Titration Curves

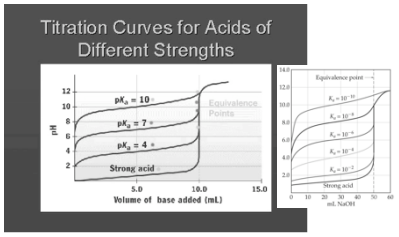
Titrations: pH Curves & Indicators

- *A pH (Titration) Curve is a plot of pH of the solution being analyzed (y-axis) as a function of the amount of titrant added (x-axis).*
- *Equivalence point (stoichiometric): Enough moles of titrant has been added to react exactly with the solution being analyzed. An indicator provides a visible color change to determine an (End point) volume of titrant.*

Neutralization / Titration Curves

Are there differences in the neutralization of HCl versus HF? ….1) mass wise? …. 2) pH wise?

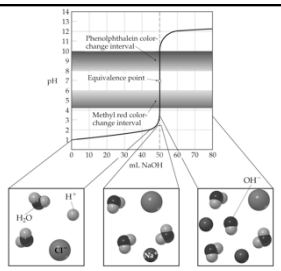
A) 1.NO 2.NO B) 1.YES 2.YES C) 1.YES 2.NO D) 1.NO 2.YES



pH differences in the titration of acids: strong acids = 7 @ equivalence point;
Weak acids: the stronger the weak acid (higher pKa/ lower Ka value) the weaker the conjugate base (relatively lower pH @ the equivalence point).

*Solving **Strong Acid - Strong Base** Titration Problems*

- *Treat as a stoichiometry problem - reaction is assumed to run to completion – the conjugate base has negligible basicity so the pH @ the equivalence point = 7.*



What volume of 1.00M NaOH (aq) is needed to neutralize 50.0 mL of 1.00M HCl (aq)? What is the pH of the solution that results from the reaction?

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$NaOH_{(aq)} + HCl_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$

1.00 M 1.00 M

? mL 50.0 mL

$M_{NaOH} \times V_{NaOH} = M_{HCl} \times V_{HCl}$

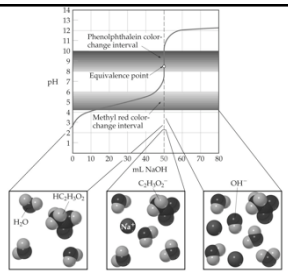
$V_{NaOH} = \frac{M_{HCl} \times V_{HCl}}{M_{NaOH}} = \frac{1.00\,M \times 50.0\,mL}{1.00\,M}$

$V_{NaOH} = 50.0\,mL$

pH $NaCl_{(aq)}$ = 7

*Solving **Weak Acid - Strong Base** Titration Problems*

- *Step 1 - Treat as a stoichiometry problem - reaction is assumed to run to completion - then consider the conjugate base for Step 2.*
- *Step 2 - Treat as an equilibrium problem – using the conjugate base's equilibrium constant (K_b) calculate pH.*



50.0 mL of 0.50M NaOH (aq) is needed to neutralize 10.0 mL of acetic acid $HC_2H_3O_2$ (aq), Ka = 1.8 x 10^{-5}.

What is the molarity of $HC_2H_3O_2$ (aq)? What is the pH of the solution that results from the completed reaction?

50.0 mL of 0.50M NaOH (aq) is needed to neutralize 10.0 mL of acetic acid $HC_2H_3O_2$ (aq). What is the molarity of $HC_2H_3O_2$ (aq)?

M = 50.0 mL x 0.50M /10.0 mL

M = 2.5 M

What is the pH of the solution that results from the completed reaction?

moles $HC_2H_3O_2$ (aq) = 0.0100L x 2.5M= 0.025 mol

moles $HC_2H_3O_2$ (aq) = moles $NaC_2H_3O_2$ = 0.025 mol

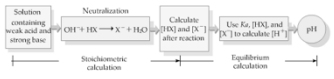
Molarity $NaC_2H_3O_2$ (aq) = 0.025 mol / 0.060 L =

0.42 mol/L $C_2H_3O_2^-$(aq) *TOTAL Volume Solution*

K_b = Kw / Ka = 1 x 10^{-14} / 1.8 x 10^{-5} = 5.6 x 10^{-10}

Use ICE Table, Solve for [OH-], then pH

Using ICE Table,



$HC_2H_3O_{2(aq)} + NaOH_{(aq)} \rightarrow NaC_2H_3O_{2(aq)} + H_2O_{(l)}$

$NaC_2H_3O_{2(aq)} \rightleftharpoons Na^+_{(aq)} + C_2H_3O_2^-{}_{(aq)}$

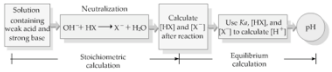
$C_2H_3O_2^-{}_{(aq)} + H_2O_{(l)} \rightleftharpoons HC_2H_3O_{2(aq)} + OH^-_{(aq)}$

$K_b = \frac{[HC_2H_3O_2][OH^-]}{[C_2H_3O_2^-]}$

$[OH^-] = \frac{K_b \cdot [C_2H_3O_2^-]}{[HC_2H_3O_2]}$

	$C_2H_3O_2^-$	$HC_2H_3O_2$	OH^-
I	0.42 M	0	0
C	−x	+x	+x
E	0.42 − x	x	x

Solving for [OH-], then pH



$K_b = \frac{x^2}{0.42 - x}$

$K_{a\,HC_2H_3O_2} = 1.8 \times 10^{-5}$

by approximation

$5.6 \times 10^{-10} = \frac{x^2}{0.42}$

$K_w = K_a \times K_b$

$x = \sqrt{5.6 \times 10^{-10} \cdot 0.42}$

$K_b = \frac{1 \times 10^{-14}}{1.8 \times 10^{-5}}$

$x = 1.5 \times 10^{-5}$

$K_{b\,C_2H_3O_2^-} = 5.6 \times 10^{-10}$

$[OH^-] = 1.5 \times 10^{-5}$

$[H^+] = \frac{K_w}{[OH^-]} = \frac{1 \times 10^{-14}}{1.5 \times 10^{-5}}$

$[H^+] = 6.7 \times 10^{-10}$

pH = 9.2

QUESTION

Some Conjugate Acid–Base Pairs

Acid	K_a	Base	K_b
HNO_3	(Strong acid)	NO_3^-	(Negligible basicity)
HF	6.8×10^{-4}	F^-	1.5×10^{-11}
$HC_2H_3O_2$	1.8×10^{-5}	$C_2H_3O_2^-$	5.6×10^{-10}
H_2CO_3	4.3×10^{-7}	HCO_3^-	2.3×10^{-8}
NH_4^+	5.6×10^{-10}	NH_3	1.8×10^{-5}
HCO_3^-	5.6×10^{-11}	CO_3^{2-}	1.8×10^{-4}
OH^-	(Negligible acidity)	O^{2-}	(Strong base)

What volume of 0.500M NaOH (aq) is needed to neutralize 10.0 mL of 1.00M HNO_3 (aq)?

A) 5.0mL B) 10.0mL C) 15.0mL D) 20.0mL

What is the pH of the solution that results from the reaction?

A) 0.3 B) 13.7 C) 7 D) Cannot determine

QUESTION

Some Conjugate Acid–Base Pairs

Acid	K_a	Base	K_b
HNO_3	(Strong acid)	NO_3^-	(Negligible basicity)
HF	6.8×10^{-4}	F^-	1.5×10^{-11}
$HC_2H_3O_2$	1.8×10^{-5}	$C_2H_3O_2^-$	5.6×10^{-10}
H_2CO_3	4.3×10^{-7}	HCO_3^-	2.3×10^{-8}
NH_4^+	5.6×10^{-10}	NH_3	1.8×10^{-5}
HCO_3^-	5.6×10^{-11}	CO_3^{2-}	1.8×10^{-4}
OH^-	(Negligible acidity)	O^{2-}	(Strong base)

25.0 mL of 0.50M NaOH (aq) is needed to neutralize 10.0 mL of NH_4NO_3 (aq). What is the molarity of NH_4NO_3 (aq)?

A) O.625M B) 1.00M C) 1.25M D) 2.50M

What is the pH of the solution that results from the reaction?

A) 2.6 B) 11.4 C) 7.0 D) Cannot determine

QUESTION

Some Conjugate Acid–Base Pairs

Acid	K_a	Base	K_b
HNO_3	(Strong acid)	NO_3^-	(Negligible basicity)
HF	6.8×10^{-4}	F^-	1.5×10^{-11}
$HC_2H_3O_2$	1.8×10^{-5}	$C_2H_3O_2^-$	5.6×10^{-10}
H_2CO_3	4.3×10^{-7}	HCO_3^-	2.3×10^{-8}
NH_4^+	5.6×10^{-10}	NH_3	1.8×10^{-5}
HCO_3^-	5.6×10^{-11}	CO_3^{2-}	1.8×10^{-4}
OH^-	(Negligible acidity)	O^{2-}	(Strong base)

25.0 mL of 0.50M NaOH (aq) is needed to neutralize 10.0 mL of NH_4NO_3 (aq).

What is the pH of the solution that results from the reaction?

A) 2.6 B) 11.4 C) 7.0 D) Cannot determine

QUESTION

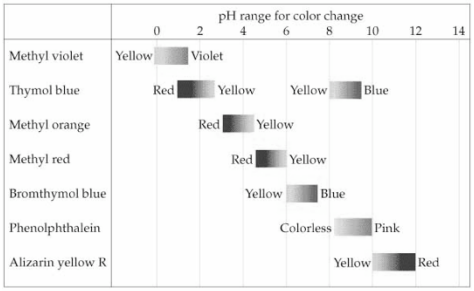
Suppose you have 50.0 mL each of 0.10 *M* solutions of propanoic acid ($K_a = 1.3 \times 10^{-5}$); acetic acid ($K_a = 1.8 \times 10^{-5}$); HCl (all monoprotic acids). Which would require the LEAST volume of 0.10 *M* NaOH to neutralize?

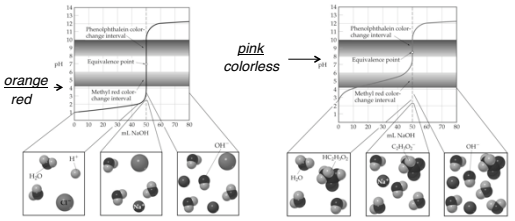
A.Propanoic acid
B.Acetic acid
C.HCl
D.They would all require the same volume.
E.It cannot be predicted without more information.

Indicators

Natural Indicators

Acid-Base Indicators





True (A) / False (B) (Refer to the illustrations above.)

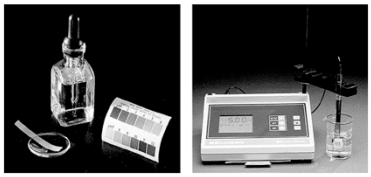
1) *An HCl sample + 30.0 mL of NaOH + methyl red will be orange.*
2) *An acetic acid sample + 50.1mL of NaOH + phenolphthalein will be colorless.*
3) *Phenolphthalein can be used in the titration of only HCl.*
4) *Methyl red can be used in the titration of only HCl.*

QUESTION

Most acid-base indicators are weak acids. In a titration of 0.50 *M* acetic acid (at 25°C, $K_a = 1.8 \times 10^{-5}$) with KOH, which indicator would best indicate the pH at the equivalence point? The approximate K_a for each choice is provided.

A. Bromophenol blue; $K_a \sim 1 \times 10^{-4}$
B. Methyl red; $K_a \sim 1 \times 10^{-5}$
C. Bromothymol blue; $K_a \sim 1 \times 10^{-7}$
D. Thymolphthalein; $K_a \sim 1 \times 10^{-10}$

Methods for Measuring the pH of an Aqueous Solution



(a) pH paper (b) pH meter
[Paper coated with indicators]

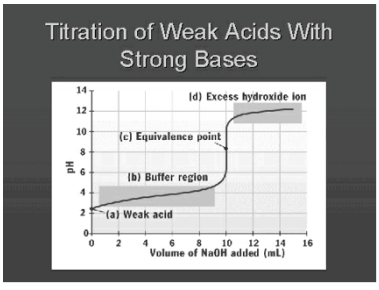
NOTE: Automated methods using a pH probe, and computer hardware & software are now commonly used to plot a Titration Curve.

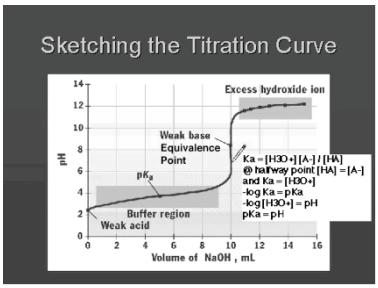
QUESTION

The acid-base indicator bromocresol purple has an interesting yellow-to-purple color change. If the approximate K_a of this indicator is 1.0×10^{-6}, what would be the ratio of purple [A^-] to yellow [HA] at a pH of 4.0?

A. 100:1
B. 1:100
C. 1:1
D. 1000:1
E. None of the above.

Titration (pH) Curve





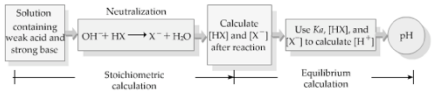
QUESTION

50.0 mL of an acid solution (HA) contains 0.0200 mole of the acid. The solution is titrated with 0.200 *M* NaOH. Half way to the equivalence point the pH is 5.25. What is the total volume of the solution at that point and what is the K_a of the acid?

A. 0.100 L; $K_a = 5.6 \times 10^{-6}$
B. 0.150 L; $K_a = 5.6 \times 10^{-6}$
C. 0.100 L; $K_a = 1.8 \times 10^{-9}$
D. 0.150 L; $K_a = 1.8 \times 10^{-9}$

QUESTION

What is the pH of a solution made from adding 500. mL of 2.00 M $HOAc_{(aq)}$ (Ka = 1.8 x 10^{-5}) to 100. mL of 5.100M $NaOH_{(aq)}$.
(This question relates to the titration of acetic acid.)



A) 4.74 B) 4.76 C) 9.24 D) 9.26

QUESTION

If 25.0 mL of 0.250 M HCl were titrated with 0.500 M NaOH, what is the initial pH, the pH at the equivalence point and the volume of the **total solution** at the equivalence point?

A. 1.000; 7.00; 25.0 mL
B. 0.602; 7.00; 50.0 mL
C. 0.602; 7.00; 37.5 mL
D. 1.000; 7.00; 12.5 mL

QUESTION

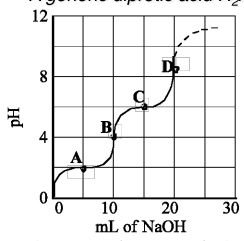
What is the initial pH and the pH at the equivalence point of the titration of 30.0 mL of 0.100 *M* benzoic acid, $C_6H_5CO_2H$ ($K_a = 6.4 \times 10^{-5}$), with 0.100 M NaOH at 25°C?

A. 2.60, 8.60
B. 2.86, 5.55
C. 2.60, 8.45
D. 2.86, 8.60
E. 2.86, 8.45

Titration Curves

Polyprotic Acids

A generic diprotic acid H_2A:



- *What is a specific example of a diprotic acid?*
- *What would phosphoric acid look like?*