Answer on Question #38463-Chemistry-Organic Chemistry

Question

What is the ratio or how much water and vinegar should be added in one bottle so the pH would become 5.5?

Solution

Since it is not specified, vinegar of what concentration of acetic acid is taken, the task is solved to find the water/acetic acid ratio.

Acetic acid dissociation equation:

$$CH_3COOH \leftrightarrow CH_3COO^- + H^+$$

Dissociation constant of acetic acid, which is reference datum is:

$$K_a = \frac{[CH_3COO^-][H^+]}{[CH_3COOH]} = 1.8 \cdot 10^{-5}$$

pH of the solution:

$$pH = -lg[H^+] = 5.5$$

Hence

$$[H^+] = 10^{-pH} = 10^{-5.5} = 3.16 \cdot 10^{-6}\ mol/L$$

As is clear from the dissociation equation:

$$[CH_3COO^-] = [H^+] = 3.16 \cdot 10^{-6}\ mol/L$$

$$[CH_3COOH] = \frac{[CH_3COO^-][H^+]}{K_a} = \frac{3.16 \cdot 10^{-6} \cdot 3.16 \cdot 10^{-6}}{1.8 \cdot 10^{-5}} = 5.55 \cdot 10^{-7}\ mol/L$$

Total concentration of acetic acid:

$$C_a = [CH_3COOH] + [CH_3COO^-] = 3.16 \cdot 10^{-6} + 5.55 \cdot 10^{-7} = 3.71 \cdot 10^{-6}\ mol/L$$

Molarity formula:

$$C_a = \frac{m_a}{M_{CH_3COOH} \cdot V_{solution}}$$

Volume of the acetic acid solution is equal to the sum of the acid and water volumes:

$$V_{solution} = V_a + V_w$$

Mass of acetic acid may be expressed as a product of its density and volume:

$$m_a = \rho_a \cdot V_a$$

Let's substitute last two equations into the molar concentration formula:

$$C_a = \frac{\rho_a \cdot V_a}{M_{CH_3COOH} \cdot (V_a + V_w)}$$

Having substituted the values we have:

$$3.71 \cdot 10^{-6} = \frac{1049 \cdot V_a}{60.05 \cdot (V_a + V_w)}$$

$$\frac{V_a}{V_a + V_w} = 2.13 \cdot 10^{-7}$$

$$V_a = 2.13 \cdot 10^{-7} \cdot (V_a + V_w)$$

$$(1 - 2.13 \cdot 10^{-7}) \cdot V_a = 2.13 \cdot 10^{-7} \cdot V_w$$

$$\frac{V_w}{V_a} = \frac{(1 - 2.13 \cdot 10^{-7})}{2.13 \cdot 10^{-7}} \approx \frac{1}{2.13 \cdot 10^{-7}}$$

If the mixture is prepared using vinegar containing 5%vol. acetic acid, then

$$\frac{V_w}{V_{vin.}} = \frac{V_w - V_a \cdot (100 - 5)}{V_a \cdot (100/5)} = \frac{1 - 2.13 \cdot 10^{-7} \cdot 95}{2.13 \cdot 10^{-7} \cdot 20} \approx \frac{1}{4.26 \cdot 10^{-6}}$$

Answer: to prepare the vinegar-water mixture of pH = 5.5 volume ratio water/acetic acid should be $1 / 2.13 \cdot 10^{-7}$, i.e. if the total volume of the mixture is 1 L, one should take only 0.213 μL of pure acetic acid or 4.26 μL of 5% vinegar.