Q1.

a) Name and discuss the mechanisms thought to occur during coagulation (5 points)

Solution:

1) Compression of electrical double layer and
2) Charge neutralization

**See book for more explanation

b) If there is no bicarbonate present in a well water that is to be softened to remove magnesium, which chemical must you add? (2 points)

Solution:

If there is no bicarbonate, then the water has only noncarbonate hardness and the chemicals required are lime and sodium carbonate (soda ash).

c) Water softening is a chemical process aimed at reducing the presence of certain ions naturally present in the water. What are those ions, and, for each, under which new chemical form are they extracted from the water at the end of the treatment? (4 points)

Solution:

Calcium (Ca^{2+}) and magnesium (Mg^{2+}) . Calcium carbonate ($CaCO_3$) and magnesium hydroxide ($Mg(OH)_2$)

d) In a few words, explain physically why the depth H of a settling tank does not enter the expression for the critical settling velocity, $V_c=Q/WL$. (4 points)

Solution:

The particle removal efficiency increases with decreasing the depth/height of the sedimentation tank and a zero height will provide the maximum particle removal (theoretically). However, in practice it's not possible since a 2-dimensional structure won't be able to hold any water.

e) A can of a volatile chemical (benzene) has spilled into a small pond. List the data you would need to gather to calculate concentration of benzene in the stream leaving the pond using the mass balance technique. Assume steady state condition and no sorption of benzene to the bottom of the pond. (5 points)

Solution:

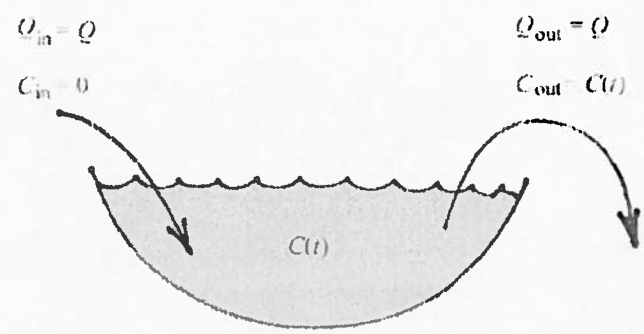
The approach to answer this question is to write a mass-balance equation for the system and use it to identify the data required for solution. In simplified terms, assume steady state and no sorption to the bottom of the pond.

Mass in = Mass that volatilizes + Mass that flows out of the pond downstream
The „Mass in" is a function of the benzene concentration and the volume in the can.
The „Mass that volatilizes" can be estimated from Henry"s law and the rate of vaporization.
The mass that flows downstream may be estimated from the concentration and the flow rate of the stream. Because the concentration is the required unknown, the problem may be solved for concentration.

2. A bankrupt chemical company has been taken over by new management. On the property they found a 20,000 m^3 brine pond containing 25 g/L of salt and they propose to flush it through a discharge pipe leading to the Atlantic ocean, which is nearby and which has a salinity of 30 g/L. What flow rate of freshwater (in L/s) must they use to reduce the salinity of the pond to 500 mg/L within one year? (5 points)

$C_t = C_0 e^{\left(-\frac{Q}{V}t\right)}$; $1\ m^3 = 1000\ L$

Denote the salinity in the pond by its time-dependent concentration $C(t)$.
Then make a mass budget with the control volume taken as the entire pond.



The salt budget takes the form:

$$V\frac{dC}{dt} = Q_{in}C_{in} - Q_{out}C_{out} + S - KVC$$

in which the source $S = 0$ because there is no chemical formation of new salt inside the pond and $K = 0$ because there is no reaction that removes salt from inside the pond. We also have: $Q_{in} = Q_{out} = Q$, the volumetric flow rate of the flushing. $C_{in} = 0$ because the entering water is fresh (no salt content) and $C_{out} = C(t)$ since the water being flushed out has the salinity of the water in the pond.

The budget then reduces to:

$$V\frac{dC}{dt} = -Q\,C(t)$$

The solution of this 1st-order differential equation is:

$$C(t) = C(t=0)\exp\left(-\frac{Q}{V}t\right)$$

Now, plug the numbers

$$(500\ mg/L) = (25{,}000\ mg/L)\exp\left(-\frac{Q}{20{,}000\ m^3}\times 365\ days\right)$$

and solve for the flow rate Q. The solution is:

$$Q = 214.4\frac{m^3}{day} = \frac{214.4\times 10^3\ L}{day} = 2.48\ L/s.$$

3. One of the most common types of fertilizers used by farmers is a form of the highly soluble salt ammonium chloride (NH_4Cl). At a certain farm, water runoff from fields carries dissolved ammonium chloride to a nearby pond, resulting in a dissolved concentration of NH_4Cl in the pond of 5 mg/L. At the same time, ammonia gas (NH_3) is being produced by cows that feed around the farmer's pond, resulting in an atmospheric level of 500 ppb above the water surface.

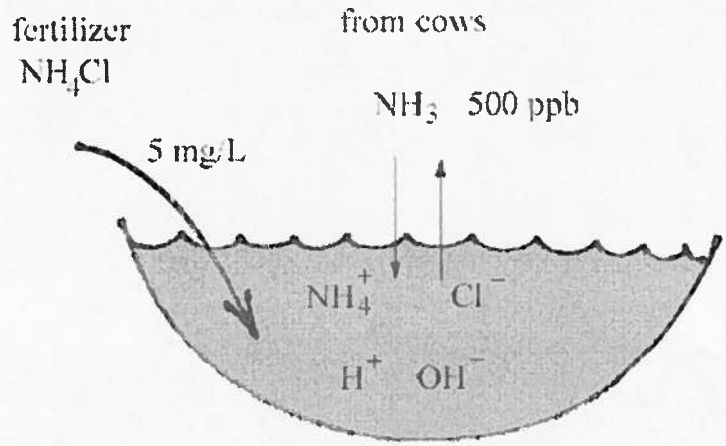
   In water, the following reactions take place

   $NH_4Cl \rightarrow NH_4^+ + Cl^-$
   $NH_4^+ \leftrightarrow NH_3 + H^+$

   The first equation represents complete dissociation (dissolution of a salt), and the second equation is reversible with equilibrium constant $[NH_3]\,[H^+]\,/\,[NH_4^+] = 5.89 \times 10^{-10}$ M. Assume that the ambient temperature is 25^0 C and the air pressure is 1 atm. Neglect the effects of other impurities such as CO_2. Calculate the pH of the pond water. (10 points)

   MW of NH_4Cl=53.5 g/mol; K_H (Henry's constant) = 62 M/atm; $[H^+][OH^-]= 10^{-14}$
   Molecular weights: H=1, N=14, Cl=35.5, O=16
   $pH=-\log_{10}[H^+]$; $H_2O = H^+ + OH^-$; $[NH_3]=K_H P_{NH3}$; P_{HH3}= mole fraction x P_{total};
   ppb= $V_i/V_{total} \times 10^9$ = $moles_i/moles_{total} \times 10^9$

(a) The chemistry of the pond and surrounding air consists of the following elements:



The fertilizer is a salt, which dissociated completely in the water. Thus,

$$NH4Cl \rightarrow NH_4^+ + Cl^-$$

While the ammonium ion NH_4^+ undergoes additional chemical changes, the Cl^- ion remains inactive. Its concentration is then entirely due to the NH_4Cl input.

To get that concentration, we first need to convert the given mass amount of NH_4Cl into moles. For this, we begin with the molecular weight of this molecule:

$$\text{MW of } NH_4Cl = 14 + 4 \times 1 + 35.50 = 53.50 \text{ g/mol}$$

The number of moles of NH_4Cl in a 5 mg/L solution is:

$$\frac{5 \times 10^{-3} \; g/L}{53.50 \; g/mol} = 9.35 \times 10^{-5} \; mol/L = 9.35 \times 10^{-5} \; M$$

Since one molecule of NH_4Cl generates one ion of Cl^-, one mole of NH_4Cl generates one mole of Cl^-, and

$$[Cl^-] = 9.35 \times 10^{-5} \text{ M}$$

Another piece of information that we have is that the NH_3 in the pond is in equilibrium with an atmospheric concentration of 550 ppb = 550 x 10^{-9} atm. By virtue of Henry's Law, with constant K_H read from table on page 96:

$$[NH_3] = K_H P_{NH3} = (62 \text{ M/atm})(550 \times 10^{-9} \text{ atm}) = 3.41 \times 10^{-5} \text{ M}$$

Now, we turn to the chemical reactions that occur in the water. There are two chemical equilibria

$$NH_4^+ \longleftrightarrow NH_3 + H^+$$
$$H_2O \longleftrightarrow H^+ + OH^-$$

each with its constant of equilibrium:

$$\frac{[NH_3][H^+]}{[NH_4^+]} = 5.89 \times 10^{-10} \; M \Rightarrow \frac{[H^+]}{[NH_4^+]} = \frac{5.89 \times 10^{-10}}{3.41 \times 10^{-5}} = 1.73 \times 10^{-5}$$
$$[H^+][OH^-] = 10^{-14} \; M^2$$

To close the set of equations, we add the requirement of electroneutrality, which takes the form:

$$[NH_4^+] + [H^+] = [Cl^-] + [OH^-]$$

Since we already know $[NH_3]$ and $[Cl^-]$, we have three equations for the following three unknowns: $[NH_4^+]$, $[H^+]$ and $[OH^-]$.

We are after the pH of the water, which demands that we know [H^+]. For this, we need to eliminate all other unknowns. Using the first two equations to solve for [NH_4^+] and [OH^-], we substitute into the electroneutrality equation, to obtain:

$$\frac{[H^+]}{1.73\times10^{-5}}+[H^+]=9.35\times10^{-5}+\frac{10^{-14}}{[H^+]}$$

of which the solution is [H^+] = 1.71 x 10^{-9} M. [There is another solution, but it is negative and unphysical.] The pH is:

$$pH=-\log_{10}[H^+]=8.77$$

This pH is above 7 (neutral water), and we conclude that the pond is alkaline.

4. A laboratory provides the following solids analysis for a wastewater sample: TS = 200 mg/L; TDS = 30 mg/L; FSS = 30 mg/L. (a) what is the total suspended solids concentration of this sample? (2 points) (b) Does this sample have appreciable organic matter? Why or why not? (3 points)

a)

$$TSS=TS-TDS=200\frac{mg}{L}-30\frac{mg}{L}=\boxed{170\frac{mg}{L}}$$

b)

$$VSS=TSS-FSS=170\frac{mg}{L}-30\frac{mg}{L}=140\frac{mg}{L}$$

Because volatile solids consist primarily of organic matter, it can be concluded that approximately 70% (140/200) of the solids are organic.

5. Water defined by the following analysis to be softened by excess-lime treatment in a two-stage system.

1 2 3 4 = column 2/column 3 = column 4x5

Component	mg/L	Equivalent weight (EW)	meq/L	mg/L as $CaCO_3$
CO_2	8.8	22	0.4	20
Ca^{2+}	70	20	3.5	175
Mg^{2+}	9.7	12.2	0.80	40
Na^{+}	6.9	23	0.30	15
Alk	115	50	2.30	115
SO_4^{2-}	96	48	2.0	100
Cl^{-}	10.6	35.5	0.30	15

The practical limits of removal can be assumed to be 30 mg/L of $CaCO_3$ and 10 mg/L of $Mg(OH)_2$, expressed as $CaCO_3$.

a) Determine total, carbonate and non-carbonate hardness, expressed in mg/L as $CaCO_3$ (3 points)

b) Calculate the quantity of softening chemicals required ~~in pounds, expressed~~ in mg/L as $CaCO_3$ (7 points)

Molecular weights: Ca=40; C=12, O=16

P#1

Q. 5

sol^n:

Total hardness (TH) $= Ca^{2+} + Mg^{2+}$

$= 175 + 40$

$= \underline{215}$ mg/g as $CaCO_3$

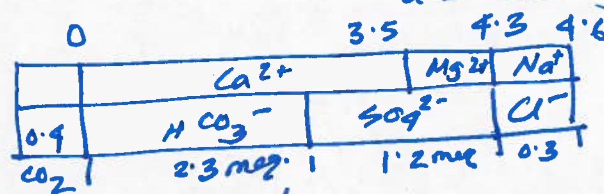
Carbonate hardness

Alk < TH ; Carbonate hardness (CH) = alk

$\Rightarrow$ CH = $\underline{115 \text{ mg/L}}$ as $CaCO_3$

Noncarbonate hardness: (NCH)

NCH = TH − CH = 215 − 115 = $\underline{100}$ mg/L as $CaCO_3$



Lime required:

1) To react with CO_2 = 20 mg/L
2) To remove carbonate hardness (caused by Ca^{2+}) react with $Ca(HCO_3)_2$ = 115 mg/L
3) To remove Mg Noncarbonate hardness (to react with $MgSO_4$) = 40 mg/L
4) Excess lime to raise pH (30-70 mg/L) = 30 mg/L

Total lime = $\underline{205 \text{ mg/L}}$ as $CaCO_3$

Soda Ash required:

Soda ash = non carbonate hardness = $\underline{100 \text{ mg}}$ as CaC