrochemical reactions
  -- electrons are given up by metals in an oxidation reaction
  -- these electrons are consumed in a reduction reaction
- Metals and alloys are ranked according to their corrosiveness in standard emf and galvanic series.
- Temperature and solution composition affect corrosion rates.
- Forms of corrosion are classified according to mechanism
- Corrosion may be prevented or controlled by:
  -- materials selection
  -- reducing the temperature
  -- applying physical barriers
  -- adding inhibitors
  -- cathodic protection