Strong Acid/Strong Base Titration Problem Set

By S.E. Van Bramer
Widener University
One University Place
Chester, PA 19013
svanbram@science.widener.edu
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2.A sodium hydroxide solution of unknown concentration is titrated against 0.8765 g KHPh (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

$$mass_{KHPh} := 0.8765 \cdot gm$$

$$MW_{KHPh} := 204.3 \cdot gm \cdot mole^{-1}$$

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

Moles of KHPh

$$mole_{KHPh} := \frac{mass_{KHPh}}{MW_{KHPh}}$$

$$mole_{KHPh} = 4.29 \cdot 10^{-3} \cdot mol$$

Moles of NaOH

From the reaction: NaOH + KHPh --> $H_2O + Na^{1+} + K^{1+} + Ph^{2-}$

$$mole_{NaOH} := mole_{KHPh}$$

$$mole_{NaOH} = 4.29 \cdot 10^{-3} \cdot mol$$

Concentration of NaOH

$$M_{NaOH} := \frac{mole_{NaOH}}{V_{NaOH}} \qquad M := \frac{mole}{liter}$$

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

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:

$V_{HNO3} := 25.0 \cdot mL$

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

Calculate moles of NaOH used:

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

$mole_{NaOH} := M_{NaOH} \cdot V_{NaOH}$

$mole_{NaOH} = 2.895 \cdot 10^{-3} \cdot mol$

Calculate moles of HNO3 used

From the balanced equation:

Overall equation: $NaOH + HNO_3 \text{-->} H_2O + NaNO_3$

Stepwise:

$NaOH \text{-->} Na^{1+} + OH^{1-}$

$HNO_3 + H_2O \text{-->} H_3O^{1+} + NO_3^{1-}$

Net:

$H_3O^{1+} + OH^{1-} \text{-->} 2\ H_2O$

$mole_{HNO3} := mole_{NaOH}$

$mole_{HNO3} = 2.895 \cdot 10^{-3} \cdot mol$

Concentration of HNO3

$$M_{HNO3} := \frac{mole_{HNO3}}{V_{HNO3}}$$

$M_{HNO3} = 0.116 \cdot M$

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.

$$M_{H3O} := M_{HNO3}$$

$$M_{H3O} = 0.116 \cdot M$$

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

$$pH\left(M_{H3O}\right) = 0.936$$

b.1 mL of sodium hydroxide solution added

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

$$mole_{NaOH\_added} := M_{NaOH} \cdot V_{NaOH} \qquad mole_{NaOH\_added} = 8.828 \cdot 10^{-5} \cdot mol$$

$$mole_{HNO3\_final} := mole_{HNO3} - mole_{NaOH\_added} \qquad mole_{HNO3\_final} = 2.807 \cdot 10^{-3} \cdot mol$$

$$V_{final} := 25 \cdot mL + V_{NaOH} \qquad V_{final} = 26 \cdot mL$$

$$C_{H3O} := \frac{mole_{HNO3\_final}}{V_{final}} \qquad C_{H3O} = 0.108 \cdot M$$

$$pH\left(C_{H3O}\right) = 0.967$$

c.5 mL of sodium hydroxide solution added.

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

$$mole_{NaOH\_added} := M_{NaOH} \cdot V_{NaOH} \qquad mole_{NaOH\_added} = 4.414 \cdot 10^{-4} \cdot mol$$

$$mole_{HNO3\_final} := mole_{HNO3} - mole_{NaOH\_added} \qquad mole_{HNO3\_final} = 2.454 \cdot 10^{-3} \cdot mol$$

$$V_{final} := 25 \cdot mL + V_{NaOH} \qquad V_{final} = 30 \cdot mL$$

$$C_{H3O} := \frac{mole_{HNO3\_final}}{V_{final}} \qquad C_{H3O} = 0.082 \cdot M$$

$$pH\left(C_{H3O}\right) = 1.087$$

d.10 mL of sodium hydroxide solution added.

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

$mole_{NaOH\_added} := M_{NaOH} \cdot V_{NaOH}$ $\quad mole_{NaOH\_added} = 8.828 \cdot 10^{-4} \cdot mol$

$mole_{HNO3\_final} := mole_{HNO3} - mole_{NaOH\_added}$ $\quad mole_{HNO3\_final} = 2.013 \cdot 10^{-3} \cdot mol$

$V_{final} := 25 \cdot mL + V_{NaOH}$ $\quad V_{final} = 35 \cdot mL$

$C_{H3O} := \frac{mole_{HNO3\_final}}{V_{final}}$ $\quad C_{H3O} = 0.058 \cdot M$

$pH\left(C_{H3O}\right) = 1.24$

e.20 mL of sodium hydroxide solution added.

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

$mole_{NaOH\_added} := M_{NaOH} \cdot V_{NaOH}$ $\quad mole_{NaOH\_added} = 1.766 \cdot 10^{-3} \cdot mol$

$mole_{HNO3\_final} := mole_{HNO3} - mole_{NaOH\_added}$ $\quad mole_{HNO3\_final} = 1.13 \cdot 10^{-3} \cdot mol$

$V_{final} := 25 \cdot mL + V_{NaOH}$ $\quad V_{final} = 45 \cdot mL$

$C_{H3O} := \frac{mole_{HNO3\_final}}{V_{final}}$ $\quad C_{H3O} = 0.025 \cdot M$

$pH\left(C_{H3O}\right) = 1.6$

f.30 mL of sodium hydroxide solution added.

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

$mole_{NaOH\_added} := M_{NaOH} \cdot V_{NaOH}$ $\qquad mole_{NaOH\_added} = 2.648 \cdot 10^{-3} \cdot mol$

$mole_{HNO3\_final} := mole_{HNO3} - mole_{NaOH\_added}$ $\qquad mole_{HNO3\_final} = 2.472 \cdot 10^{-4} \cdot mol$

$V_{final} := 25 \cdot mL + V_{NaOH}$ $\qquad V_{final} = 55 \cdot mL$

$C_{H3O} := \dfrac{mole_{HNO3\_final}}{V_{final}}$ $\qquad C_{H3O} = 4.494 \cdot 10^{-3} \cdot M$

$pH\left(C_{H3O}\right) = 2.347$

g.32.8 mL of sodium hydroxide solution added.

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

$mole_{NaOH\_added} := M_{NaOH} \cdot V_{NaOH}$ $\qquad mole_{NaOH\_added} = 2.895 \cdot 10^{-3} \cdot mol$

$mole_{HNO3\_final} := mole_{HNO3} - mole_{NaOH\_added}$ $\qquad mole_{HNO3\_final} = 0 \cdot mol$

$V_{final} := 25 \cdot mL + V_{NaOH}$ $\qquad V_{final} = 57.8 \cdot mL$

$C_{H3O} := \dfrac{mole_{HNO3\_final}}{V_{final}}$ $\qquad C_{H3O} = 0 \cdot M$

$pH\left(C_{H3O}\right) =$

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

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

$C_{H3O} := \sqrt{K_w}$

$pH\left(C_{H3O}\right) = 7$

h.35 mL of sodium hydroxide solution added.

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

$mole_{NaOH\_added} := M_{NaOH} \cdot V_{NaOH}$ $\qquad mole_{NaOH\_added} = 3.09 \cdot 10^{-3} \cdot mol$

$mole_{HNO3\_final} := mole_{HNO3} - mole_{NaOH\_added}$ $\qquad mole_{HNO3\_final} = -1.942 \cdot 10^{-4} \cdot mol$

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 HNO_3 has been consumed and there is excess NaOH. So, the calculation needs to be reworked as:

$mole_{NaOH\_final} := mole_{NaOH\_added} - mole_{HNO3}$ $\qquad mole_{NaOH\_final} = 1.942 \cdot 10^{-4} \cdot mol$

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

$V_{final} := 25 \cdot mL + V_{NaOH}$ $\qquad V_{final} = 60 \cdot mL$

$C_{OH} := \frac{mole_{NaOH\_final}}{V_{final}}$ $\qquad C_{OH} = 3.237 \cdot 10^{-3} \cdot M$

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

$C_{H3O} := \frac{K_w}{C_{OH}}$

$pH(C_{H3O}) = 11.51$

S.E. Van Bramer
svanbram@science.widener.edu

i.40 mL of sodium hydroxide solution added.

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

$mole_{NaOH\_added} := M_{NaOH} \cdot V_{NaOH}$ $\quad mole_{NaOH\_added} = 3.531 \cdot 10^{-3} \cdot mol$

$mole_{NaOH\_final} := mole_{NaOH\_added} - mole_{HNO3}$ $\quad mole_{NaOH\_final} = 6.356 \cdot 10^{-4} \cdot mol$

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

$V_{final} := 25 \cdot mL + V_{NaOH}$ $\quad V_{final} = 65 \cdot mL$

$C_{OH} := \frac{mole_{NaOH\_final}}{V_{final}}$ $\quad C_{OH} = 9.778 \cdot 10^{-3} \cdot M$

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

$C_{H3O} := \frac{K_w}{C_{OH}}$

$pH(C_{H3O}) = 11.99$

j.50 mL of sodium hydroxide solution added.

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

$mole_{NaOH\_added} := M_{NaOH} \cdot V_{NaOH}$ $\quad mole_{NaOH\_added} = 4.414 \cdot 10^{-3} \cdot mol$

$mole_{NaOH\_final} := mole_{NaOH\_added} - mole_{HNO3}$ $\quad mole_{NaOH\_final} = 1.518 \cdot 10^{-3} \cdot mol$

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

$V_{final} := 25 \cdot mL + V_{NaOH}$ $\quad V_{final} = 75 \cdot mL$

$C_{OH} := \frac{mole_{NaOH\_final}}{V_{final}}$ $\quad C_{OH} = 0.02 \cdot M$

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

$C_{H3O} := \frac{K_w}{C_{OH}}$

$pH(C_{H3O}) = 12.306$