Answer on Question#38992-Chemistry-Organic Chemistry

Question

Arrange the following 0.1 M solutions in order of increasing pH and state why you placed each solution in that position: $NaCH_3COO$, HCl, HCN, NaOH, NH_3, NaCN, KNO_3, H_2SO_4, NH_4Cl, H_2SO_3, $NaHCO_3$, Na_3PO_4 and CH_3COOH.

Answer

pH of the solutions increases in the following range:

$H_2SO_4 < HCl < H_2SO_3 < CH_3COOH < HCN < NH_4Cl < KNO_3 < NaCH_3COO < NaHCO_3 < NaCN < NH_3 < Na_3PO_4 < NaOH$

There are three types of substances: acids, salts and bases.

Acids (pH<7): H_2SO_4, HCl, CH_3COOH, H_2SO_3 and HCN

Salts: $NaHCO_3$, NaCN, $NaCH_3COO$, Na_3PO_4, KNO_3 and NH_4Cl

Bases (pH>7): NaOH and NH_3 (note: NH_3 has no OH-groups but it is a base because in water solution it exists as NH_4OH ($NH_3 + H_2O \rightarrow NH_4OH$)).

Acids and bases are divided into weak and strong. Strong acids dissotiate easily and, thus, have lower pH, while weak acids dissociate hardly and have higher pH. Strong bases dissociate easily and, thus, have higher pH, while weak bases dissociate hardly and have lower pH. NaOH is a strong base, that is why it is last in the range. NH_4OH is a weak base.

The strength of the acids decrease in the range:

$HCl > H_2SO_4 > H_2SO_3 > CH_3COOH > HCN$

If one doesn't know which acid is stronger, one should find the pKa values for the acid: the greater the pKa the weaker the acid (note: HCl is stronger than H_2SO_4 but since the latter forms two hydrogen ions when dissociating it has lower pH).

pH of a salt solution depends on how the salt hydrolyze (if it does) in water solution. For such diluted solutions (0.1M) it may be assumed that salts hydrolyze completely. All salts are divided on:

- salts of strong acids and weak bases (so called acidic salts),
- salts of strong bases and weak acids (so called basic salts),
- salts of weak acids and weak bases,
- salts of strong acids and strong bases.

NH_4Cl is a salt of strong acid and weak base.

Salts of strong acids and weak bases hydrolyze producing strong acid. For NH_4Cl:

$NH_4Cl + H_2O \leftrightarrow NH_4OH + HCl$

Net ionic form: $NH_4^+ + H_2O \leftrightarrow NH_4OH + H^+$

That is why this solution is acidic (pH < 7)

KNO_3 is a salt of strong acid and strong base. Such salts don't hydrolyze and their solution pH = 7. So, KNO_3 solution has pH = 7.

There are no salts of weak acids and weak bases in the given list of salts.

$NaHCO_3$, NaCN, $NaCH_3COO$, Na_3PO_4 are salts of a strong base (NaOH) and weak acids (actually H_3PO_4 is not weak but medium acid).

Salts of strong bases and weak acids hydrolyze producing strong base. Equations for four such salts are as follows:

$NaHCO_3 + H_2O \leftrightarrow H_2CO_3 + NaOH$

Net ionic form: $HCO_3^- + H_2O \leftrightarrow H_2CO_3 + OH^-$

$NaCN + H_2O \leftrightarrow HCN + NaOH$

Net ionic form: $CN^- + H_2O \leftrightarrow HCN + OH^-$

$NaCH_3COO + H_2O \leftrightarrow CH_3COOH + NaOH$

Net ionic form: $CH_3COO^- + H_2O \leftrightarrow CH_3COOH + OH^-$

$Na_3PO_4 + 3\ H_2O \leftrightarrow H_3PO_4 + 3\ NaOH$

Net ionic form: $PO_4^{3-} + 3\ H_2O \leftrightarrow H_3PO_4 + 3\ OH^-$

Since Na_3PO_4 forms three hydroxyl ions when hydrolyzing, its solution is most basic (even more basic them ammonia solution). All other salts form only one hydroxyl ion. The weaker the acid formed when salt hydrolyzes the more basic the solution is. The strength of the acids decreases in the range: $CH_3COOH > H_2CO_3 > HCN$, so the pH of these three salts increases in the range: $NaCH_3COO < NaHCO_3 < NaCN$