P3. The Adventures of Hodja Nasreddin

Equipment

Item	Quantity	Label
Part A		
pH meter with stand and probe stored in 3 M KCl	1	
Volumetric pipette, 50 mL	1	
Glass rod	1	
Part B		
Thermometer	1	
Funnel for filtration	1	
Cotton wool	1	
Glass beaker, 200 mL	2	
Measuring cylinder, 50 mL	1	
Plastic Pasteur pipette, 3 mL	2	
Plastic cup, 250 mL	20	

Chemicals

Name	State	Concentration	Quantity	Placed in	Label
Part A					
Solution **X3**	aq	To be determined	200 mL	Plastic bottle, 250 mL	**X3**
Solution **X4**	aq	To be determined	200 mL	Plastic bottle, 250 mL	**X4**
Solution **X5**	aq	To be determined	200 mL	Plastic bottle, 250 mL	**X5**
Solution **X6**	aq	To be determined	200 mL	Plastic bottle, 250 mL	**X6**
Part B					
Solution **Y1**	aq	-	3 mL	Eppendorf tube, 4 mL	**Y1**
Sliced red cabbage	s	-	15 g	Glass bottle, 100 mL	**RC**
Hydrochloric acid	aq	0.0100 M	100 mL	Plastic bottle, 250 mL	**HCl 0.01 M**

15 % of total										
Question	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	**Total**
Points	2	0	50	12	1	9	2	10	1	**87**

Part A

The chemist Nasreddin prepared solutions of **different acids** with the same pH value. To do this, he took:

- a strong monoprotic acid HA,

- a weak monoprotic acid HB,

- a diprotic acid H_2C.

He obtained six solutions (**X1–X6**), all with **the same pH value** when rounded to the nearest integer. These six solutions included three solutions of individual acids and three pairwise mixtures, which contained individual acids in a 1 : 1 molar ratio (not necessarily in order given below).

HA	HB	H_2C	HA + HB (1 : 1)	HA + H_2C (1 : 1)	HB + H_2C (1 : 1)

In this part, you need to **perform titrations** of solutions **X3–X6** with a pH meter. Unfortunately, on the way to IChO 2026, Nasreddin lost solutions **X1** and **X2**, but he promises to help in determining their composition.

1. Using a volumetric pipette, **transfer** 50.0 mL of **X3** into a **plastic cup**.
2. **Measure** the pH of **X3** using the pH meter.

Q3.1 **Tick** the pH value of **X3** to the nearest integer. 2 pt

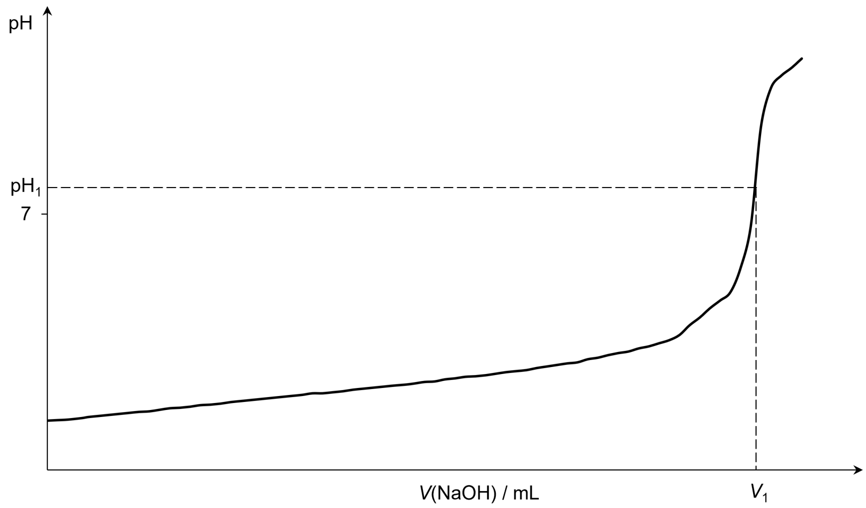
3. Using the pH meter, **titrate** 50.0 mL of **X3** with 0.0100 M NaOH solution by adding **0.5 mL portions** of NaOH solution and measuring the pH of the resulting solution until it reaches ~10. **Do not use** the stirring plate in this experiment.
4. **Record** the pH values. When a more accurate measurement is required, **wait** until the displayed pH value is stable for at least 5 seconds.
5. **Repeat** steps 1, 3 and 4 for **X4–X6**.

Q3.2 **Record** your results for the titration of solutions **X3–X6**. You **may sketch** the titration curves on the provided grids, but they will not be graded. 0 pt

Q3.3 **Determine** the ranges of NaOH volume (in mL) that correspond to the equivalence points during the titrations of **X3–X6**. **Tick** the appropriate boxes based on your results from **Q3.2**.
For example, if the equivalence point lies in the range $4.0 < V \leq 4.5$, you **must tick** the box as shown below: 50 pt

V_{NaOH}	3.5	☐	4.0	☑	4.5	☐	5.0

Nasreddin provides the following titration curve of 50.0 mL **X1** with 0.0100 M NaOH solution, where $V_1 = 34.75$ mL:



He also notes that for solution **X2**, the ratio between the total V(NaOH) to reach the second equivalence point relative to V(NaOH) to reach the first equivalence point is approximately 3 : 2.

Q3.4 **Determine** the composition of **X1–X6**. **Tick** the appropriate boxes. 12 pt

Q3.5 **Give** the pH of the resulting solution after mixing equal volumes of **X1–X6**. 1 pt

Part B

Nasreddin also prepared universal indicators **Y1** and **Y2** for acid−base titration. To prepare **Y2**, he made an extract from red cabbage.

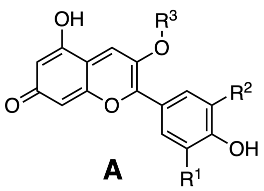
Prepare a fresh solution of **Y2** from red cabbage as follows:

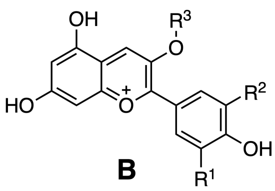
1. **Transfer** all the sliced red cabbage into the 200 mL glass beaker with 60 mL of water.
2. **Place** the beaker on the hotplate and **heat** it at 70–95°C for 20 min.
3. **Filter** the extract through the funnel with cotton wool and **collect** the **Y2** solution in the clean 200 mL glass beaker.
4. **Determine** the order of colour transitions of **Y2** as pH changes using the available solutions and equipment. Using 100 μL of **Y2** per 1 mL of analyte provides the most reliable results.

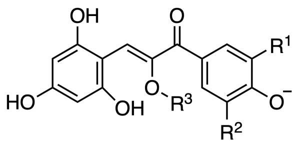
Q3.6 **Arrange** the colours of **Y2** in order of increasing pH using the colour abbreviations listed below. 9 pt

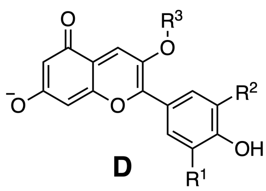
Red/pink	Yellow	Green	Blue	Violet
R	Y	G	B	V

The extract of red cabbage contains anthocyanins responsible for such a wide range of colours. Below are the structures of anthocyanins at different pH:


A


B


C


D

Q3.7 **Arrange A–D** according to which structures are most dominant as the pH is changed from low to high. 2 pt

To prepare **Y1**, Nasreddin mixed two individual indicators from the table:

#	Indicator	pH range of colour changes
1	Bromophenol blue (**BPB**)	yellow < 3.0 – 4.6 < blue
2	Congo red (**CR**)	blue < 3.0 – 5.2 < red
3	Bromocresol green (**BG**)	yellow < 3.8 – 5.4 < blue
4	Methyl red (**MR**)	red < 4.4 – 6.2 < yellow
5	Chlorophenol red (**CPR**)	yellow < 5.2 – 6.8 < purple
6	Bromothymol blue (**BTB**)	yellow < 6.0 – 7.6 < blue
7	Phenol red (**PR**)	yellow < 6.8 – 8.2 < pink
8	Thymol blue (**TB**)	yellow < 8.0 – 9.6 < blue
9	Phenolphthalein (**PP**)	colourless < 8.2 – 10.0 < pink
10	Alizarin yellow R (**AYR**)	yellow < 10.1 – 12.0 < red

Determine the pH ranges of the colour changes of **Y1** using the pH meter and available solutions. Using 5 μL of **Y1** per 1 mL of analyte provides the most reliable results.

Q3.8	**Tick** the appropriate boxes for the pH ranges of the colour changes of **Y1**.	10 pt

Q3.9	**Determine** the composition of **Y1**. **Tick** the appropriate boxes.	1 pt