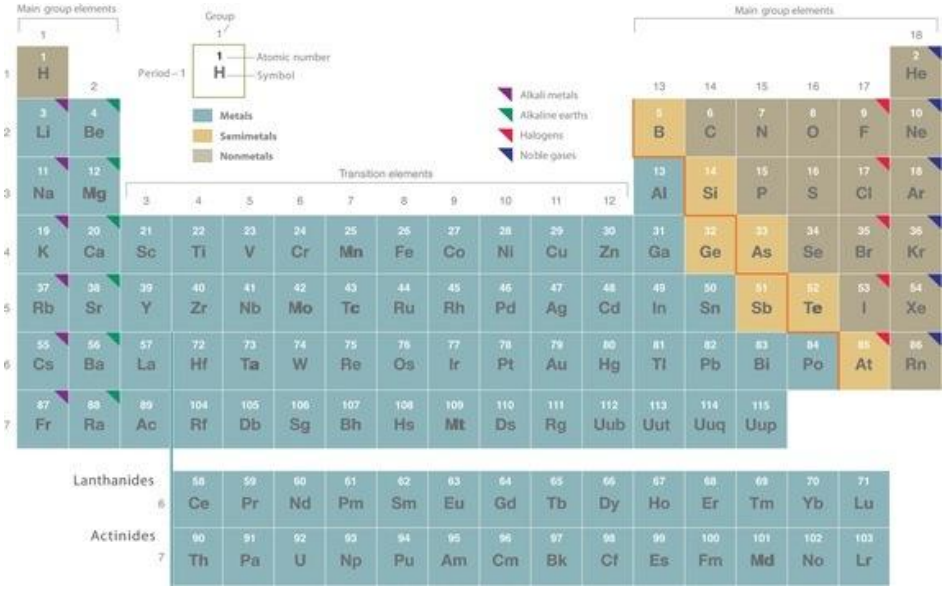
Introduction to Chemical Engineering

Chapter 11

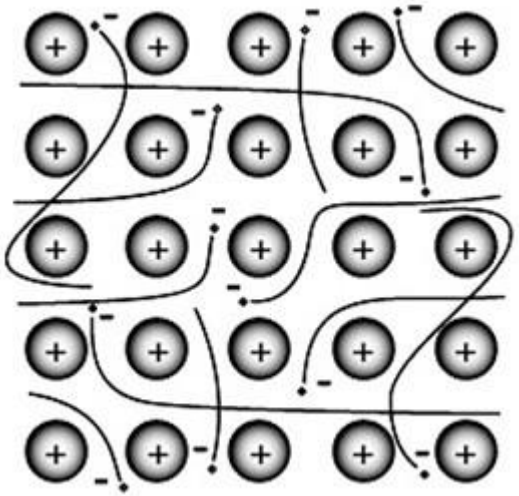
Materials
(*An Important Equipment Feature*)

11.1 Metals and corrosion

- **Metal: a material that is typically hard, opaque, shiny and has good electrical and thermal conductivity**

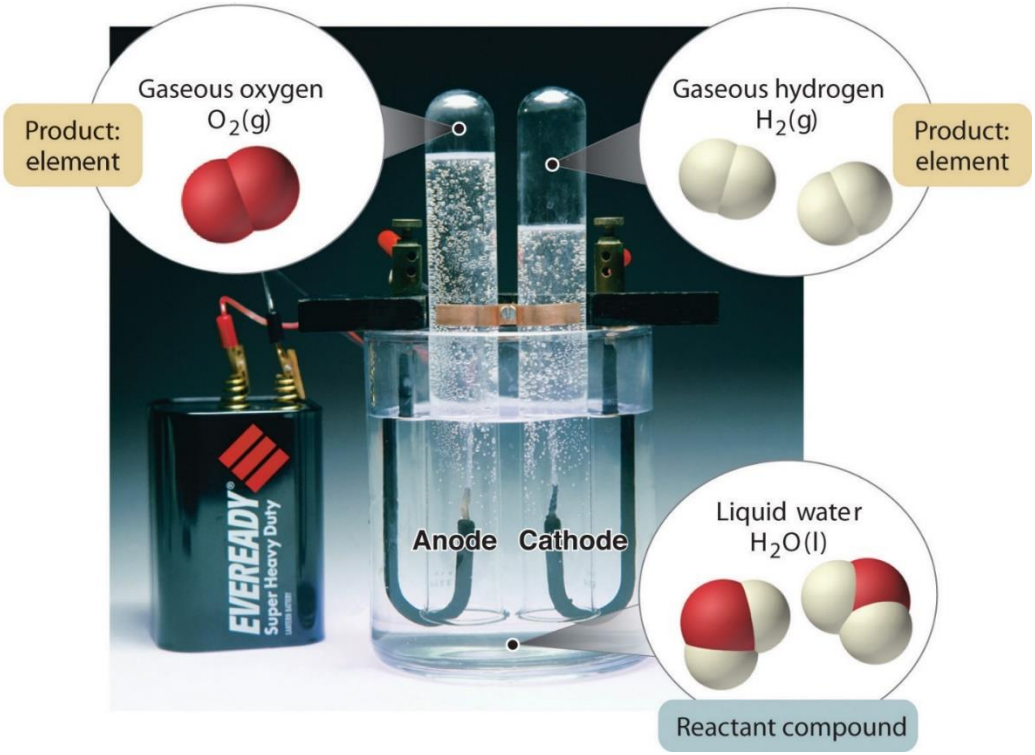


Metallic bonding



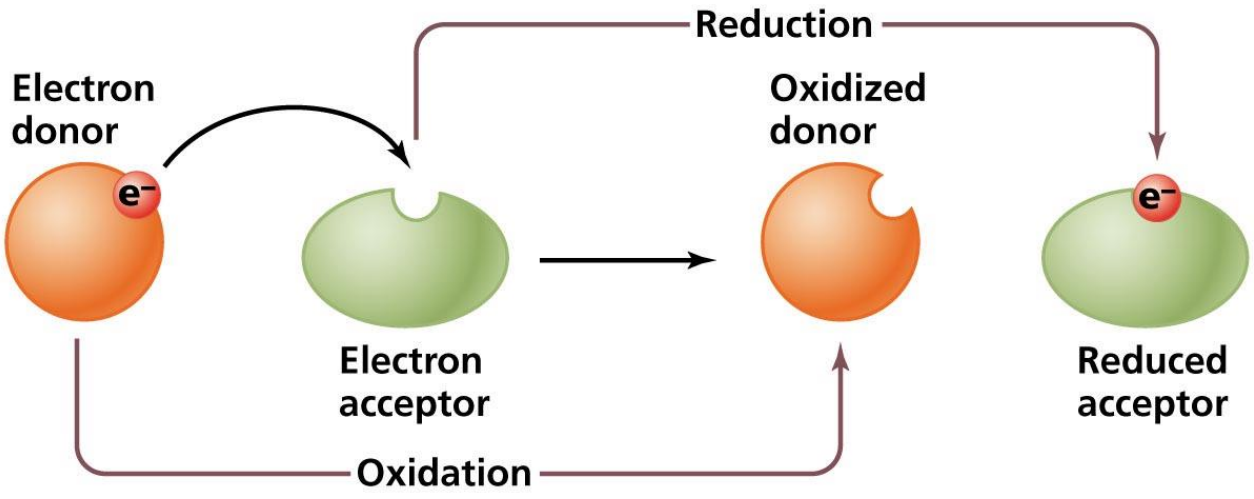
11.1 Metals and corrosion

- **Electrochemistry**



11.1 Metals and corrosion

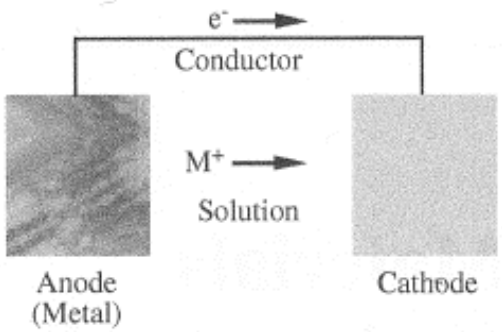
- **Redox reactions includes all chemical reactions in which atoms have their oxidation state changed; in general, redox reactions involve the transfer of electrons between species.**



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

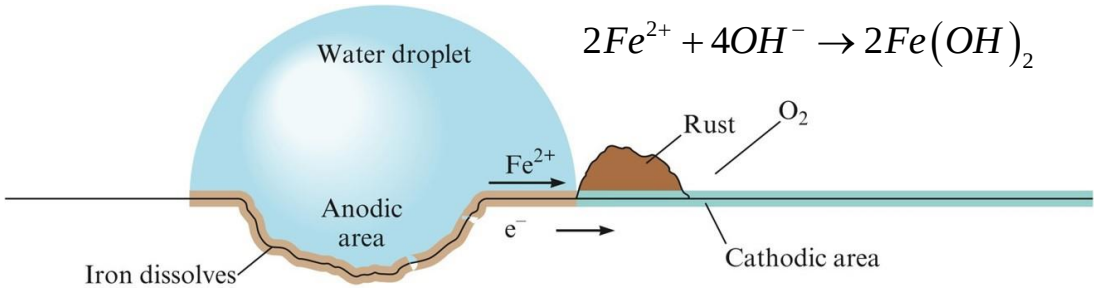
11.1 Metals and corrosion

- **Rust (iron oxide: Fe_2O_3) formation**



$$4Fe(OH)_2 + O_2 \rightarrow 2Fe_2O_3 + 4H_2O$$

$$2Fe^{2+} + 4OH^- \rightarrow 2Fe(OH)_2$$



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

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

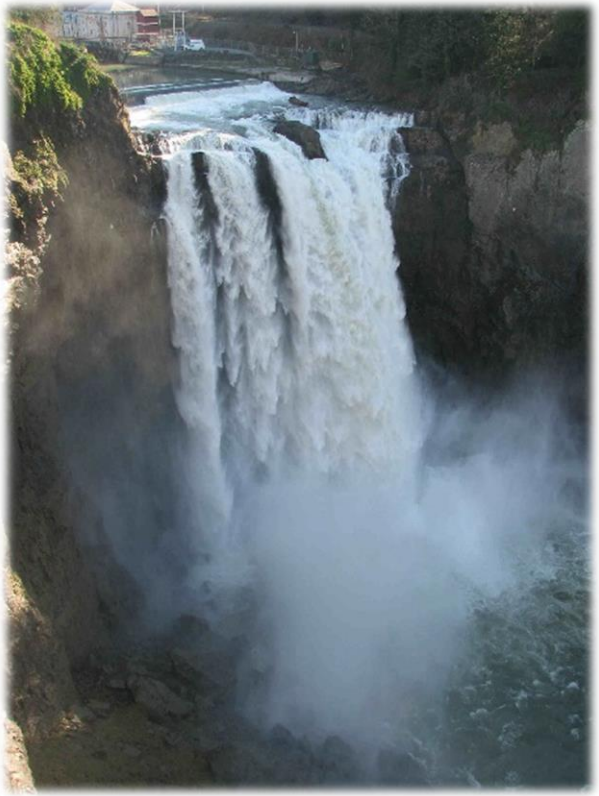
11.1 Metals and corrosion

- **Abbreviated oxidation-reduction series**

More noble or cathodic (reaction proceeds less)

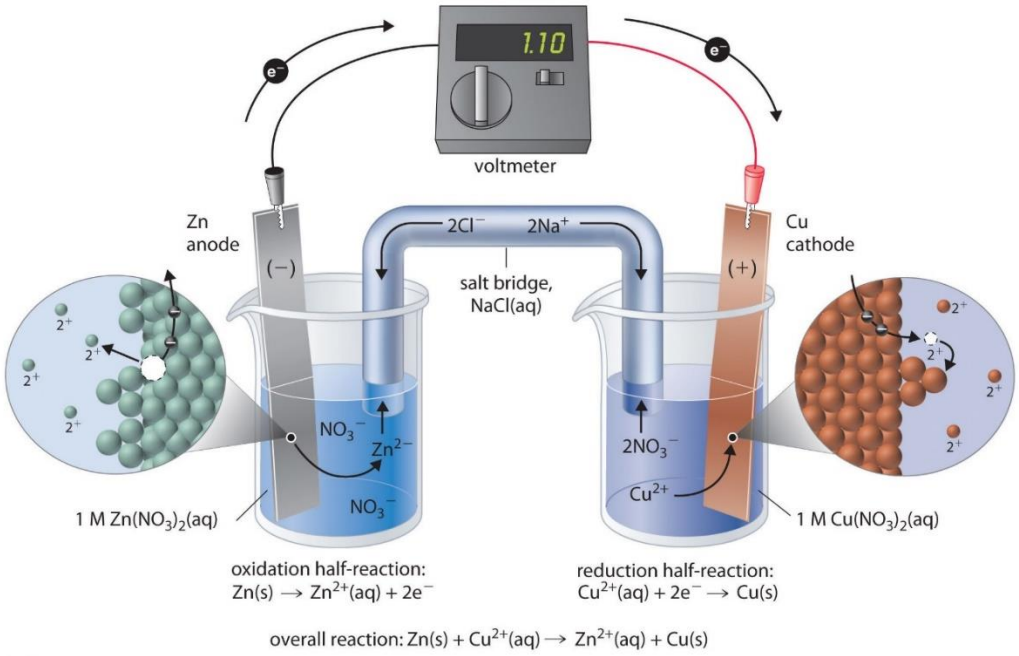
$Au \rightarrow Au^{3+} + 3e^-$
$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$
$Pt \rightarrow Pt^{2+} + 2e^-$
$Fe^{2+} \rightarrow Fe^{3+} + e^-$
$4(OH^-) \rightarrow O_2 + 2H_2O + 4e^-$
$Cu \rightarrow Cu^{2+} + 2e^-$
$Sn^{2+} \rightarrow Sn^{4+} + 2e^-$
$H_2 \rightarrow 2H^+ + 2e^-$
$Pb \rightarrow Pb^{2+} + 2e^-$
$Sn \rightarrow Sn^{2+} + 2e^-$
$Ni \rightarrow Ni^{2+} + 2e^-$
$Co \rightarrow Co^{2+} + 2e^-$
$Fe \rightarrow Fe^{2+} + 2e^-$
$Cr \rightarrow Cr^{3+} + 3e^-$
$Zn \rightarrow Zn^{2+} + 2e^-$
$Al \rightarrow Al^{3+} + 3e^-$
$Mg \rightarrow Mg^{2+} + 2e^-$
$Na \rightarrow Na^+ + e^-$

More reactive or anodic (reaction proceeds more)



11.1 Metals and corrosion

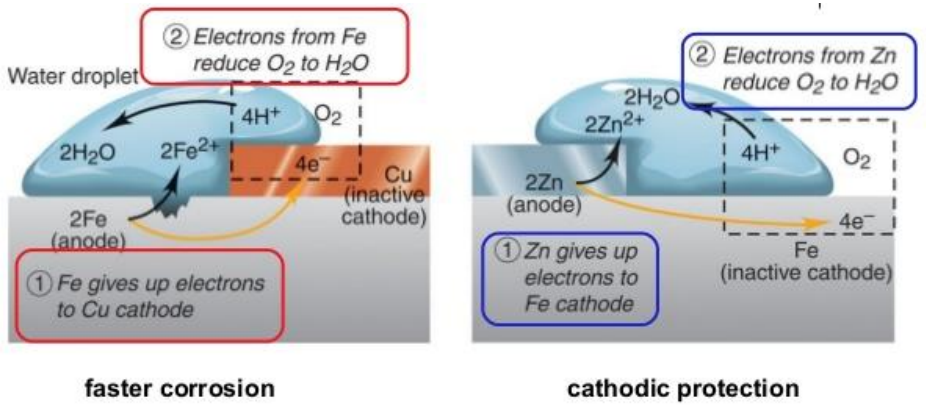
- **Electrochemical corrosion**

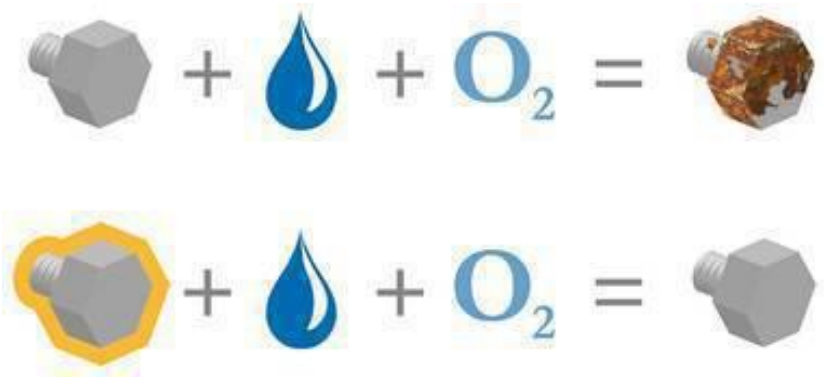


Spontaneous chemical reaction ($\Delta G < 0$)

11.1 Metals and corrosion

- **Strategies to reduce corrosion**
  - Similar metals
  - Thicker metal
  - Sacrificial anode
  - Noble metal
  - Protective oxide
  - Corrosion inhibitors
  - Paint
  - Nonmetals





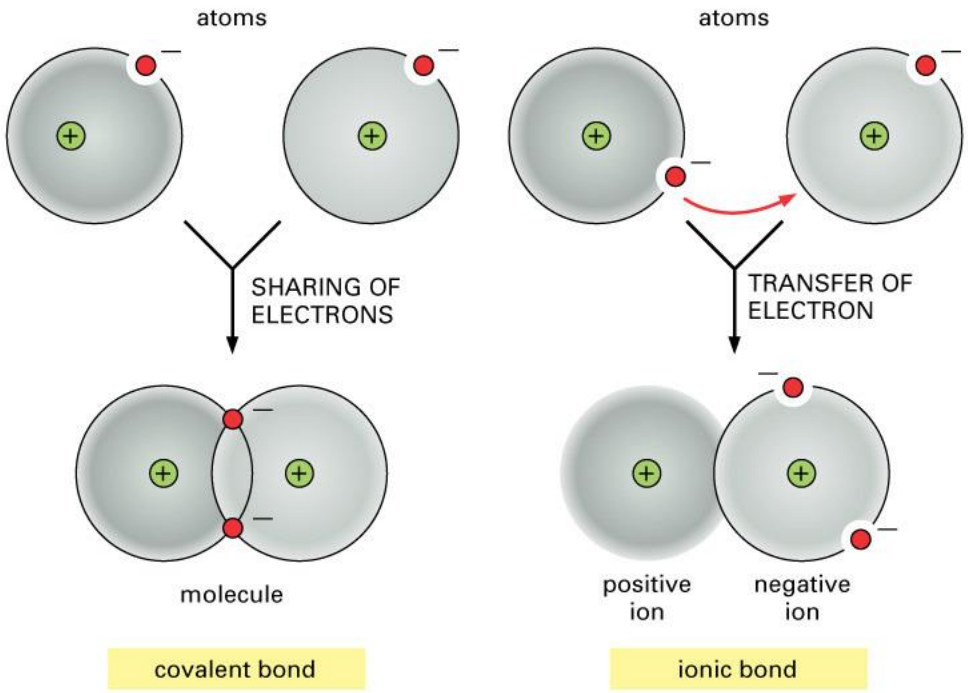
11.2 Ceramics

- **Ceramic: an inorganic, nonmetallic solid material comprising metal, nonmetal or metalloid atoms primarily held in ionic and covalent bonds**
- **Examples: alumina (Al_2O_3), silica (SiO_2) and diamond (C)**

pseudo-ceramic

11.2 Ceramics

- **Ionic and covalent bonding in ceramics**



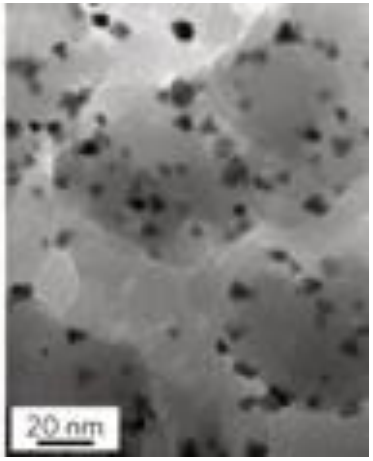
Localized electrons: very low electrical conductivity and reactivity

11.2 Ceramics

- **Application of ceramics: high temperature resistance and low reactivity**

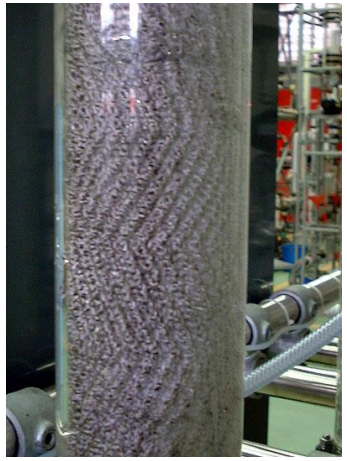
Furnace lining

Catalyst support



Pipes

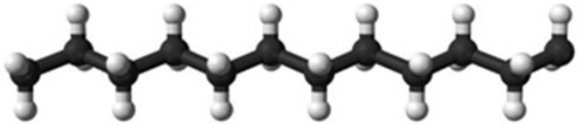
Column packing

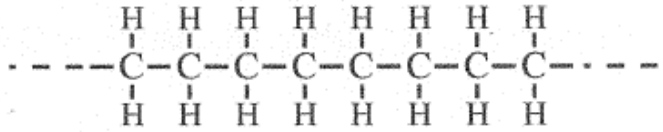


11.3 Polymers

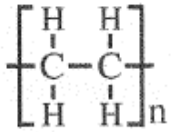
- **Polymer: a large molecule, or macromolecule composed of many repeated subunits**

Polyethylene (PE)



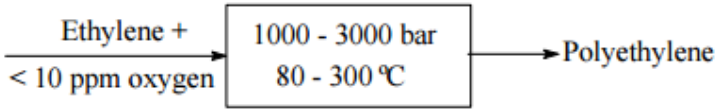


or

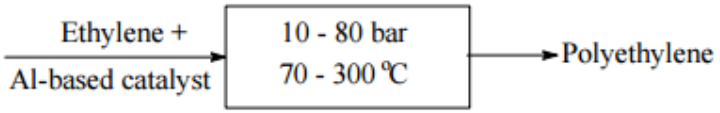


(abbreviated)

High pressure process



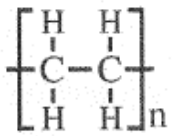
Low pressure process



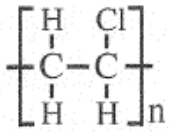
11.3 Polymers

- **Substituting other atoms in place of the hydrogen atoms**

Polyethylene (PE)

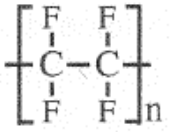


Polyvinylchloride (PVC)



High hardness, insulator, chemical resistance

Polytetrafluoroethylene (PTFE)

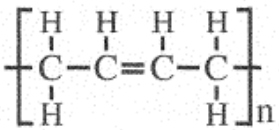


Non-sticking, heat resistance, non-wetting, low friction, chemical resistance

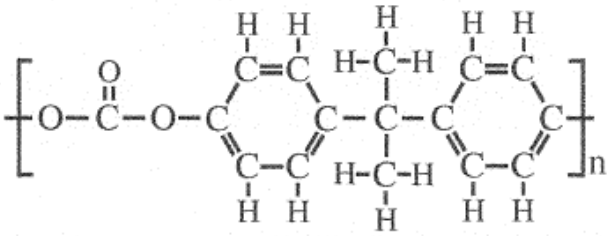
11.3 Polymers

- **Less-flexible polymers**

Polybutadiene

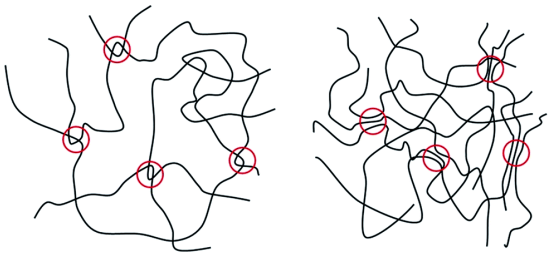


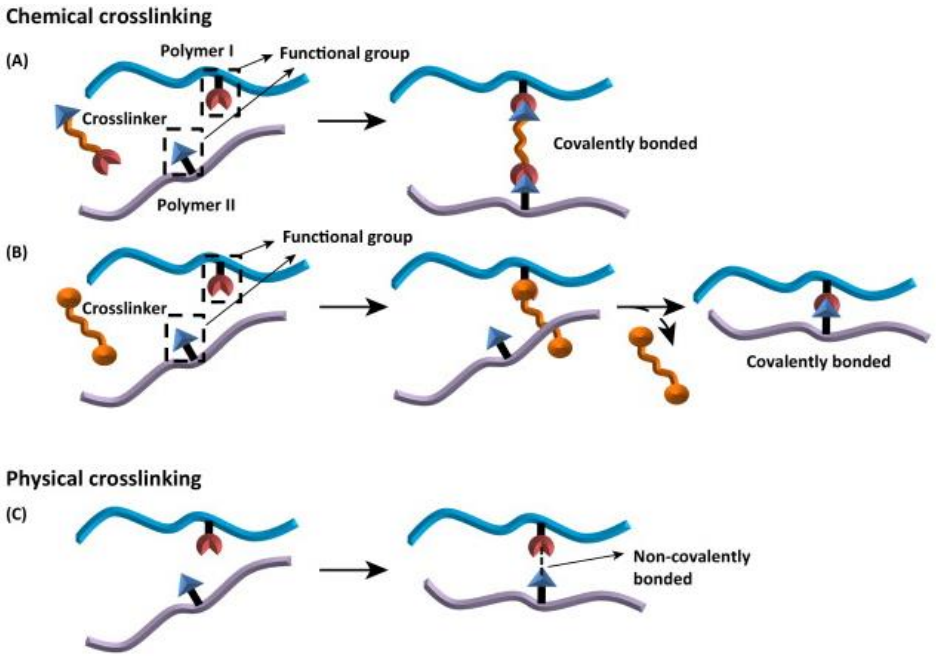
Polycarbonate



11.3 Polymers

- **Polymer properties are affected by the interaction between polymer chains.**
  - **Crosslinking**
  - **Weaker bonding**
  - **Physical tangling**
  - **Crystallinity**

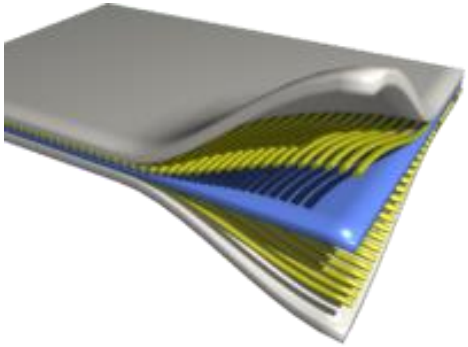


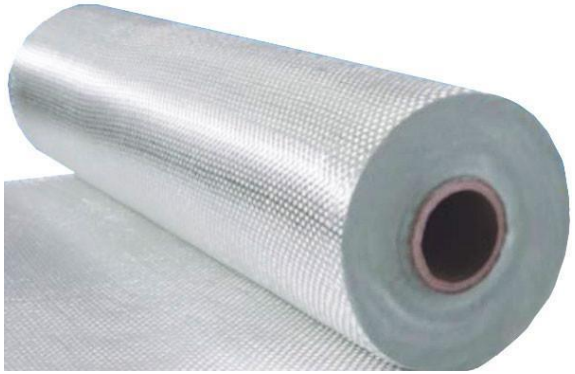


11.4 Composites

- **Summary**
  - **Metals** are very strong and easy to work with but are subject to corrosion.
  - **Ceramics** can withstand high temperature and highly reactive environments but are brittle.
  - **Polymers** are very easy to customize, are tough and flexible and are not subject to corrosion but are not strong and cannot withstand high temperature or highly reactive environment.

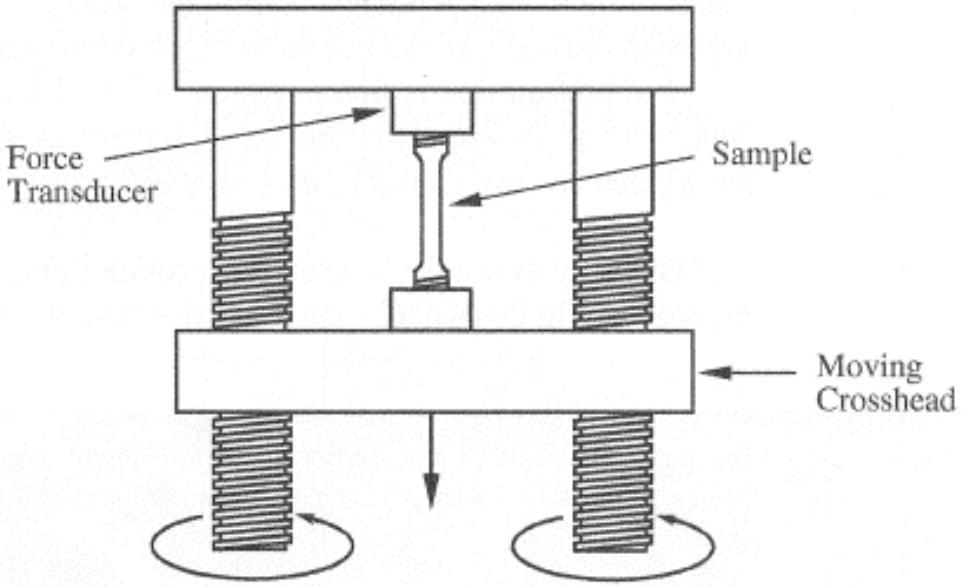
- **Composite: materials comprised of polymers and either metals or ceramics**





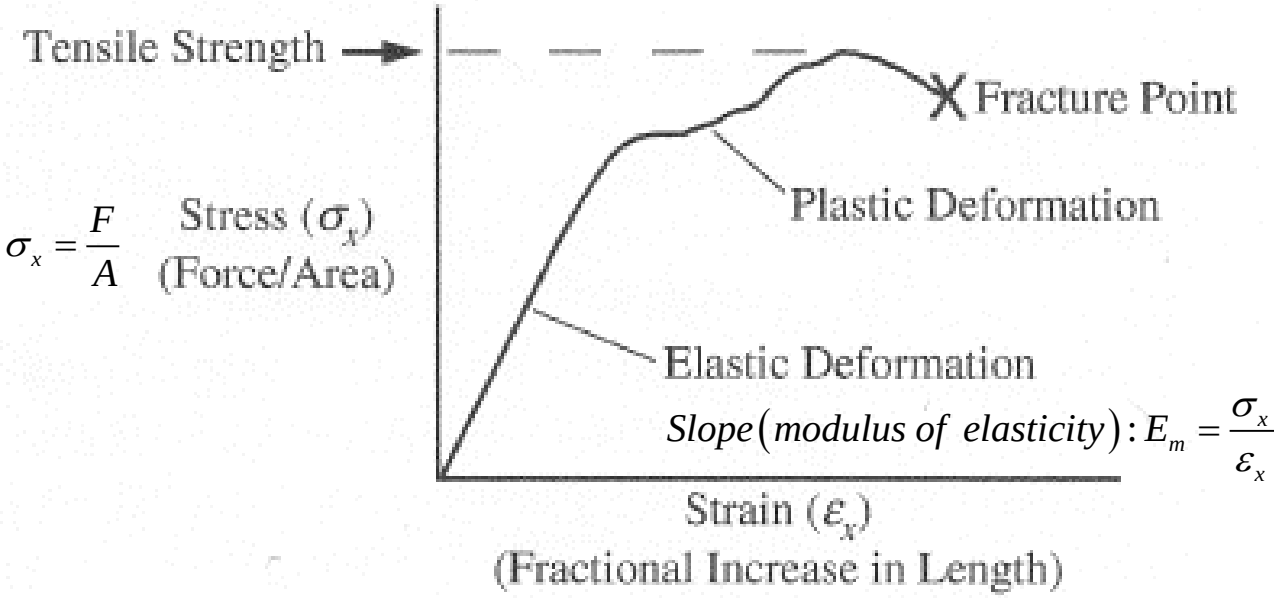
11.5 Strength of materials

- **Tensile strength:** the capacity of a material or structure to withstand loads tending to elongate, as opposed to compressive strength, which withstands loads tending to reduce size.



11.5 Strength of materials

- **Stress-strain curve**



$$\sigma_x = \frac{F}{A} \quad \text{Stress } (\sigma_x) \text{ (Force/Area)}$$

$$Slope\left(modulus\ of\ elasticity\right): E_m = \frac{\sigma_x}{\varepsilon_x}$$

$$\varepsilon_x = \frac{\Delta l}{l_0}$$

11.5 Strength of materials

- **Physical properties of some materials**

Material	Density (g/cm^3)	Modulus of Elasticity (psi)	Tensile Strength (psi)
Iron	7.9	15×10^6	$42–73 \times 10^3$
Steel	7.9	30×10^6	$47–200 \times 10^3$
Copper	9.0	15×10^6	$25–50 \times 10^3$
Aluminum	2.7	10×10^6	$10–19 \times 10^3$
Magnesium	1.7	6.5×10^6	$23–50 \times 10^3$
Glass fiber	2.5	10×10^6	250×10^3
Clay brick	2.5-5	15×10^6	$16–20 \times 10^3$
Polystyrene	1.1	4.5×10^5	7×10^3
Polyethylene	0.95	$0.2–1.2 \times 10^5$	$2–4 \times 10^3$

Example 11.4

How much force would be required to elastically stretch a rod of aluminum (diameter = 0.44 *in*) from a length of 4.0 *cm* to 4.004 *cm*?