3 Acids and bases

Arrhenius theory:
An acid is a substance that produces hydrogen ions (H^+)/hydronium ions (H_3O^+) when it dissolves in water. A base is a substance that produces hydroxide ions (OH^-) when it dissolves in water.

Lowry-Brønsted theory:
An acid is a proton (H^+ ion) donor.
A base is a proton (H^+ ion) acceptor.

Strong acids ionise completely in water to form a high concentration of H_3O^+ ions.
Weak acids ionise incompletely in water to form a low concentration of H_3O^+ ions.

Strong bases dissociate completely in water to form a high concentration of OH^- ions.
Weak bases dissociate/ionise incompletely in water to form a low concentration of OH^- ions.

Conjugate acid-base pairs
When the acid, HA, loses a proton, its conjugate base, A-, is formed.
When the base, A-, accepts a proton, its conjugate acid, HA, is formed.

Ampholyte or amphiprotic substance a substance that can act as either as an acid or as a base.

Concentrated acids/bases contain a large amount (number of moles) of acid/base in proportion to the volume of water.
Dilute acids/bases contain a small amount (number of moles) of acid/base in proportion to the volume of water.

Hydrolysis the reaction of a salt with water.

pH Scale is a scale with numbers 0 to 14 that is used to express the acidity of alkalinity of a solution.

K_w is the equilibrium constant for the ionisation of water or the ionic product of water or the ionisation constant of water, i.e. $K_w = [H_3O^+][OH^-] = 1 \times 10^{-14}$ at 298 K.

Auto-ionisation of water the reaction of water with itself to form H_3O+ ions and OH^- ions.

Neutralisation is the reaction between an acid an a base to produce a salt and water.

Titration is an experiment that is used to determine the concentration of an acid or a base by using a neutralisation reaction with a standard solution.

A **Standard solution** is a solution of which the concentration is known and remains constant for a time.

Equivalence point of a titration is the point at which the acid /base has completely reacted with the base/acid.

Endpoint of a titration is the point where the indicator changes colour.

Acid	Formula	Strength
Hydrochloric acid	HCl	strong
Sulphuric acid	H_2SO_4	strong
Nitric acid	HNO_3	strong
Phosphoric acid	H_3PO_4	weak
Sulphurous acid	H_2SO_3	weak
Carbonic acid	H_2CO_3	weak
Oxalic acid	$(COOH)_2$ $H_2C_2O_4$	weak
Acetic acid (etanoic acid)	CH_3COOH	weak

Base	Formula	Strength
Sodium hydroxide	NaOH	strong
Potassium hydroxide	KOH	strong
Lithium hydroxide	LiOH	strong
Calcium hydroxide	$Ca(OH)_2$	weak
Magnesium hydoxide	$Mg(OH)_2$	weak
Ammonia	NH_3	weak
Potassium carbonate	K_2CO_3	weak
Sodium bicarbonate	$NaHCO_3$	weak
Sodium carbonate	Na_2CO_3	weak

Acids

Brønsted-Lowry: Proton donor

Strong acids
(ionise completely)

covalent → no ions → ionises

$HCl(g) + H_2O(l) \rightleftharpoons H_3O^+(aq) + Cl^-(aq)$
hydrochloric acid

$HNO_3(g) + H_2O(l) \rightleftharpoons H_3O^+(aq) + NO_3{}^-(aq)$
nitric acid

$H_2SO_4(l) + 2H_2O(l) \rightleftharpoons 2H_3O^+(aq) + SO_4{}^{-2}(aq)$
sulfuric acid

$K_a = \frac{[C\ell^-][H_3O^+]}{[HCl]}$ = VERY BIG

Weak acids
(ionise incompletely)

covalent → no ions → ionises

$CH_3COOH + H_2O(l) \rightleftharpoons H_3O^+(aq) + CH_3COO^-(aq)$
acetic acid — acetate ion
ethanoic acid — ethanoate ion

$H_2CO_3 + H_2O(l) \rightleftharpoons H_3O^+(aq) + HCO_3{}^-(aq)$
carbonic acid

$(COOH)_2 + H_2O \rightleftharpoons H_3O^+(aq) + H(COO)_2{}^{-1}$
$H_2C_2O_4 + H_2O \rightleftharpoons H_3O^+(aq) + HC_2O_4{}^-$
oxalic acid — oxalate ion

$K_a = \frac{[HCO_3^-][H_3O^+]}{[H_2CO_3]}$ = small

Bases

Brønsted-Lowry: Proton acceptor

Strong bases
(dissociate completely)

ionic → has ions → dissociate

$KOH \overset{}{\underset{H_2O}{\rightleftharpoons}} K^+(aq) + OH^-(aq)$

$NaOH \underset{H_2O}{\rightleftharpoons} Na^+(aq) + OH^-(aq)$

$LiOH \underset{H_2O}{\rightleftharpoons} Li^+(aq) + OH^-(aq)$

K_b = VERY BIG

Weak bases
(dissociate/ionise incompletely)

Covalent NH_3 ionises and forms NH_4OH that weakly dissociates

$NH_3 + H_2O \rightleftharpoons NH_4{}^+(aq) + OH^-(aq)$

Na_2CO_3 dissociates completely and give $CO_3{}^{-2}$ that hydrolyses incompletely

$Na_2CO_3 \longrightarrow 2Na^+(aq) + CO_3{}^{-2}(aq)$
$CO_3{}^{-2} + H_2O \rightleftharpoons HCO_3{}^- + 2OH^-$

K_b = small

Reactions of acids

Acid and reactive metal → salt + hydrogen gas

$2HCl(aq) + Zn(s) \rightarrow ZnCl_2(aq) + H_2(g)$
$H_2SO_4(aq) + Mg(s) \rightarrow MgSO_4(aq) + H_2(g)$

Acid and metal hydroxide → salt + water

$2HCl(aq) + Zn(OH)_2(s) \rightarrow ZnCl_2(aq) + 2H_2O(l)$
$H_2SO_4(aq) + 2NaOH(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(l)$

If the base is NH_3:
$2HCl(aq) + NH_3(g) \rightarrow NH_4Cl(aq)$ or
$2HCl(aq) + NH_3(g) \rightarrow NH_4{}^+(aq) + Cl^-(aq)$

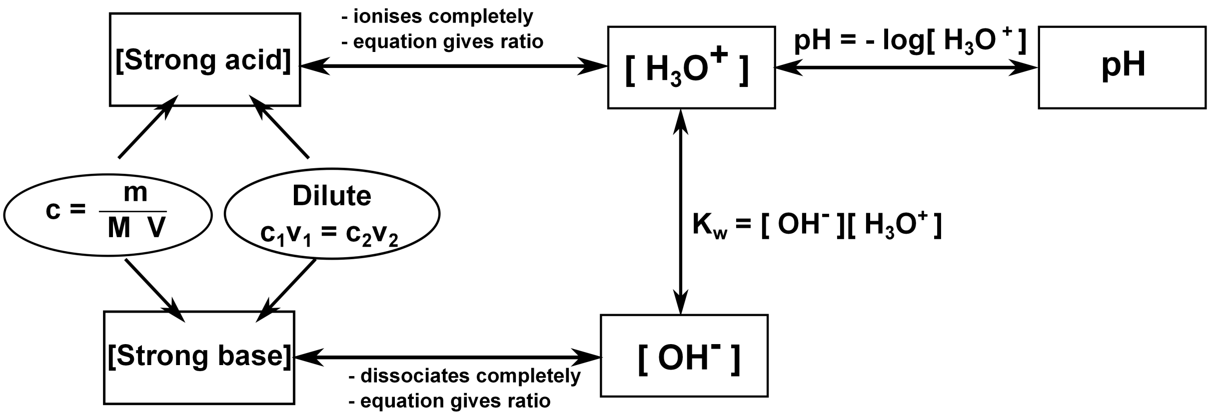
Acid and metal oxide → salt + water

$2HCl(aq) + ZnO(s) \rightarrow ZnCl_2(aq) + H_2O(l)$
$H_2SO_4(aq) + Na_2O(aq) \rightarrow Na_2SO_4(aq) + H_2O(l)$

Acid and metal carbonate → salt + water + carbon dioxide

$2HCl(aq) + ZnCO_3(s) \rightarrow ZnCl_2(aq) + H_2O(l) + CO_2(g)$
$H_2SO_4(aq) + Na_2CO_3(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(l) + CO_2(g)$

Calculations with acids and bases



Indicator	Colour in acid	Colour in base	coulour chage pH
Litmus	Red	Blue	4,5 - 8,3
Phenolphthalein	Colourless	Pink	8,3 - 10,0
Bromothymol blue	Yellow	Blue	6,0 - 7,7
Methyl orange	Orange	Yellow	3,1 - 4,4

<table>
<tr><td>Concentration</td><td>$c = \frac{n}{V}$ en $n = \frac{m}{V}$ of $c = \frac{m}{M\,V}$ (V in dm^3)</td></tr>
<tr><td>Dilutions</td><td>$\underbrace{C_1\ V_1}_{old} = \underbrace{C_2\ V_2}_{new}$
NB. New volume = original volume + water added !!</td></tr>
<tr><td>Conjugated acid base pairs</td><td>conjugated pairs 2
$\underset{}{\overset{base}{NH_3(g)}} + \underset{acid}{H_2O(\ell)} \rightleftharpoons \overset{conj\ acid}{NH_4^+(aq)} + \underset{conj\ base}{OH^-(aq)}$
conjugated pair 1
The conjugated base of a strong acid is weak and the conjugated acid of a strong base is weak.</td></tr>
<tr><td>Outo-protolysis of water</td><td>Water is an ampholite and can undergo protolysis:
$H_2O(l) + H_2O(l) \rightleftharpoons H_3O^+(aq) + OH^-(aq)$
$K_w = [H_3O^+][OH^-] = 1 \times 10^{-14}$ by 25° C
Bigger $[H_3O^+] \rightarrow$ smaller $[OH^-]$
Neutral solution $[H_3O^+] = [OH^-]$
Acidic solution $[H_3O^+] > [OH^-]$
Basic solution $[H_3O^+] < [OH^-]$</td></tr>
<tr><td>pH scale</td><td>$pH = -\log [H_3O^+]$ (IEB no calculations)
Bigger pH $\rightarrow$ lower $[H_3O^+]$
<table><tr><td>$[H_3O^+]$</td><td>10^{-2}</td><td>10^{-3}</td><td>10^{-4}</td><td>$mol.dm^{-3}$</td></tr><tr><td>pH</td><td>2</td><td>3</td><td>4</td><td></td></tr></table>If $[H_3O^+]$ decreases by factor 10 the pH increases by 1.</td></tr>
<tr><td>Titration</td><td>$\frac{n_a}{n_b} = \frac{C_a.V_a}{C_b.V_b}$</td></tr>
</table>

Ion	**Hydrolysis**	**Reason**
Cl^-, SO_4^{-2}, NO_3^-	None	Conjugated base of strong acid
Na^+, K^+, Li^+	None	Ion from a strong base
CO_3^{-2} carbonate CH_3COO^- acetate / ethanoate $(COO)_2^{-2}$ $C_2O_4^{-2}$ oxalate	$CO_3^{-2} + H_2O \rightleftharpoons HCO_3^- + 2OH^-$ $CH_3COO^- + H_2O \rightleftharpoons CH_3COOH + OH^-$ $(COO)_2^{-2} + 2H_2O \rightleftharpoons (COOH)_2 + 2OH^-$ $C_2O_4^{-2} + 2H_2O \rightleftharpoons C_2O_4H_2 + 2OH^-$	Conjugated base of weak acid
NH_4^+	$NH_4^+ + H_2O \rightleftharpoons NH_3 + H_3O^+$	Conjugated acid of weak base

Write balanced equations for the following:

a. Ionization of nitric acid in water

b. Sodium hydroxide dissolves in water

c. Reaction of oxalic acid and lithium oxide

d. Reaction of ammonia with water

e. Reaction of sulphuric acid and water

f. Neutralisation that produces potassium sulphate

g. Ionisation of oxalic acid in water

h. Reaction between lithium hydroxide and water

i. Reaction between ammonia and hydrochloric acid

QUESTION 3

3.1 Calculate how much water must be added to 30 cm^3 of a 0,2 mol.dm^{-3} HCl solution to change the concentration to 0,03 mol.dm^{-3}.

3.2 A solution of acid HX with concentration 0,15 mol.dm^{-3} is prepared. The concentration of hydronium ions in the solution is 3,2 $\times$ 10^{-6} mol·dm^{-3}.

a. Write an equation for the reaction of HX with water.

b. Is HX a strong acid? Explain.

c. Name the conjugated acid base pairs in the reaction.

3.3 X cm^3 of water is added to 300 cm^3 of a 0,15 mol.dm^{-3} sulphuric acid solution. The concentration decreases to 0,045 mol.dm^{-3}.

a. Calculated the volume X of water that is added.

b. Calculate the concentration of the hydronium ions in the solution.

c. Calculate the pH of the diluted solution.(Not IEB)

3.4 0,5 g of lithium hydroxide is used to prepare 200 cm^3 of solution.

a. Calculate the concentration of the lithium hydroxide
b. What is the concentration of the hydroxide ions in the solution?
c. What is the concentration of the lithium ions in the solution?
d. Calculate the hydronium ion concentration in the solution.
e. Calculate the pH of the solution. (Not IEB)

3.5 The pH of household ammonia is 11,61. Calculate the $[H^+]$ and the $[OH^-]$ of this dilute solution. (Not IEB.)

Hydrolysis

Hydrolysis is the reaction of a salt with water.

Example: ammonium chloride

What acid and base can be used to prepare the salt?
NH_4Cl can be prepared by the reaction of ammonia with hydrochloric acid.
It is a reaction between a strong acid and a weak base and the solution is acidic.

Consider the reactions of the ions with water to explain why the solution is acidic.
Cl^- does not hydrolyse. It is the weak conjugated base of a strong acid.

NH_4^+ is the conjugated acid of a weak base.
It hydrolyses to form H_3O^+, that makes the solution acidic:
$NH_4^+ + H_2O \rightleftharpoons NH_3 + H_3O^+$

a. Give the formulas of the acid and the base that can be used to prepare the salt and indicate if the solution is acidic, basic or neutral.

Compound	**Acidic**	**Base**	**Solution**
ammonium nitrate			
potassium chloride			
sodium oxalate			
ammonium carbonate			
sodium sulphite			
lithium carbonate			
sodium acetate			

b. Sodium oxalate is dissolved in water. Is the solution acidic, basic or neutral? Use equations to explain the answer.

Titrations

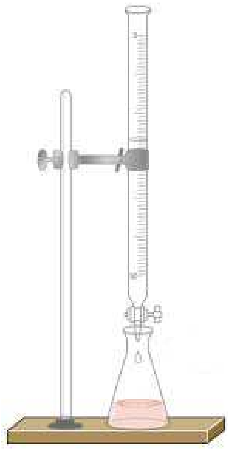
A titration is an experiment that is used to determine the unknown concentration of an acid or a base, by using a neutralisation reaction with a standard solution.

Example:

The concentration of a H_2SO_4 solution is unknown. A standard NaOH solution can be used to determine the concentration of the acid. A **standard solution** is a solution of which the concentration is known and remains constant for a time.

$$2NaOH + H_2SO_4 \rightarrow Na_2SO_4 + 2H_2O$$

The acid is usually used in the burette, as the base is soapy and can cause blockage of the burette. A specific volume of NaOH is transfered to the conical flask with a pipette. An indicator is added to the flask. The H_2SO_4 is placed in the burette and added drop wise to the NaOH in the flask.



When the **end point** is reached the colour of the indicator changes permanently. The volume of the acid that is used is read on the burette.

The unknown concentration can be determined with separate steps in a stoichiometric calculation or with the following equation:

$$\frac{n_a}{n_b} = \frac{c_a.V_a}{c_b.V_b}$$

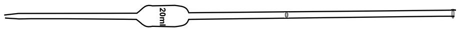
Indicator	**Colour in acid**	**Colour in base**	**coulour chage pH**
Phenolphthalein	Colourless	Pink	8,3 - 10,0 (basic)
Bromothymol blue	Yellow	Blue	6,0 - 7,7 (neutral)
Methyl orange	Orange	Yellow	3,1 - 4,4 (acidic)

Choice of indicators:

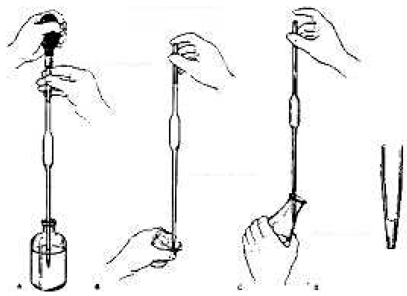
Strong acid + strong base $\rightarrow$ end point neutral $\rightarrow$ bromothymol blue best
Strong acid + weak base $\rightarrow$ end point acidic $\rightarrow$ methyl orange is best
Weak acid + strong base $\rightarrow$ end point basic $\rightarrow$ phenolphthalein is best
Weak acid + weak base $\rightarrow$ end point neutral $\rightarrow$ bromothymol blue best

Good video to watch on titration technique and glassware:
https://www.youtube.com/watch?v=sFpFCPTDv2w

Glassware

Pipette: 

A pipette is used to measure a fixed volume. The liquid is sucked up in the pipette to a level above the mark. Place a finger on top of the pipet and lift it until the level of the bottom of the meniscus is level with the mark.
Use a rubber pro-pipette on the pipette for concentrated acids to prevent getting acid into your mouth.



The pipette is designed to deliver the correct volume when it is pressed against the side of the conical flask. Drops that remain in the pipette must not be blown out!!

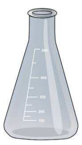
The pipet may be rinsed with distilled water, but must **afterwards/lastly** rinsed with the solution that will be used in it. Any water drops in the pipette will dilute the solution that is measured and lower the concentration.

Buret:

The volume of the acid was read **before** and **after** the experiment to determine the volume of acid that was used. The first experiment is done quickly just to give an indication of the volume needed. The experiment is repeated three times and the average volume is determined. Near the end point only one small drop was added at a time.

The burette is rinsed with distilled water and finally with tthe solutions that is used in the burette. Any water drops in the pipette will dilute the solution that is measured and lower the concentration.

Conical flask or Erlenmeyer flask:



The shape of the flask ensure good mixture of the liquids when it is swirled and prevent spilling.

During the experiment, the sides of the flask must be washed down with distilled water to ensure that all the added acid and base molecules are part of the reaction. The water does not change the moles acid or base in the flask.