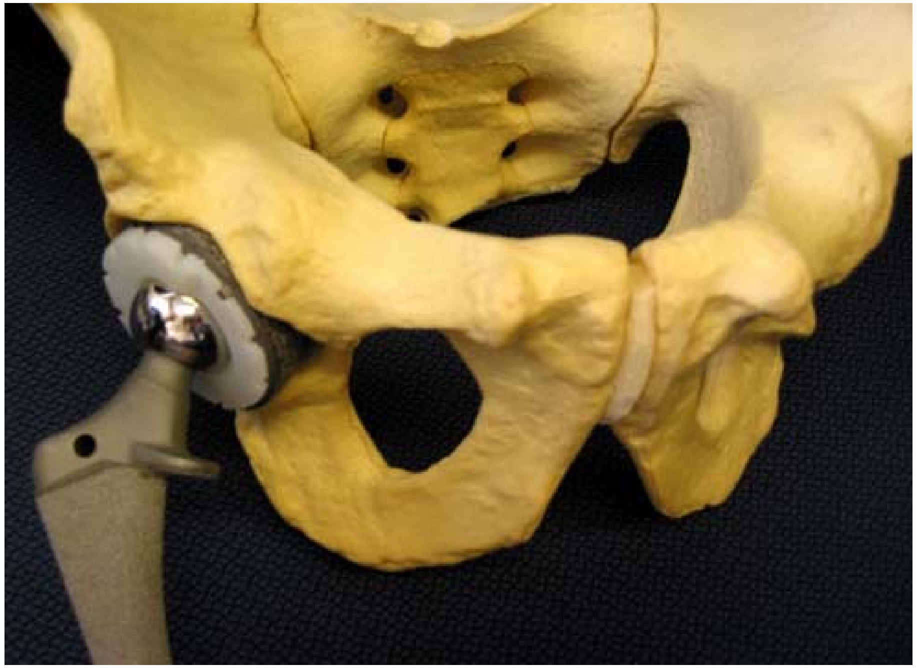
Selection criteria for Biomaterials

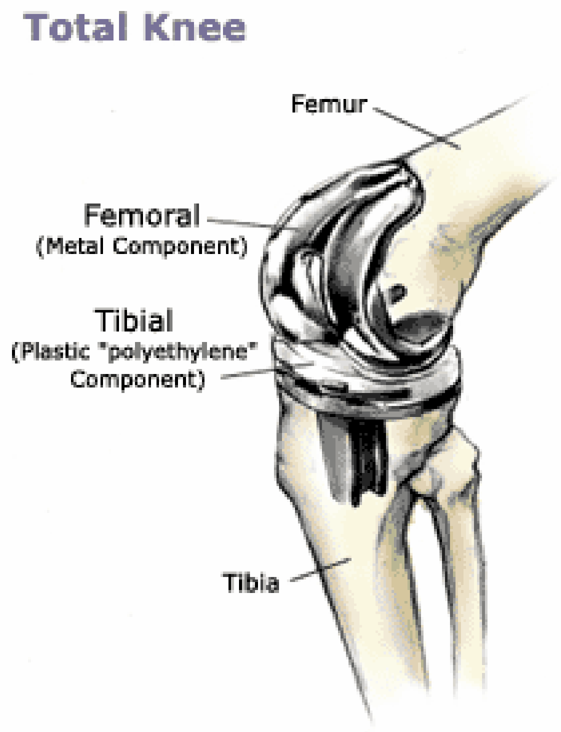
- Biomaterials and biomedical devices are used throughout the human body.
- 2 important aspects:
  - Functional performance
  - Biocompatibility



Hip joint prosthesis

Functional performance

- The material must satisfy it´s design requirements in service:
  - Load transmission and stress distribution (e.g. bone replacement)
  - Articulation to allow movement (e.g. artificial knee joint)



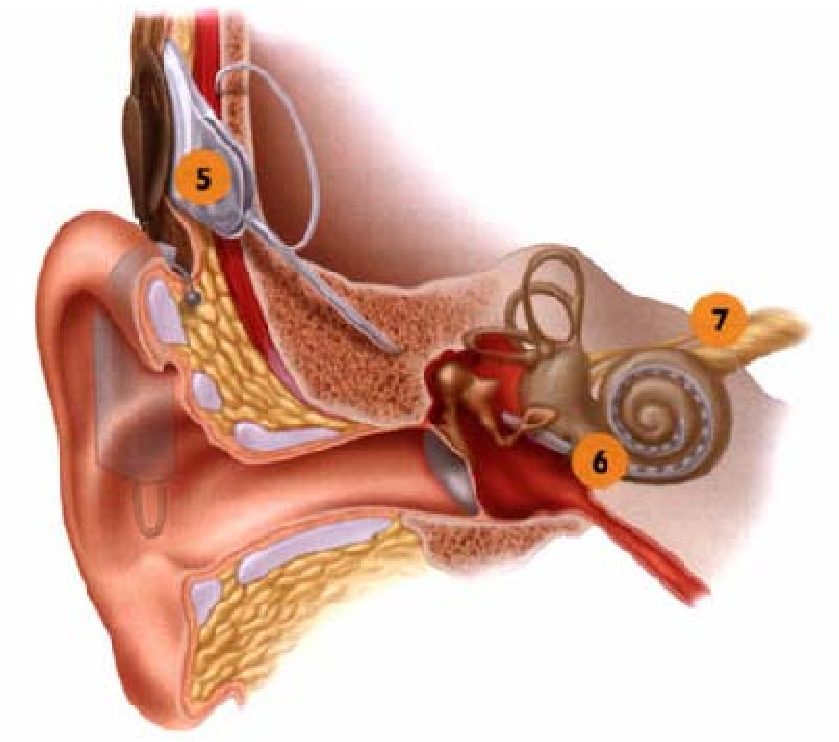
Functional performance

- Control of blood and fluid flow (e.g. artificial heart)
- Space filling (e.g. cosmetic surgery)

Artificial heart

Functional performance

- Electrical stimuli
  (e.g. pacemaker)
- Light transmission
  (e.g. implanted lenses)
- Sound transmission
  (e.g. cochlear implant)



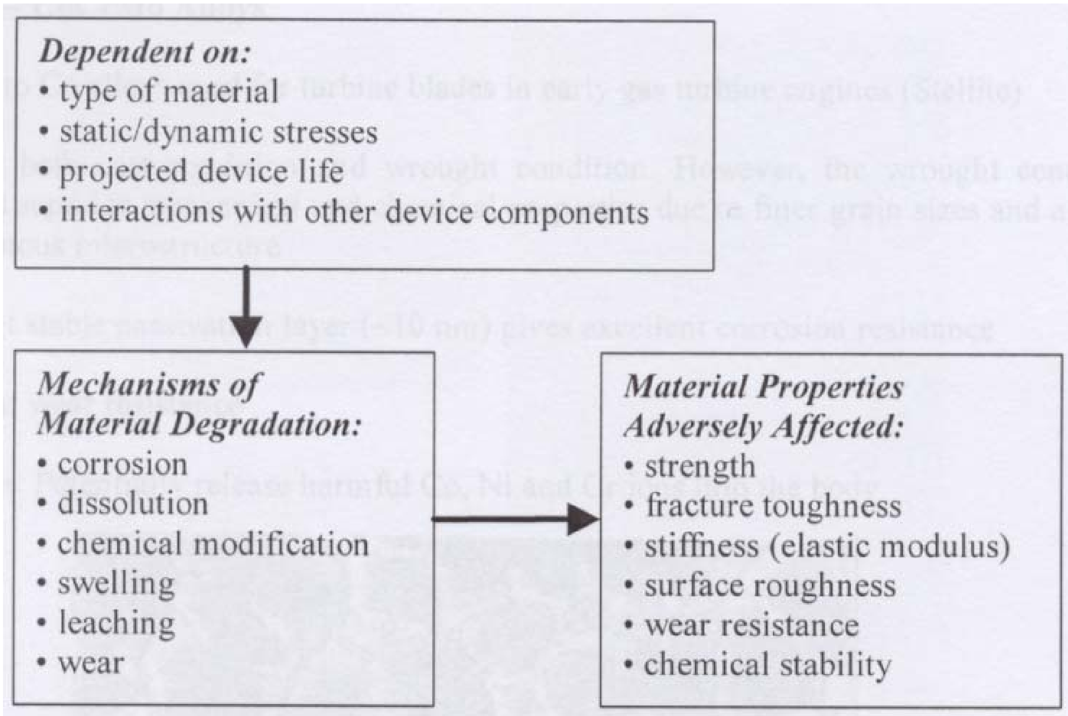
Cochlear implant

Biocompatibility

- The biomaterials/devices must not degrade in its properties within the body (unless this is wanted).

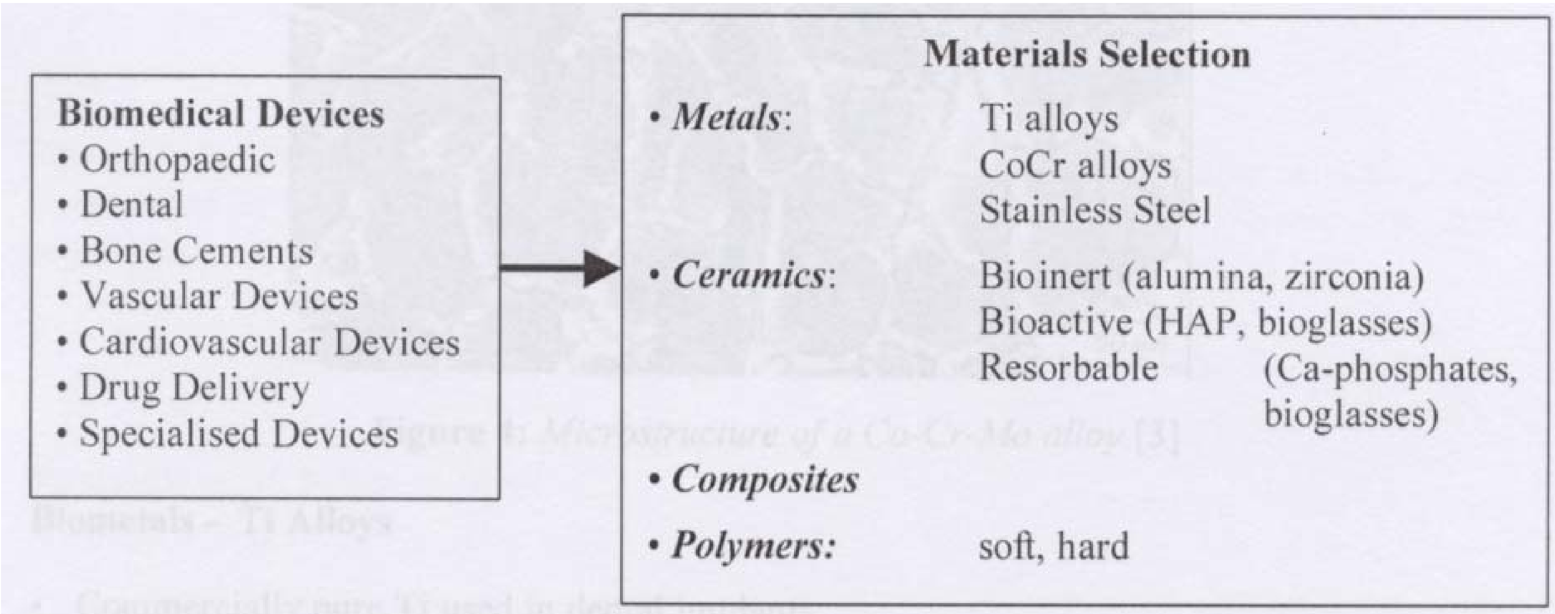
- The biomaterials/devices (and any degradation product) must not cause any adverse reaction within the host´s body.

Biocompatibility:



Selection criteria for Biomaterials

- The technical materials used to build most structures are divided into four classes:
  - Metals
  - Ceramics (including glasses)
  - Composites
  - Polymers



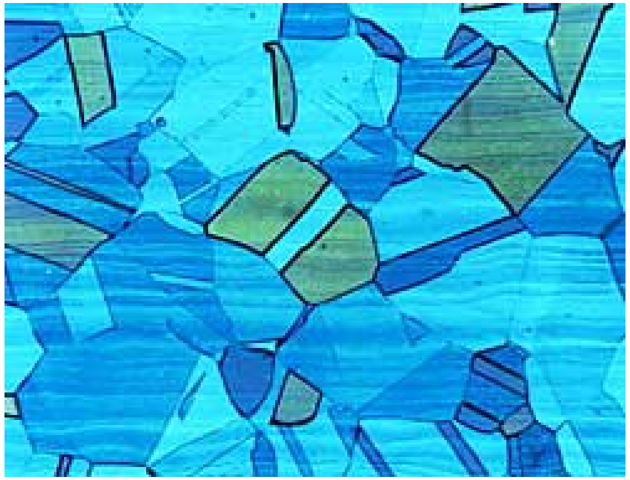
Metals

- Metals are widely used as biomaterials due to their
  - strength and toughness
- Implant metals are generally biocompatible:
  - Stainless steel
  - Titanium
  - Cobalt alloys
- Some people are allergic to ions released from these metals.
- Major problem:
  - Generation of fine wear particles in service can lead to:
    - Inflammation and
    - Implant loosening

Courtesy R. Zenz

Metals used in medicine

- Stainless steel (most common **316L**)
  - 60-65% iron, 17-19% cromium, 12-14% nickel, > than 0.030% carbon, minor amounts of nitrogen, manganese, molybdenum, phosphorous, silicon, and sulfur.
  - Low carbon content for better resistance to in vivo corrosion.
  - Cromium: corrosion resistance by formation of surface oxide.
  - Nickel: improves strenght by increasing face centered cubic phase (austenite).
  - Due to potential long term release of Ni^{2+}, Cr^{3+} and Cr^{6+} restricted to temporary devices.
  - Used as screws and fittings for orthopedics.



Microstructure of austenitic stainless steel

Courtesy R. Zenz

Metals used in medicine

- Ti alloys
  - Light
  - Good mechanical properties
  - Good corrosion resistance due to TiO_2 solid oxid layer.

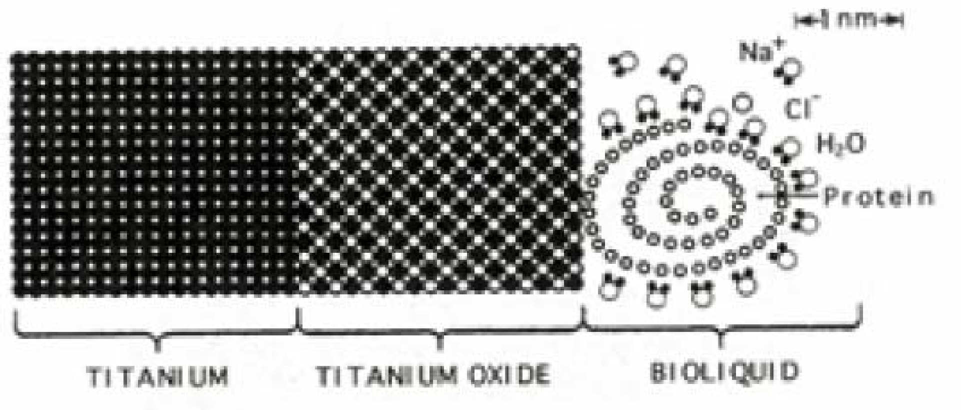
  - Pure Ti, grade 4 **CP** Ti (ASTM F67)
  - Ti 99% wt (non-alloyed)
  - 0.4% O
  - Commercially pure Ti used in dental implants.

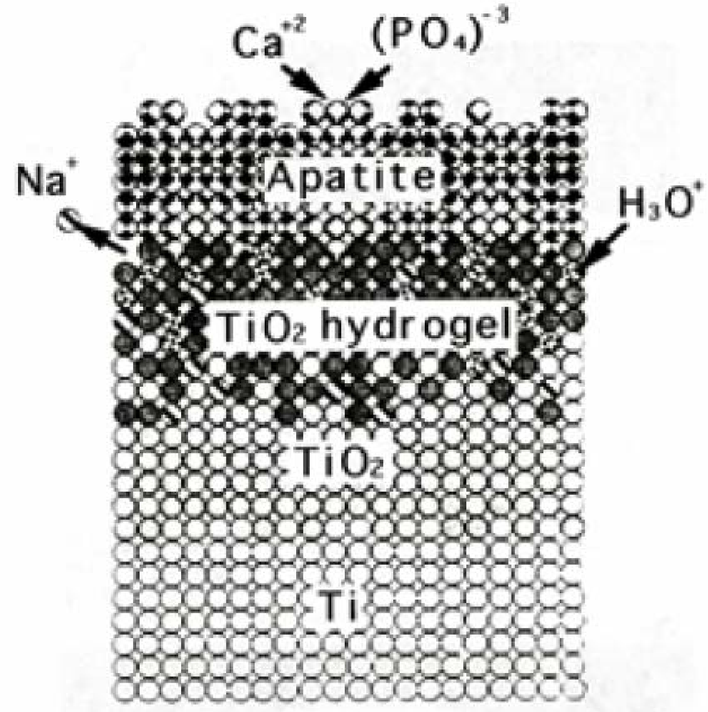
  - Ti-6Al-4V **ELI** (ASTM F136)
    Ti 89% wt Al 6% wt V 4%
    is widely used for implants and porous surface-coating.
  - Contains impurities (N, 0.13% O, Fe, H, C)
  - Impurities increasing interstitial content increase strength and fatigue limit. (N increases hardening, O increases tensile (yield) strength)

 Courtesy R. Zenz

Metals used in medicine

- Ti alloys
  - The TiO_2 surface can form a bio-liquid layer:
    - Protein, water, salts attach.
    - Provides sites of cell attachment.
    - Seems to aid in bone osteo-integration and the formation of hydroxyapatite crystals.



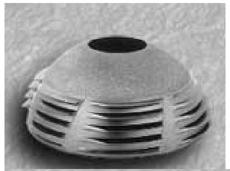


Metals used in medicine

- Ti-6Al-4V **ELI** (ASTM F136)
  - Hip and knee implants
  - Screws and fittings
  - Dental implants
  - Pacemaker housings
- Resistant to stress corrosion cracking and corrosion fatique in body fluids.
- One fo the few materials that permits bone growth at the interface.
- But, titanium has unsatisfactory wear

Metals used in medicine

- Cobalt based alloys
  - Common types for surgical applications:
    - ASTM F75, F799, F790, F562
  - Difficult to process because of difficulties in controlling final microstructure
  - Used in both cast and powder-pressing+forged (superior mechanical and chemical properties due to finer grain sizes and more homogenous microstructure) conditions.
  - Excellent wear resistance
  - Problem: Addition of Cr, W and Ni to improve machinability and fatigue, yield, tensile strength additionally result i potentially release of harmful ions into the body.


Titanlegierung (ISO 5832/3)


INNENPFANNE


KERAMIK-INLAY


CoCrMo-Legierung (ISO 5832/4)


(CoCrMo, ISO 5832/4 ASTM F75)

Dental Metals

- Amalgam (arab.: al-magam; softening salve)
  - Used since 150 years
  - Mixture of solid alloy and mercury (moldable and strong).
  - Solid alloy composed of silver (65%), tin (29%), copper (6%), zinc (2%) and mercury.
    - Mercury (3%) is fluid in mixture and forms Ag_3Sn, Ag_2Hg_3, Sn_7Hg
  - Deformable mixture packed in cavety
  - Hardens in time (25% of total strength in 1 hour, full strenght in a day).
  - Amalgam is stable, strong, inexpensive and endurable (8-10years).

 Courtesy R. Zenz

Dental Metals

- Gold and gold alloy:
  - Noble metal-known since thousands of years
  - First dental biomaterial
  - Biocompatible
  - Pure gold is to soft for dental applications
  - Enrichment by platinum
  - Excelent biomaterial/processing/dental applications
  - Resist high mechanical loading
  - High endurance
  - Aesthetics: metallic color

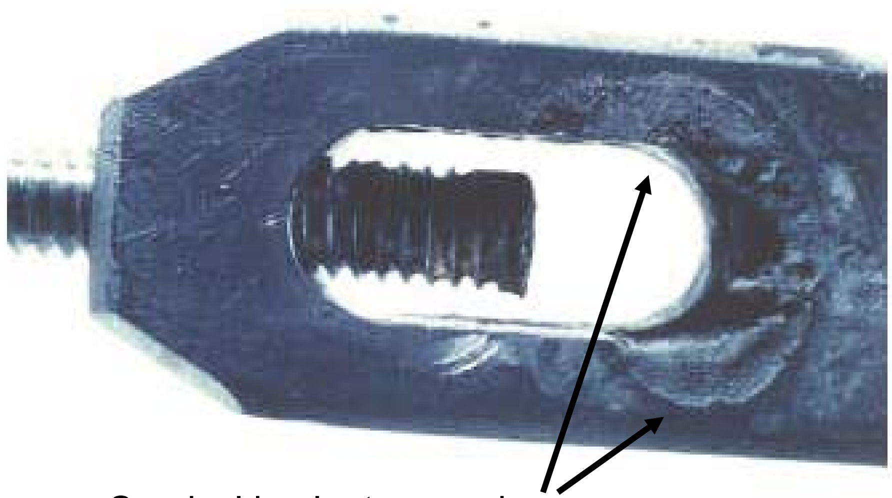
Courtesy R. Zenz

Dental Metals

- Alloys
  - Ca. 1400 different dental alloys
  - Applicable for all kind of restoration
  - Contain only biocompatible materials
  - Palladium, Silver, Gold, Cupper, Platinu
  - Should not contain: Ni, Cd, Be
  - Aesthetics: metallic color

Metals: Corrosion

- Corrosion is continued degradation of metals to oxide, hydroxide or other compounds through chemical reactions.
- The human body is an aggressive medium for inducing corrosion in metals: water, dissolved oxygen, proteins, chloride and hydroxide.



Surgical implant: corrosion

Corrosion: „Redox"-Chemistry

- Reduction and Oxidation:

LEO goes GER

Loss of **E**lectrons is **O**xidation

Gain of **E**lectrons is **R**eduction

(reduction of oxidation number)

„Redox“-Chemistry

- A redox reaction:

$$Cu(s) + 2Ag^{+}(aq) \longrightarrow Cu^{2+}(aq) + 2Ag(s)$$

Ox. #: 0 +1 +2 0

Assigning Oxidation Numbers

Category	Oxidation #	Example
1) Neutral substances containing only a single element	0	N_2, He
2) Monatomic ions	same as the charge	$Na^{+} = +1$
3) Hydrogen combined with a nonmetal	+1	HBr, CH_4, OH^{-}
4) Hydrogen combined with a metal	-1	NaH, CaH_2
5) Metals in Group IA	+1	Li_3N, Na_2S
6) Metals in Group IIA	+2	Mg_3N_2
7) Oxygen	-2	H_2O, NO
(Exceptions: H_2O_2, O_2^{2-})	-1	
8) Halogens	-1	AlF_3, HCl

„Redox"-Chemistry

- A redox reaction:

$$Cu(s) + 2Ag^{+}(aq) \longrightarrow Cu^{2+}(aq) + 2Ag(s)$$

Ox. #: 0 +1 +2 0

oxidation

reduction

- We can envision breaking up the full redox reaction into two 1/2 reactions:

$$Cu(s) + 2Ag^{+}(aq) \longrightarrow Cu^{2+}(aq) + 2Ag(s)$$

oxidation

reduction

$$Cu(s) \longrightarrow Cu^{2+}(aq) + 2e^{-}$$

$$Ag^{+}(aq) + e^{-} \longrightarrow Ag(s)$$

"half-reactions"

„Redox“-Chemistry

Redox Reaction Example (cont.)

- Note that the 1/2 reactions are combined to make a full reaction:

$$Cu(s) + 2Ag^{+}(aq) \longrightarrow Cu^{2+}(aq) + 2Ag(s)$$

oxidation: $Cu(s) \rightarrow Cu^{2+}(aq)$

reduction: $2Ag^{+}(aq) \rightarrow 2Ag(s)$

- The important thing to remember: electrons are neither created or destroyed during a redox reaction. They are transferred from the species being oxidized to that being reduced.

Corrosion: Basic Reactions

- Ionization: Direct formation of metalic cations under acidic or reducing (i.e. oxygen poor) conditions.

$$M \rightarrow M^+ + e^-$$

- Oxidation: Direct reaction of metal with oxygen.

$$M + O_2 \rightarrow MO_2$$

- Hydroxylation: The reaction of water under alkaline (basic) or oxidizing conditions to yield a hydroxide or hydrated oxide.

$$2M + O_2(aq) + 2H_2O \rightarrow 2M(OH)_2$$

Corrosion

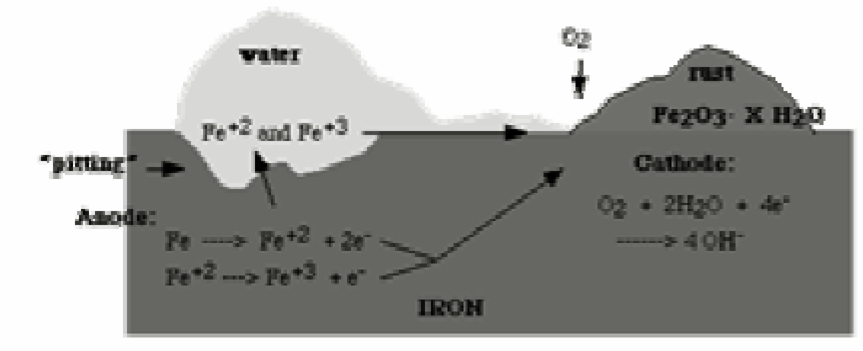
- Mechanism:
  - Materials have tendency to reach their lowest possible free energy (corroded state is preferred).
  - Most alloys, oxides, hydroxides, sulfides have negative free energy of formation and they are thermodynamically favored over the pure metal !
  - Metal atoms ionize, go into solution and combine with oxygen.
  - Metal flakes off

$$Al \rightarrow Al_2O_3 \qquad \Delta G = -1576 \text{ kJ mol-1}$$

Corrosion

- Formation of rust:
  - Oxidation of iron to ferrous (2+) ion: **$Fe \rightarrow Fe^{2+} + 2e^-$**
  - Oxidation of ferrous ions to ferric (3+) ions: **$Fe^{2+} \rightarrow Fe^{3+} + 1e^-$**
  - Reduction of oxygen using electrons generated by oxydation:

$O_2\ (g) + 2H_2O + 4e^- \rightarrow 4OH^-$



Overall Reaction 1:

$4Fe^{+2} + O_2 + 8H_2O \rightarrow \underline{2Fe_2O_3 . H_2O\ (s)} + 8H^+$

RUST

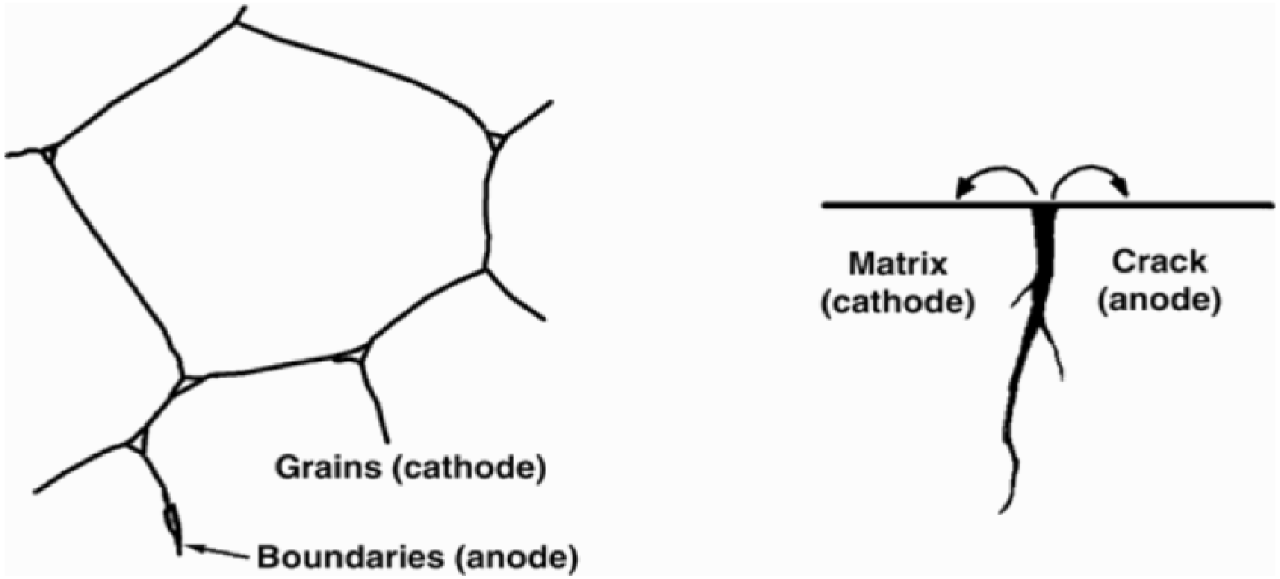
Overall Reaction 2:

$4Fe^{+2} + O_2 + 2H_2O \rightarrow 4Fe^{+3} + 4OH^- \rightarrow$
$4Fe^{+3} + 12OH^- \rightarrow \underline{4Fe(OH)_3}$

Galvanic corrosion –can be very rapid

● If two dissimilar metals are present in the same environment, the one that is most negative in the *galvanic series* will become the anode, and bimetallic (or galvanic) corrosion will occur

●Galvanic action can also result in corrosion within a single metal, if there is inhomogeneity in the metal or in its environment



● Micro-corrosion cells.

Left: grain boundaries are anodic with respect to the grain interior.
Right: crevice corrosion due to oxygen-deficient zone in the metal's environment

 Courtesy R. Zenz

Corrosion

- To avoid corrosion:
  - Consider the composition of the biological invironment (ions, pH, oxygen pressure, etc.)
  - Use appropriate metals.
  - Avoid implantation of dissimilar metals.
  - Minimize pits and crevices.
  - Avoid transfer of metal from tools to the implant during surgery.