CHEM 20 – ACIDS & BASES REVIEW

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ACID & BASE DEFINITIONS

EXPERIMENTAL PROPERTIES OF ACIDS AND BASES

	Acid	Base

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	Acid	Base
How does the solution affect the colour of litmus paper?		
pH		
Relation between $[H_3O^+_{(aq)}]$ and $[OH^-_{(aq)}]$	$[H_3O^+_{(aq)}]$ $[OH^-_{(aq)}]$	$[H_3O^+_{(aq)}]$ $[OH^-_{(aq)}]$
Does the solution conduct electricity?		
Other		

EXPERIMENTAL PROPERTIES OF ACIDS AND BASES

	Acid	Base
How does the solution affect the colour of litmus paper?	Turns blue litmus paper red. (Red means Acid)	Turns red litmus paper blue. (Blue means Basic)
pH	pH < 7.0	pH > 7.0
Relation between $[H_3O^+_{(aq)}]$ and $[OH^-_{(aq)}]$	$[H_3O^+_{(aq)}] >>> [OH^-_{(aq)}]$	$[H_3O^+_{(aq)}] <<< [OH^-_{(aq)}]$
Does the solution conduct electricity?	Yes. Strong acids are strongly conductive, weak acids are weakly conductive.	Yes. Strong bases are strongly conductive, weak bases are weakly conductive.
Taste: do not taste lab chemicals!	Tastes tart or sour (eg: lemon juice is high in citric acid, and vinegar is high in acetic acid)	Tastes bitter (eg: soap or baking soda)
Touch: many acids and bases can cause severe chemical burns!		Feels slippery or soapy (eg: soap)
	React with some metals to produce hydrogen gas	

Experimental to Theoretical Definition

- However, experimental definitions don't tell us what is going on in solution, they simply describe a situation.
- The first acid-base theory that was reasonably accurate and is still used in many situations today was proposed by Arrhenius in the late 1800s.

Svante Arrhenius (1859 - 1927)

https://en.wikipedia.org/wiki/Svante_Arrhenius

TEACHING PORTFOLIO NOTE:

I have used the definitions of “Arrhenius” and “modified Arrhenius” that appear in official Alberta textbook(s). I am aware that most high school and post-secondary intro chemistry textbooks don’t list two different types of Arrhenius acid-base theory.

This note is intentionally repeated at the end of the Arrhenius section.

Original Recipe Arrhenius Acid-Base Theory

- All ionic compounds dissociate when dissolved in water to form a **cation** and an **anion**

Ionic compound → cation + anion

$NaCl_{(s)} \rightarrow Na^{+}_{(aq)} + Cl^{-}_{(aq)}$

- Bases are soluble ionic compounds that dissolve in water to form a cation and the **hydroxide ion**

Base → cation + hydroxide

$NaOH_{(s)} \rightarrow Na^{+}_{(aq)} + OH^{-}_{(aq)}$

- Acids are soluble compounds that ionize in water to form **hydrogen ions** and an anion

Acid → hydrogen ion + anion

$HCl_{(g)} \rightarrow H^{+}_{(aq)} + Cl^{-}_{(aq)}$

- **Neutralization** reactions occur between the hydroxide ion and hydrogen ion to produce water

$OH^{-}_{(aq)} + H^{+}_{(aq)} \rightarrow H_2O_{(l)}$

Problems with Original Recipe
Arrhenius Acid-Base Theory

- Does not explain why ammonia ($NH_{3(g)}$) is a weak base when dissolved or why carbon dioxide ($CO_{2(g)}$) is a weak acid when dissolved.
- Does not explain why some substances like $NaHSO_{4(aq)}$ can neutralize both acids and bases.
- To explain these, the Arrhenius theory was modified.

Modified Arrhenius Acid-Base Theory

- Acidic and basic substances react with water, producing either the hydronium ion or the hydroxide ion.
- Some compounds can react to from *either* the hydroxide or hydronium ion, depending on conditions (these are "**amphoteric**" substances)
- Neutralization is a reaction between hydronium and hydroxide to form water.

$$OH^-_{(aq)} + H_3O^+_{(aq)} \rightarrow 2H_2O_{(l)}$$

Modified Arrhenius Acid and Base Definitions

	Acid	Base
	When dissolved in water, acids react to form hydronium ion: $H_3O^+_{(aq)}$	When dissolved in water, bases either dissociate or react with water to form hydroxide ions: $OH^-_{(aq)}$
	$HA_{(aq)} + H_2O_{(l)} \rightarrow A^-_{(aq)} + H_3O^+_{(aq)}$	$MOH \rightarrow M^+_{(aq)} + OH^-_{(aq)}$
Eg:	$HCl_{(aq)} + H_2O_{(l)} \rightarrow Cl^-_{(aq)} + H_3O^+_{(aq)}$	$NaOH \rightarrow Na^+_{(aq)} + OH^-_{(aq)}$
		- OR -
		$B_{(aq)} + H_2O_{(l)} \rightarrow HB^+_{(aq)} + OH^-_{(aq)}$
Eg:		$NH_{3(aq)} + H_2O_{(l)} \rightarrow NH_4^+_{(aq)} + OH^-_{(aq)}$

Here,
"HA" stands for any acid.
"M" stands for any metal ion
"B" is any base. *It is not the element boron*

More definitions of acids and bases exist! Chem 30 will cover Bronsted-Lowry acids and bases, and early university chemistry will likely cover Lewis and Solvent-System definitions

Explaining The Weird Ones With Modified Arrhenius Theory

- Ammonia ($NH_{3(g)}$)

$$NH_{3(aq)} + H_2O_{(l)} \rightarrow NH_4^+{}_{(aq)} + OH^-{}_{(aq)}$$

- Carbon dioxide ($CO_{2(g)}$)

$$CO_{2(g)} + H_2O_{(l)} \rightarrow H_2CO_{3(aq)}$$

$$H_2CO_{3(aq)} + H_2O_{(l)} \rightarrow HCO_3^-{}_{(aq)} + H_3O^+{}_{(aq)}$$

TEACHING PORTFOLIO NOTE REPEATED:

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Amphoteric substances can't pick a side

- We are using sodium hydrogen phosphate as an example, however, there are many, many aphoteric substances.
- First, the sodium hydrogen phosphate dissociates.

$$Na_2HPO_{4(aq)} \rightarrow 2Na^+_{(aq)} + HPO_4^{2-}{}_{(aq)}$$

- As a base (ignoring Na^+ spectator ion):

$$HPO_4^{2-}{}_{(aq)} + H_2O_{(l)} \rightarrow H_2PO_4^-{}_{(aq)} + OH^-_{(aq)}$$

- As an acid (ignoring Na^+ spectator ion):

$$HPO_4^{2-}{}_{(aq)} + H_2O_{(l)} \rightarrow PO_4^{3-}{}_{(aq)} + H_3O^+_{(aq)}$$

More Definitions

- **Monoprotic acid** – an acid that is only capable of reacting with water once, producing one hydronium ion for each molecule of acid. This is because the acid only possesses one ionizable proton. Eg: hydrochloric acid (HCl) or acetic acid (CH_3COOH).

- **Polyprotic acid** – an acid that has more than one ionizable proton. A polyprotic acid can react with water two or more times producing a hydronium ion from each reaction. Eg: Sulphuric Acid ($H_2SO_{4(aq)}$) which has two ionizable protons, and citric acid ($C_3H_5O(COOH)_3$) which has three ionizable protons.

- **Monoprotic base** – a base that can only react with water once, producing only one hydroxide ion **or** a base that on dissociation in water produces only one hydroxide ion. Eg: sodium hydroxide (NaOH) or ammonia (NH_3)

- **Polyprotic base** – a base that can react multiple times with water, forming multiple hydroxide ions or a base that produces multiple hydroxide ions when it dissociates in water. Eg: calcium hydroxide ($Ca(OH)_2$) or sodium carbonate (Na_2CO_3)

Polyprotic Acid Reactions

- An unknown acid, H_2A, can react two times with water. These are the reactions that will occur.

[Reaction 1]	$H_2A_{(aq)} + H_2O_{(l)} \rightarrow HA^-_{(aq)} + H_3O^+_{(aq)}$
[Reaction 2]	$HA^-_{(aq)} + H_2O_{(l)} \rightarrow A^{2-}_{(aq)} + H_3O^+_{(aq)}$
[Net Reaction]	$H_2A_{(aq)} + 3H_2O_{(l)} \rightarrow A^{2-}_{(aq)} + 2H_3O^+_{(aq)}$

A "net reaction" is what happens when you add together multiple reactions.

Since the product HA^- from reaction 1 is consumed in reaction 2, they cancel when all the reactions are added.

However, the H_3O^+ is not consumed, and ends up in the final net reaction.

The idea of adding reactions like this is introduced fully in Chem 30.

Sample Set of Polyprotic Acid Reactions

- Oxalic acid, HOOCCOOH, can react two times with water. These are the reactions that will occur.

[Reaction 1]	$HOOCCOOH_{(aq)} + H_2O_{(l)} \rightarrow HOOCCOO^{-}{}_{(aq)} + H_3O^{+}{}_{(aq)}$
[Reaction 2]	$HOOCCOO^{-}{}_{(aq)} + H_2O_{(l)} \rightarrow OOCCOO^{2-}{}_{(aq)} + H_3O^{+}{}_{(aq)}$
[Net Reaction]	$HOOCCOOH_{(aq)} + 3H_2O_{(l)} \rightarrow OOCCOO^{2-}{}_{(aq)} + 2H_3O^{+}{}_{(aq)}$

Polyprotic Base Reactions

- An unknown base, B, can react three times with water. These are the reactions that will occur.

[Reaction 1] $B_{(aq)} + H_2O_{(l)} \rightarrow HB^{+}_{(aq)} + OH^{-}_{(aq)}$

[Reaction 2] $HB^{+}_{(aq)} + H_2O_{(l)} \rightarrow H_2B^{2+}_{(aq)} + OH^{-}_{(aq)}$

[Reaction 3] $H_2B^{2+}_{(aq)} + H_2O_{(l)} \rightarrow H_3B^{3+}_{(aq)} + OH^{-}_{(aq)}$

[Net Reaction] $B_{(aq)} + 3H_2O_{(l)} \rightarrow H_3B^{3+}_{(aq)} + 3OH^{-}_{(aq)}$

- An unknown metal (R, with a charge of *x*+) hydroxide will dissociate to form multiple hydroxide ions when it is dissolved.

[Reaction 4] $R(OH)_{x(s)} \rightarrow R^{x+}_{(aq)} + x\ OH^{-}_{(aq)}$

Real World Polyprotic Base Reactions

- Sodium citrate $Na_3C_3H_5O(COO)_3$ is a polyprotic base that can react three times with water in the correct conditions. These are the reactions that will occur.

  [Dissolution] $Na_3C_3H_5O(COO)_{3(s)} \rightarrow 3Na^+_{(aq)} + C_3H_5O(COO)_3^{3-}{}_{(aq)}$

  Ignore sodium spectator ions for acid-base chemistry

  [Reaction 1] $C_3H_5O(COO)_3^{3-}{}_{(aq)} + H_2O_{(l)} \rightarrow HC_3H_5O(COO)_3^{2+}{}_{(aq)} + OH^-_{(aq)}$

  [Reaction 2] $HC_3H_5O(COO)_3^{2+}{}_{(aq)} + H_2O_{(l)} \rightarrow H_2C_3H_5O(COO)_3^{+}{}_{(aq)} + OH^-_{(aq)}$

  [Reaction 3] $H_2C_3H_5O(COO)_3^{+}{}_{(aq)} + H_2O_{(l)} \rightarrow H_3C_3H_5O(COO)_{3(aq)} + OH^-_{(aq)}$

  [Net Reaction] $C_3H_5O(COO)_3^{3-}{}_{(aq)} + 3H_2O_{(l)} \rightarrow H_3C_3H_5O(COO)_{3(aq)} + 3OH^-_{(aq)}$

Note that in the generic example "B" was assumed to be neutral. However, citrate has a 3⁻ charge. The ion charges in all the reactions are adjusted to account for the difference

- Calcium hydroxide ("lime") is very slightly soluble in water (a saturated solution is roughly 1.4 x 10^{-4} mol/L). This is the dissolution reaction:

  [Reaction 4] $Ca(OH)_{2(s)} \rightarrow Ca^{2+}{}_{(aq)} + 2OH^-_{(aq)}$

pH and pOH

QUESTIONS

- What is pH and pOH?
- Why do we use them rather than concentrations?

WHAT ARE pH AND pOH?

- Both are a measure of how acidic or basic a solution is.
- pH = - log $[H^+_{(aq)}]$ *or* pH = - log $[H_3O^+_{(aq)}]$

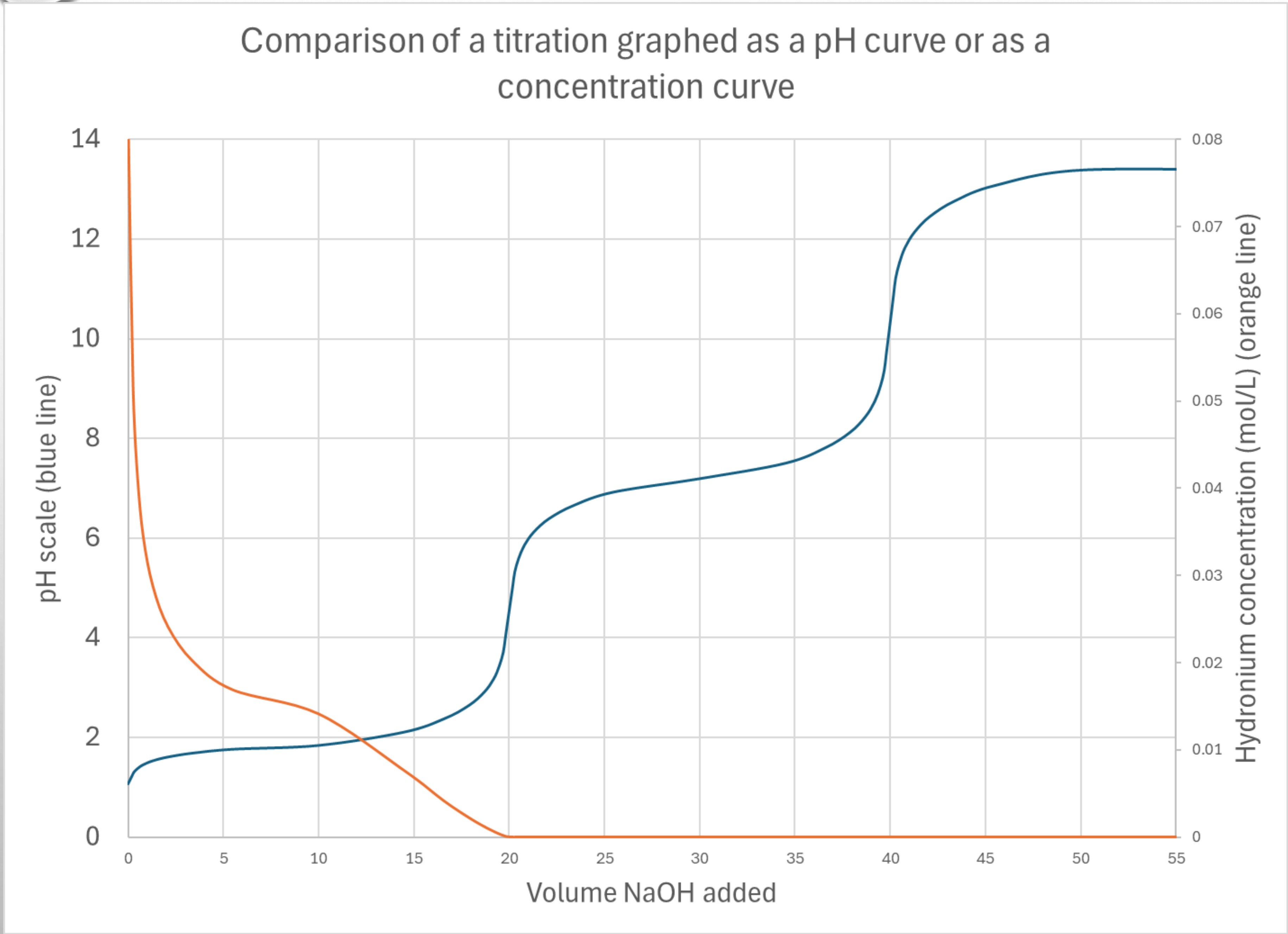
  (Depending on the Acid-Base definition you are using)
- pOH = - log $[OH^-_{(aq)}]$

Why do we use them rather than concentrations?

$[H_3O^+]$	$[OH^-]$		pH	pOH
1 M	10^{-14} M		0	14
10^{-1} M	10^{-13} M		1	13
10^{-2} M	10^{-12} M		2	12
10^{-3} M	10^{-11} M	acidic	3	11
10^{-4} M	10^{-10} M		4	10
10^{-5} M	10^{-9} M		5	9
10^{-6} M	10^{-8} M		6	8
10^{-7} M	10^{-7} M	neutral	7	7
10^{-8} M	10^{-6} M		8	6
10^{-9} M	10^{-5} M		9	5
10^{-10} M	10^{-4} M		10	4
10^{-11} M	10^{-3} M	basic	11	3
10^{-12} M	10^{-2} M		12	2
10^{-13} M	10^{-1} M		13	1
10^{-14} M	1 M		14	0

- To simplify calculations and determining if something is acidic or basic.
- To make it easier to look at data that spans several orders of magnitude (especially in titrations)

Image credit: https://chem.libretexts.org/Courses/Anoka-Ramsey_Community_College/Introduction_to_Chemistry/15%3A_Acids_and_Bases/15.08%3A_pH_and_pOH_Calculations



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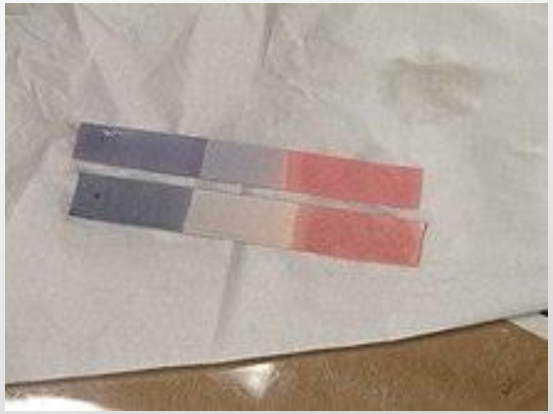
Titrations

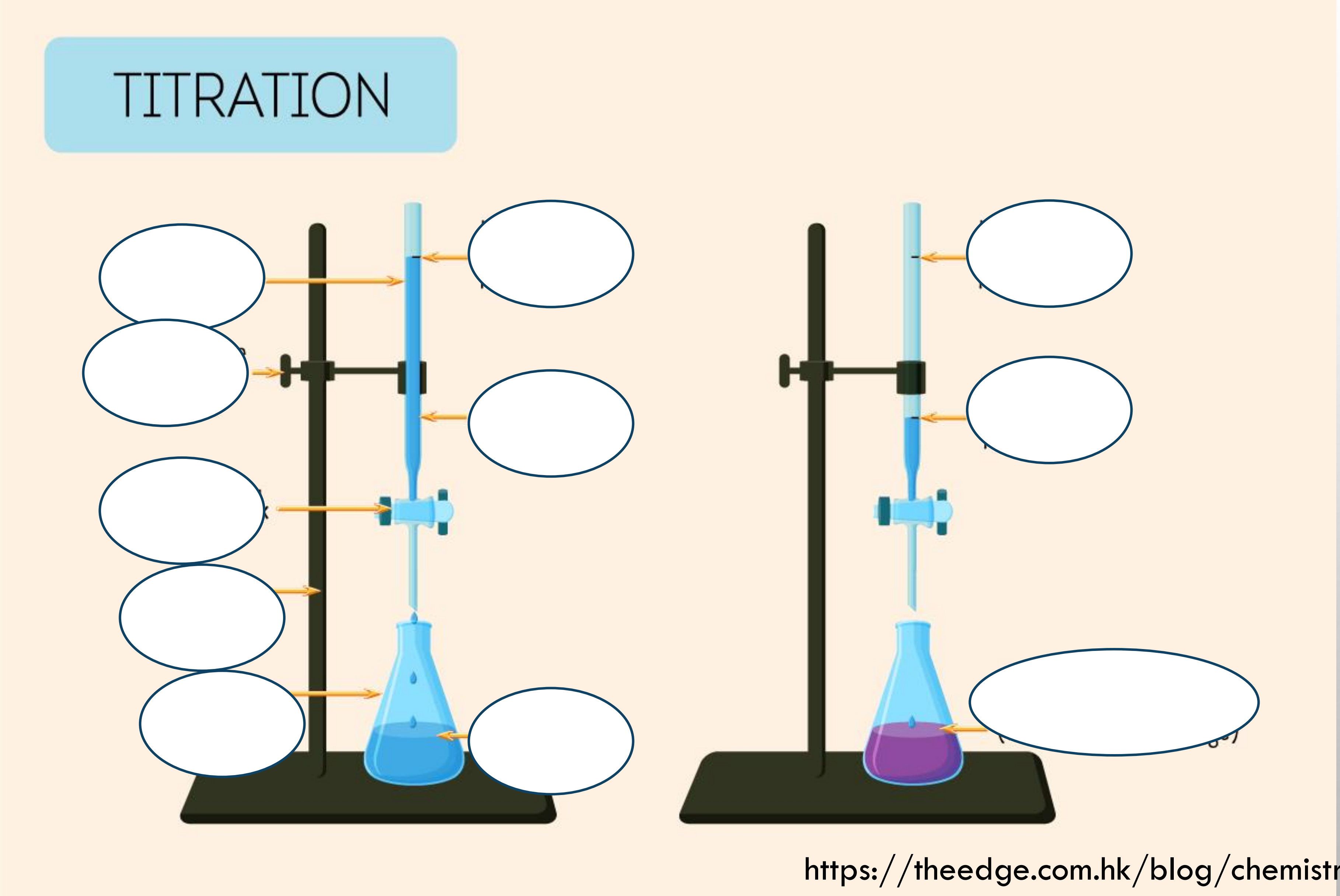
Titration

- A titration is a method of quantitative chemical analysis to determine the concentration (or amount) of an **analyte** in a known volume of solution (or mass of solid) by the gradual addition of a **standard** solution.
- The **endpoint** of the titration can be determined using an **indicator** (most common at the high school level) that changes colour, or some other method. A common other method is by graphing the change of something as the standard is added, perhaps monitoring pH with a pH electrode.



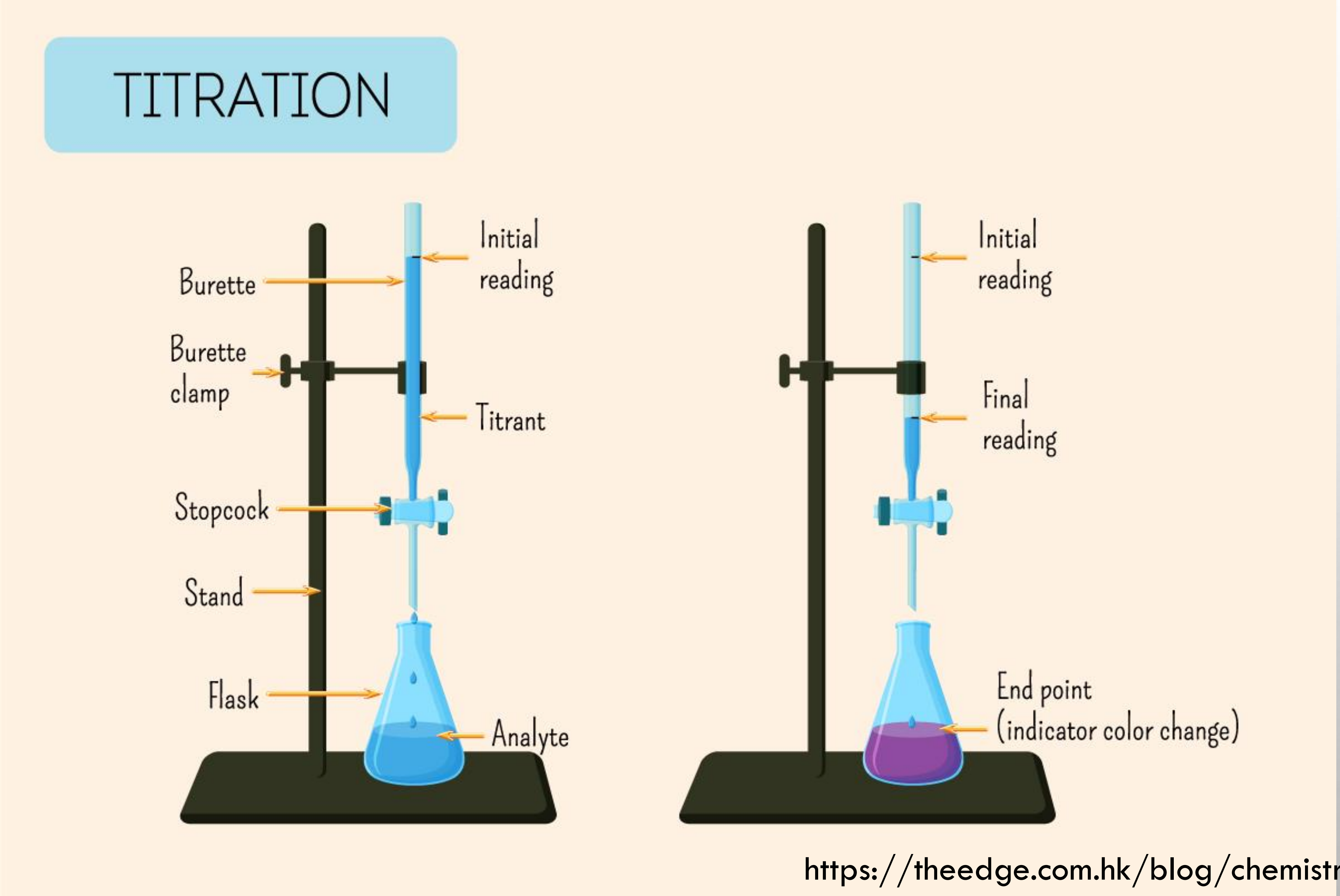
Litmus paper before and after use.
https://en.wikipedia.org/wiki/Litmus

DEFINITIONS



https://theedge.com.hk/blog/chemistry-how-to-titration/

DEFINITIONS



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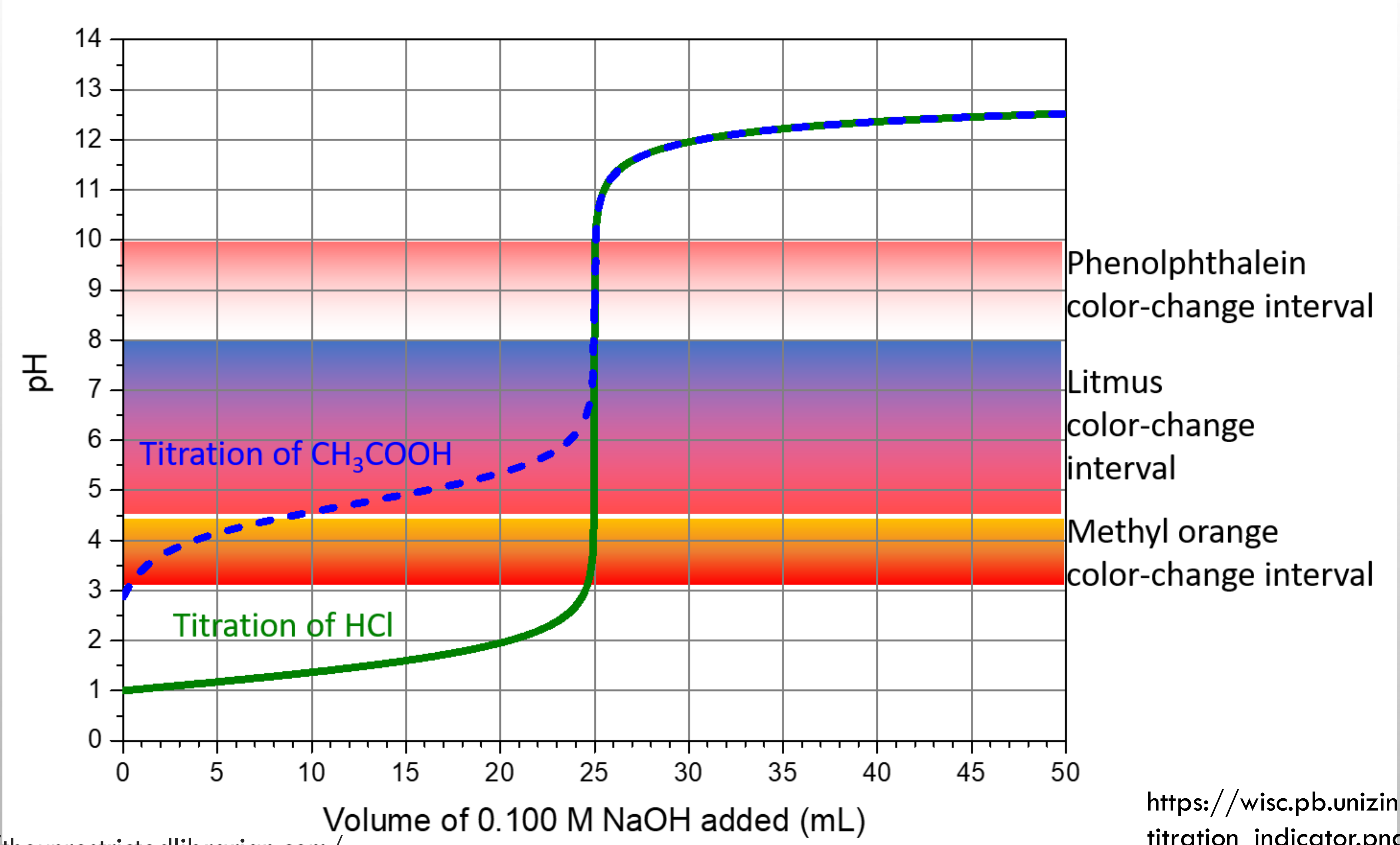
WHAT IS HAPPENING?



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- Teachers will match the colour change region for the indicator with the region of the greatest pH change for the titration curve.

  In chem 30, you will start to learn how to chose your indicators for acid-base titrations.

https://wisc.pb.unizin.org/app/uploads/sites/564/2021/05/titration_indicator.png

Indicators

- Litmus is one indicator extracted from natural sources.
- Another indicator can be extracted from purple carrots.
- The indicator in purple carrots is:
  - Purple-red or bright red when exposed to acid
  - Blue when exposed to base

- What portions of this paper towel soaked in purple carrot juice were exposed to vinegar? What portions were exposed to baking soda dissolved in water (aqueous sodium hydrogen carbonate solution)? Are there any other interesting sections?
    - Purple-red when exposed to acid
    - Blue when exposed to base

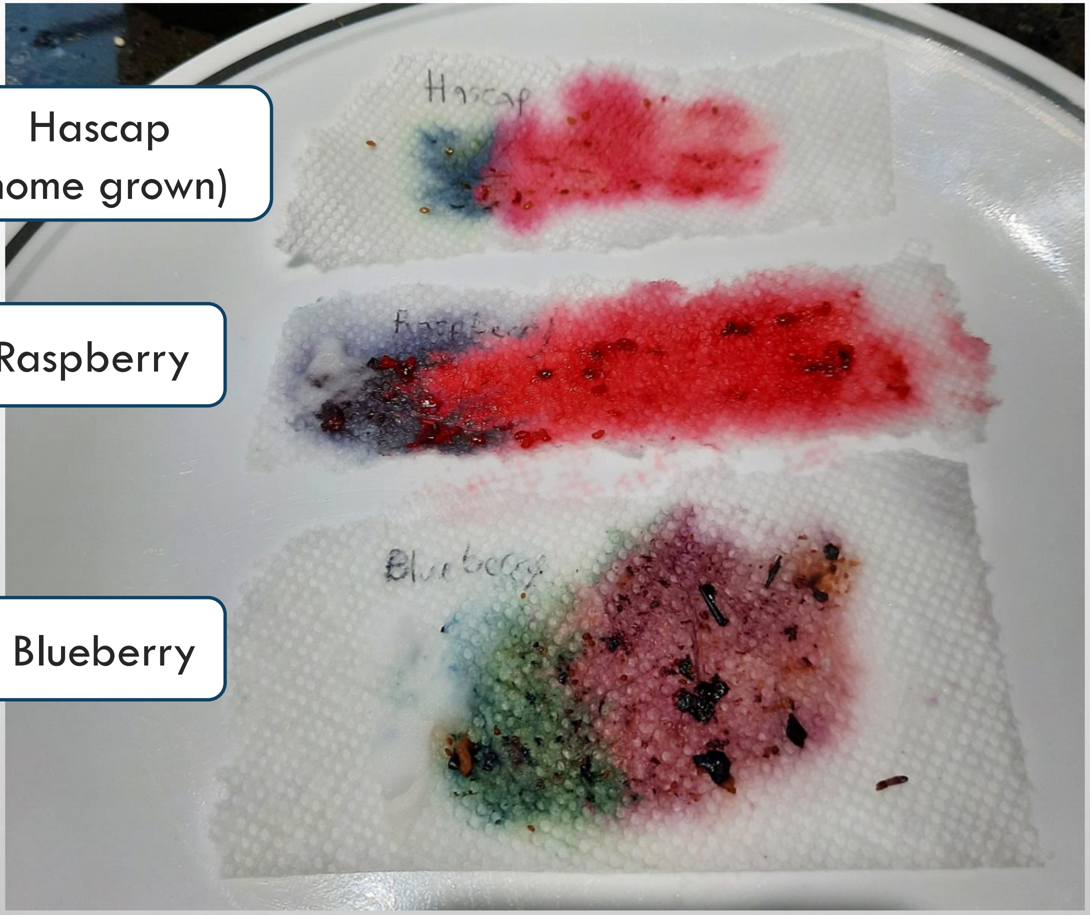
(White areas were not exposed to purple carrot juice.)

- So… in further answer to your question during our online tutoring session about other edible indicators, yes there are others. I mentioned some, like the well documented red cabbage and red onions, and my own personal experience with purple basil (no photos, but my homemade salad dressing was interesting last year). It got me thinking, so did a little exploratory research. Yes, it turns out there are other indicators in my house…
- One grape was skinned, and three frozen berries were mercilessly smeared on paper towels in the service of science. The jam was like that when I opened the fridge, I swear.

More reading about red cabbage indicator (aimed at a slightly younger age that you are)
https://www.acs.org/education/activities/red-cabbage-indicator.html

Distracted by the Chemistry!

This side was treated with a solution of baking soda (sodium hydrogen carbonate) in water



This side was treated with pure white vinegar. I suspect that the high concentration of citric acid in berries meant that the indicator was already in acid form.

I believe that the slightly different colours are due to slightly different chemical compounds. Much like tigers and lions are both types of cats, the chemicals are likely all different "anthrocyanins."

Distracted by the Chemistry, Part 2!

Red grape skins suspended in a baking soda solution. Very slight colour change to blue around the edges of the skins after ~30 min. Looks like the cell walls are keeping things out. For now…

Strawberry jam

This side was treated with a solution of baking soda. *Slight* colour change.

This side was treated with pure white vinegar.