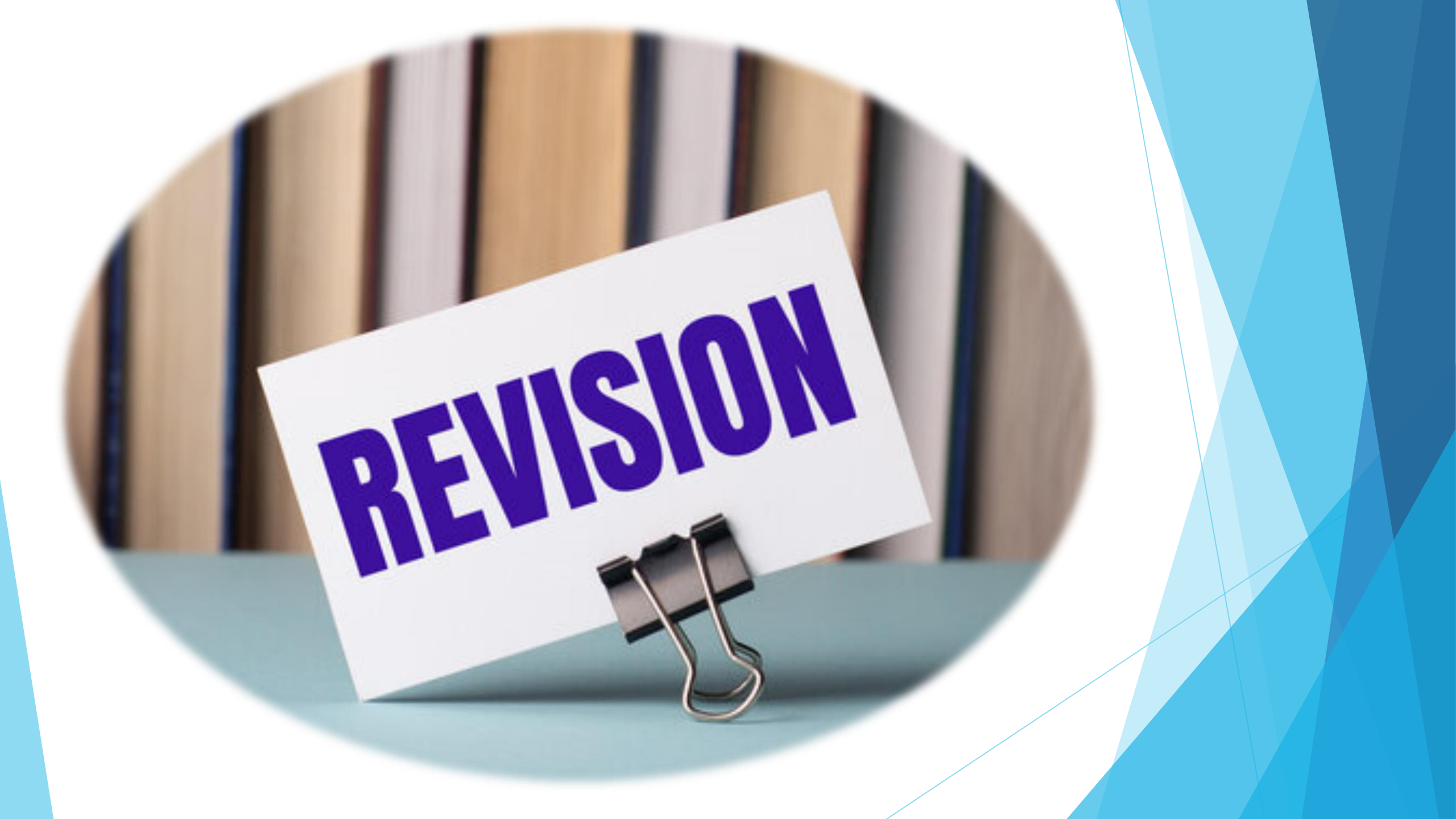


A terrarium containing a small, vibrant green tree with a visible root system and soil. The terrarium is set against a blurred background of green foliage and warm, golden light. The overall image conveys a sense of environmental stewardship and sustainability.

Fundamental Principles of Environmental Engineering

By Dr. Abdelmeguid E. Aboubaraka



REVISION

Process selection

Contaminant Properties

Source water quality

Removal efficiency

Reliability

Flexibility

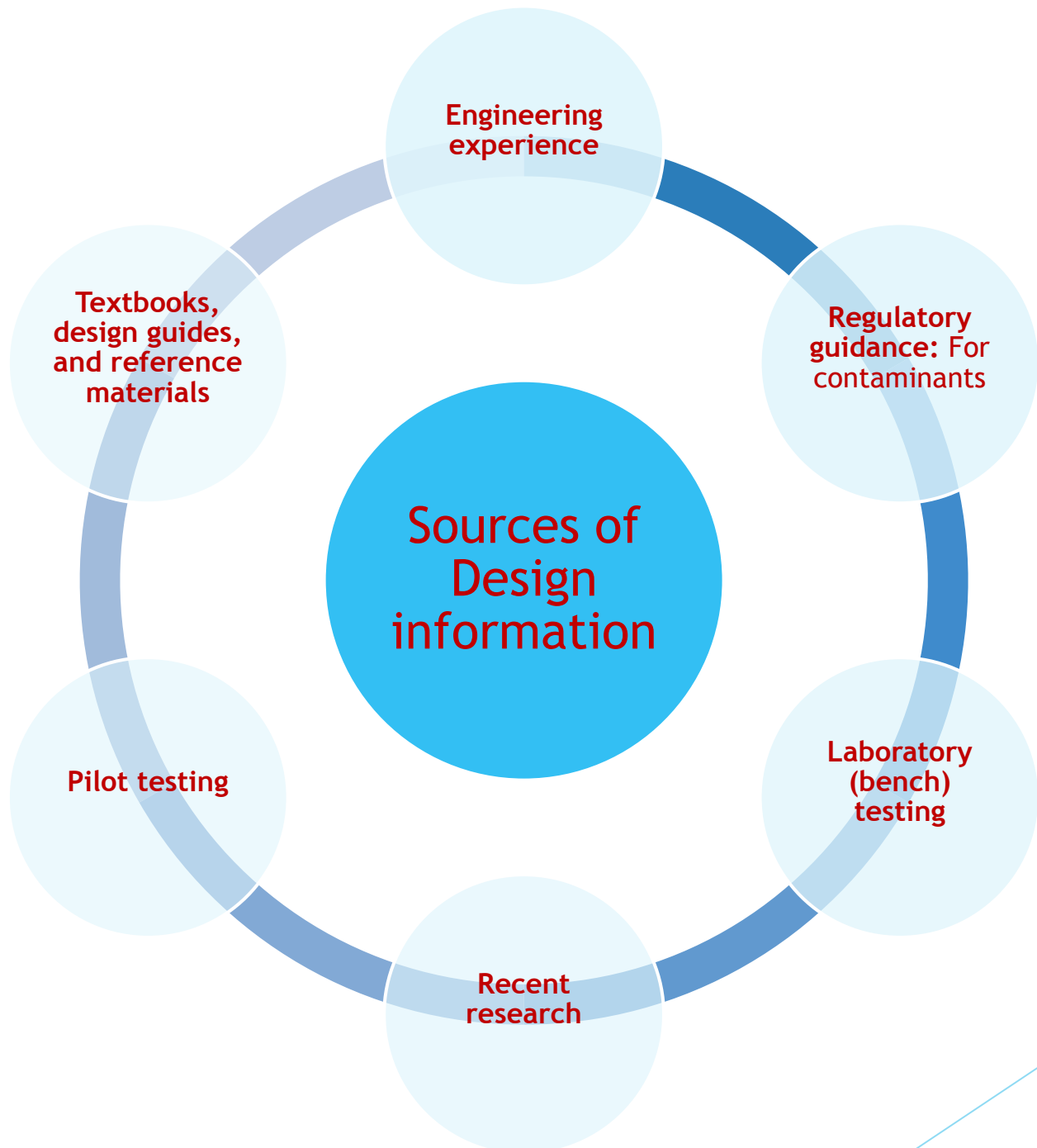
Sustainability and Energy Considerations

Cost

Utility Experience

Successful Operating History

Desired finished-water quality



**Sources of
Design
information**

**Engineering
experience**

**Regulatory
guidance: For
contaminants**

**Laboratory
(bench)
testing**

**Recent
research**

Pilot testing

**Textbooks,
design guides,
and reference
materials**



Life-Cycle Assessment

- Goals and scope
- Quantify inputs and outputs.
- Environmental impacts
- Result interpretation

Life-Cycle Assessment of Water Treatment Facilities

Specific energy consumption during pumping



plant operation

- Energy consumption
80%
- Chemicals and consumable
- Waste

Specific energy consumption during pumping

$$P_W = \frac{Q_F P}{e}$$

where P_W = power, W (or rate of energy consumption, kWh/d)
 Q_F = feed water flow rate, m³/d or ML/d
 P = pressure, Pa
 e = efficiency

$$P = \rho gh$$

where ρ = density of fluid, kg/m³
 g = gravitational constant, 9.81 m/s²
 h = head, m

Specific energy consumption is the energy consumed per unit volume of water produced and can be calculated from

$$E = \frac{P_W}{Q_P}$$

where E = specific energy consumption, kWh/m³
 Q_P = product water flow rate, m³/d or ML/d

$$r = \frac{Q_P}{Q_F}$$

where r = is the recovery.

Calculate the specific energy consumption of the following cases

A- Reverse osmosis (RO) system designed to produce $19,000 \text{ m}^3/\text{d}$ (Q_p) (5 mgd) at 80 percent recovery. The RO feed pumps operate at 16 bar (232 psi) and 87 percent efficiency

B- Distribution pumps operating at $3785 \text{ m}^3/\text{d}$ (1 mgd), 90 m head (295 ft), and 85 percent efficiency.

Solution

Part 1

1. Calculate the feed water flow using

$$r = \frac{Q_P}{Q_F}$$

$$Q_F = Q_P/r = (19,000 \text{ m}^3/\text{d})/(0.80) = 23,750 \text{ m}^3/\text{d}$$

Calculate the pump power

$$1 \text{ bar} = 10^5 \text{ N/m}^2$$

$$1 \text{ N} \cdot \text{m} = 1 \text{ J} = 1 \text{ W} \cdot \text{s},$$

$$\text{so } 1 \text{ kWh} = 3.6 \times 10^6 \text{ N} \cdot \text{m}$$

$$P_W = \frac{Q_F P}{e} = \frac{(23,750 \text{ m}^3/\text{d})(16 \times 10^5 \text{ N/m}^2)}{0.87(86,400 \text{ s/d})}$$
$$= 5.06 \times 10^5 \text{ N} \cdot \text{m/s} = 506 \text{ kW}$$

Calculate specific energy consumption

$$E = \frac{P_W}{Q_P} = \frac{506 \text{ kW}(24 \text{ h/d})}{19,000 \text{ m}^3/\text{d}} = 0.64 \text{ kWh/m}^3$$

Part 2

Calculate the pressure produced by the pump

$$1 \text{ N} = 1 \text{ kg} \cdot \text{m}/\text{s}^2$$

$$P = \rho gh = (1000 \text{ kg}/\text{m}^3)(9.81 \text{ m}/\text{s}^2)(90 \text{ m}) = 8.83 \times 10^5 \text{ N}/\text{m}^2$$

Calculate specific energy consumption

Note that $Q_F = Q_P$ so the flow cancels out

$$E = \frac{P}{e} = \frac{8.83 \times 10^5 \text{ N}/\text{m}^2}{0.85} \left(\frac{1 \text{ kWh}}{3.6 \times 10^6 \text{ N} \cdot \text{m}} \right) = 0.29 \text{ kWh}/\text{m}^3$$



Fundamental Principles of Environmental Engineering

A-Units of Expression for Chemical Concentrations

Mass concentration

is expressed as units of mass of a component per volume of solution.

- ▶ constituents are present in water in
- ▶ $\text{mg/L} = (\text{PPm})$
- ▶ $\mu\text{g/L} = \text{parts per billion (ppb)}$,
- ▶ $\text{parts per trillion (ppt)} = \text{ng/L}$

they are only equivalent when the solution has a density of 1 kg/L .

$$88 \text{ kg} = 88 \text{ kg} \left(1000 \frac{\text{g}}{\text{kg}} \right) \left(1000 \frac{\text{mg}}{\text{g}} \right) \left(1000 \frac{\mu\text{g}}{\text{mg}} \right) = 88,000,000,000 \mu\text{g}$$

kg to μg , the sequence might be any one of the following:

$$\text{kg} \Rightarrow \text{g} \Rightarrow \text{mg} \Rightarrow \mu\text{g}$$

$$\text{kg} \Rightarrow \mu\text{g}$$

A-Units of Expression for Chemical Concentrations

- ▶ Molar concentration is preferred, particularly when working with chemical stoichiometry or when the basis for the mass is not clear.
- ▶ can be converted to mass concentrations if the molecular weight is known:

$$[A](MW) = C_A$$

Molar concentration

(gram moles per liter)
(gmmols/L).

or molarity [A] Molarity is the number of gram moles of solute per liter of solution

Gram moles = the mass in grams/
the molecular mass

where [A] = molar concentration of component A, mol/L
MW = molecular weight of component A, g/mol
 C_A = mass concentration of component A, g/L

For example,

Consider calcium carbonate. This substance has a mass density equals 2.6 g/cc. Suppose, 35 mg is dissolved in a liter of water, find the corresponding molarity.

- ▶ **The answer**
- ▶ The mass of 35 mg is 0.035 g.
- ▶ Calcium carbonate has a molecular weight of 100 g/mol;
- ▶ thus, 0.035 g is $0.035/100 = 0.00035$ gmol.
- ▶ The volume corresponding to 0.35 g is $0.035/2.6 = 0.0135$ cc = 0.0000135 L
- ▶ the total volume of the mixture is 1.0000135 L.
- ▶ the corresponding molarity of 35 mg dissolved in one liter of water is
- ▶ $0.00035/1.0000135 = 0.00035$ M.

A-Units of Expression for Chemical Concentrations

Mole fraction or mass fraction

- is the ratio of the amount or mass of a given component to the total amount or mass of all components
- are most suitable for concentrated solutions.

$$X_A = \frac{n_A}{\sum_{i=1}^N n_i}$$

$$C_A = \frac{m_A}{\sum_{i=1}^N m_i}$$

where X_A = mole fraction of component A
 n_A, n_i = amounts of component A and component i ,
 C_A = mass fraction of component A
 m_A, m_i = mass of component A and component i , kg
 N = number of components

Example

The results of an analysis in a sample of water are shown in the table below. Calculate the mole fractions of the respective species.

Ions	Conc (mg/L)
Ca(HCO ₃) ₂	150
Mg(HCO ₃) ₂	12.0
Na ₂ SO ₄	216.0

Ions	Conc (mg/L)	Molecular Mass	Moles/Liter	Mole Fraction
Ca(HCO ₃) ₂	150	$40.1(2) + 2\{1 + 12 + 3(16)\} = 202.2$	0.74 ^a	0.32 ^b
Mg(HCO ₃) ₂	12.0	$24.3(2) + 2\{1 + 12 + 3(16)\} = 170.6$	0.07	0.03
Na ₂ SO ₄	216.0	$23(2) + 32.1 + 4(16) = 142.1$	1.52	0.65
		Sum = Σ	2.33	1.00

$$^a \frac{150}{202.2} = 0.74$$

$$^b \frac{0.74}{2.33} = 0.32$$

A-Units of Expression for Chemical Concentrations

Mass concentration

Stoichiometric Factors

“X” is a common method of expressing concentration in environmental engineering because water quality parameters are often composed of multiple constituents.

- ▶ nitrogen can be present in water as NH_3 , NH_4^+ , NO_3^- , or NO_2^- , each of which has a different molecular weight
- ▶ The concentration of hardness, alkalinity
- ▶

$$\text{mg/L chloride as NaCl} = \frac{\text{mg Cl}^-}{\text{L}} \times \frac{\text{formula weight of sodium chloride}}{\text{formula weight of chlorine}}$$

A- Units of Expression for Chemical Concentrations

Normality (N) or equivalents/volume (eq/L)

of analyte dissolved and diluted to a 1-L volume, designated by

$$N = \frac{m_A}{(\text{EW}) V}$$

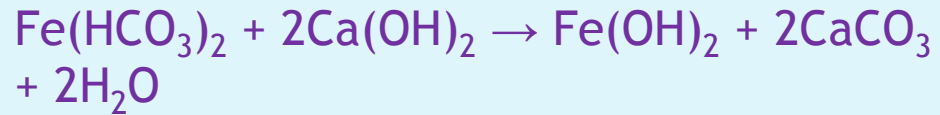
where N = normality of component A, eq/L
 m_A = mass of component A, g
EW = equivalent weight of component A, g/eq
 V = volume of solution, L

The equivalent weight is expressed as

$$\text{EW} = \frac{\text{MW}}{z}$$

where z is the equivalents per mole of the component. For ionic species in water, z is equal to the valence; for oxidation–reduction reactions, z is equal to the number of electrons transferred; and for acid/base reactions, z is equal to the number of replaceable hydrogen atoms or their equivalent.

Equivalent mass based on ionic charge



the equivalent mass OF $\text{Fe}(\text{HCO}_3)_2$ is
MW of $\text{Fe}(\text{HCO}_3)_2/2$

Equivalent mass based on acid-base reactions



The equivalent mass of H_3PO_4 is MW of
 $\text{H}_3\text{PO}_4/2$

equivalent mass of NaOH is MW NaOH/1

▶ Equivalent mass based on oxidation-reduction reactions



- ▶ The ferrous is oxidized to the ferric form from an oxidation state of +2 to +3.
- ▶ equivalent mass of $\text{Fe}(\text{OH})_2$ is then $4\text{MW Fe}(\text{OH})_2/4$.
- ▶ the equivalent mass of oxygen is $\text{MW O}_2/4$

Equivalent concentration and normality.

- ▶ first convert the molar concentration to mass concentration by multiplying it by the molecular mass (MM).
- ▶ the equivalent concentration, $[C]_{\text{eq}}$, is
- ▶ The concentration expressed as geq/L is the normality.
- ▶ **Example** : The concentration of $\text{Ca}(\text{HCO}_3)_2$ is 0.74 gmol/L . Convert this concentration to geq/L .

$$[C]_{\text{eq}} = \frac{[C](MM)}{\text{eq. mass}}$$

$$[C]_{\text{eq}} = \frac{[C](MM)}{\text{eq. mass}}$$

$$[C] = 0.74 \text{ gmol/L}$$

$$MM = 40.1(2) + 2\{1 + 12 + 3(16)\} = 202.2$$

$$\text{Therefore, eq. mass} = \frac{\text{Ca}(\text{HCO}_3)_2}{2} = \frac{202.2}{2}$$

$$[C]_{\text{eq}} = \frac{0.74(202.2)}{\frac{202.2}{2}} = 1.48 \text{ geq/L}$$

A- Units of Expression for Chemical Concentrations

Log molar concentrations

are used because concentrations often vary by many orders of magnitude, making logarithms convenient.

$$[C] = 2 \times 10^{-5} \text{ mol/L,}$$

then $\log[C] = -4.7$ and

$$[C] = 10^{-4.7} \text{ mol/L.}$$

► **The *p* notation**

the negative of the base-10 log of the value:

$$pC = -\log(C)$$

C = is the concentration of a constituent in solution (in mol/L).

The pH of a solution is defined as

$$\text{pH} = -\log[\text{H}^+]$$

The *p* notation can be used for any value, not just concentrations.

Calculate the concentration of 0.85 mM solution of calcium in units of

mg/L,

meq/L,

mg/L as CaCO₃,

log molar

concentration,

p notation.

To mg/L

(the MW of Ca = 40 g/mol = 40 mg/mmol)

$$0.85 \text{ mmol/L} = (0.85 \text{ mmol/L})(40 \text{ mg/mmol}) = 34 \text{ mg/L}$$

To meq/L

Calcium ion are divalent and have a charge of +2

$$0.85 \text{ mmol/L} = (0.85 \text{ mmol/L})(2 \text{ meq/mmol}) = 1.7 \text{ meq/L}$$

Ca in mg/L as CaCO₃

The MW of CaCO₃ = 100 g/mol.

$$0.85 \text{ mmol/L} = (0.85 \text{ mmol/L})(100 \text{ mg/mmol}) = 85 \text{ mg/L as CaCO}_3$$

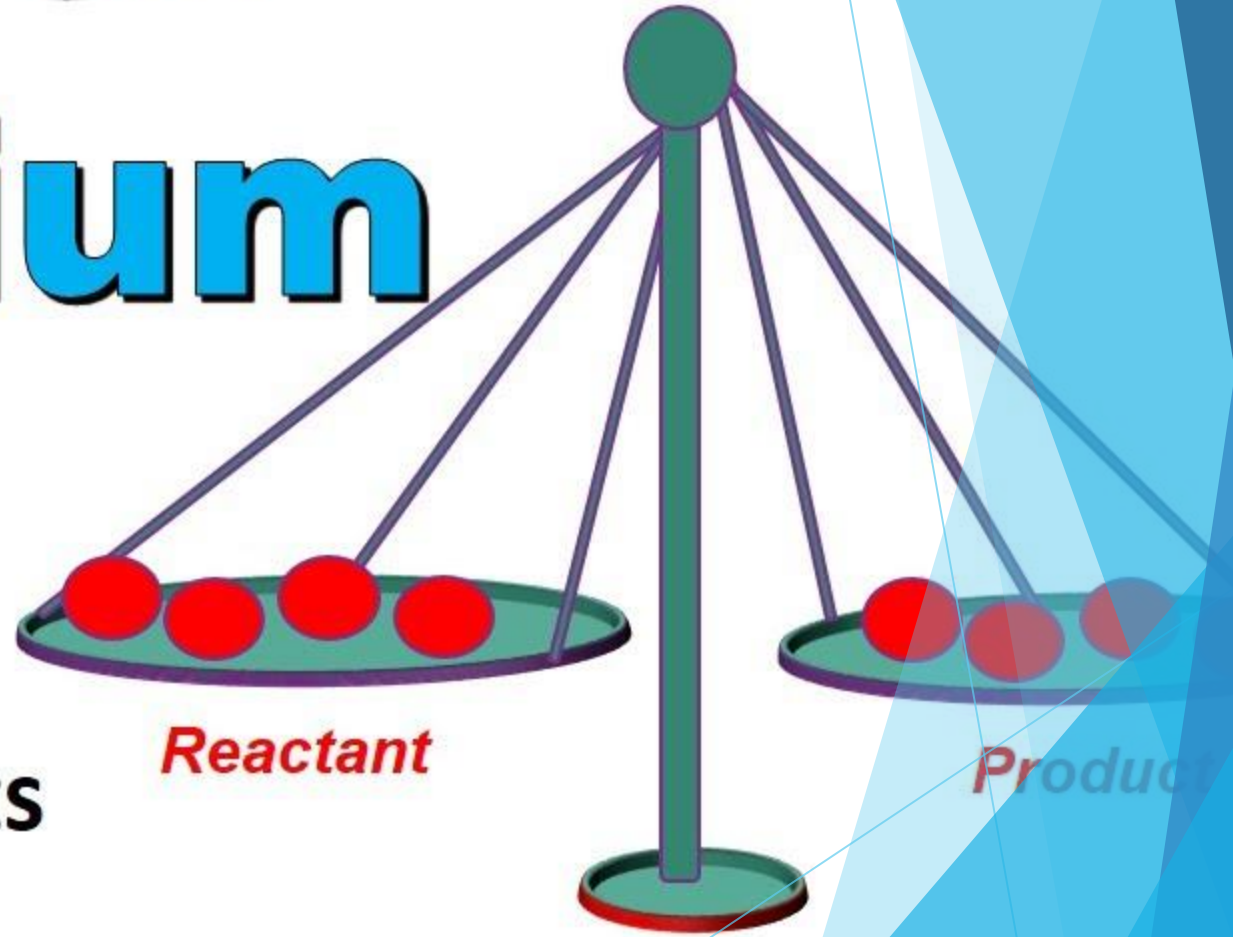
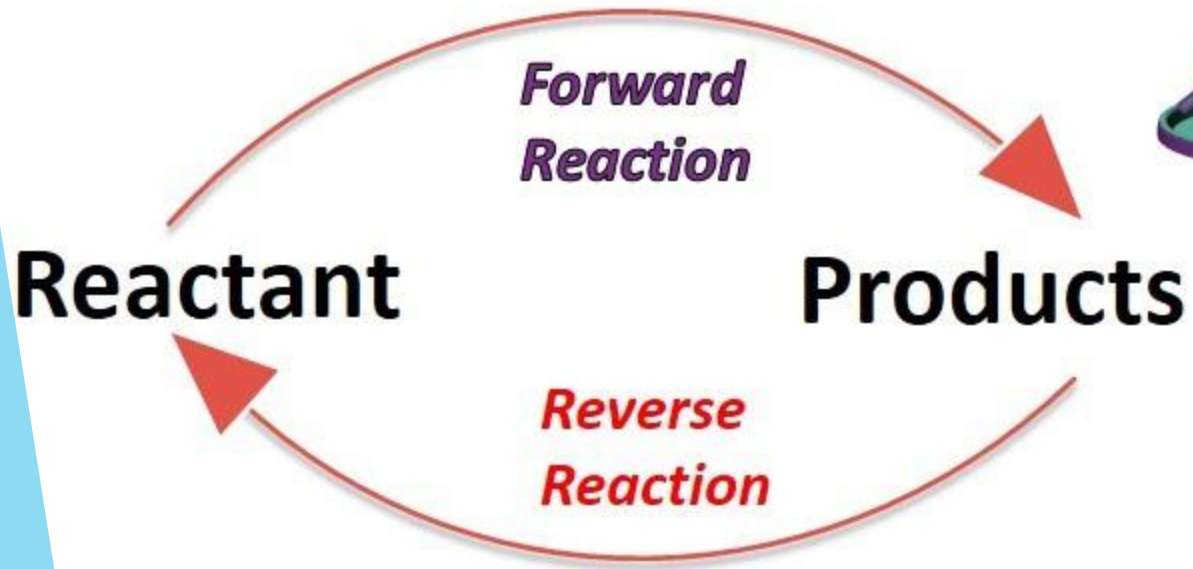
Ca in log molar concentration and p notation.

$$\log(0.85 \times 10^{-3} \text{ mol/L}) = -3.07$$

$$[\text{Ca}] = 10^{-3.07} \text{ M}$$

$$\text{pCa} = 3.07$$

Chemical Equilibrium



Chemical reactions

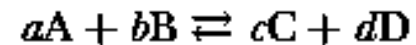
used in water treatment to change the physical, chemical, and biological nature of water to accomplish water quality objectives.

The most important reaction:

- ▶ acids and bases,
- ▶ precipitation of solids,
- ▶ complexation of metals,
- ▶ oxidation of reduced species

The reaction stoichiometry:

The relationship between the relative amount of each reactant needed to produce an amount of each product



where a, b, c, d = stoichiometric coefficients of species A, B, C, D, respectively, unitless



Irreversible reactions consume reactants and form products until one of the reactants is totally consumed. Oxidation–reduction reactions



At equilibrium, both bicarbonate and carbonate can be present in solution and the relative concentration of each will depend on the solution pH



Reversible reactions are those that proceed until an equilibrium condition is reached; at this equilibrium, both reactants and products may be present.

Symbol	Description	Comments
→	Irreversible reaction	Single arrow points from the reactants to the products, e.g., $A + B \rightarrow C$.
⇌	Reversible reaction	Double arrows used to show that the reaction can proceed in the forward or reverse direction, depending on the solution characteristics.
[]	Brackets	Concentration of a chemical species in standard units (mol/L for aqueous phase).
{ }	Braces	Activity of a chemical constituent.
(s)	Solid phase	Designates a chemical species present in solid phase, e.g., calcium carbonate, $\text{CaCO}_3(\text{s})$.
(l)	Liquid phase	Designates a chemical species present in liquid phase, e.g., liquid benzene, $\text{C}_6\text{H}_6(\text{l})$.
(aq)	Aqueous (dissolved)	Designates a chemical species dissolved in water, e.g., ammonia in water, $\text{NH}_3(\text{aq})$.
(g)	Gas	Designates a chemical species present in gas phase, e.g., chlorine gas, $\text{Cl}_2(\text{g})$.
\xrightarrow{x}	Catalysis	Chemical species, represented by x, catalyzes reaction, e.g, cobalt (Co) is the catalyst in the reaction $\text{SO}_3^{2-} + 0.5\text{O}_2 \xrightarrow{\text{Co}} \text{SO}_4^{2-}$.
↑	Volatilization	Arrow directed up following a component is used to show volatilization of given component, e.g., $\text{CO}_3^{2-} + 2\text{H}^+ \rightleftharpoons \text{CO}_2(\text{g}) \uparrow + \text{H}_2\text{O}$.
↓	Precipitation	Arrow directed down following a component is used to show precipitation of given component, e.g., $\text{Ca}^{2+} + \text{CO}_3^{2-} \rightleftharpoons \text{CaCO}_3(\text{s}) \downarrow$.

Example

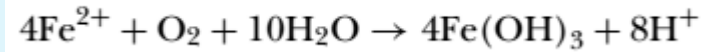
A groundwater used as a drinking water supply contains 2.6 mg/L of Fe^{2+}

Calculate the amount of O_2 that will be needed to oxidize it and the amount of $\text{Fe}(\text{OH})_3$ that will be produced.

Assume that the reaction proceeds to completion.

▶ The answer

- ▶ removing Fe^{2+} from water is to oxidize it with oxygen to produce insoluble ferric hydroxide $[\text{Fe}(\text{OH})_3]$ according to the following reaction:



- ▶ 1mol of O_2 is capable of oxidizing 4mol of Fe^{2+} ;
- ▶ it will form 4mol of $\text{Fe}(\text{OH})_3$ and 8mol of H^+ .
- ▶ Using reaction stoichiometry and the molecular weight of the chemical species to calculate the mass of reactants and products participating in a reaction

The answer

- ▶ Determine the molecular weight of each species from the atomic weights
- ▶ MW of Fe^{2+} = 55.8 g/mol
MW of O_2 = (2)16.0 g/mol = 32.0 g/mol
MW of $\text{Fe}(\text{OH})_3$ = 55.8 + (3)(1.0) + (3)(16.0) = 106.8 g/mol

- ▶ Calculate the concentration of oxygen required to oxidize the iron.
$$= (32 \times 2.6) / (56 \times 4) = 0.37 \text{ mg/L O}_2$$
- ▶ Therefore, 0.37 mg/L of O_2 is capable of oxidizing 2.6 mg/L of Fe^{2+}
- ▶ Calculate the concentration $\text{Fe}(\text{OH})_3$ that will be produced.
$$= 2.6 \times 106.8 / 56 = 4.98 \text{ mg/L Fe}(\text{OH})_3$$
- ▶ Therefore, 4.98 mg/L of $\text{Fe}(\text{OH})_3$ will be produced when 2.6 mg/L of Fe^{2+} is oxidized

Concentration and Activity

The ability of a species to participate in chemical reactions depends on its chemical *activity*. At equilibrium, the amounts of reactants and products present will depend on the activity of each species.

The activity of a species is related to its concentration by an activity coefficient:

$$\{A\} = \gamma[A]$$

where $\{A\}$ = activity of species A

γ = activity coefficient for species A

$[A]$ = concentration of species A

- ▶ The activity coefficient for ionic species depends on the overall ionic content of the solution, which is characterized by the ionic strength. The ionic strength is calculated using the equation

$$I = \frac{1}{2} \sum_i C_i z_i^2$$

where I = ionic strength of solution, mol/L
 C_i = concentration of species i , mol/L
 z_i = charge (valence) on species i , unitless

$$I = (2.5 \times 10^{-5}) (\text{TDS})$$

$$I = (1.6 \times 10^{-5}) (\text{EC})$$

where TDS = total dissolved solids, mg/L
EC = electrical conductivity, $\mu\text{S}/\text{cm}$

Example

For water with an ionic strength of 5 mM (corresponding to TDS of about 200 mg/L), calculate the activity coefficients of Na⁺ and Ca²⁺ at 25°C.

For solutions up to $I \leq 0.5$ M, Davies equation

$$\log(\gamma) = -Az^2 \left(\frac{\sqrt{I}}{1 + \sqrt{I}} - 0.3I \right)$$

where A = constant (for water at 25°C, A = 0.50)

- ▶ the activity coefficients for Na⁺

$$5 \text{ mM} = 0.005 \text{ M}$$

$$\log(\gamma_{\text{Na}^+}) = -0.50(1)^2 \left[\frac{\sqrt{0.005}}{1 + \sqrt{0.005}} - 0.3(0.005) \right] = -0.0323$$

$$\gamma_{\text{Na}^+} = 10^{-0.0323} = 0.93$$

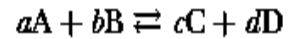
- ▶ the activity coefficient for Ca²⁺

$$\log(\gamma_{\text{Ca}^{2+}}) = -0.50(2)^2 \left[\frac{\sqrt{0.005}}{1 + \sqrt{0.005}} - 0.3(0.005) \right] = -0.129$$

$$\gamma_{\text{Ca}^{2+}} = 10^{-0.129} = 0.74$$

The charge on the species has a large influence on the value of the activity coefficient.

Equilibrium Constants



where a, b, c, d = stoichiometric coefficients of species A, B, C, D, respectively, unitless

$$K = \frac{\{C\}^c \{D\}^d}{\{A\}^a \{B\}^b}$$

where K = equilibrium constant

$\{ \}$ = activity of species

a, b, c, d = stoichiometric coefficients of species A, B, C, D, respectively

$$K = \frac{[C]^c [D]^d}{[A]^a [B]^b}$$

$$pK = -\log(K)$$

▶ Example

Calculating concentrations using equilibrium constants

▶ Sodium hypochlorite (NaOCl) is added to water as a disinfectant.

Upon addition, it immediately dissociates according to the following reaction:



The hypochlorite then participates in the following reversible acid-base reaction:



The strength of hypochlorite as a disinfectant depends on which species is present; thus, it is important to know how much is present as HOCl and how much as OCl⁻ at equilibrium.

▶ If 2 mg/L of NaOCl is added,

▶ Determine how much is present as each species at pH 7.0.

Solution

Calculate the molar concentration of NaOCl

the MW of NaOCl can be determined to be 74.5 g/mol

Total OCl⁻ = [NaOCl] = 2 mg/L / (74.5 g/mol) (10³ mg/g) = 2.68 × 10⁻⁵ M

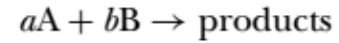
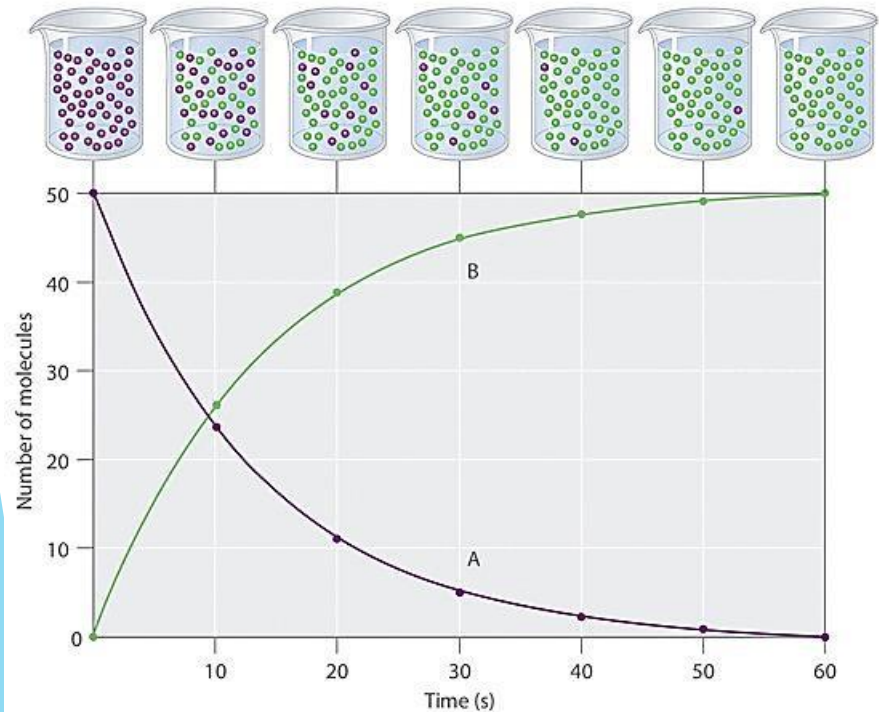
$$pK_a = 7.6 = -\log 7.6 = 10^{-7.6}$$

$$K_a = \frac{[H^+][OCl^-]}{[HOCl]} = 10^{-7.6}$$

- ▶ Determine the ratio of [OCl⁻] to [HOCl] at pH = 7.0.
at pH 7 = -log 7 = 10⁻⁷
- ▶ hydrogen ion concentration [H⁺] at pH 7.0 is equal to 10^{-7.0} M
- ▶
$$\frac{[OCl^-]}{[HOCl]} = \frac{K_a}{[H^+]} = \frac{10^{-7.6}}{10^{-7}} = 10^{-0.6} = 0.25$$
- ▶ At pH = 7.0, 25 percent of the total hypochlorite added is present as OCl⁻ and the rest is present as HOCl.
- ▶ [OCl⁻] = 0.25(2.68 × 10⁻⁵ M) = 6.71 × 10⁻⁶ M = 6.71 μM
- ▶ [HOCl] = 0.75(2.68 × 10⁻⁵ M) = 2.01 × 10⁻⁵ M = 20.1 μM

Chemical Kinetics

Chemical kinetics is the study of the rate at which chemical reactions take place, that is, the speed at which reactants are consumed and products are formed.



The rate equation for the reaction in Eq. 4-25 is

$$r_A = -k[A]^m[B]^n$$

where k = reaction rate constant, units vary (see below)

m, n = reaction order constants, unitless

Two common forms of rate equations :

First-order reactions depend on the activity of only one species and have the rate equation

$$r_A = -k[A]$$

where k = first-order reaction rate constant, s^{-1}

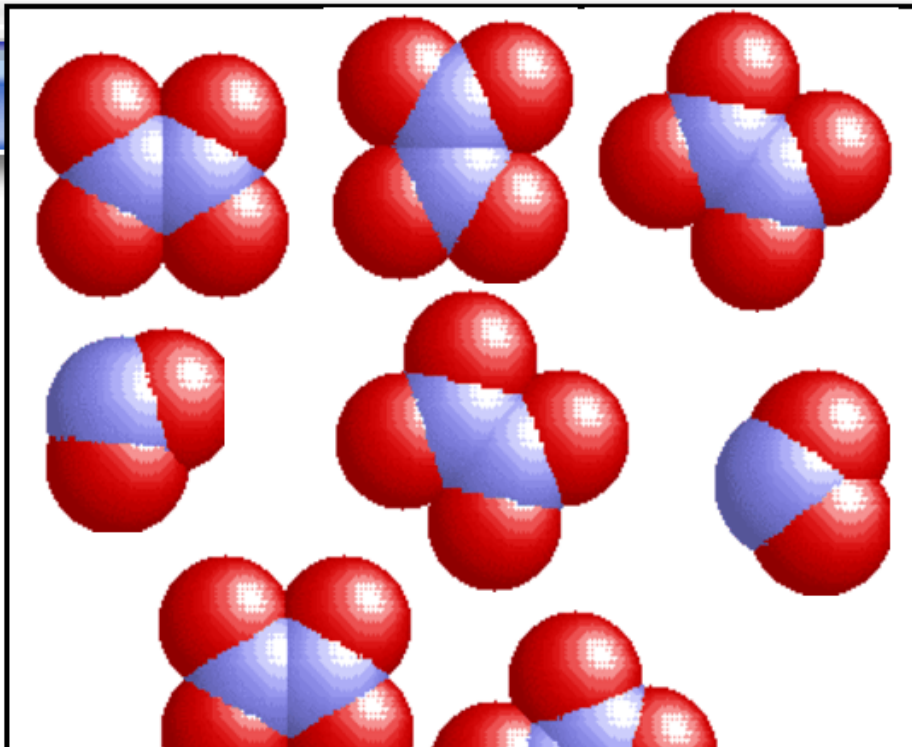
Second-order reactions depend on collisions of two molecules of the same species or on collisions between molecules of two different species

$$r_A = -k[A]^2$$

$$r_A = -k[A][B]$$

where k = second-order reaction rate constant, $L/mol \cdot s$

Reactions Used in Water Treatment



Acid-base reactions

- ▶ Acid-base reactions involve the transfer of a hydrogen ion, or proton, between two species.



where HA = acid species
H⁺ = hydrogen ion (hydrated proton, i.e., H₃O⁺)
A⁻ = conjugate base species

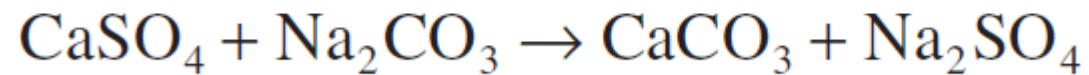
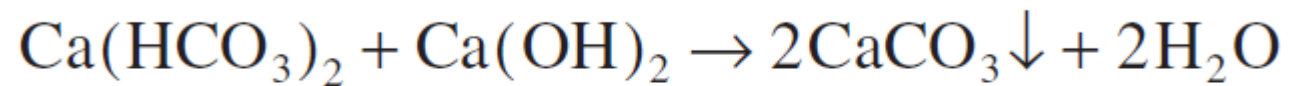
- ▶ the carbonate system is one of the most important acid-base systems in natural waters and loses two protons



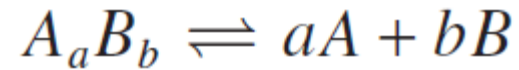
- ▶ Acid-base reactions are very fast (reaching equilibrium in less than a second), reversible reactions.
- ▶ The acid species and the conjugate base can exist simultaneously, depending on the pH of the solution.
- ▶ The equilibrium constant for an acid-base reaction is known as the acid dissociation constant, *K_a*

Precipitation- Dissolution Reactions

- ▶ In water treatment processes, dissolved contaminants can be removed by causing them to precipitate and then removing the solids from water
- ▶ The equilibrium constant between a solid and its ions in solution is known as the solubility product.
- ▶ EX: Water containing calcium bicarbonate and calcium sulfate is softened using lime and soda ash



- ▶ The equilibrium constant between a solid and its ions in solution is known as the solubility product.

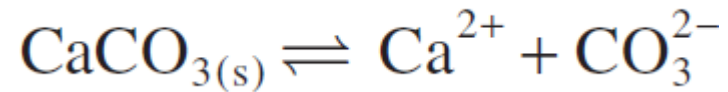


$$K = \frac{\{A\}^a \{B\}^b}{\{A_a B_b\}}$$

$$K_{sp} = \{A\}^a \{B\}^b$$

At equilibrium, neither reactants nor products increase or decrease with time. Thus, K_{sp} 's, being constants, can be used as indicators whether or not a given solid will form or dissolve in solution.

- ▶ For example,
- ▶ CaCO_3 has a K_{sp} of $4.8(10^{-9})$ at 25°C . This value decreases to $2.84(10^{-9})$ at 60°C . The equilibrium reaction for this solid is



$$\begin{aligned} K_{sp} &= \{\text{Ca}^{2+}\}(\text{CO}_3^{2-}) = 4.8(10^{-9}) \text{ at } 25^\circ\text{C} \\ &= \{\text{Ca}^{2+}\}(\text{CO}_3^{2-}) = 2.84(10^{-9}) \text{ at } 60^\circ\text{C} \end{aligned}$$

- ▶ This means that there are fewer particles of the ions existing than required to maintain equilibrium at this higher temperature.
- ▶ As a consequence, some of the particles will combine to form a precipitate, the CaCO_3 solid.

Oxidation- Reduction Reactions

Reactions that involve the transfer of electrons between two chemical species are known as oxidation-reduction, or redox, reactions.

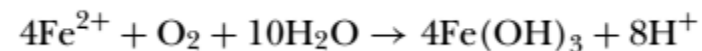
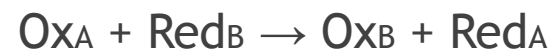
In water treatment, disinfection and chemical oxidation are common redox reactions.

In a redox reaction, one species is reduced (gains electrons) and one species is oxidized (loses electrons).

Redox reactions are typically reported as half reactions to show the number of electrons transferred.

Redox reactions are irreversible reactions that proceed until one of the reactants is totally consumed.

- ▶ The general expression
- ▶ $\text{Ox}_A + n\text{e}^- \rightarrow \text{Red}_A$
- ▶ where Ox_A = oxidized species A
- ▶ n = number of electrons transferred e^- = electron Red
- ▶ Oxidized species A is called an oxidant (or electron acceptor)
- ▶ The half reaction for the oxidation of a species
- ▶ $\text{Red}_B \rightarrow \text{Ox}_B + n\text{e}^-$
- ▶ Ox_B = oxidized species B
- ▶ Red_B = reduced species B
- ▶ Reduced species B is called a reductant (or electron donor)
- ▶ overall oxidation-reduction reaction



A hand is shown holding a small globe of the Earth. The globe is surrounded by several circular icons connected by lines, representing various energy and environmental concepts: a sun, a wind turbine, an oil pumpjack, solar panels, a gas pump, a corn cob, a recycling symbol, and a flame. The background is a soft-focus green and blue bokeh, with a blue geometric shape on the right side.

THANK YOU FOR ATTENTION

Any question!