Water treatment I

Water treatment I

- 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

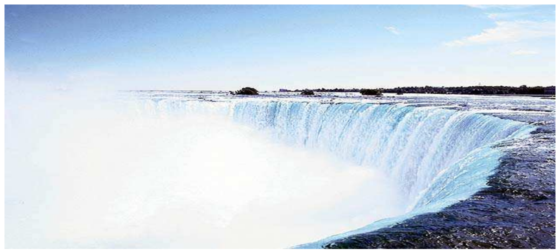
- Factors determining drinking water quality
  - Physical: color and turbidity, temperature, taste and odor
  - Chemical: toxic chemicals and chemicals that make water non-palatable
  - Microbiological: pathogens
  - Radiological: ex) uranium

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

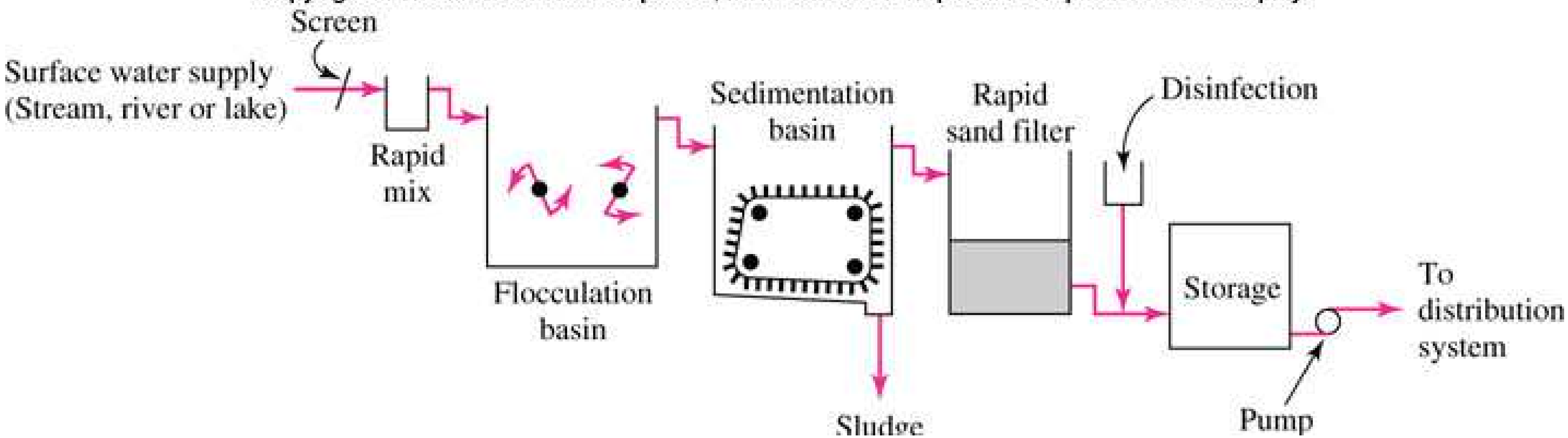
- Surface water
  - Variable composition
  - Low mineral content
  - Low hardness
  - High turbidity
  - Colored
  - DO present



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

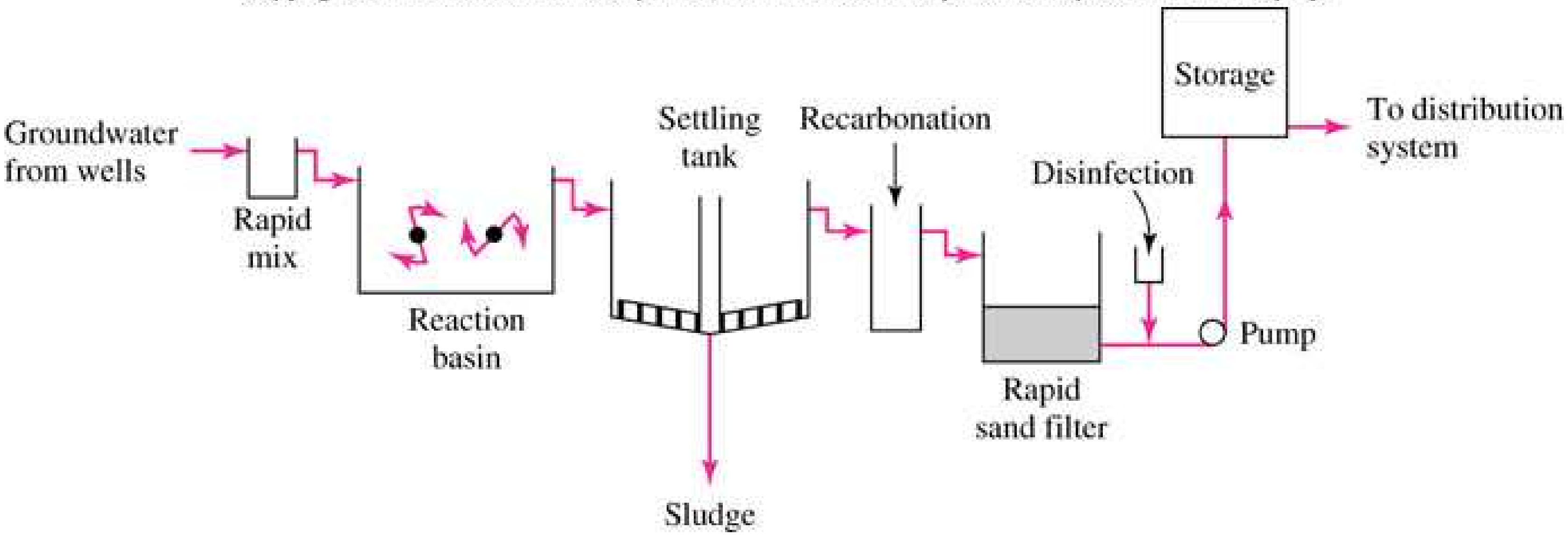
Water treatment systems

- 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 involved in particles in water

  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

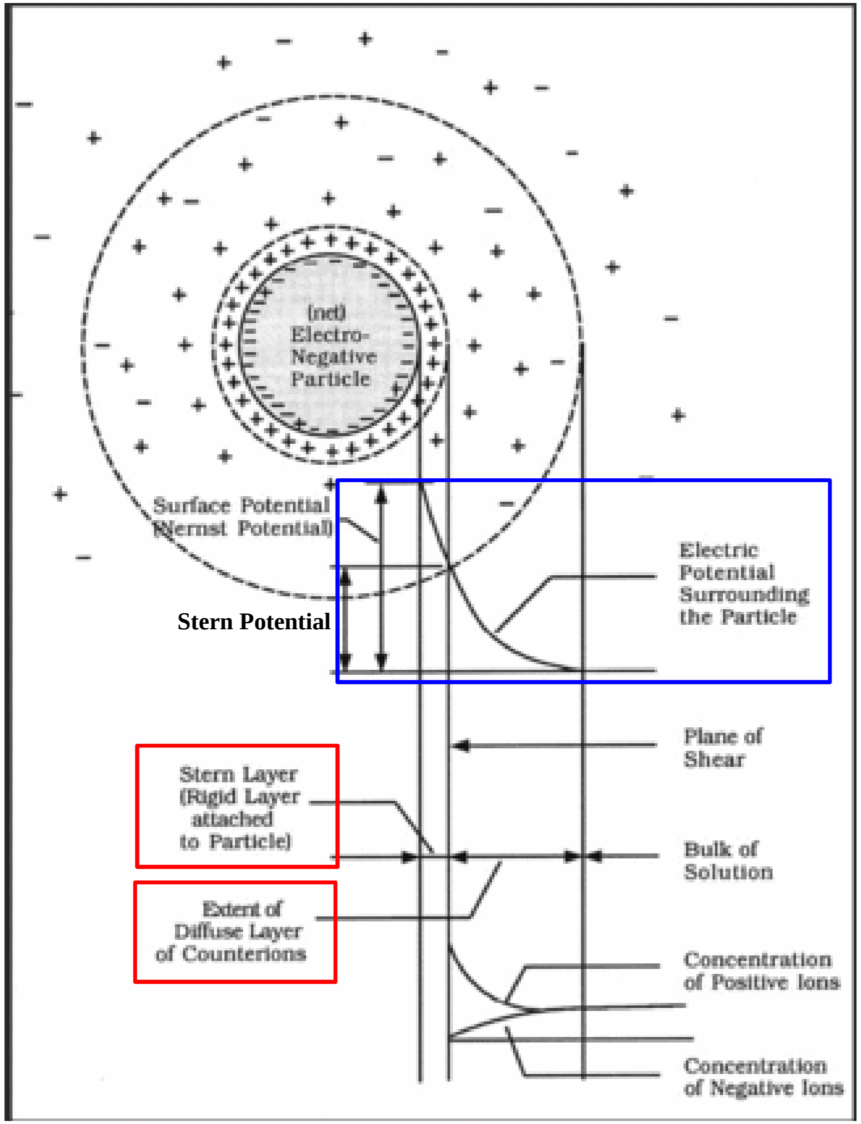
- Small particles (0.001 to 1 μm)
- Usually negatively charged
- Stability of colloidal suspension
  - "Stable" colloidal suspension:

    particles are like-charged (usually (-) charge)

    → 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

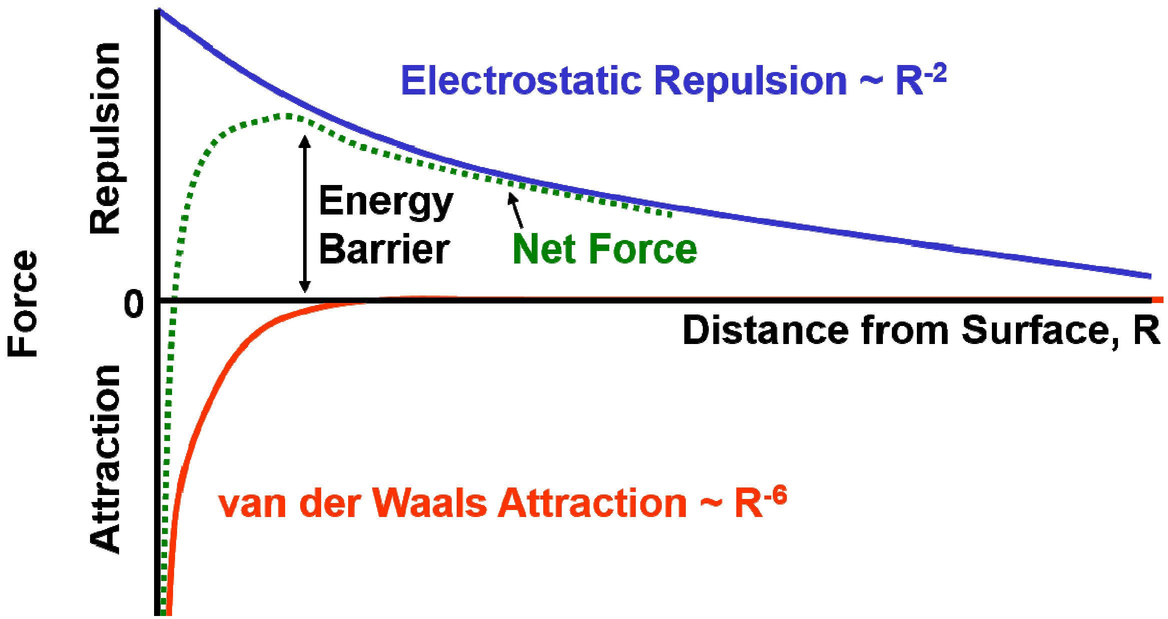
Colloids – electrical double layer



- 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

http://imk209.wikispaces.com

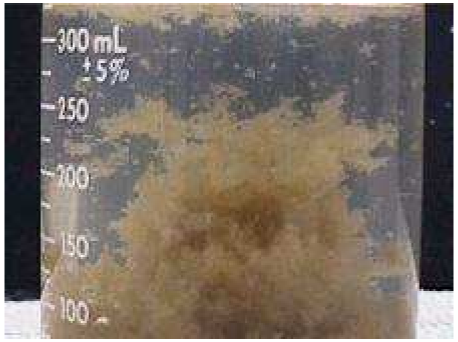
Colloids – electrical double layer



- 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)



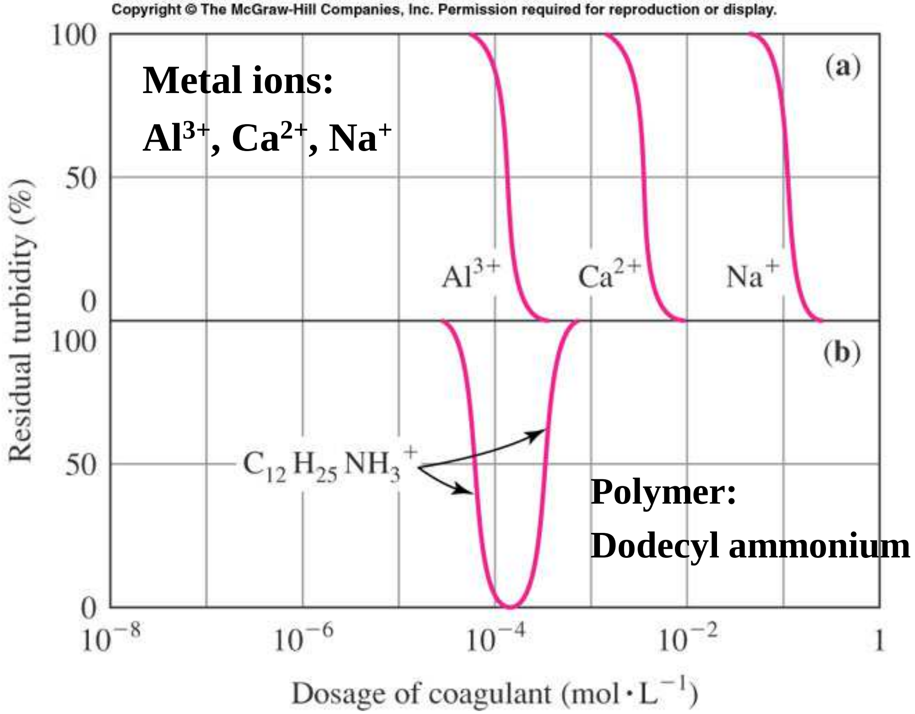
http://www.wrights-trainingsite.com/WT%20coagfloconb.html

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 (-) → (+)

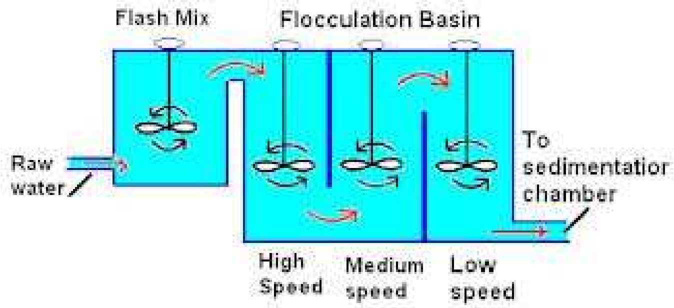
Coagulants

- Key properties
  - Trivalent cation (if a metal salt is to be used)
  - Nontoxic
  - Insoluble in neutral pH

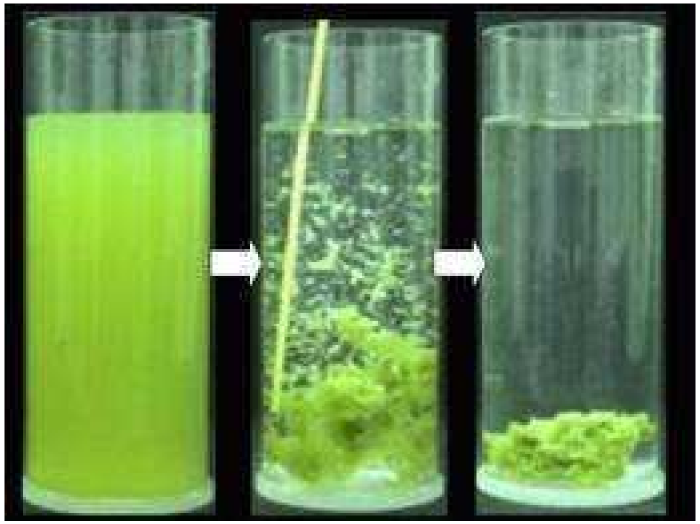
- Commonly used coagulants
  - Al^{3+} or Fe^{3+} salts
  - Alum ($Al_2(SO_4)_3 \cdot 14H_2O$): most common
    - Alum dissolution: $Al_2(SO_4)_3 \cdot 14H_2O \leftrightarrow 2Al^{3+} + 3SO_4^{2-} + 14H_2O$
  - Ferric (Fe^{3+}) cations: $Fe_2(SO_4)_3 \cdot 7H_2O$, $FeCl_3 \cdot 7H_2O$

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

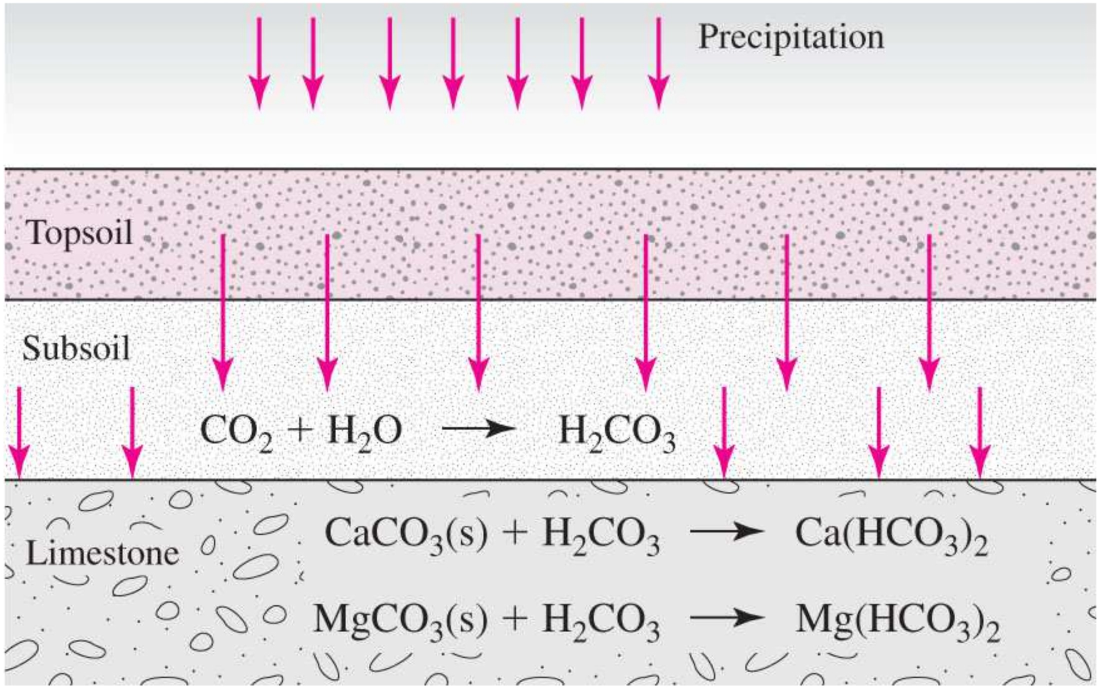
Softening

- 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



- As rainwater infiltrates, the water gets CO_2 by the respiration of microorganisms
- Recall $CO_2 + H_2O \rightarrow H_2CO_3$
- 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

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

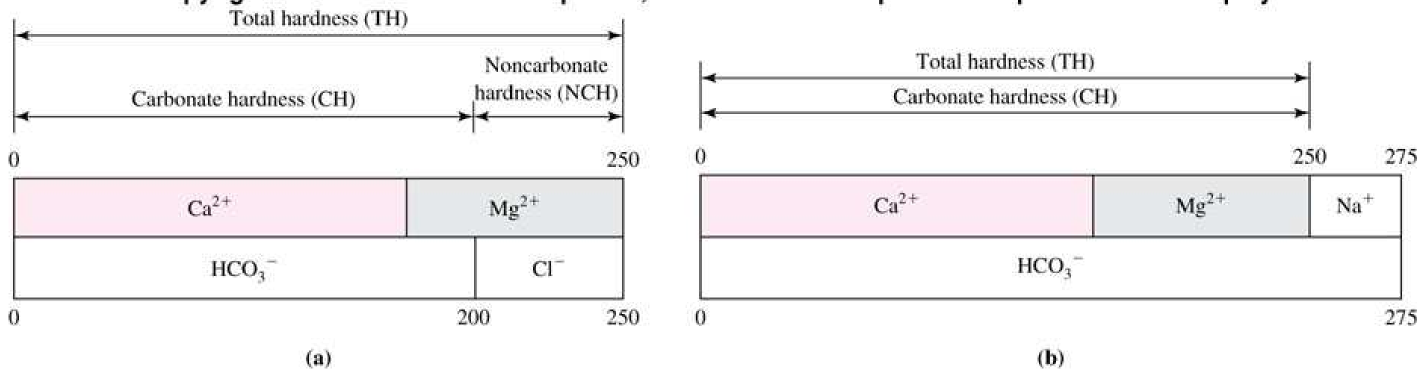
$$= \sum_{i=1}^{n} (X^{m+})_i$$

  - 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 > Alk** (≈ **[HCO_3^-]** + 2[CO_3^{2-}]), **CH = Alk**, NCH = TH - CH
    - When **TH ≤ Alk**, **CH = TH**, NCH = 0



Hardness

- Units
  - eq/L or meq/L
  - mg/L as $CaCO_3$ (recall alkalinity unit)
  - Unit conversion: (mg/L as $CaCO_3$) = 50 x (meq/L)

    (as $CaCO_3$ 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:

$$Ca^{2+} + CO_3{}^{2-} \rightleftharpoons CaCO_3\,(s)$$

$$Mg^{2+} + 2OH^{-} \rightleftharpoons Mg(OH)_2(s)$$

- 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

Hardness

Slide#22 solution)

Don't have to consider Na^+, K^+, SO_4^{2-} and Cl^-

Ion	**Conc. (mg/L)**	**Ion weight**	**Conc. (mM)**	**Conc. (meq/L)**
Ca^{2+}	40	40	1.0	2.0
Mg^{2+}	10	24.3	0.41	0.82
HCO_3^-	110	61	1.8	1.8

$TH = (Ca^{2+}) + (Mg^{2+}) = 2.8$ meq/L

TH in mg/L as $CaCO_3$ = 2.8 meq/L x 50 mg/meq = 140 mg/L as $CaCO_3$

Since $(Ca^{2+}) + (Mg^{2+}) > (HCO_3^-)$,

$CH = (HCO_3^-) = 1.8$ meq/L = 90 mg/L as $CaCO_3$

NCH = TH – CH = 140 – 90 = 50 mg/L as $CaCO_3$