

Water treatment I

Water treatment

- Water treatment process overview
- Coagulation & flocculation
- Softening (removing hardness)

Water treatment

- Goal of municipal water treatment: to provide water that is both potable and palatable
 - potable: safe to drink; palatable: pleasant to drink
- Factors determining drinking water quality
 - Physical: color and turbidity, temperature, taste and odor
 - Chemical: toxic chemicals and chemicals that make water non-palatable
 - Microbiological: pathogens
 - Radiological: ex) uranium

Indicator for pathogens

- Indicator is needed for pathogens because it is not practical to analyze all different species
- Total coliforms
 - Most frequently used indicator for pathogens
 - Reasons for using total coliforms as an indicator:
 - Inhabit the intestinal tracks of humans and other mammals
 - Exist in large numbers in individuals
 - Survive in natural waters for relatively long without growth
 - Relatively easy to analyze

Sources of drinking water

- Surface water

- Variable composition
- Low mineral content
- Low hardness
- High turbidity
- Colored
- DO present



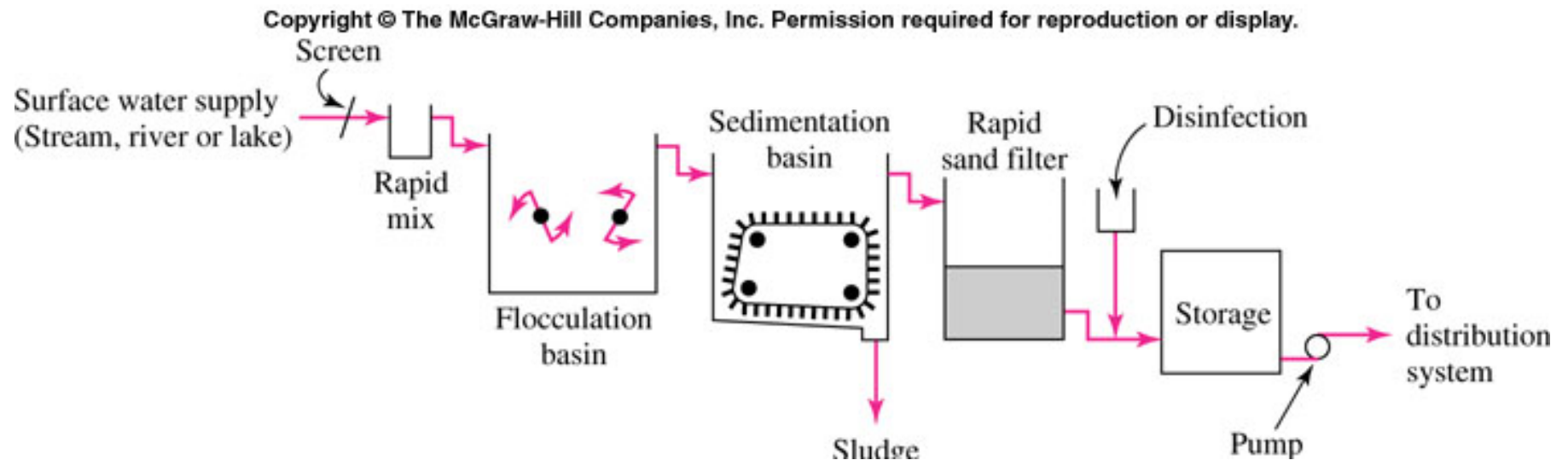
- Groundwater

- Constant composition
- High mineral content
- High hardness
- High Fe, Mn
- Low turbidity
- Low color
- Low DO



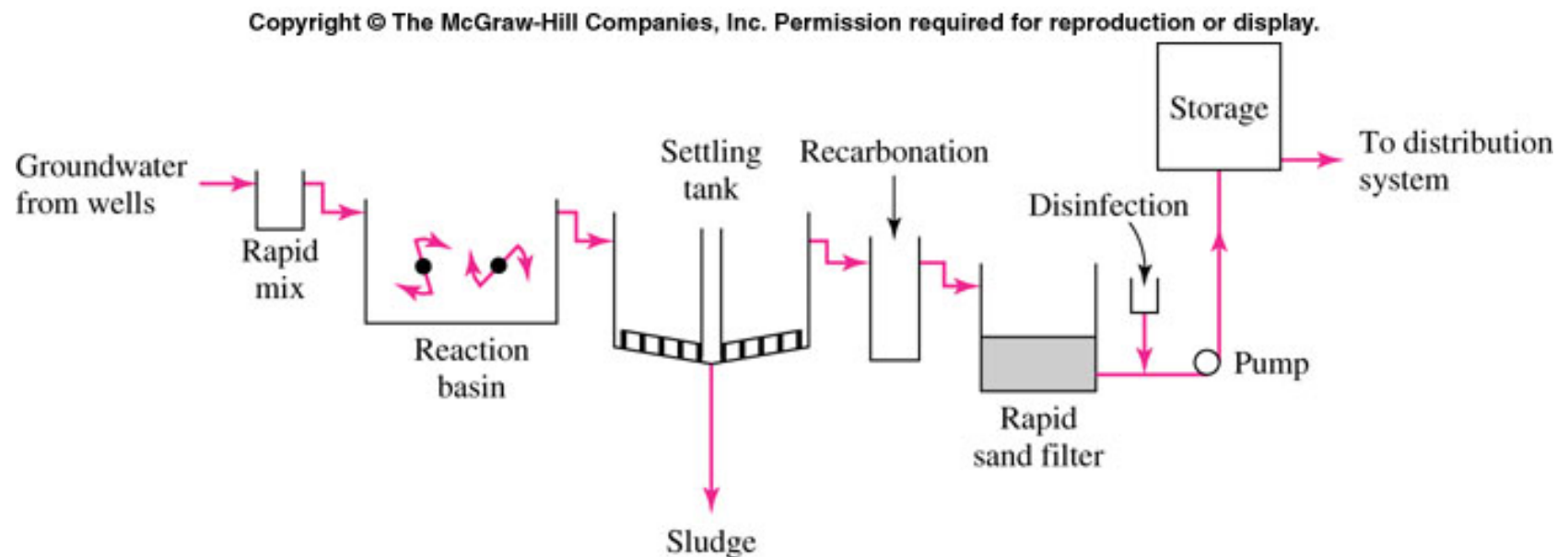
Water treatment systems

- Coagulation plant: conventional surface water treatment



Water treatment systems

- Water softening plant: for groundwater with high hardness



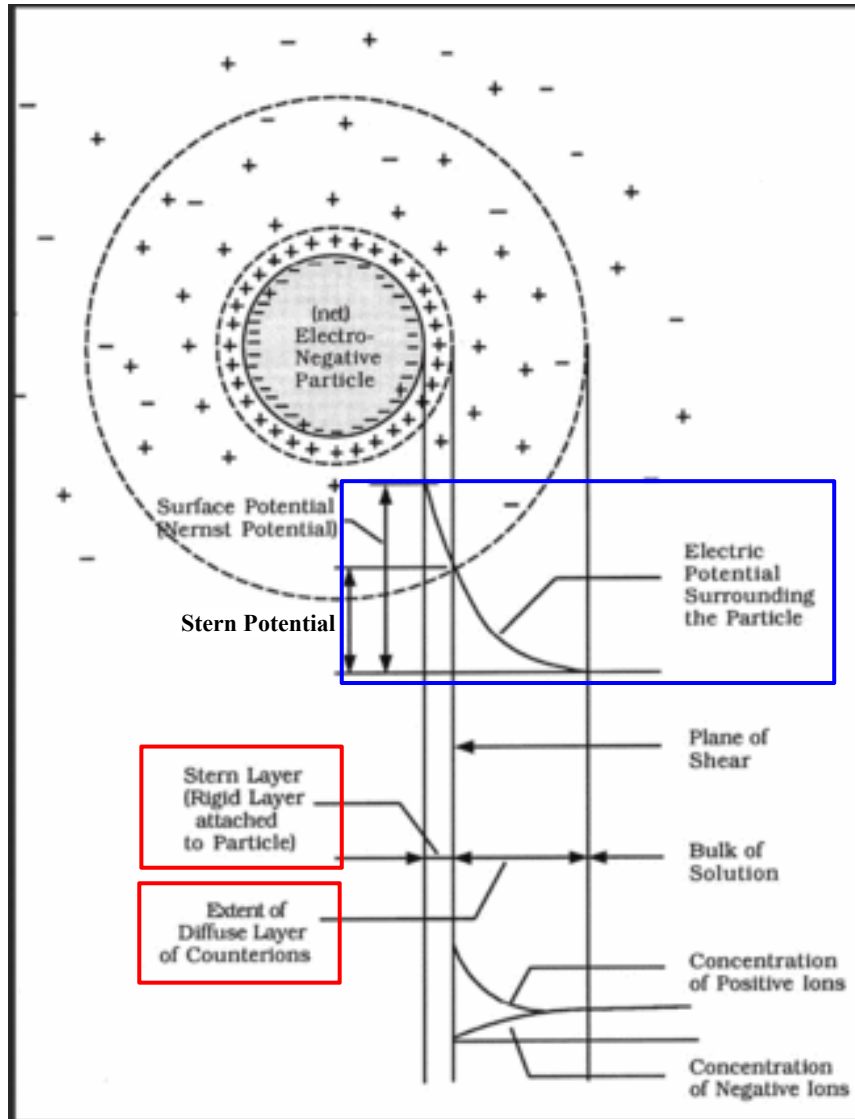
Particle removal in water

- In surface water treatment, remove particles first
- Concerns
 - Particles..
 - Cause turbidity and color in water
 - Clog filters, foul membranes, reduce disinfection efficiency
 - And some particles...
 - Are pathogenic (viruses, bacteria, cysts, ...)
 - Harbor pathogens
 - Have toxic substances
 - Are involved in disinfection byproduct formation

Colloids

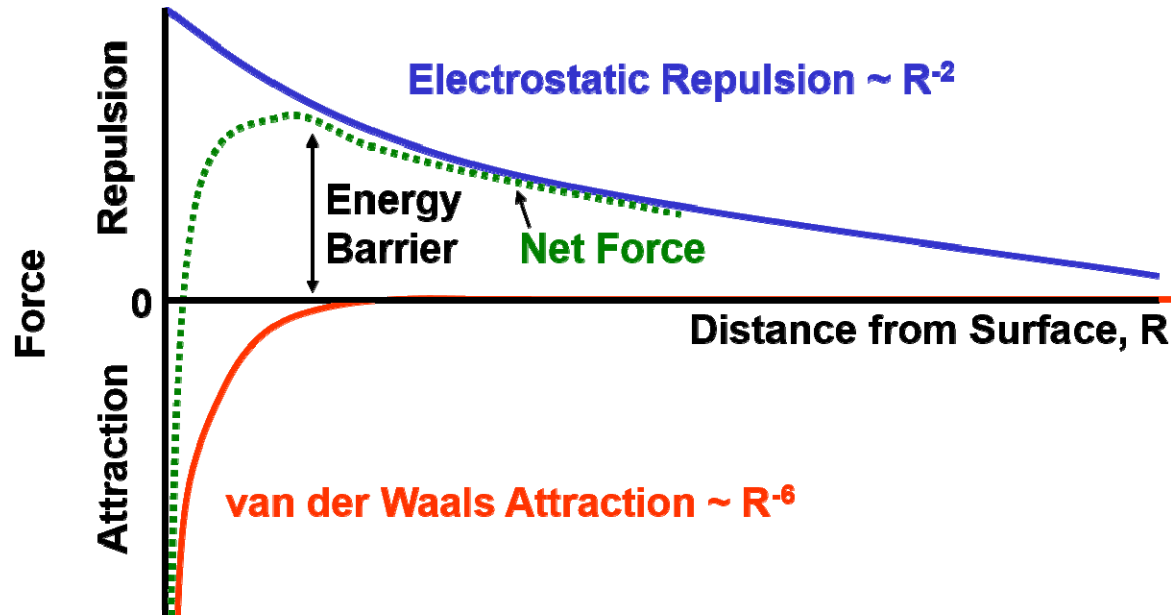
- Small particles (0.001 to 1 μm)
- Usually negatively charged
- Stability of colloidal suspension
 - “Stable” colloidal suspension: particles are like-charged →
→ particles repel each other → particles do not stick together or settle down easily
 - Destabilization of colloidal suspension: neutralizing the particle charge so that the particles can stick together and settle down

Colloids – electrical double layer



- Ion distribution near the charged colloid is different from the bulk liquid
- Stern layer: rigid layer, ions attached to particle
- Diffuse layer: ions are mobile

Colloids – electrical double layer



- Need “jumping” the energy barrier for particle adhesion
- Ways to reduce the energy barrier
 - Reduce the surface charge of the particle
 - Increase the ionic strength of the solution (compresses the electrical double layer)

Coagulation-flocculation

- Coagulation-flocculation process is used to remove colloidal particles from water
 - Coagulation: a chemical process; change the particle surface properties so that particles can stick together when they collide
 - Flocculation: a physical process; create conditions that allows particles to grow in size
- Result: formation of a “floc” (larger, settleable particles)



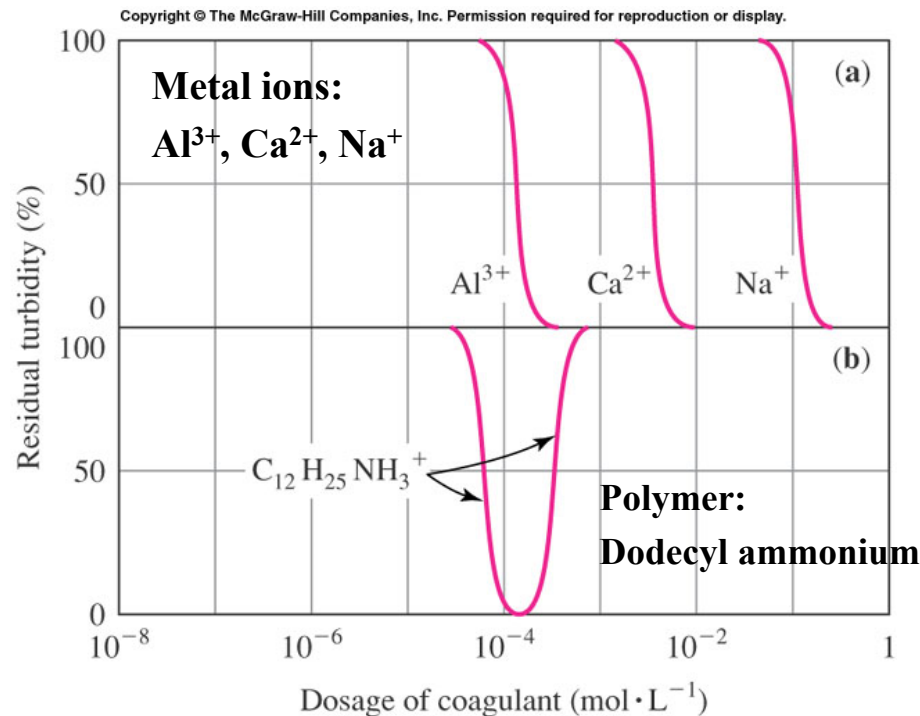
<http://www.wrights-trainingsite.com/WT%20coagfloconb.html>

Mechanisms of Coagulation-flocculation

- Charge neutralization
- Compression of the electric double layer
- Inter-particle bridging
- Enmeshment in a precipitate

Coagulation

- Goal: To alter the surface charge of the particles so that the particles can stick together to form an initial “floc”
- Coagulants: chemicals added to water for coagulation
- Metal salts or polymeric materials are used as coagulants



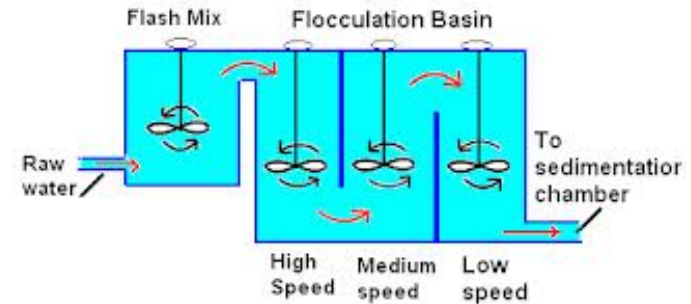
- Among metal ions, trivalent ions are most effective
- For some coagulants, charge reversal may occur if overdosed (-) → (+)

Coagulants

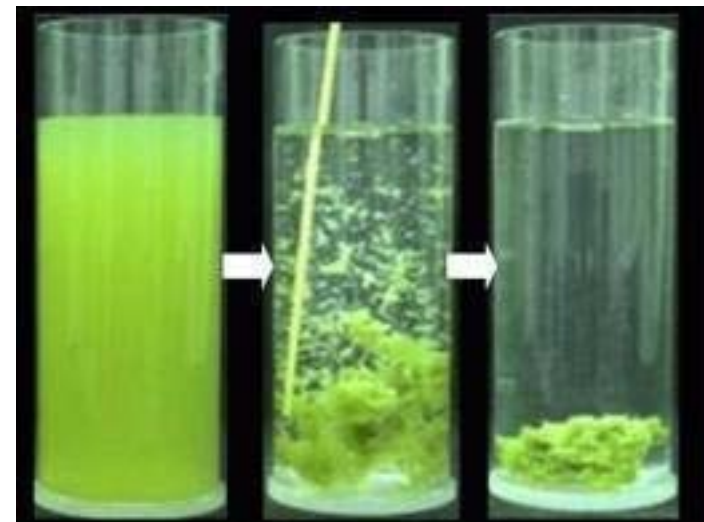
- Key properties
 - Trivalent cation (if a metal salt is to be used)
 - Nontoxic
 - Insoluble in neutral pH
- Commonly used coagulants
 - Al^{3+} or Fe^{3+} salts
 - Alum ($\text{Al}_2(\text{SO}_4)_3 \cdot 14\text{H}_2\text{O}$): most common
 - Alum dissolution: $\text{Al}_2(\text{SO}_4)_3 \cdot 14\text{H}_2\text{O} \leftrightarrow 2\text{Al}^{3+} + 3\text{SO}_4^{2-} + 14\text{H}_2\text{O}$
 - Ferric (Fe^{3+}) cations: $\text{Fe}_2(\text{SO}_4)_3 \cdot 7\text{H}_2\text{O}$, $\text{FeCl}_3 \cdot 7\text{H}_2\text{O}$

Flocculation

- Goal: allow particles to grow by gentle mixing so that they can easily settle
- Usually configured as a three step process
- Too little mixing → not enough energy for particles to stick together
- Too much mixing → particles break down



<http://chemistry.tutorvista.com>



<http://www.tech-faq.com>

Softening

- Goal: to reduce hardness of water
- Hardness
 - The term used to characterize a water that does not lather well, causes a scum, and leaves scales
 - Caused by polyvalent cations (+2, +3, ...)



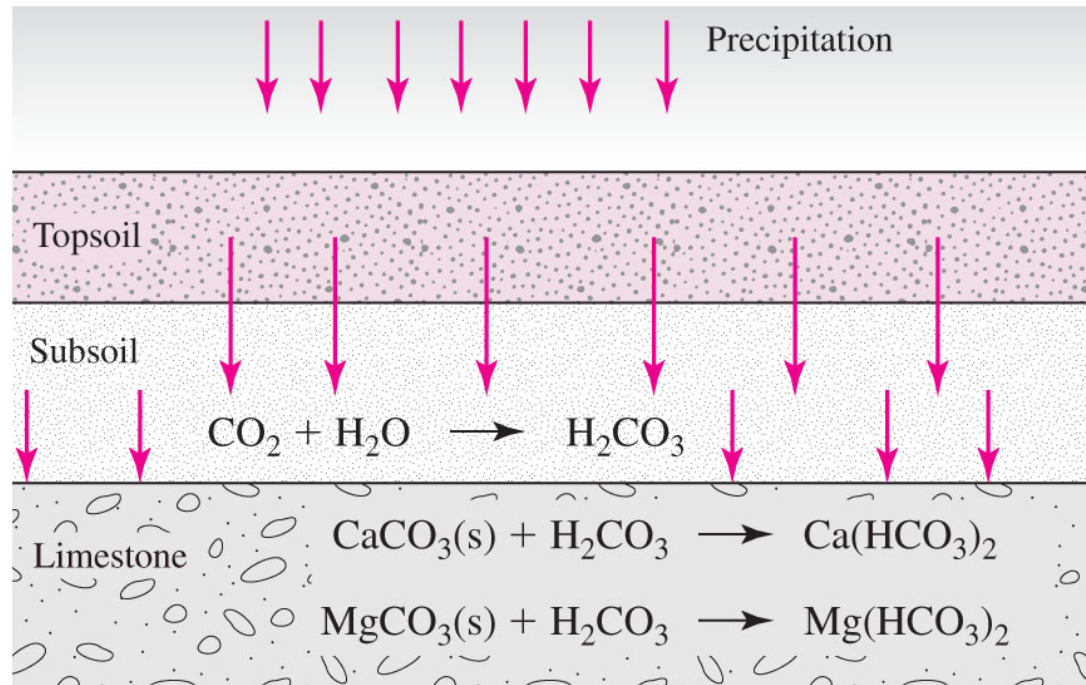
<http://www.watersoftenerbest.blogspot.com>



<http://www.proenv.com>

Formation of hardness

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- As rainwater infiltrates, the water gets CO_2 by the respiration of microorganisms
- Recall $\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3$
- Carbonic acid (H_2CO_3) dissolves limestone (CaCO_3 , MgCO_3)
- Hardness is of concern in limestone areas

Hardness

- Total hardness (TH)
 - Technically: the sum of all polyvalent cations

$$TH = (Ca^{2+}) + (Mg^{2+}) + (Fe^{3+}) + (Fe^{2+}) + (Ba^{2+}) + \dots$$

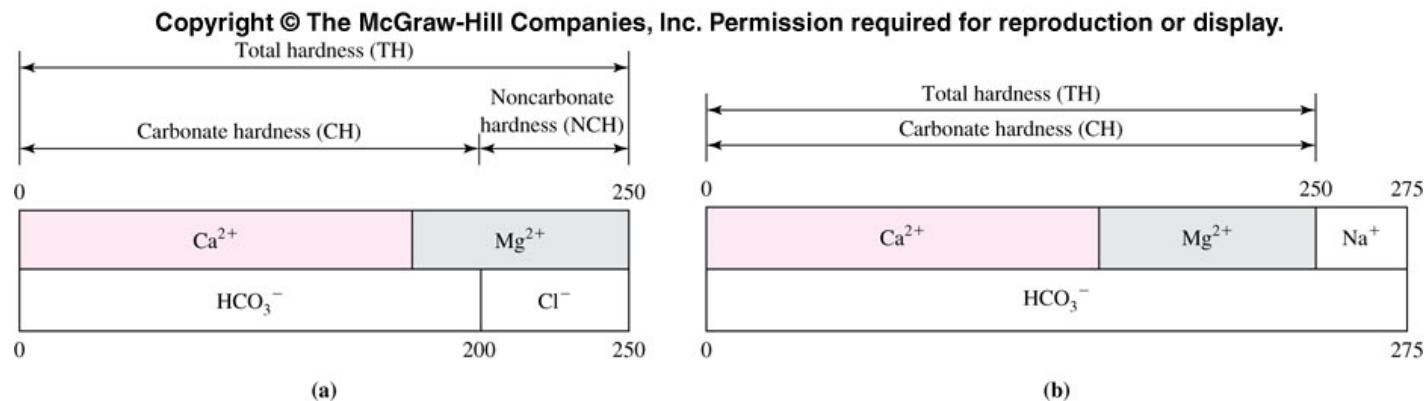
$$= \sum_{i=1}^n (X^{m+})_i$$

- Practically (most of the time): the sum of Ca^{2+} and Mg^{2+}

$$TH \cong (Ca^{2+}) + (Mg^{2+})$$

Hardness

- Carbonate and noncarbonate hardness
 - Total hardness (TH) is divided into carbonate (CH) and noncarbonate (NCH) hardness ($TH = CH + NCH$)
 - Carbonate hardness: the maximum amount of hardness that can be associated with carbonates (HCO_3^- and CO_3^{2-})
 - When $TH > \text{Alk}$ ($\approx [\text{HCO}_3^-] + 2[\text{CO}_3^{2-}]$), $CH = \text{Alk}$, $NCH = TH - CH$
 - When $TH \leq \text{Alk}$, $CH = TH$, $NCH = 0$



Hardness

- Units
 - eq/L or meq/L
 - mg/L as CaCO₃ (recall alkalinity unit)
 - Unit conversion: (mg/L as CaCO₃) = 50 x (meq/L)
(as CaCO₃ is 50 mg/meq)

Term	Concentration range (mg/L as CaCO ₃)
Soft	<17.1
Slightly hard	17.1-60
Moderately hard	60-120
Hard	120-180
Very hard	>180

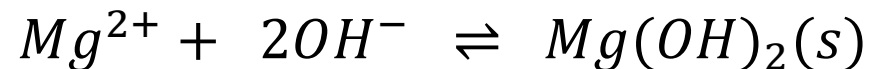
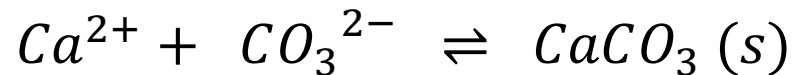
Hardness

Q: A sample of water having a pH of 7.0 has the following concentration of ions. Calculate the total hardness and the carbonate hardness of the water sample.

Ion	Concentration (mg/L)	Ion	Concentration (mg/L)
Ca ²⁺	40	HCO ₃ ⁻	110
Mg ²⁺	10	SO ₄ ²⁻	67.2
Na ⁺	11.8	Cl ⁻	11
K ⁺	7.0		

Lime-soda softening

- Addition of lime (Ca(OH)_2) and soda ash (Na_2CO_3)
- Precipitates Ca^{2+} and Mg^{2+} using following reactions:



- Target on Ca^{2+} and carbonate hardness first, leaving as much Mg^{2+} and noncarbonate hardness as possible
 - pH of water should be ~ 10.3 for Ca^{2+} precipitation and ~ 11 for Mg^{2+} precipitation
 - Have to provide CO_3^{2-} for noncarbonate hardness

Reading assignment

Textbook Ch 10 p. 453-481