Corrosion of Metals

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Course structure

Learning modules

1. Introduction to corrosion
2. Corrosion rate
3. Uniform corrosion
4. Galvanic corrosion
5. Crevice corrosion
6. Pitting corrosion
7. Intergranular corrosion
8. Stress corrosion cracking
9. Dealloying
10. Review

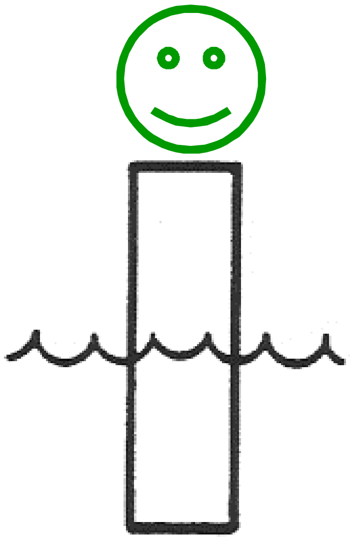
Module 1: Introduction

Module learning objectives

By the end of this module learners will be able to:

1. Describe the three possible behaviors of a metal in an aqueous (water based) solution
2. List the four requirements of an corrosion cell
3. Describe the anode and cathode reactions that occur in a corrosion cell
4. Describe the three forms of anode and cathode electrical contact
5. List four factors that influence the corrosion performance of a metal component

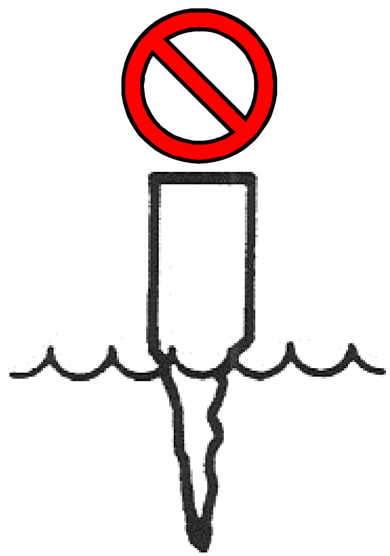
Metal behavior in an environment



Immune

Å No reaction

Å No corrosion

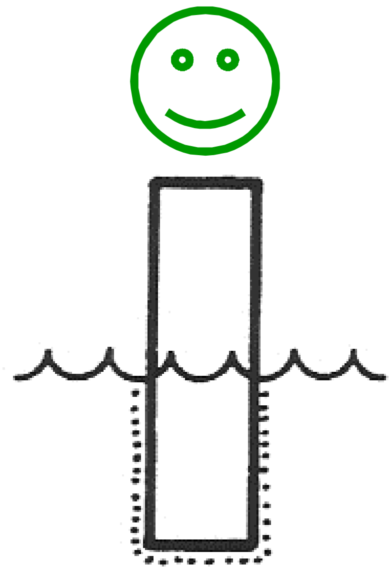


Active

Å Metal dissolves

Å Form non-protective corrosion products

Å Corrosion products do not interfere with further corrosion



Passive

Å Protective film formed

Å Passive layer

Å Slows reaction rate

Å Corrosion resistance depends on integrity of passive layer

Å Metal can become active if layer broken or dissolves

Several forms of corrosion

1. Uniform
2. Localized
    a. Galvanic
    b. Pitting
    c. Crevice
    d. Intergranular
    e. Stress corrosion cracking
    f. Dealloying

Other forms of corrosion

- Combination of corrosion and other degradation mechanisms

Corrosion and electrochemistry

Electrochemical reaction between one or more materials and environment

- Results in deterioration of the material

Course focus

- Corrosion of metals
- Aqueous environments (water based liquids)

- Electrochemical reaction
- Electrochemical cell
- Anode & cathode reactions
- Factors affecting corrosion

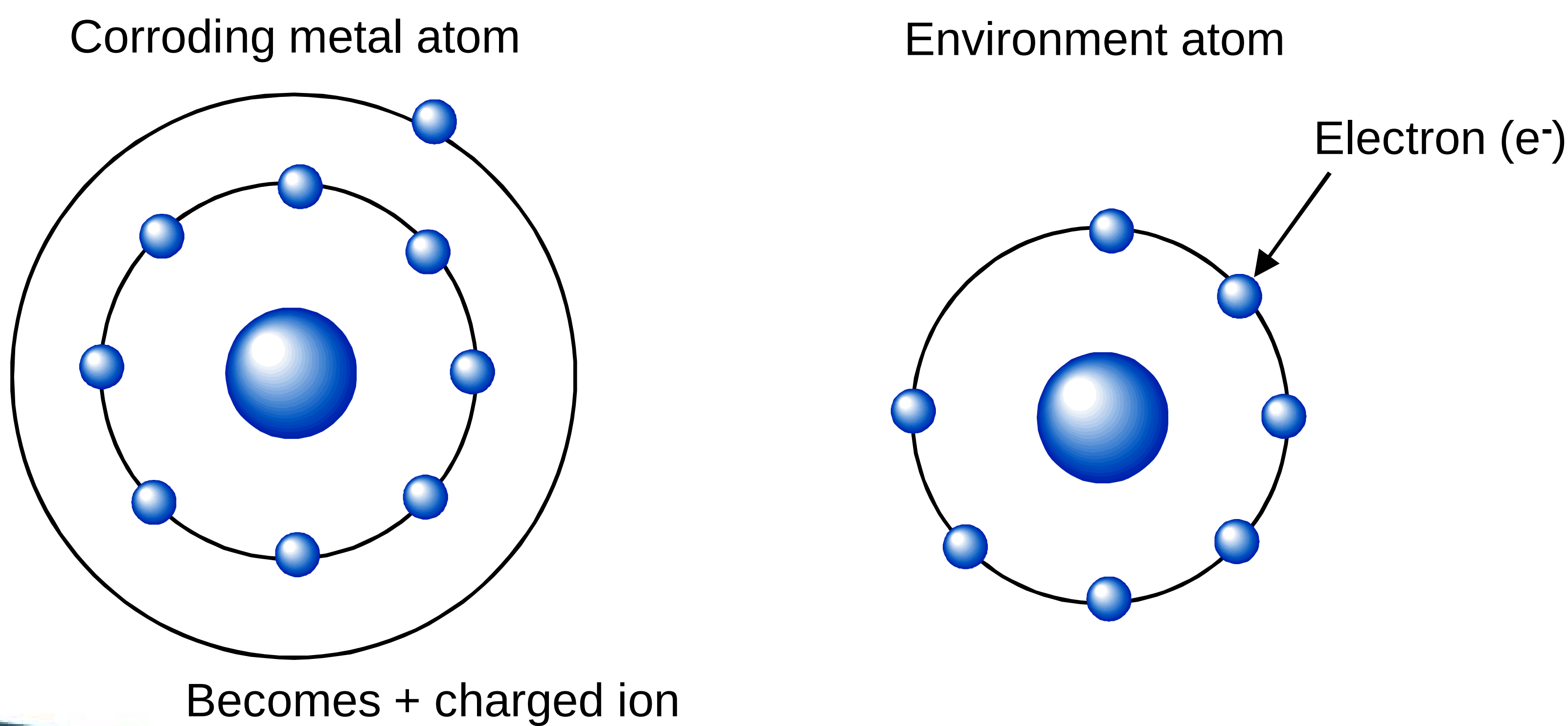
Electrochemical reaction

Chemical changes of metal and environment

Electrical charges flowing from metal to environment

Loss of electrons called oxidation

Gaining electrons called reduction



Oxidation reaction – lose electrons

$M \rightarrow M^{n+} + ne^-$

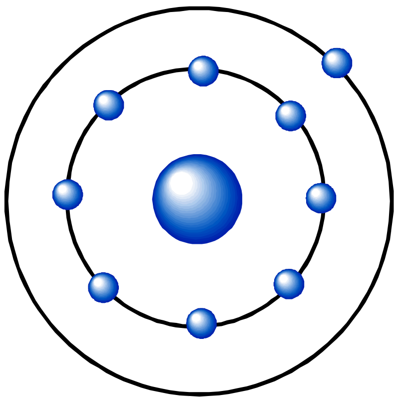
$Fe \rightarrow Fe^{2+} + 2e^-$

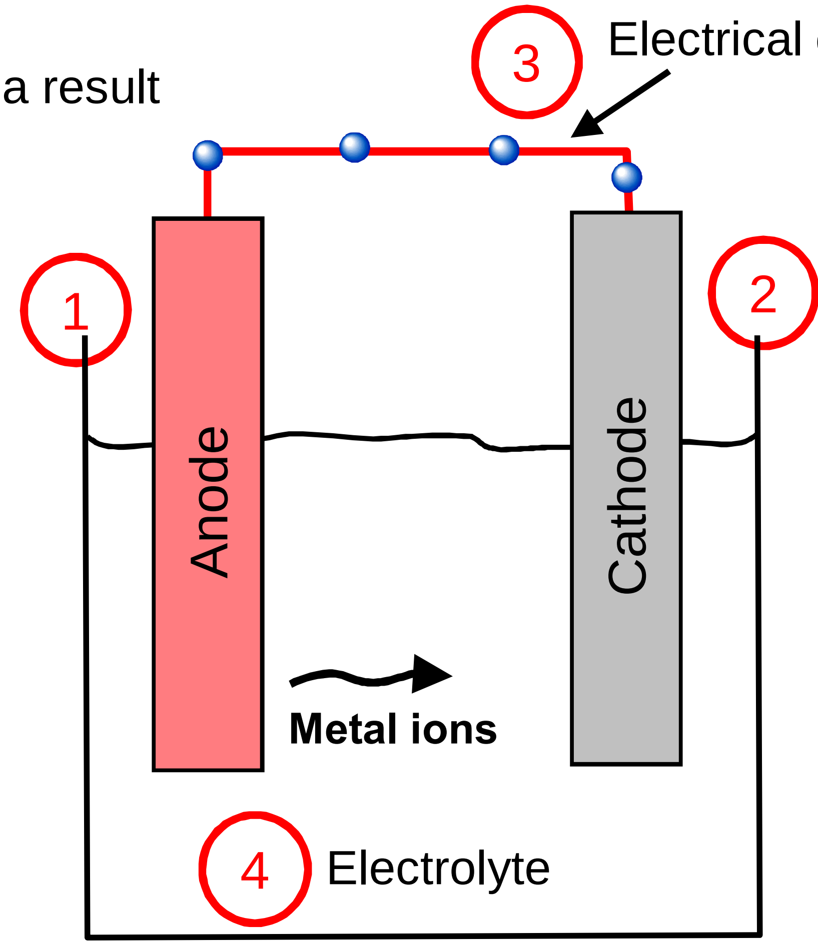
$Al \rightarrow Al^{3+} + 3e^-$

Electrochemical cell

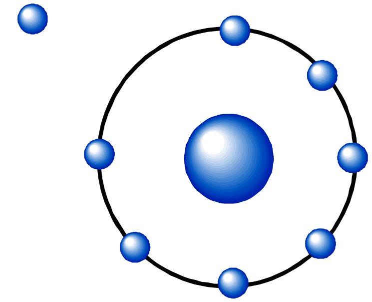
Electrical current flow as a result of transfer of electrons

Corrosion
Oxidation reactions





Reduction reactions



Conductive fluid in contact with anode and cathode
Contains corrosive species that reacts with anode to form metal ions
Provides ionic current path for metal ions created at anode

Reduction reactions at cathode

6 possible reduction reactions

$2H^+ + 2e^- \rightarrow H_2$ (gas) Hydrogen ion reduction in acid

$2H_2O + 2e^- \rightarrow H_2 + 2OH^-$ Water reduction in neutral or alkaline solutions

$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$ Oxygen reduction in aerated acid

$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$ Oxygen reduction in aerated neutral and alkaline solutions

$Fe^{3+} + e^- \rightarrow Fe^{2+}$ Metal ion reduction

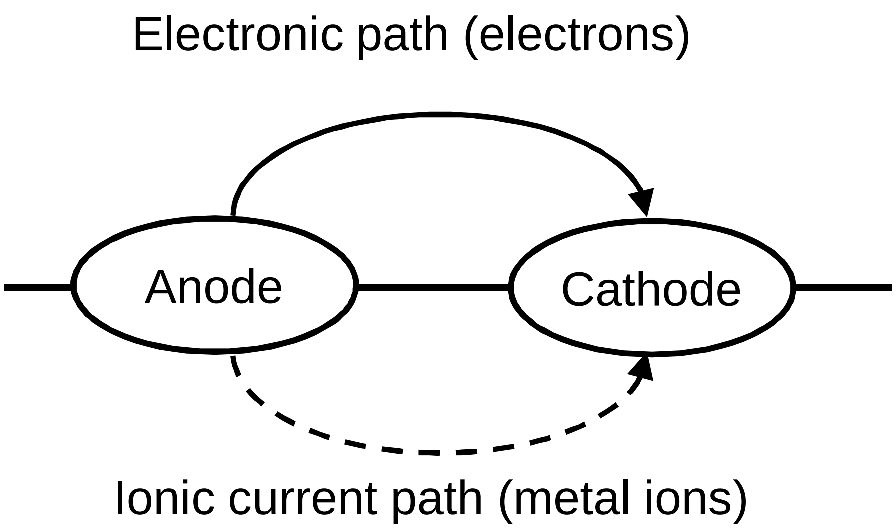
$Cu^{2+} + 2e^- \rightarrow Cu$ Metal deposition

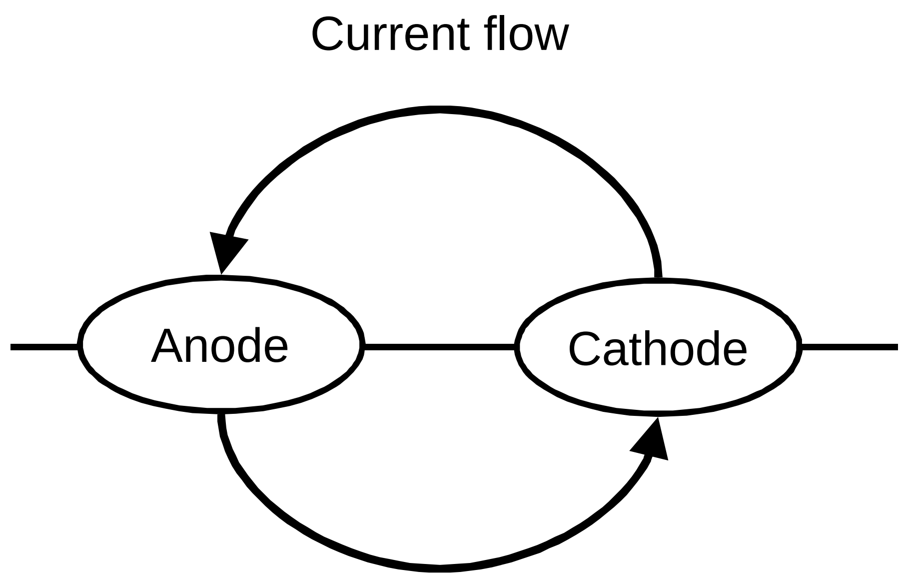
Two paths for current

There are reduction reactions that result in formation of negative ions

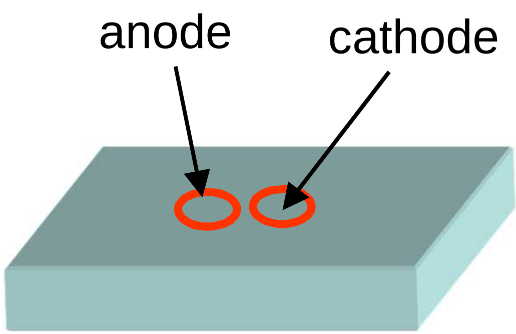
Å Ions move from cathode towards anode along ionic current path

Å Current flow same as shown here

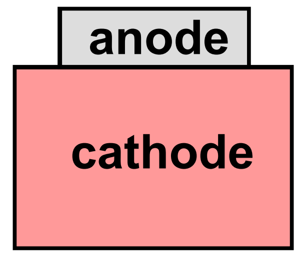




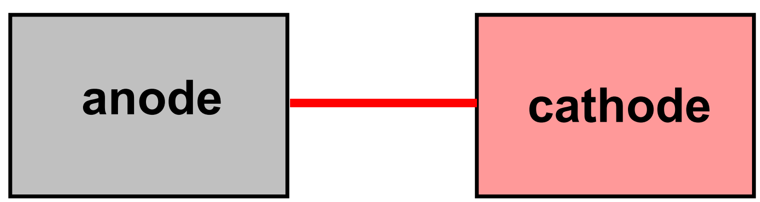
Electrical contact in an electrochemical cell



Single piece of metal



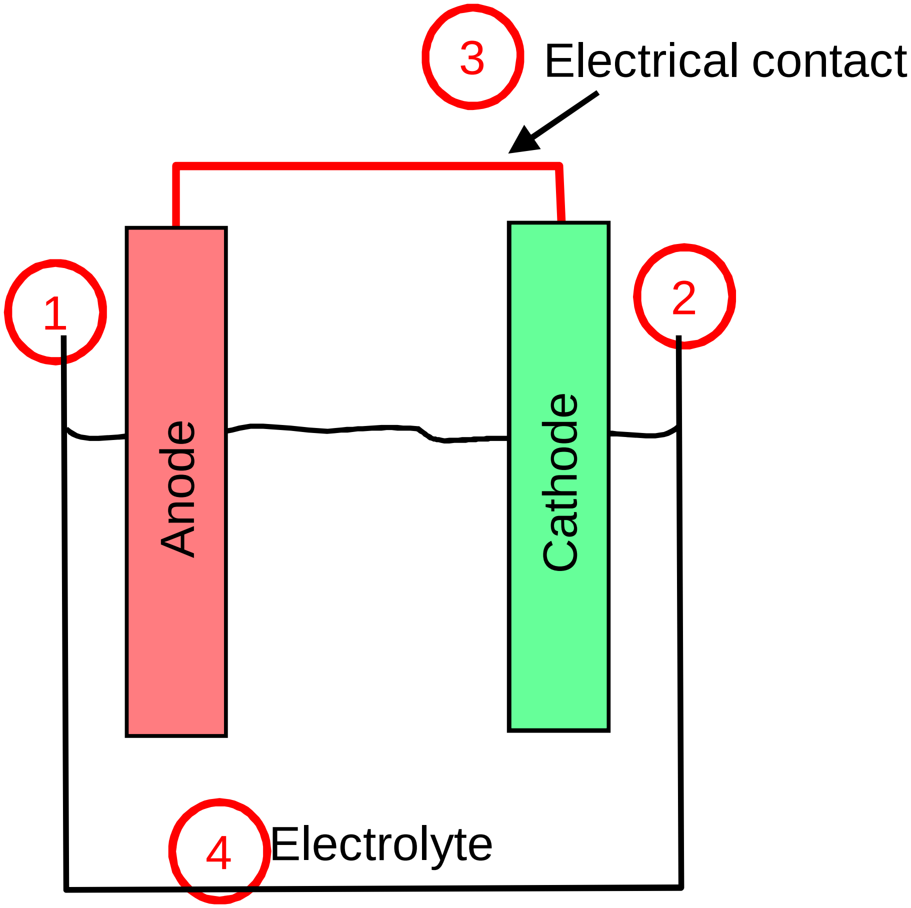
Two metals in contact



Two metals not in direct contact but joined electrically

Preventing formation of electrochemical cells

Eliminate one of the four components

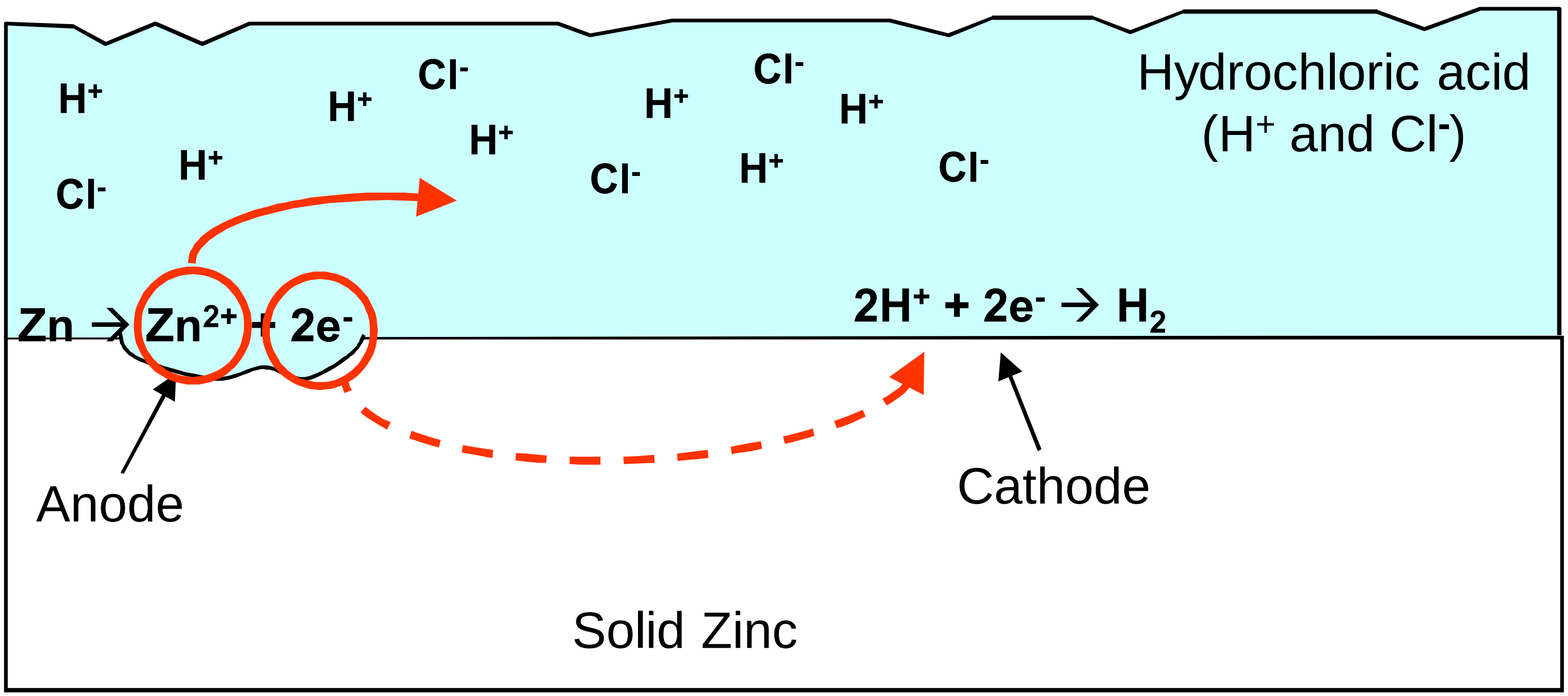


Anode and cathode reactions

$Zn + 2H^+ \rightarrow Zn^{2+} + H_2$ (gas)

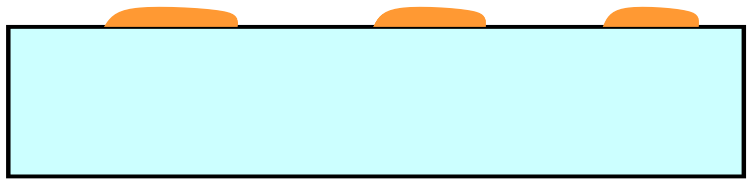
Å $Zn \rightarrow Zn^{2+} + 2e^-$

Å $2H^+ + 2e^- \rightarrow H_2$ (gas)



Corrosion products

Some corrosion reactions result in formation of corrosion product on metal surface.



Corrosion in water

Å OH^- react with M^{n+} from anode reaction

Å Produce solid product

Corrosion of steel in water

Å $Fe^{2+} + 2OH^- \rightarrow Fe(OH)_2$ ← Ferrous hydroxide

Å $2Fe(OH)_2 + \frac{1}{2}O_2 + H_2O \rightarrow 2Fe(OH)_3$ ← Ferric hydroxide

Å Ferric hydroxide most common form of rust

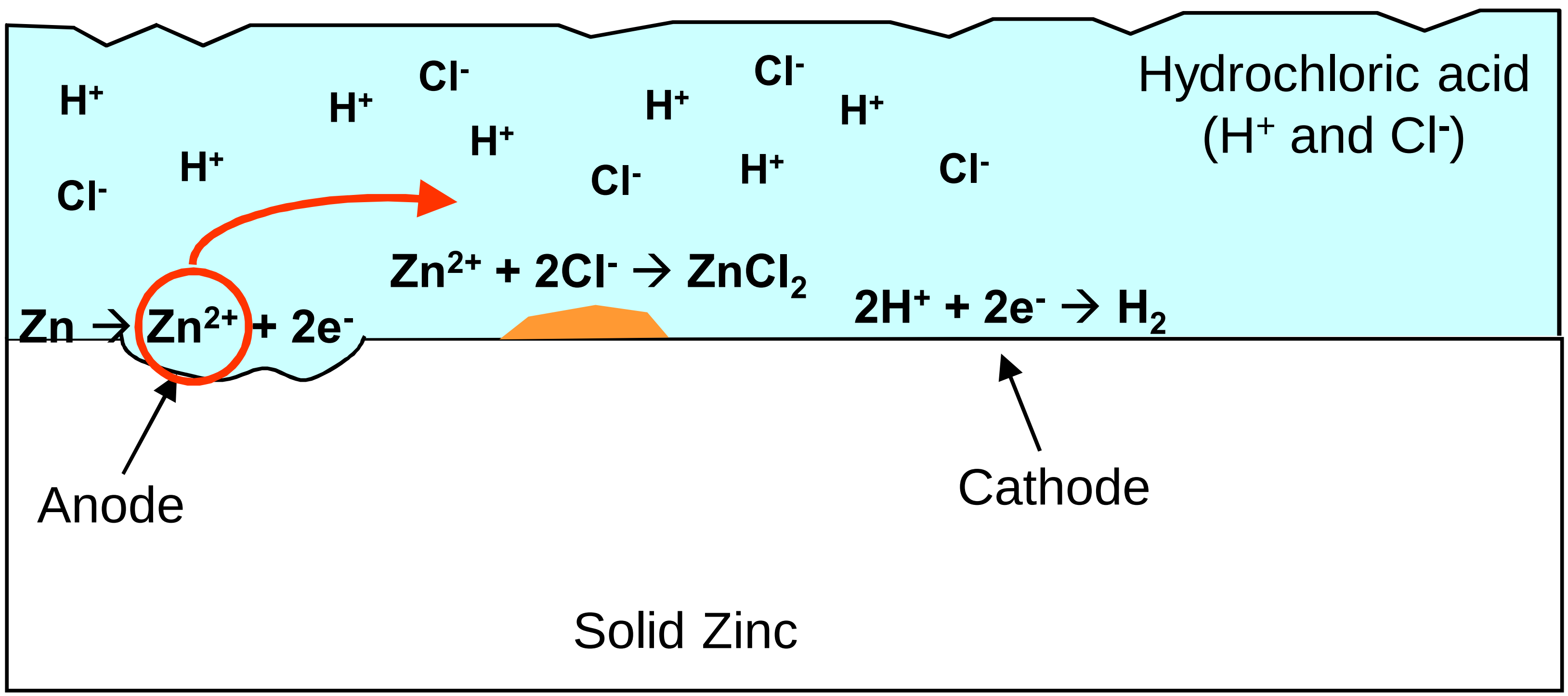
Corrosion in many acids results in formation of corrosion product

Å Metal ions react with negative ions in acid

$Zn + 2HCl \rightarrow ZnCl_2 + H_2$ (gas)

$Zn + H_2SO_4 \rightarrow ZnSO_4 + H_2$ (gas)

$Fe + 2HCl \rightarrow FeCl_2 + H_2$ (gas)



Hydrochloric acid
(H+ and Cl-)
H+
Cl-
Zn2+ + 2Cl- → ZnCl2
2H+ + 2e- → H2
Zn → Zn2+ + 2e-
Anode
Cathode
Solid Zinc

Factors for corrosion performance of a metal component

1. Material
2. Environment
3. Stress
4. Geometry of item

Click each topic for more information

Click Next after reviewing each topic

Material

Corrosion performance of any metal depends on

ÅComposition

ÅMicrostructure

Different metals have different inherent corrosion behaviors

Microscopic variations in composition can reduce corrosion resistance

Microstructure features

ÅGrain size

ÅPrecipitates on grain boundaries

ÅNon-metallic inclusions within grains

Environment

Atmosphere

Soil

Chemicals

Environments vary with respect to factors that influence corrosion such as

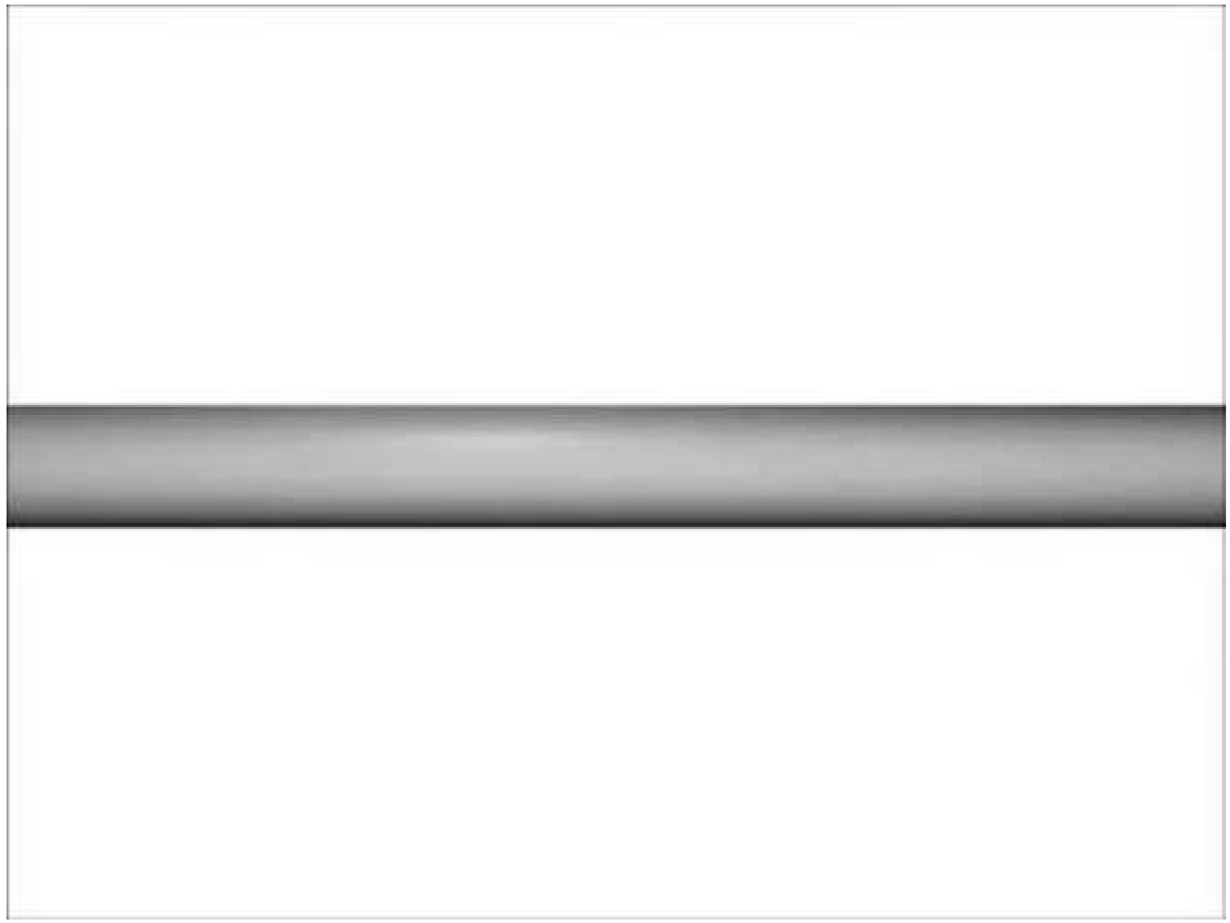
Å Moisture, temperature, chemical make-up, and pH

Corrosiveness depends on specific chemistry of environment and metal of concern

Understanding the environment is required to better understand the criteria for materials selection or corrosion prevention measures.

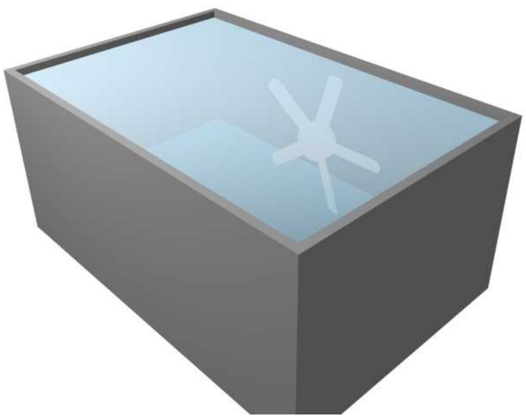
Other environment factors

Velocity of solution



Fluid flow through pipe

Agitation of fluid



State of stress

Mechanical stresses on a metal component or joint

Susceptibility to stress corrosion cracking increases as tensile stresses increase

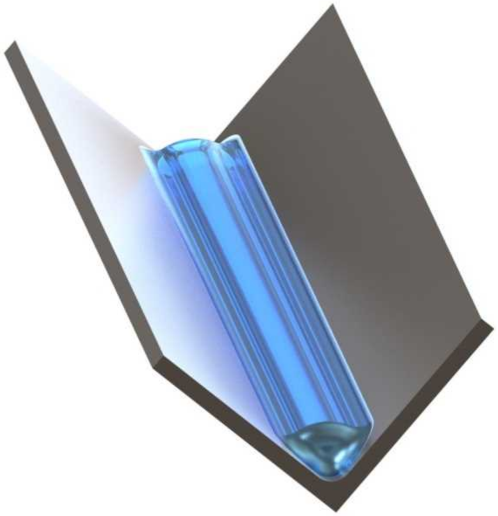
Possible sources of stress

- External
- Residual stress that result from manufacturing processes
- Differential thermal expansion

Item geometry

Gaps between components

Features that retain liquid



Stress concentrators

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