

CHAPTER 17: CORROSION AND DEGRADATION

ISSUES TO ADDRESS...

- Why does corrosion occur?
- What metals are most likely to corrode?
- How do temperature and environment affect corrosion rate?
- How do we suppress corrosion?



THE COST OF CORROSION

- **Corrosion:**

- the destructive electrochemical 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 \$400 billion/yr**

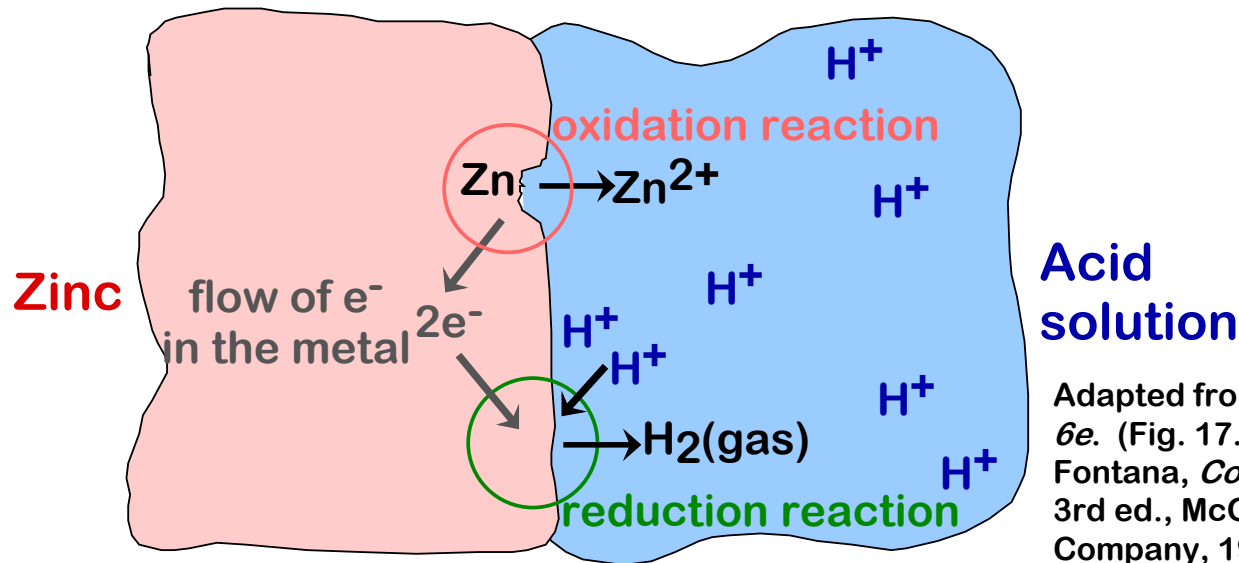
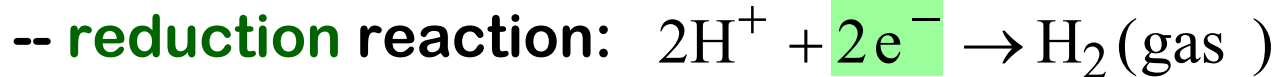
* H.H. Uhlig and W.R. Revie, *Corrosion and Corrosion Control: An Introduction to Corrosion Science and Engineering*, 3rd ed., John Wiley and Sons, Inc., 1985.

**Economic Report of the President (1998).



CORROSION OF ZINC IN ACID

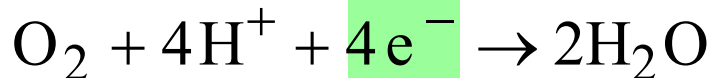
- Two reactions are necessary:



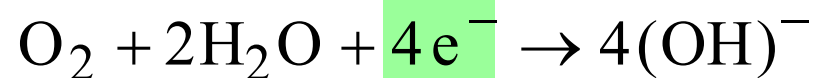
Adapted from Fig. 17.1, *Callister 6e*. (Fig. 17.1 is from M.G. Fontana, *Corrosion Engineering*, 3rd ed., McGraw-Hill Book Company, 1986.)

- Other **reduction** reactions:

-- in an acid solution



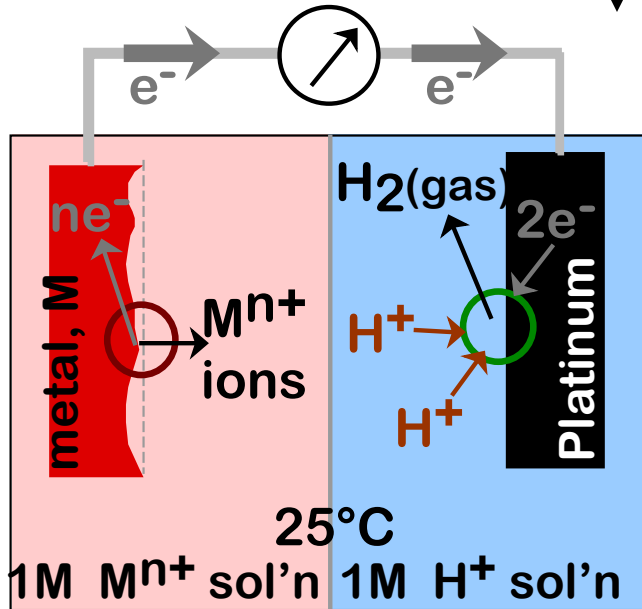
-- in a neutral or base solution



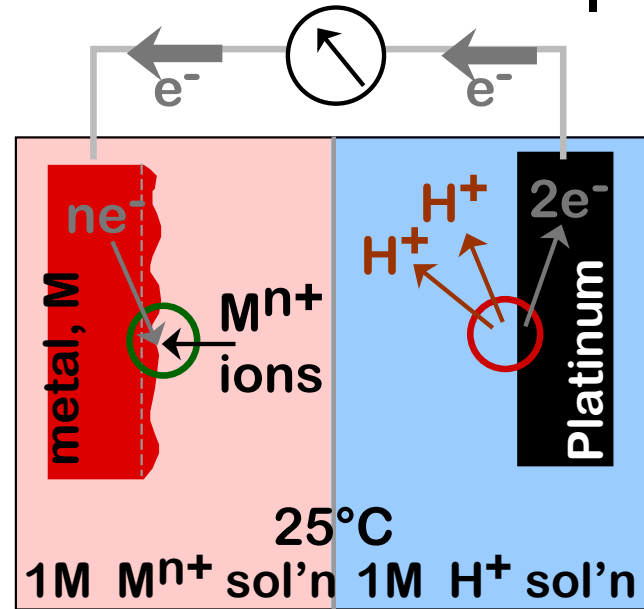
STANDARD HYDROGEN (EMF) TEST

- Two outcomes:

--Metal sample mass ↓



--Metal sample mass ↑



--Metal is the anode (-)

--Metal is the cathode (+)

$$V_{\text{metal}}^0 < 0 \quad (\text{relative to Pt})$$

$$V_{\text{metal}}^0 > 0 \quad (\text{relative to Pt})$$

Standard Electrode Potential



STANDARD EMF SERIES

- EMF series

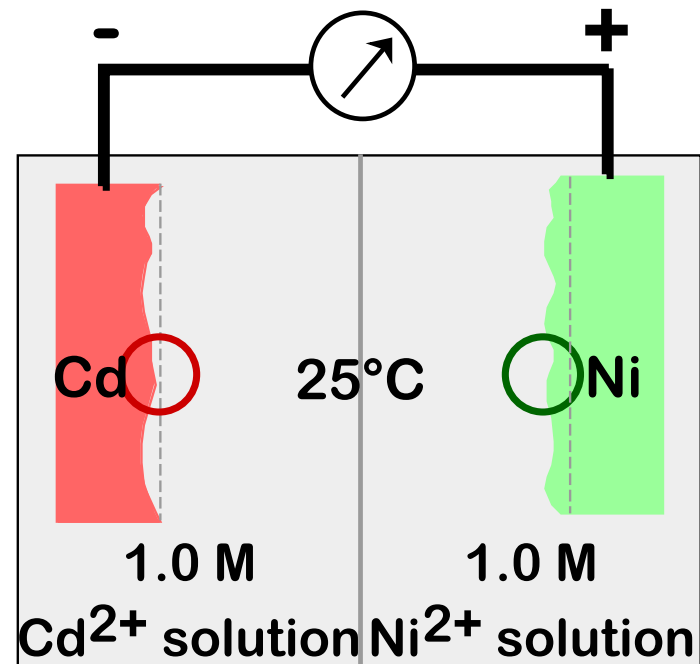
metal	V_{metal}°
Au	+1.420 V
Cu	+0.340
Pb	-0.126
Sn	-0.136
Ni	-0.250
Co	-0.277
Cd	-0.403
Fe	-0.440
Cr	-0.744
Zn	-0.763
Al	-1.662
Mg	-2.262
Na	-2.714
K	-2.924

more cathodic ↑

more anodic ↓

$\Delta V^{\circ} = 0.153\text{V}$

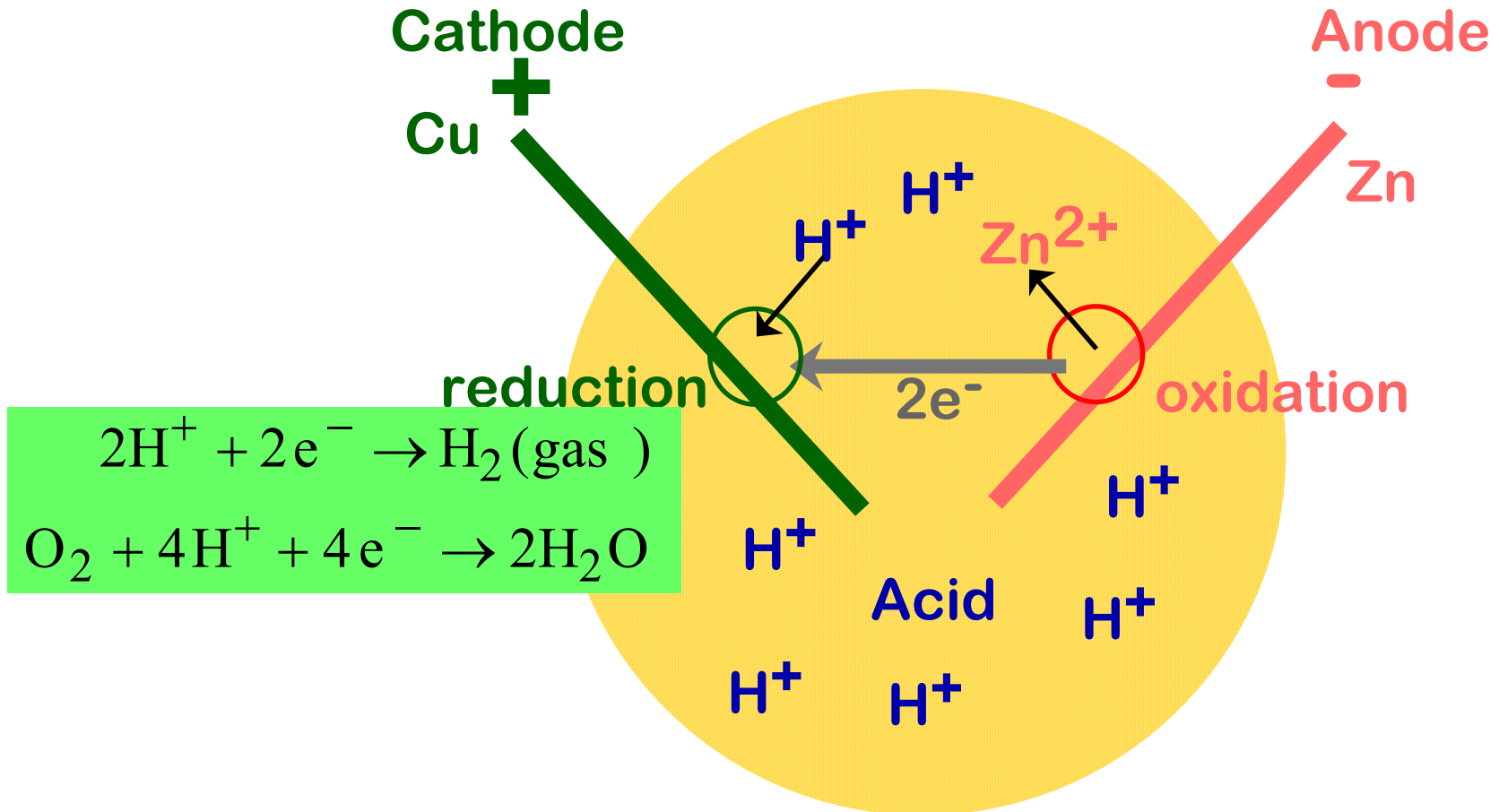
- Metal with smaller V_{metal}° corrodes.
- Ex: Cd-Ni cell



Data based on Table 17.1, Callister 6e.



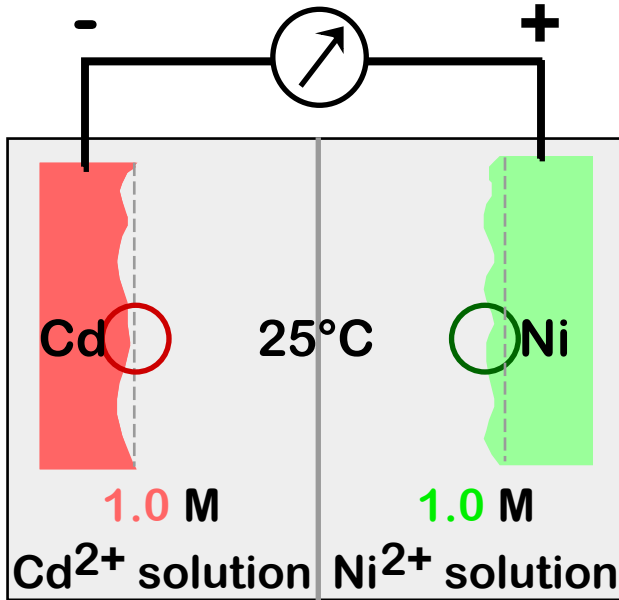
CORROSION IN A GRAPEFRUIT



EFFECT OF SOLUTION CONCENTRATION

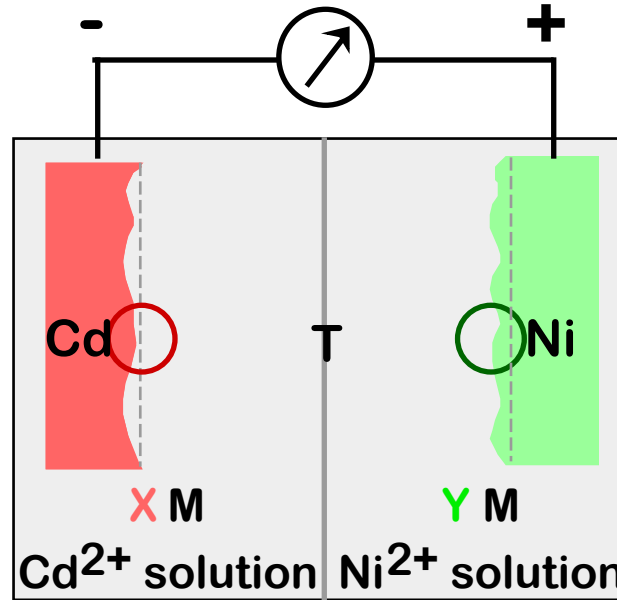
- Ex: Cd-Ni cell with standard 1M solutions

$$V_{\text{Ni}}^{\circ} - V_{\text{Cd}}^{\circ} = 0.153$$



- Ex: Cd-Ni cell with non-standard solutions

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



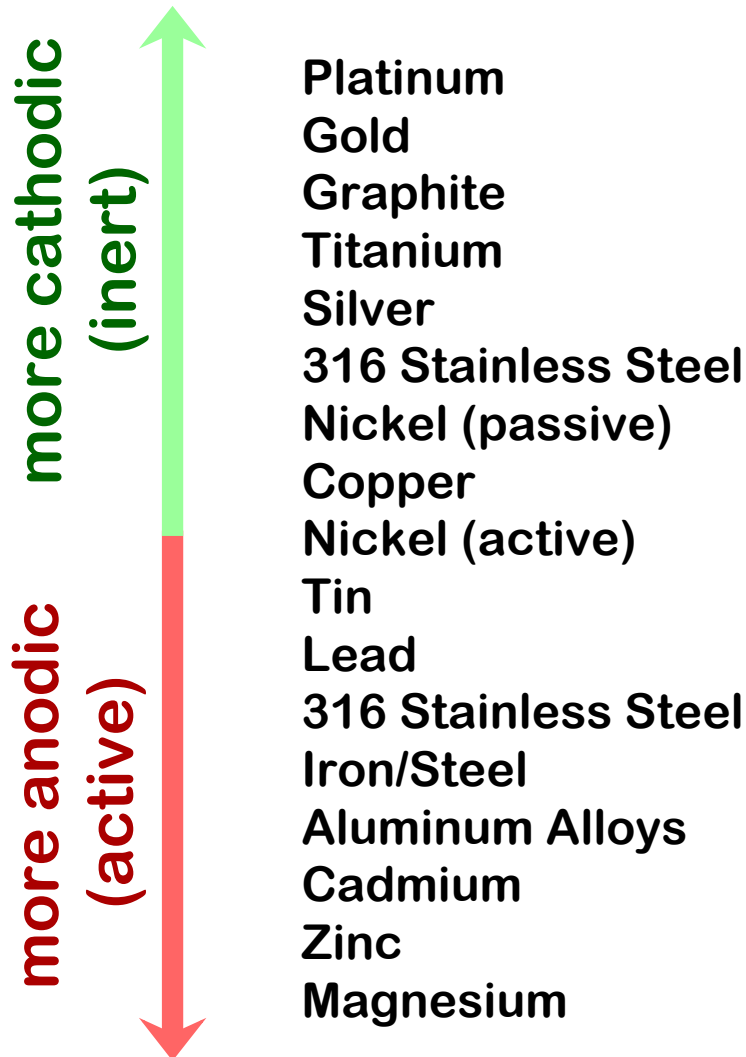
$n = \#e^-$
per unit
oxid/red
reaction
(=2 here)

$F =$
Faraday's
constant
=96,500
C/mol.

- Reduce $V_{\text{Ni}} - V_{\text{Cd}}$ by
 - increasing **X**
 - decreasing **Y**

GALVANIC SERIES

- Ranks the reactivity of metals/alloys in seawater



Based on Table 17.2, *Callister 6e*. (Source of Table 17.2 is M.G. Fontana, *Corrosion Engineering*, 3rd ed., McGraw-Hill Book Company, 1986.)



FORMS OF CORROSION

- **Stress corrosion**

Stress & corrosion work together at crack tips.

- **Uniform Attack**

Oxidation & reduction occur uniformly over surface.

- **Selective Leaching**

Preferred corrosion of one element/constituent (e.g., Zn from brass (Cu-Zn)).

- **Intergranular**

Corrosion along grain boundaries, often where special phases exist.

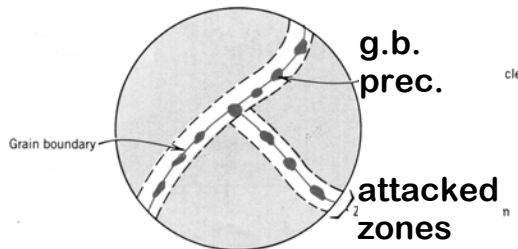
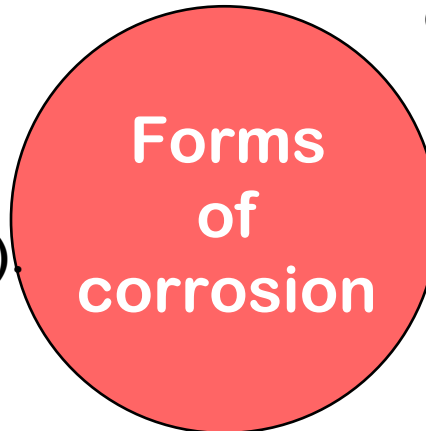


Fig. 17.9, Callister 6e.

- **Galvanic**

Dissimilar metals are physically joined. The more anodic one corrodes. (see Table 17.2) Zn & Mg very anodic.



- **Erosion-corrosion**

Break down of passivating layer by erosion (pipe elbows).

- **Pitting**

Downward propagation of small pits & holes.

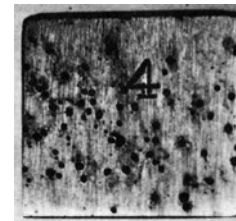


Fig. 17.8, Callister 6e. (Fig. 17.8 from M.G. Fontana, *Corrosion Engineering*, 3rd ed., McGraw-Hill Book Company, 1986.)

- **Crevice** Between two pieces of the same metal.

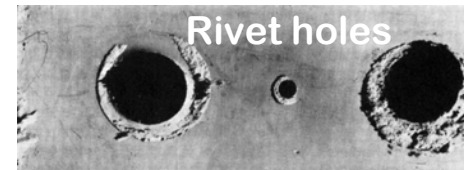
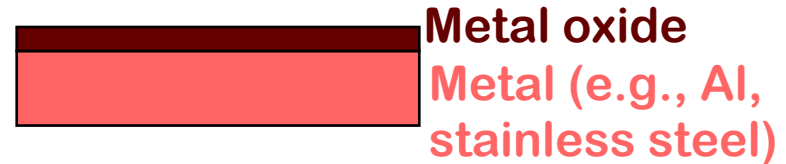


Fig. 17.6, Callister 6e. (Fig. 17.6 is courtesy LaQue Center for Corrosion Technology, Inc.)

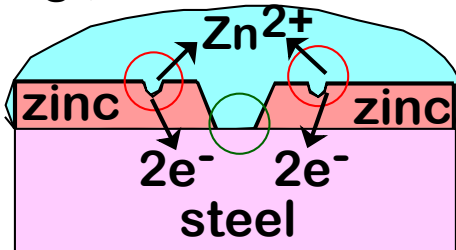


CONTROLLING CORROSION

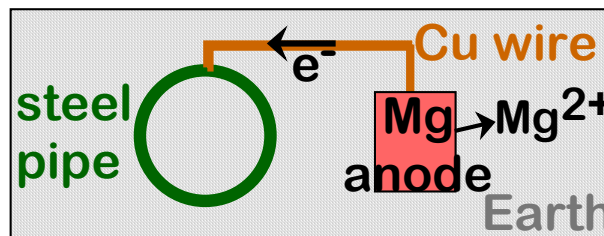
- **Self-protecting metals!**
 - Metal ions combine with O to form a thin, adhering oxide layer that slows corrosion.
- **Reduce T (slows kinetics of oxidation and reduction)**
- **Add inhibitors**
 - Slow oxidation/reduction reactions by removing reactants (e.g., remove O₂ gas by reacting it w/an inhibitor).
 - Slow oxidation reaction by attaching species to the surface (e.g., paint it!).
- **Cathodic (or sacrificial) protection**
 - Attach a more anodic material to the one to be protected.



e.g., zinc-coated nail



e.g., Mg Anode



Adapted from Fig. 17.14, *Callister 6e.*

Adapted from Fig. 17.13(a), *Callister 6e.* (Fig. 17.13(a) is from M.G. Fontana, *Corrosion Engineering*, 3rd ed., McGraw-Hill Book Co., 1986.)



SUMMARY

- Corrosion occurs due to:
 - the natural tendency of metals to give up electrons.
 - electrons are given up by an **oxidation** reaction.
 - these electrons then are part of a **reduction** reaction.
- Metals with a more negative **Standard Electrode Potential** are more likely to corrode relative to other metals.
- The **Galvanic Series** ranks the reactivity of metals in seawater.
- Increasing T speeds up oxidation/reduction reactions.
- Corrosion may be controlled by:
 - using metals which form a protective oxide layer
 - adding inhibitors
 - reducing T
 - painting
 - using cathodic protection.

