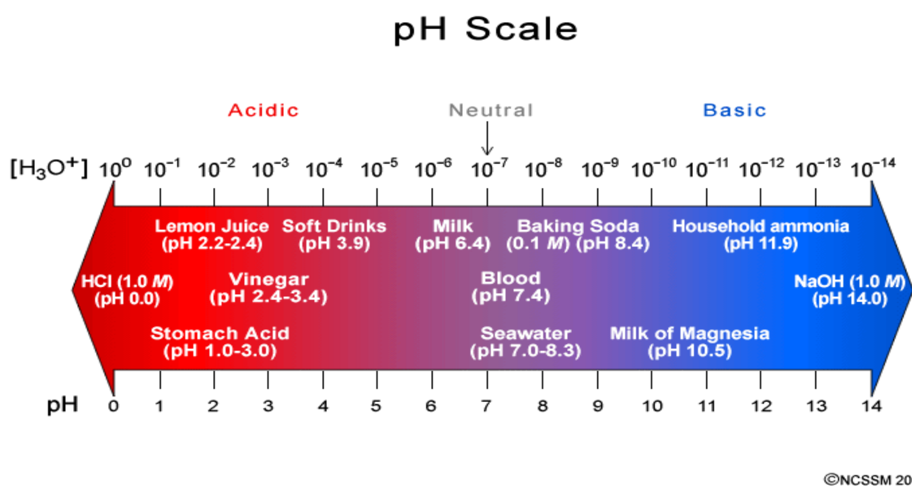
Acids and Bases Lesson 3



- The pH of a solution is defined as the negative logarithm, to the base ten, of the hydronium ion concentration.

- In a neutral solution at 25°C, the hydronium ion and the hydroxide ion concentrations are both 1.0×10^{-7} mol/L. Thus, the pH of a neutral solution is 7.

  $pH = -\log_{10}(1.0 \times 10^{-7}) = 7.00$

Example: What will be the pH of an aqueous solution containing 0.040 M sodium hydroxide?

Example: What is the hydronium ion concentration of a solution with a pH of 2.50?

Determining pOH

- pOH is another way to express how acidic or basic a solution is.

- It's basically just the opposite of pH.

$pH + pOH = 14.00$ $pOH = -\log_{10}[OH^-]$ $pOH = 14.00 - pH$

Example: A solution has a pH of 3.00, is it an acid or base? What would be the pOH of the same solution?

Example: An aqueous solution containing 0.040 M sodium hydroxide has the following pOH:

See pH Assignment

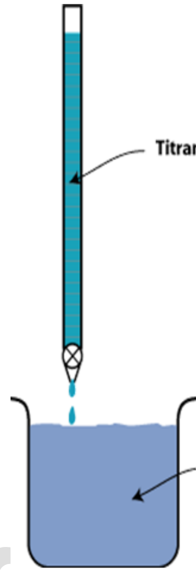
Neutralization

- **Recall:** neutralization refers to the double displacement reaction which occurs when an acid is mixed with a base, the products of neutralization are a __________ (ionic compound) and _______________________. **← this is only true for a STRONG acid and a STRONG base.**

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

- Now if we look at the **net ionic equation:** $H^+_{(aq)} + OH^-_{(aq)} \rightarrow H_2O_{(l)}$
- This is because when we have equal moles of acid and base, we will have a _________________ solution (a pH of 7)
- If you did not have a BOTH strong acids and bases, the pH when the moles are equal would not be exactly 7. It would depend on the Ka and Kb of the acids and bases
  - Strong acid + Strong base → pH = 7 (neutral) when neutralized.
  - Strong acid + weak base → pH < 7 (acidic) when neutralized.
  - Weak acid + strong base → pH > 7 (basic) when neutralized.

Acid-Base Titrations



- To achieve neutralization we use a process called titration.
  - One reactant is carefully added to another reactant until the two have combined in their exact stoichiometric proportions.
  - When the moles are equal this is called the **equivalency point**
- The objective of a titration is usually to find the number of moles or grams, the concentration, or the percentage of the analyte (the substance we are looking for) in a sample.
- This is usually done by measuring the precise volume and concentration of a titrant (the solution being added from the burette) needed to react completely with the analyte. Stoichiometric relationships are then used to determine the quantity of analyte that was present from the number of moles (volume × molarity) of titrant added.
  - During titration, the solution reaches an ________________ point where the moles of acid equals the moles of the base (this does not necessarily mean pH = 7).
  - During a titration, the equivalency point is shown using an ________________
  - When doing titrations we use a ________________ because it is really accurate at measuring volumes.
  - When performing a titration you add your titrant to the analyte (with indicator) until there is ONE DROP that has a ________________ colour change.

From: http://www.chemguide.co.uk/physical/acidbaseeqia/phcurves.html

Sorting out some confusing terms

- *The term "neutral point" is best avoided.*
- *The term "equivalence point" means that the solutions have been mixed in exactly the right proportions according to the equation.*
- *The term "end point" is where the indicator changes colour. As you will see on the page about indicators, that isn't necessarily exactly the same as the equivalence point.*

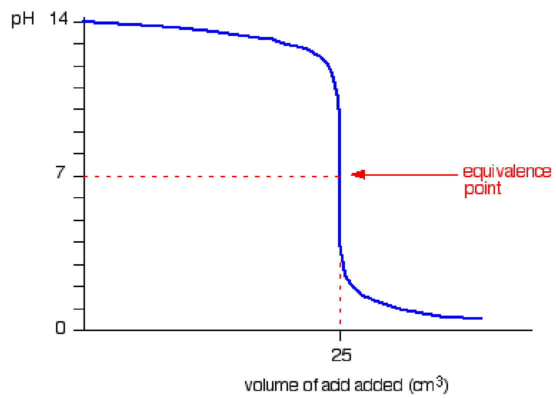
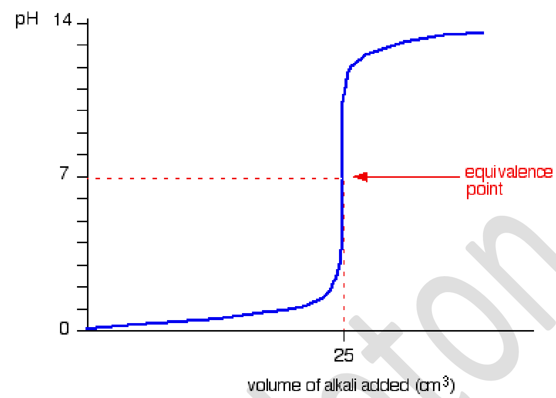
Simple pH curves

Although you normally run the acid from a burette into the alkali in a flask, you may need to know about the titration curve for adding it the other way around as well. Alternative versions of the curves have been described in most cases.

Titration curves for strong acid v strong base (alkali)

We'll take hydrochloric acid and sodium hydroxide as typical of a strong acid and a strong base.

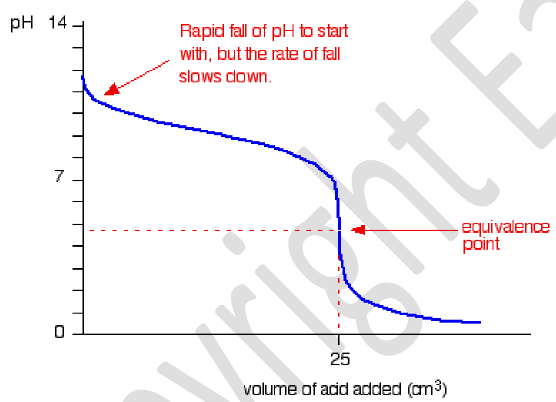
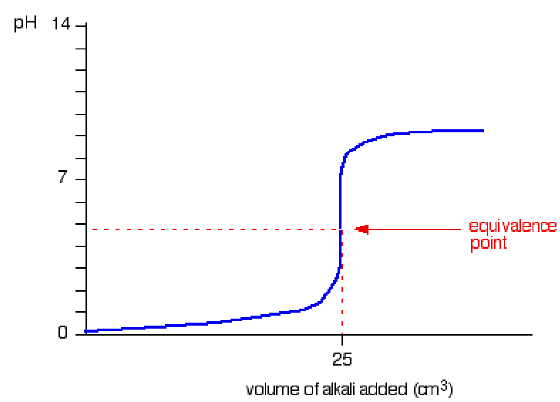
$$NaOH_{(aq)} + HCl_{(aq)} \longrightarrow NaCl_{(aq)} + H_2O_{(l)}$$

Running acid into the alkali	*Running alkali into the acid*
	

Titration curves for strong acid v weak base

This time we are going to use hydrochloric acid as the strong acid and ammonia solution as the weak base.

$$NH_{3(aq)} + HCl_{(aq)} \longrightarrow NH_4Cl_{(aq)}$$

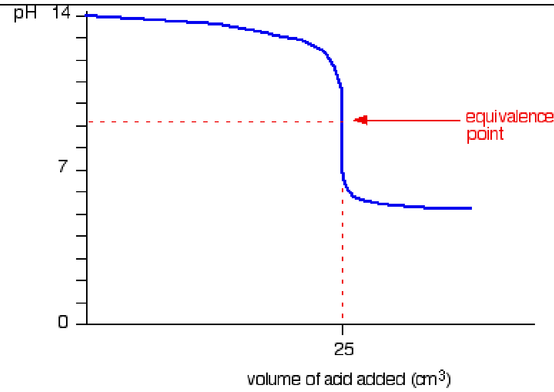
Running acid into the alkali	*Running alkali into the acid*
	

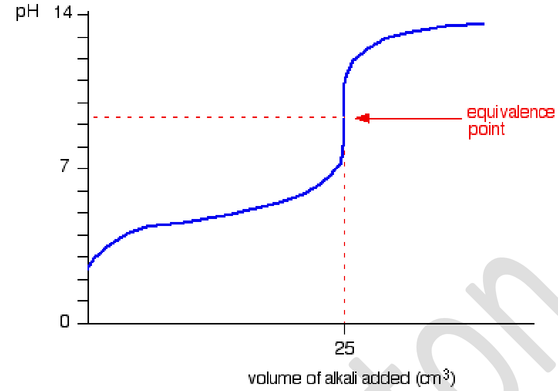
Titration curves for weak acid v strong base

We'll take ethanoic acid and sodium hydroxide as typical of a weak acid and a strong base.

- $$CH_3COOH_{(aq)} + NaOH_{(aq)} \longrightarrow CH_3COONa_{(aq)} + H_2O_{(l)}$$

• *Running acid into the alkali*	*Running alkali into the acid*



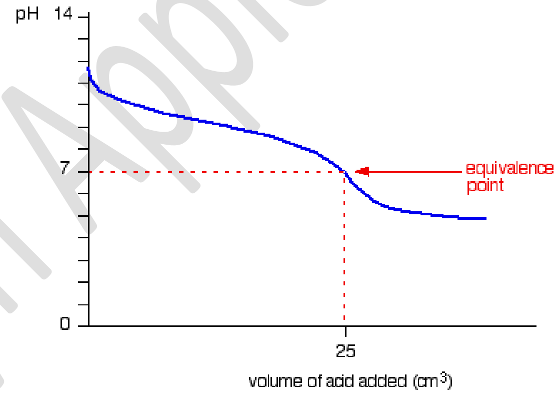


Titration curves for weak acid v weak base

The common example of this would be ethanoic acid and ammonia. $CH_3COOH + NH_3 \rightarrow CH_3COONH_4$

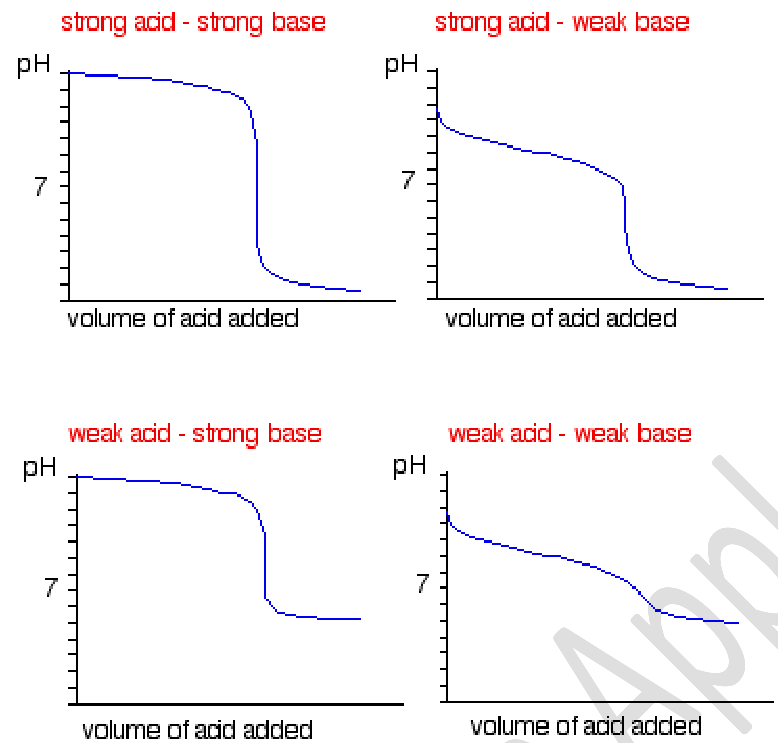
It so happens that these two are both about equally weak - in that case, the equivalence point is approximately pH 7.

Running acid into the alkali:



A summary of the important curves

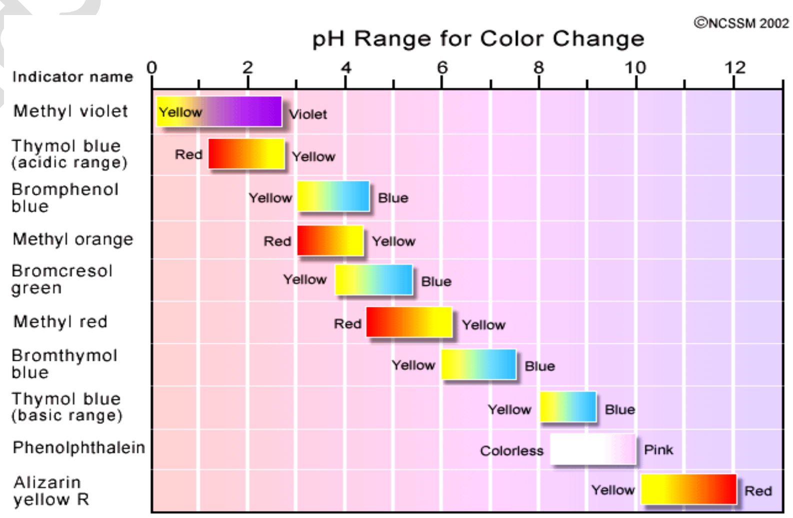
The way you normally carry out a titration involves adding the acid to the alkali. Here are reduced versions of the graphs described above so that you can see them all together.



Acid-Base Indicators

- Indicators are chemicals that appear different ________ in acids and bases.
- Indicators are weak acids or bases
- Indicators change colours when the pH (or pOH) of a solution reaches a certain _________, so they can be used to determine the pH of solutions.
- Indicators change colour based on their own equilibrium

  $In^{-}_{(aq)} + H^{+}_{(aq)} \rightleftharpoons HIn_{(aq)}$



- Indicators don't change colour sharply at one particular pH (given by their pK_{ind}). Instead, they change over a narrow range of pH.
  - Assume the equilibrium is firmly to one side, but now you add something to start to shift it. As the equilibrium shifts, you will start to get more and more of the second colour formed, and at some point the eye will start to detect it.

Example - A given solution turns methyl orange yellow, litmus blue, and phenolphthalein pink. What is the approximate pH of the solution?

Indicator	pH range	Colour change
methyl orange	3.2 - 4.4	red to yellow
litmus	5.8 - 8.0	red to blue
phenolphthalein	8.2 - 10.0	colourless to pink

- Methyl orange in yellow when pH is above ____ Litmus is blue when pH is above _____, and Phenolphthalein is pink when pH is above ______.
- Therefore the solution would have to have a pH ___________

Determining Equivalence Point

- How does one know when the equivalence point has been reached when titrating?
- Measure the pH electronically using pH electrodes and computerized titrators. If a titration is followed using a pH meter the results can be graphed and a **titration curve** results:
- This curve represents the addition of a base to an acidic solution.
- The pH changes very slowly until the **equivalence point** is approached. As the equivalence point is approached, the pH changes very rapidly with the addition of just one or two drops of additional base. The equivalence point is **the center of the straight/vertical portion of the curve.**
- Indicators are the method of choice in student labs because they are cheap and easy to use. They are also used in the field, where instrumentation is limited.
- Looking at the equivalence point for this graph, determine what a good indicator might be:

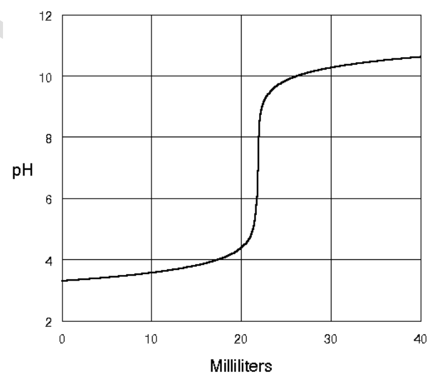
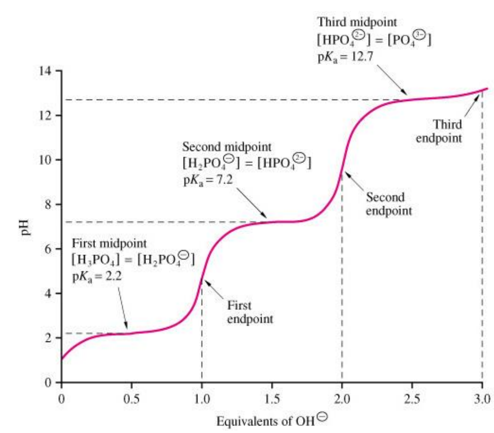


Fig.1. Titration curve for typical wastewater.

Polyprotic acids

- If the titration is done with a polyprotic acid, like phosphoric acid, the following titration curve results:
- The curve has three stages representing the equivalence point for each of the three hydrogen ions in H_3PO_4.



Determine the approximate pH at each equivalence point in the titration with H_3PO_4.

Indicators & Le Chatelier's Principle:

Litmus is a weak acid. It has a seriously complicated molecule which we will simplify to HLit. The "H" is the proton which can be given away to something else. The "Lit" is the rest of the weak acid molecule.

There will be an equilibrium established when this acid dissolves in water. Taking the simplified version of this equilibrium:

- $HLit_{(aq)} \rightleftharpoons H^{+}_{(aq)} + Lit^{-}_{(aq)}$

The un-ionised litmus is red, whereas the ion is blue.

Now use Le Chatelier's Principle to work out what would happen if you added hydroxide ions or some more hydrogen ions to this equilibrium.

Adding hydroxide ions:

Adding hydrogen ions:

pH Ranges of Common Indicators

Indicator	pH range	Colour at low end of range	Colour at middle of range	Colour at high end of range
methyl violet	0.0–1.6	yellow	green	blue
orange IV	1.4–2.8	red	orange	yellow
methyl yellow	2.9–4.0	red	orange	yellow
bromophenol blue	3.0–4.6	yellow	green	blue
methyl orange	3.2–4.4	red	orange	yellow
bromocresol green	3.8–5.4	yellow	green	blue
methyl red	4.8–6.0	red	orange	yellow
chlorophenol red	5.2–6.8	yellow	orange	red
litmus	5.5–8.0	red	purple	blue
bromothymol blue	6.0–7.6	yellow	green	blue
phenol red	6.6–8.0	yellow	orange	red
phenolphthalein	8.2–10.0	colourless	pink	red
thymolphthalein	9.4–10.6	colourless	light blue	blue
alizarin yellow	10.1–12.0	yellow	orange	red
indigo carmine	11.4–13.0	blue	green	yellow

(Lide, David R., ed. *CRC Handbook of Chemistry and Physics: A Ready-Reference of Chemical and Physical Data*. 87th ed. Boca Raton: Taylor & Francis Group, 2006.)

Choosing The Right Indicator

When choosing an indicator to use for a titration you need to consider where about the equivalence point will lie. This is where your knowledge of pH curves for strong/weak acids/bases comes in.

To determine the correct indicator:

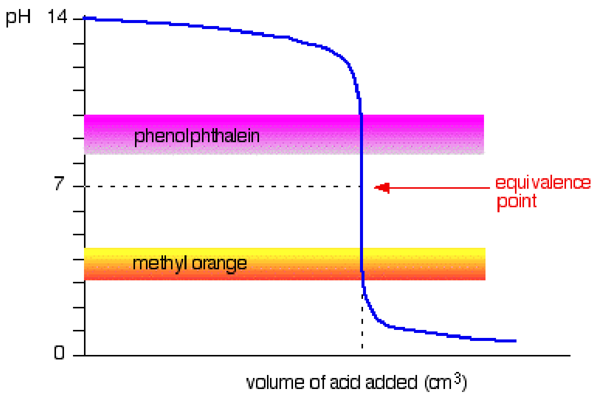
1. Determine which type (strong or weak) of acid and base you are working with.
2. Draw a rough sketch of the pH curve for that titration.
3. Identify the approximate pH of the equivalence point.
4. Look at your table of common indicators and choose one that changes colour over that pH range.

Remember that the equivalence point of a titration is where you have mixed the two substances in exactly equation proportions. You obviously need to choose an indicator which changes colour as close as possible to that equivalence point. That varies from titration to titration.

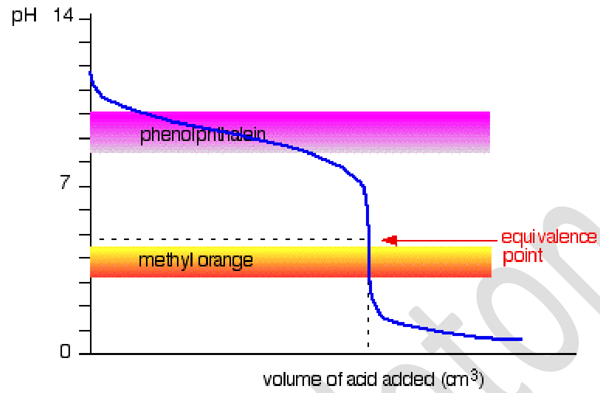
Examples:

Which indicator would you choose for the titration in the following diagrams?

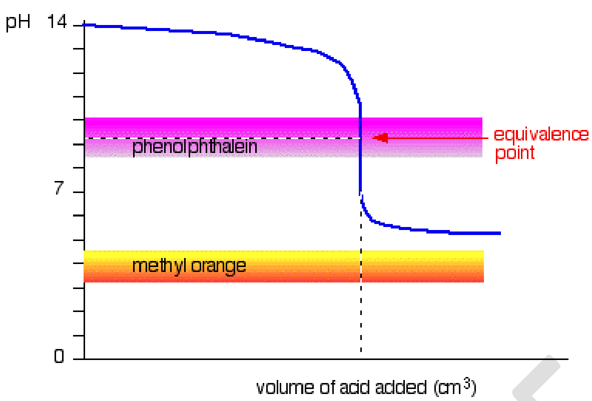
Strong acid v strong base



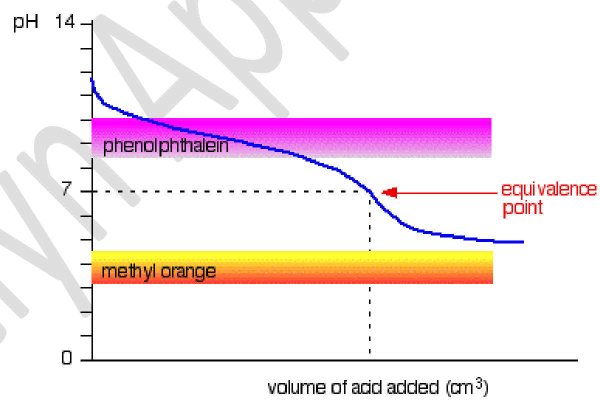
Strong acid v weak base



Weak acid v strong base



Weak acid v weak base



Name: ____________________________

pH

1. Calculate the pH of each of the following:
   a) an aqueous solution that has a hydronium ion concentration of 3.0×10^{-3} M

   b) an aqueous solution that has a hydroxide ion concentration of 6.0×10^{-4} M

   c) an aqueous solution containing 0.0020 M barium hydroxide

   d) 250.0 mL of an aqueous solution containing 1.26 g of nitric acid

2. Calculate the hydronium concentration of
   a) 100.0 mL of an aqueous solution containing 0.60 g of sodium hydroxide

   b) a blood sample with a pH of 7.40

   c) orange juice with a pH of 3.20

3. Calculate the pH of a solution created by dissolving one pellet (0.10 g) of sodium hydroxide in 1.0 L of pure water.

4. The pH of an aqueous solution of NaOH is 12.9. What is the molarity of the solution?

5. What is the pH of a 0.00125 M HBr solution? If 175 mL of this solution is diluted to a total volume of 3.00 L, what is the pH of the diluted solution?

6. A container is labeled 500.0 mL of 0.00157 M nitric acid solution. A chemist finds that the container was not sealed and that some evaporation has taken place. The volume of solution is now 447.0 mL.
   a. What was the original pH of the solution?

   b. What is the pH of the solution now?

7. An acetic acid solution has a pH of 4.0. What are the $[H_3O^+]$ and $[OH^-]$ in this solution?

8. What is the pH of a 0.000460 M solution of $Ca(OH)_2$?

9. A solution of HCl has a pH of 1.50. Determine the pH of the solutions made in each of the following ways.

   a. 1.00 mL of the solution is diluted to 1000.0 mL with water.

   b. 25.00 mL is diluted to 200.0 mL with distilled water.

   c. 18.83 mL of the solution is diluted to 4.000 L with distilled water.

d. 1.50 L is diluted to 20.0 kL with distilled water.

10. A hydrochloric acid solution has a pH of 1.70. What is the [H_3O^+] in this solution? Considering that HCl is a strong acid, what is the HCl concentration of the solution?

11. Calculate the pH of the following aqueous solutions:
    a. an aqueous solution containing 3.0×10^{-5} M hydronium ions

    b. an aqueous solution containing 6.5×10^{-4} M hydroxide ions

    c. the solution obtained when 7.2 g hydrogen chloride is dissolved in 5.0 L of water

    d. a 500.0 mL aqueous solution containing 1.0 g sodium hydroxide

12. What are the hydronium ion and the hydroxide ion concentrations of the following:

    a) a solution with a pH = 5.00

    b) a solution with a pH = 9.55

13. Fill in the blanks in the following table. For each solution indicate whether the solution is acidic or basic.

pH	**pOH**	**[H_3O^+]**	**[OH^-]**	**A or B**
4.0				
	11.6			
		1.8×10^{-9}		

			3.5×10^{-2}	

14. Calculate the pH of the solution obtained when 50.00 mL of 0.150 M Hydrochloric acid is added to 75.0 mL of a 0.111 M aqueous sodium hydroxide solution

Name:___________________

Indicators Assignment

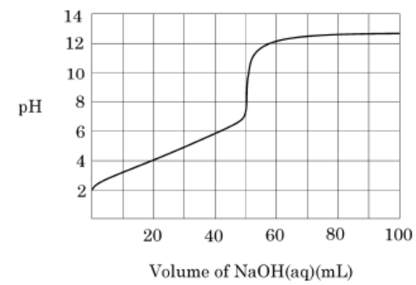
1 An unknown solution is tested with three indicators. The solution is blue when bromocresol green is added, orange with chlorophenol red, and yellow when thymol blue is added.

name of indicator	colour at acidic end of range	pH range for colour change	colour at basic end of range
bromocresol green	yellow	3.8 to 5.4	blue
chlorophenol red	yellow	5.2 to 6.8	red
thymol blue	yellow	8.0 to 9.6	blue

According to this information, what is the most likely pH of the solution?

A. 3.0
B. 6.0
C. 7.0
D. 8.0

2 An acidic solution was titrated with NaOH(aq) and the data plotted on the graph shown.



Using the pH Ranges of Common Indicators table supplied with this examination, the BEST choice of indicator for this titration is

A. orange IV.
B. alizarin yellow.
C. chlorophenol red.
D. phenolphthalein.

3 a. Draw the pH curve you would expect to get if you added 1 mol dm^{-3} hydrochloric acid to 25 cm^3 of 1 mol dm^{-3} sodium hydroxide solution. Mark the position of the equivalence point on the curve.

b. Now draw the pH curve you would expect if you added 1 mol dm^{-3} sodium hydroxide solution to 25 cm^3 of 1 mol dm^{-3} hydrochloric acid. Mark the position of the equivalence point on the curve.

4 Repeat this for the following combinations of acid and alkali, in each case marking the position of the equivalence point.

a) Adding 1 mol dm^{-3} hydrochloric acid to 25 cm^3 of 1 mol dm^{-3} ammonia solution.

b) Adding 1 mol dm^{-3} ammonia solution to 25 cm^3 of 1 mol dm^{-3} hydrochloric acid.

c) Adding 1 mol dm^{-3} ethanoic acid to 25 cm^3 of 1 mol dm^{-3} sodium hydroxide solution.

d) Adding 1 mol dm^{-3} sodium hydroxide solution to 25 cm^3 of 1 mol dm^{-3} ethanoic acid solution.

e) Adding 1 mol dm^{-3} ethanoic acid to 25 cm^3 of 1 mol dm^{-3} ammonia solution.

Name:________________________

Indicator Assignment 2

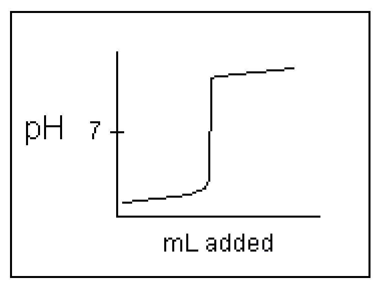
1. Multiple Choice:
   In the titration of a weak acid with a strong base, which indicator would be the best choice?
   a. Methyl orange b. Bromscresol Green c. Phenolphthalein
2. Which indicator (identified by a letter) could be used to titrate aqueous NH_3 with HCl Solution?

Indicator	Acid Range Color	Colour changes pH	Basic Range Colour
a.	Pink	1.2 – 2.8	Yellow
b.	Blue	3.4 – 4.6	Yellow
c.	Yellow	6.5 – 7.8	Purple
d.	Colourless	8.3 – 9.9	Red
e.	None of these		

3. Consider the titration of the pairs of aqueous acids and bases listed on the left. For which pair is the pH at the equivalence point stated **incorrectly**?

Acid Base Pair	pH at Equivalence Point
$HCl + NH_3$	Less than 7
$HNO_3 + Ca(OH)_2$	Equal to 7
$HClO_4 + NaOH$	Equal to 7
$HClO + NaOH$	Less than 7
$CH_3COOH + KOH$	Greater than 7

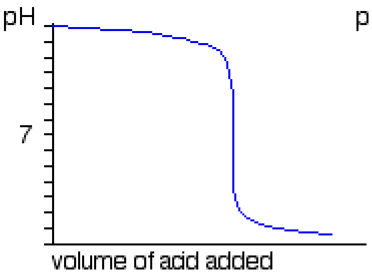
4. The following titration curve is the kind of curve expected for the titration of a ____ acid with a ____ base.



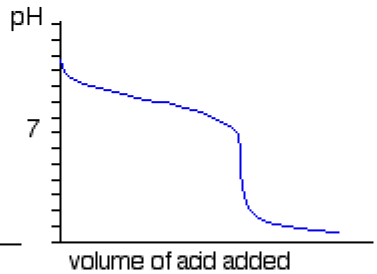
   a. strong, strong
   b. weak, strong
   c. weak, weak
   d. strong, weak
5. Which colour does the universal indicator turn in hydrochloric acid? Universal indicator: pH 1 – 4 red, pH 5 – 6 yellow, pH 7 green, pH 8 – 9 blue, pH 10 – 14 purple.
   a. Red
   b. Yellow
   c. Green
   d. Blue
   e. Purple
6. Which of the following pieces of apparatus would you NOT use in a titration?
   a. A gas jar
   b. Burette
   c. Erlenmeyer flask
   d. Stand with clamp
7. for the following curves, determine the best indicator to use:
   a. bromothymol blue b. phenolphthalein

c. bromcresol green

strong acid - strong base

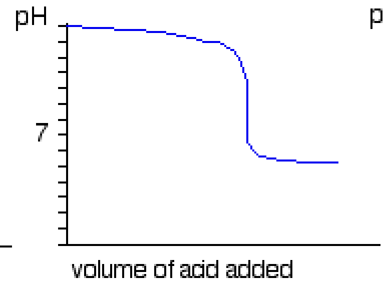


strong acid - weak base



d. methyl orange

weak acid - strong base



weak acid - weak base