

Strong Acid/Strong Base Titration Problem Set

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2. A sodium hydroxide solution of unknown concentration is titrated against 0.8765 g KHP (Potassium acid phalate, a monoprotic acid, MW 204.3 g/mol). 48.6 mL of the sodium hydroxide solution is required to reach the endpoint of the titration. What is the concentration of the unknown sodium hydroxide solution.

Information given in problem

$$\text{mass}_{\text{KHP}} := 0.8765 \cdot \text{gm}$$

$$\text{MW}_{\text{KHP}} := 204.3 \cdot \text{gm} \cdot \text{mole}^{-1}$$

$$V_{\text{NaOH}} := 48.6 \cdot \text{mL}$$

Moles of KHP

$$\text{mole}_{\text{KHP}} := \frac{\text{mass}_{\text{KHP}}}{\text{MW}_{\text{KHP}}}$$

$$\text{mole}_{\text{KHP}} = 4.29 \cdot 10^{-3} \cdot \text{mol}$$

Moles of NaOH



$$\text{mole}_{\text{NaOH}} := \text{mole}_{\text{KHP}}$$

$$\text{mole}_{\text{NaOH}} = 4.29 \cdot 10^{-3} \cdot \text{mol}$$

Concentration of NaOH

$$M_{\text{NaOH}} := \frac{\text{mole}_{\text{NaOH}}}{V_{\text{NaOH}}}$$

$$M := \frac{\text{mole}}{\text{liter}}$$

$$M_{\text{NaOH}} = 0.088 \cdot \text{M}$$

3. This sodium hydroxide solution is then used to titrate an unknown nitric acid sample. 25.0 mL of the nitric acid solution is titrated. 32.8 mL of the sodium hydroxide solution is required to reach the endpoint. What is the concentration of the nitric acid solution?

Information Given:

$$V_{\text{HNO}_3} := 25.0 \cdot \text{mL}$$

$$V_{\text{NaOH}} := 32.8 \cdot \text{mL}$$

Calculate moles of NaOH used:

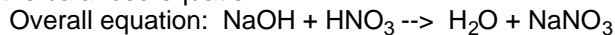
$$M_{\text{NaOH}} = 0.088 \cdot \text{M} \quad \text{Molarity found in previous question}$$

$$\text{mole}_{\text{NaOH}} := M_{\text{NaOH}} \cdot V_{\text{NaOH}}$$

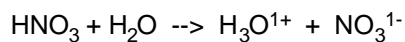
$$\text{mole}_{\text{NaOH}} = 2.895 \cdot 10^{-3} \cdot \text{mol}$$

Calculate moles of HNO3 used

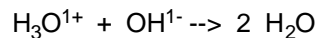
From the balanced equation:



Stepwise:



Net:



$$\text{mole}_{\text{HNO}_3} := \text{mole}_{\text{NaOH}}$$

$$\text{mole}_{\text{HNO}_3} = 2.895 \cdot 10^{-3} \cdot \text{mol}$$

Concentration of HNO3

$$M_{\text{HNO}_3} := \frac{\text{mole}_{\text{HNO}_3}}{V_{\text{HNO}_3}}$$

$$M_{\text{HNO}_3} = 0.116 \cdot \text{M}$$

4. Calculate the pH at the following points in the titration of the unknown nitric acid sample.
 a. 0 mL of sodium hydroxide solution added.

$$M_{\text{H}_3\text{O}} := M_{\text{HNO}_3}$$

$$M_{\text{H}_3\text{O}} = 0.116 \cdot M$$

$$\text{pH}(X) := -\log(X \cdot M^{-1})$$

$$\text{pH}(M_{\text{H}_3\text{O}}) = 0.936$$

b. 1 mL of sodium hydroxide solution added

$$V_{\text{NaOH}} := 1 \cdot \text{mL}$$

$$\text{mole}_{\text{NaOH_added}} := M_{\text{NaOH}} \cdot V_{\text{NaOH}}$$

$$\text{mole}_{\text{NaOH_added}} = 8.828 \cdot 10^{-5} \cdot \text{mol}$$

$$\text{mole}_{\text{HNO}_3_final} := \text{mole}_{\text{HNO}_3} - \text{mole}_{\text{NaOH_added}}$$

$$\text{mole}_{\text{HNO}_3_final} = 2.807 \cdot 10^{-3} \cdot \text{mol}$$

$$V_{\text{final}} := 25 \cdot \text{mL} + V_{\text{NaOH}}$$

$$V_{\text{final}} = 26 \cdot \text{mL}$$

$$C_{\text{H}_3\text{O}} := \frac{\text{mole}_{\text{HNO}_3_final}}{V_{\text{final}}}$$

$$C_{\text{H}_3\text{O}} = 0.108 \cdot M$$

$$\text{pH}(C_{\text{H}_3\text{O}}) = 0.967$$

c. 5 mL of sodium hydroxide solution added.

$$V_{\text{NaOH}} := 5 \cdot \text{mL}$$

$$\text{mole}_{\text{NaOH_added}} := M_{\text{NaOH}} \cdot V_{\text{NaOH}}$$

$$\text{mole}_{\text{NaOH_added}} = 4.414 \cdot 10^{-4} \cdot \text{mol}$$

$$\text{mole}_{\text{HNO}_3_final} := \text{mole}_{\text{HNO}_3} - \text{mole}_{\text{NaOH_added}}$$

$$\text{mole}_{\text{HNO}_3_final} = 2.454 \cdot 10^{-3} \cdot \text{mol}$$

$$V_{\text{final}} := 25 \cdot \text{mL} + V_{\text{NaOH}}$$

$$V_{\text{final}} = 30 \cdot \text{mL}$$

$$C_{\text{H}_3\text{O}} := \frac{\text{mole}_{\text{HNO}_3_final}}{V_{\text{final}}}$$

$$C_{\text{H}_3\text{O}} = 0.082 \cdot M$$

$$\text{pH}(C_{\text{H}_3\text{O}}) = 1.087$$

d. 10 mL of sodium hydroxide solution added.

$$V_{\text{NaOH}} := 10 \cdot \text{mL}$$

$$\text{mole}_{\text{NaOH_added}} := M_{\text{NaOH}} \cdot V_{\text{NaOH}}$$

$$\text{mole}_{\text{NaOH_added}} = 8.828 \cdot 10^{-4} \cdot \text{mol}$$

$$\text{mole}_{\text{HNO3_final}} := \text{mole}_{\text{HNO3}} - \text{mole}_{\text{NaOH_added}}$$

$$\text{mole}_{\text{HNO3_final}} = 2.013 \cdot 10^{-3} \cdot \text{mol}$$

$$V_{\text{final}} := 25 \cdot \text{mL} + V_{\text{NaOH}}$$

$$V_{\text{final}} = 35 \cdot \text{mL}$$

$$C_{\text{H3O}} := \frac{\text{mole}_{\text{HNO3_final}}}{V_{\text{final}}}$$

$$C_{\text{H3O}} = 0.058 \cdot \text{M}$$

$$\text{pH}(C_{\text{H3O}}) = 1.24$$

e. 20 mL of sodium hydroxide solution added.

$$V_{\text{NaOH}} := 20 \cdot \text{mL}$$

$$\text{mole}_{\text{NaOH_added}} := M_{\text{NaOH}} \cdot V_{\text{NaOH}}$$

$$\text{mole}_{\text{NaOH_added}} = 1.766 \cdot 10^{-3} \cdot \text{mol}$$

$$\text{mole}_{\text{HNO3_final}} := \text{mole}_{\text{HNO3}} - \text{mole}_{\text{NaOH_added}}$$

$$\text{mole}_{\text{HNO3_final}} = 1.13 \cdot 10^{-3} \cdot \text{mol}$$

$$V_{\text{final}} := 25 \cdot \text{mL} + V_{\text{NaOH}}$$

$$V_{\text{final}} = 45 \cdot \text{mL}$$

$$C_{\text{H3O}} := \frac{\text{mole}_{\text{HNO3_final}}}{V_{\text{final}}}$$

$$C_{\text{H3O}} = 0.025 \cdot \text{M}$$

$$\text{pH}(C_{\text{H3O}}) = 1.6$$

f. 30 mL of sodium hydroxide solution added.

$$V_{\text{NaOH}} := 30 \cdot \text{mL}$$

$$\text{mole}_{\text{NaOH_added}} := M_{\text{NaOH}} \cdot V_{\text{NaOH}}$$

$$\text{mole}_{\text{NaOH_added}} = 2.648 \cdot 10^{-3} \cdot \text{mol}$$

$$\text{mole}_{\text{HNO}_3_final} := \text{mole}_{\text{HNO}_3} - \text{mole}_{\text{NaOH_added}}$$

$$\text{mole}_{\text{HNO}_3_final} = 2.472 \cdot 10^{-4} \cdot \text{mol}$$

$$V_{\text{final}} := 25 \cdot \text{mL} + V_{\text{NaOH}}$$

$$V_{\text{final}} = 55 \cdot \text{mL}$$

$$C_{\text{H}_3\text{O}^+} := \frac{\text{mole}_{\text{HNO}_3_final}}{V_{\text{final}}}$$

$$C_{\text{H}_3\text{O}^+} = 4.494 \cdot 10^{-3} \cdot \text{M}$$

$$\text{pH}(C_{\text{H}_3\text{O}^+}) = 2.347$$

g. 32.8 mL of sodium hydroxide solution added.

$$V_{\text{NaOH}} := 32.8 \cdot \text{mL}$$

$$\text{mole}_{\text{NaOH_added}} := M_{\text{NaOH}} \cdot V_{\text{NaOH}}$$

$$\text{mole}_{\text{NaOH_added}} = 2.895 \cdot 10^{-3} \cdot \text{mol}$$

$$\text{mole}_{\text{HNO}_3_final} := \text{mole}_{\text{HNO}_3} - \text{mole}_{\text{NaOH_added}}$$

$$\text{mole}_{\text{HNO}_3_final} = 0 \cdot \text{mol}$$

$$V_{\text{final}} := 25 \cdot \text{mL} + V_{\text{NaOH}}$$

$$V_{\text{final}} = 57.8 \cdot \text{mL}$$

$$C_{\text{H}_3\text{O}^+} := \frac{\text{mole}_{\text{HNO}_3_final}}{V_{\text{final}}}$$

$$C_{\text{H}_3\text{O}^+} = 0 \cdot \text{M}$$

$$\text{pH}(C_{\text{H}_3\text{O}^+}) =$$

Obviously there is a problem with how this calculation was performed. The problem is that we are right at the equivalence point. So all the excess strong acid has been used. After the strong acid and base react, the only remaining species is H_2O . So the pH of this solution is based only upon the autoionization of water. So that:

$$K_w := 10^{-14} \cdot \text{M}^2$$

$$C_{\text{H}_3\text{O}^+} := \sqrt{K_w}$$

$$\text{pH}(C_{\text{H}_3\text{O}^+}) = 7$$

h.35 mL of sodium hydroxide solution added.

$$V_{\text{NaOH}} := 35 \cdot \text{mL}$$

$$\text{mole}_{\text{NaOH_added}} := M_{\text{NaOH}} \cdot V_{\text{NaOH}}$$

$$\text{mole}_{\text{NaOH_added}} = 3.09 \cdot 10^{-3} \cdot \text{mol}$$

$$\text{mole}_{\text{HNO}_3\text{_final}} := \text{mole}_{\text{HNO}_3} - \text{mole}_{\text{NaOH_added}}$$

$$\text{mole}_{\text{HNO}_3\text{_final}} = -1.942 \cdot 10^{-4} \cdot \text{mol}$$

At this point in the problem it is clear that something is wrong. The problem is that NaOH is no longer the limiting reagent. All the HNO₃ has been consumed and there is excess NaOH. So, the calculation needs to be reworked as:

$$\text{mole}_{\text{NaOH_final}} := \text{mole}_{\text{NaOH_added}} - \text{mole}_{\text{HNO}_3}$$

$$\text{mole}_{\text{NaOH_final}} = 1.942 \cdot 10^{-4} \cdot \text{mol}$$

From the amount of excess NaOH, we can calculate the final hydroxide concentration that results from the dissociation of NaOH:

$$V_{\text{final}} := 25 \cdot \text{mL} + V_{\text{NaOH}}$$

$$V_{\text{final}} = 60 \cdot \text{mL}$$

$$C_{\text{OH}} := \frac{\text{mole}_{\text{NaOH_final}}}{V_{\text{final}}}$$

$$C_{\text{OH}} = 3.237 \cdot 10^{-3} \cdot \text{M}$$

The final concentration of H₃O¹⁺ may be calculated using Kw.

$$C_{\text{H}_3\text{O}} := \frac{K_w}{C_{\text{OH}}}$$

$$\text{pH}(C_{\text{H}_3\text{O}}) = 11.51$$

i. 40 mL of sodium hydroxide solution added.

$$V_{\text{NaOH}} := 40 \cdot \text{mL}$$

$$\text{mole}_{\text{NaOH_added}} := M_{\text{NaOH}} \cdot V_{\text{NaOH}}$$

$$\text{mole}_{\text{NaOH_added}} = 3.531 \cdot 10^{-3} \cdot \text{mol}$$

$$\text{mole}_{\text{NaOH_final}} := \text{mole}_{\text{NaOH_added}} - \text{mole}_{\text{HNO}_3}$$

$$\text{mole}_{\text{NaOH_final}} = 6.356 \cdot 10^{-4} \cdot \text{mol}$$

From the amount of excess NaOH, we can calculate the final hydroxide concentration that results from the dissociation of NaOH:

$$V_{\text{final}} := 25 \cdot \text{mL} + V_{\text{NaOH}}$$

$$V_{\text{final}} = 65 \cdot \text{mL}$$

$$C_{\text{OH}} := \frac{\text{mole}_{\text{NaOH_final}}}{V_{\text{final}}}$$

$$C_{\text{OH}} = 9.778 \cdot 10^{-3} \cdot \text{M}$$

The final concentration of H_3O^{1+} may be calculated using K_w .

$$C_{\text{H}_3\text{O}} := \frac{K_w}{C_{\text{OH}}}$$

$$\text{pH}(C_{\text{H}_3\text{O}}) = 11.99$$

j. 50 mL of sodium hydroxide solution added.

$$V_{\text{NaOH}} := 50 \cdot \text{mL}$$

$$\text{mole}_{\text{NaOH_added}} := M_{\text{NaOH}} \cdot V_{\text{NaOH}}$$

$$\text{mole}_{\text{NaOH_added}} = 4.414 \cdot 10^{-3} \cdot \text{mol}$$

$$\text{mole}_{\text{NaOH_final}} := \text{mole}_{\text{NaOH_added}} - \text{mole}_{\text{HNO}_3}$$

$$\text{mole}_{\text{NaOH_final}} = 1.518 \cdot 10^{-3} \cdot \text{mol}$$

From the amount of excess NaOH, we can calculate the final hydroxide concentration that results from the dissociation of NaOH:

$$V_{\text{final}} := 25 \cdot \text{mL} + V_{\text{NaOH}}$$

$$V_{\text{final}} = 75 \cdot \text{mL}$$

$$C_{\text{OH}} := \frac{\text{mole}_{\text{NaOH_final}}}{V_{\text{final}}}$$

$$C_{\text{OH}} = 0.02 \cdot \text{M}$$

The final concentration of H_3O^{1+} may be calculated using K_w .

$$C_{\text{H}_3\text{O}} := \frac{K_w}{C_{\text{OH}}}$$

$$\text{pH}(C_{\text{H}_3\text{O}}) = 12.306$$