Solutions to Preparatory Problems for the 58th International Chemistry Olympiad 2026 Tashkent, Uzbekistan

Practical Problems

Contents

Problem 31. Blue pigment

Part A

Q1. m ~ 2.7 g

*The composition, mass and color of **X** depends on the reaction conditions and workup such as temperature and washing. The general formula of **X** is* $Cu_x(OH)_y(CO_3)_z \cdot wH_2O$.

Part B

Q2. Upon addition of sulfuric acid, the intense gas release and formation of blue solution can be observed, indicating the possible presence of carbonate anion and copper cation in **X.**

Q3. V = 2.7 mL

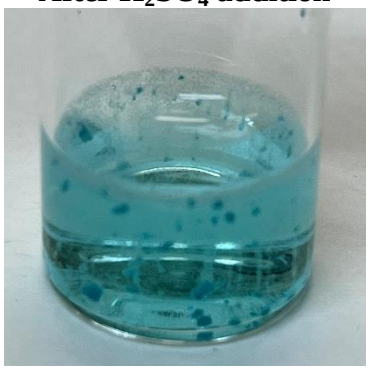
*Note: the volumes of the $Na_2S_2O_3$ depends on the composition of the pigment **X**.*

Q4. $2Cu^{2+} + 4I^- \rightarrow 2CuI + I_2$

$I_2 + 2S_2O_3^{2-} \rightarrow 2I^- + S_4O_6^{2-}$

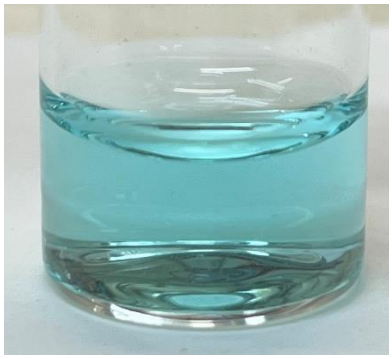
Q5. ω(Cu) ~ 18%

After H_2SO_4 addition



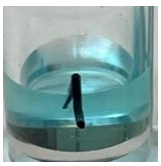
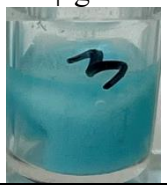
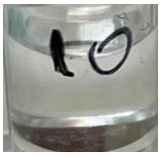
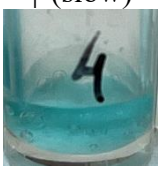
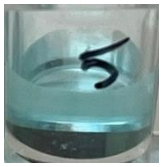
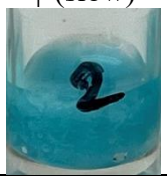
After 1 min

After 2 min – clear solution



Part C

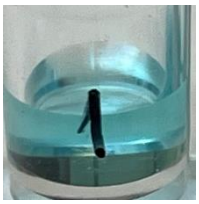
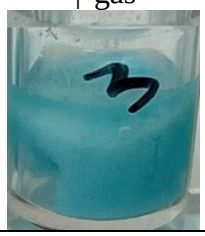
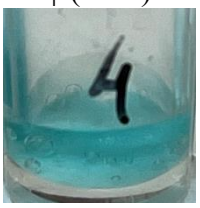
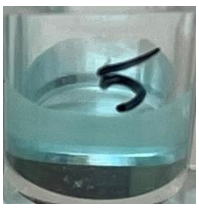
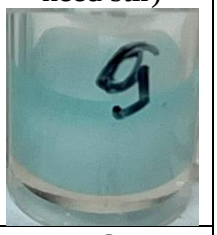
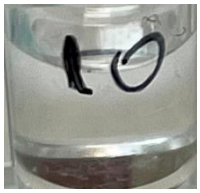
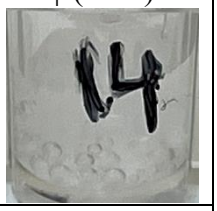
Q6. Pairwise reactions results (if performed properly; NR = no reaction):

	B	**C**	**D**	**E**	**F**
A	↓ blue ↑ gas 	NR or ↑ (very slow: after 15 min) 	NR 	↓ white (slow and maybe need stir) 	↓ blue ↑ gas (slow) 
B		NR 	↓ blue ↑ gas 	↓ white ↑ gas (slow) 	NR 
C			↑ (slow) 	NR 	NR 
D				NR 	↓ blue ↑ (slow) 
E					↓ white 

Q7. Appearance of brown color when solution of **D** reacts with dithizone indicates the presence of copper (II) ions, which can be confirmed by the color of the solution. Then, as solution of **A** is also blue, indicating the presence of copper (II) ions, it will give brown color when reacted with dithizone.

Q8. Cations: Cu^{2+}, Na^{+}, Ca^{2+}. Anions: NO_3^-, SO_4^{2-}, CO_3^{2-}, HCO_3^-

Compound Code	**A**	**B**	**C**	**D**	**E**	**F**
Salt	$CuSO_4$	$NaHCO_3$	$CaCO_3$	$Cu(NO_3)_2$	$Ca(NO_3)_2$	Na_2CO_3

	$CuSO_4$ **A**	Na_2CO_3 **F**	$NaHCO_3$ **B**	$CaCO_3$ **C**	$Ca(NO_3)_2$ **E**
$Cu(NO_3)_2$ **D**	**1** NR 	**2** ↓ blue ↑ (slow) 	**3** ↓ blue ↑ gas 	**4** ↑ (slow) 	**5** NR 
$CuSO_4$ **A**		**6** ↓ blue ↑ (slow) 	**7** ↓ blue ↑ gas 	**8** NR or ↑ (very slow: after 15 min) 	**9** ↓ white (slow and need stir) 
Na_2CO_3 **F**			**10** NR 	**11** NR 	**12** ↓ white 
$NaHCO_3$ **B**				**13** NR 	**14** ↓ white ↑ (slow) 
$CaCO_3$ **C**					**15** NR 

Q9. Additional tests that can be facilitate the compounds identification:

- Add H_2SO_4 from the **Part B** to compounds **A**-**F**:

Compound Code	**A**	**B**	**C**	**D**	**E**	**F**
Salt	NR	↑ gas	↑ gas ↓ white	NR	NR	↑ gas

- Add KI from the **Part B** to compounds **A**-**F**:

Compound Code	**A**	**B**	**C**	**D**	**E**	**F**
Salt	Brown solution + white precipitate	NR	NR	Brown solution + white precipitate	NR	NR

- Add H_2O to compound **C** (it is insoluble in water)

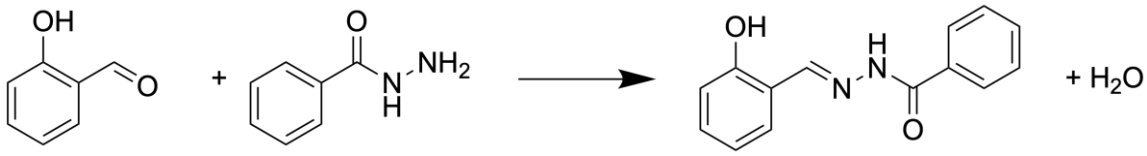
Q10. From $Ca(NO_3)_2$ (**E**) it is impossible to obtain the pigment.

Q11. Compound **C**($CaCO_3$) is insoluble in water.

The reactions were tested in 10 well plates (well volume 0.4 ml, observations are visible nicely; 2-3 drops of liquid reagent or 1 microspatula tips of solid).

Problem 32. Synthesis and characterisation of metal complexes with a hydrazone-based ligand

Q1.



Q2. m(theoretical) = 1.76 g

m(experimental) ~1.15 g

Yields ranged from 13 to 97%, with an average of 65%. The greatest sources of yield loss arose from insufficient rinsing of crude product into the funnel.

Q3. $\mathrm{n(Cu(II))} = \frac{0.51}{170.5} = 0.003$ mol

$\mathrm{n(SBH)} = \frac{0.72}{240} = 0.003$ mol

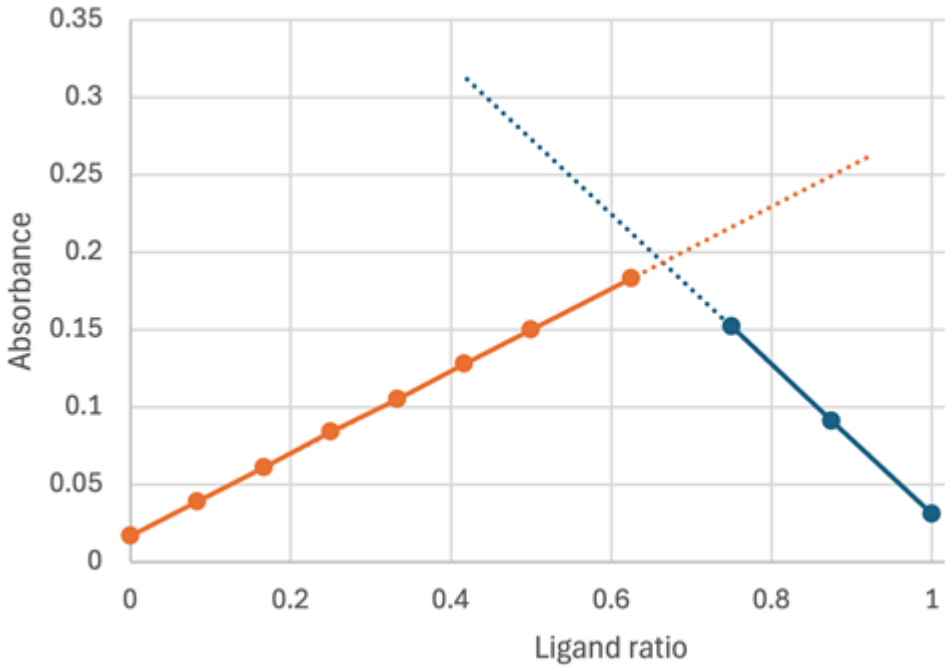
1:1 ratio of the reagents indicates the complex is expected to be in 1:1 form.

Cu-SBH ratio is 1:1.

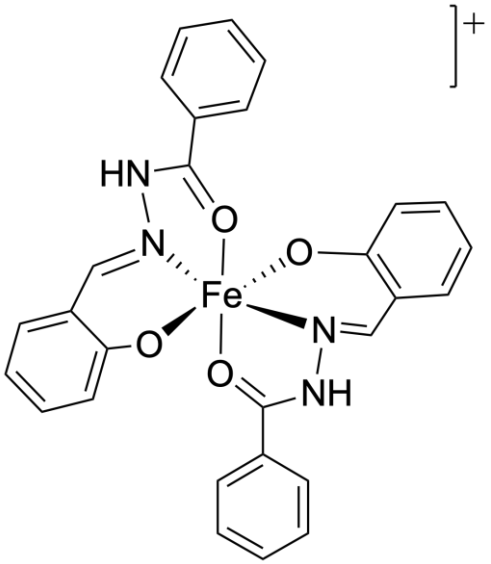
Q4. Plotting the Ligand mole fraction vs Absorbance results in 2 functions that cross each other at Ligand mole fraction = 0.66, meaning the stoichometry of Fe-SBH is 1:2.

$$y_1 = 0.266 * x + 0.017$$

$$y_2 = -0.482 * x + 0.513$$

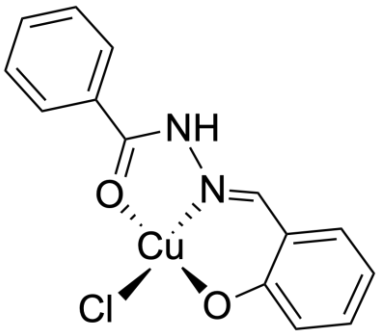


Q5.



Any structure that has correct molecular formula and complies to the chemical logic is considered correct.

Q6.



Q7. m(theoretical) = 0.003 * 338 = 1.01 g

m(experimental) ~ 0.57 g

Yield = 0.57/1.01 * 100% = 56%

The copper complex was collected as dark green crystals or powder with yields 30−89%, and average of 56%.

Problem 33. Titration of apple juice

Typical experimental results are given below.

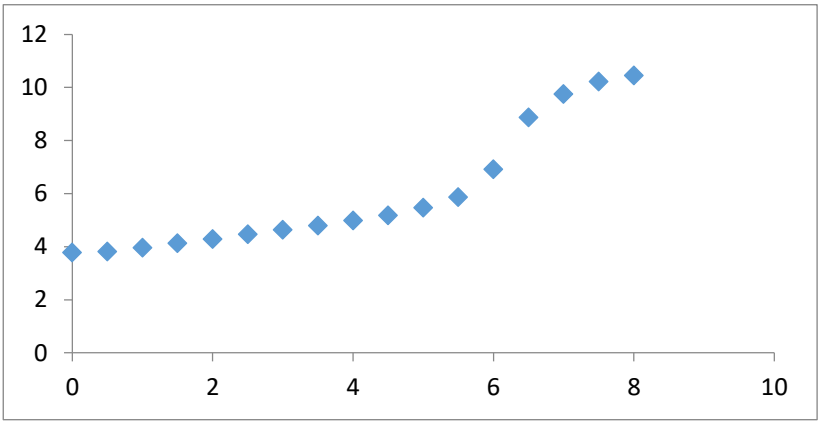
Q1. Result of potentiometric titration with 0.1000 M NaOH solution by adding 0.5 mL probes of the titrant:

V_{NaOH}	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5
pH	3.78	3.81	3.96	4.12	4.28	4.46	4.63	4.79	4.98	5.17
V_{NaOH}	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5
pH	5.46	5.86	6.91	8.87	9.75	10.21	10.45	-	-	-

The maximum value of ΔpH corresponds to the equivalence point, which is in 6.0-6.5 mL range here:

V_{NaOH}	0.0	□	0.5	□	1.0	□	1.5	□	2.0	□	2.5	□	3.0	□	3.5	□	4.0	□	4.5
V_{NaOH}	4.5	□	5.0	□	5.5	□	6.0	**X**	6.5	□	7.0	□	7.5	□	8.0	□	8.5	□	9.0

We can draw the graph of pH = $f(V_{NaOH})$ function to clearly demonstrate the equivalence point:



Q2. For a more precise titration, we need repeat the potentiometry for the 6.0-6.5 mL range by adding 0.1 mL probes of the titrant:

V_{NaOH}	6.0	6.1	6.2	6.3	6.4	6.5
pH	7.14	7.56	8.09	8.57	8.93	9.14

The maximum value of ΔpH we find at **6.1-6.2 mL** range. This is a more precise equivalent volume range of 0.1000 M NaOH solution.

Q3. $HOOC\text{-}CH_2\text{-}CH(OH)\text{-}COOH + 2NaOH \rightarrow NaOOC\text{-}CH_2\text{-}CH(OH)\text{-}COONa + 2H_2O$

Q4. For V_{NaOH} = 6.2 mL, $C_{malic\ acid} = \frac{0.1 \cdot 6.2 \cdot 134}{2 \cdot 10} = 4.15$ mg/mL.

Q5. The reaction equations is as follows:

$2Cu^{2+} + 4I^- = 2CuI + I_2$

$I_2 + 2S_2O_3^{2-} = 2I^- + S_4O_6^{2-}$

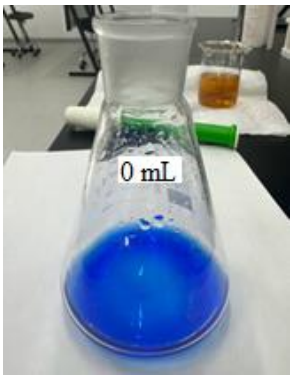
Q6. Formula for calculation of Cu(II) concentration:

$$C_{Cu(II)} = \frac{C_{S_2O_3^{2-}} V_{S_2O_3^{2-}} \frac{V_{\text{volumetric flask}}}{V_{\text{aliquot of solution 1}}}}{V_{\text{aliquot of initial solution of Cu(II)}}}.$$

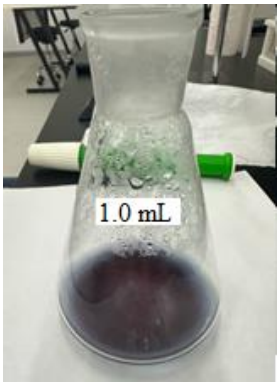
for $V_{S_2O_3^{2-}} = 2.0$ mL $\rightarrow C_{Cu(II)} = \frac{0.1000 \cdot 2.0 \cdot \frac{100}{10}}{10} = 0.2000$ M.

Q7. $2Cu^{2+} + C_6H_{12}O_6 + 5OH^- \rightarrow Cu_2O + C_6H_{11}O_7^- + 3H_2O$

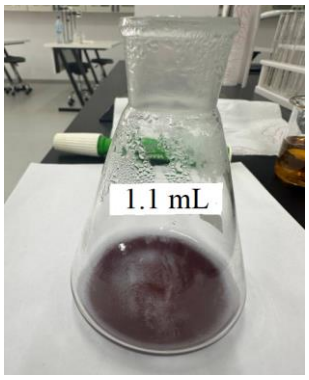
Q8. Color of the solution at the beginning ($V_{\text{apple juice}} = 0$ mL), before the equivalent point ($V_{\text{apple juice}} = (V_{eq} - 0.1)$ mL) and at the equivalence point ($V_{\text{apple juice}} = V_{eq}$ mL) are shown below:



$V_{\text{apple juice}} = 0$ mL



$V_{\text{apple juice}} = (V_{eq} - 0.1)$ mL



$V_{\text{apple juice}} = V_{eq}$ mL

$$C_{glucose} = \frac{C_{Cu(II)} V_{Cu(II)} \cdot 180}{2 \cdot V_{apple\ juice}}.$$

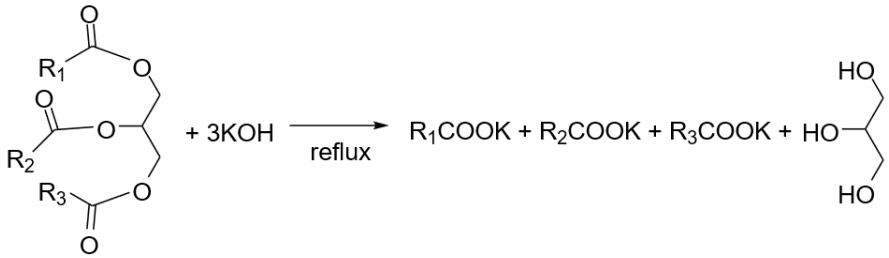
For $C_{Cu(II)} = 0.2000$ M and $V_{\text{apple juice}} = 1.1$ mL $\rightarrow C_{\text{glucose}} = \frac{0.2000 \cdot 10 \cdot 180}{2 \cdot 1.1} = 163.6$ mg/mL.

Problem 34. Cottonseed oil

Notes:

- *If cottonseed oil is not available, you may use other plant oil (sunflower, olive, corn, soy bean etc).*
- *It is important to use freshly prepare KOH solution for hydrolysis step.*
- *Instead of "Alkali Blue 6B" indicator, you can use Phenolphthalein or Thymolphthalein, if they are allowed in your countries.*

Q1.



$$KOH + HCl \rightarrow KCl + H_2O$$

Q2. $C_{KOH}\ (M) = \frac{0.5000 \times V_0(HCl)}{25.0}$

Q3. $\text{Saponification value (mg/g)} = \frac{0.5000 \times [V_0(HCl) - V(HCl)]}{m_1(\text{cottonseed oil})} \times 56.1$

Q4. Let determine the mole ratio of ICl_3 and I_2:

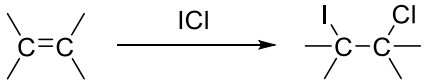
$$\frac{n_{ICl_3}}{n_{I_2}} = \frac{\frac{0.45}{233.29}}{\frac{0.50}{253.84}} \approx \frac{1}{1}.$$

The product of the reaction between 1 mole of ICl_3 and 1 mole of I_2 is ICl:

$$ICl_3 + I_2 \rightarrow 3ICl.$$

So, **X** is ICl (iodine monochloride).

Q5.



$$ICl + 2I^- \rightarrow Cl^- + I_3^-$$

$$I_3^- + 2S_2O_3^{2-} \rightarrow 3I^- + S_4O_6^{2-}$$

Q6. $C_X\ (M) = \frac{0.1000 \times V_0(Na_2S_2O_3)}{2 \times 10.0}$

Q7. $\text{Iodine value (g/100 g)} = \frac{0.1000 \times [V_0(Na_2S_2O_3) - V(Na_2S_2O_3)]}{2 \times m_2(\text{cottonseed oil})} \times 253.84 \times \frac{100}{10000}$

Q8. a) Triglycerides of short chain fatty acids require more KOH for saponification per unit mass. Therefore, **butter** oil with the highest saponification value (210–232) contains the highest number of short-chain fatty acids.

b) Triglycerides, which contain more unsaturated fatty acids, have higher iodine value. Therefore, it is **fish** oil (142–176). It has the lowest melting point and it easily spoils when heated.

Problem 35. An unknown salt

The results and calculations in this solution are based on m_{exact} = **1.0040 g**.

Q1. Table 1 looks as follows:

	$BaCl_2$	**$AgNO_3$**	**$NaNO_2$ + HCl**
Cl^-	no changes	formation of white precipitate ($AgCl\downarrow$)	no changes
Br^-	no changes	formation of yellowish precipitate ($AgBr\downarrow$)	no changes
I^-	no changes	formation of bright yellow precipitate ($AgI\downarrow$)	coloring the solution brown (I_3^-)
NO_3^-	no changes	no changes	no changes
SO_4^{2-}	formation of white precipitate ($BaSO_4\downarrow$)	formation of white precipitate ($Ag_2SO_4\downarrow$)	no changes

Q2. Ionic reaction equations as follows:

$$Cl^- + Ag^+ = AgCl\downarrow$$

$$Br^- + Ag^+ = AgBr\downarrow$$

$$I^- + Ag^+ = AgI\downarrow$$

$$3I^- + 2HNO_2 + 2H^+ = I_3^- + 2NO\uparrow + 2H_2O$$

$$SO_4^{2-} + Ba^{2+} = BaSO_4\downarrow$$

$$SO_4^{2-} + 2Ag^+ = Ag_2SO_4\downarrow$$

Q3. During dissolution of **AgHal** in the ammonia solution following reaction takes place:

$$AgHal + 2NH_3 = Ag(NH_3)_2^+ + Hal^-$$

Equilibrium constant of the above reaction can be determined as follows:

$$K = \frac{[Ag(NH_3)_2^+][Hal^-]}{[NH_3]^2} = \frac{[Ag(NH_3)_2^+]}{[Ag^+][NH_3]^2} \cdot \frac{[Ag^+][Hal^-]}{1} = \beta \cdot K_{sp}.$$

Total concentration of NH_3 in the solution can be calculated as follows:

$$c_0(NH_3) = \frac{\rho \cdot \omega \cdot 1000}{M \cdot 100} = \frac{0.958 \cdot 10 \cdot 1000}{17 \cdot 100} = 5.64\ M.$$

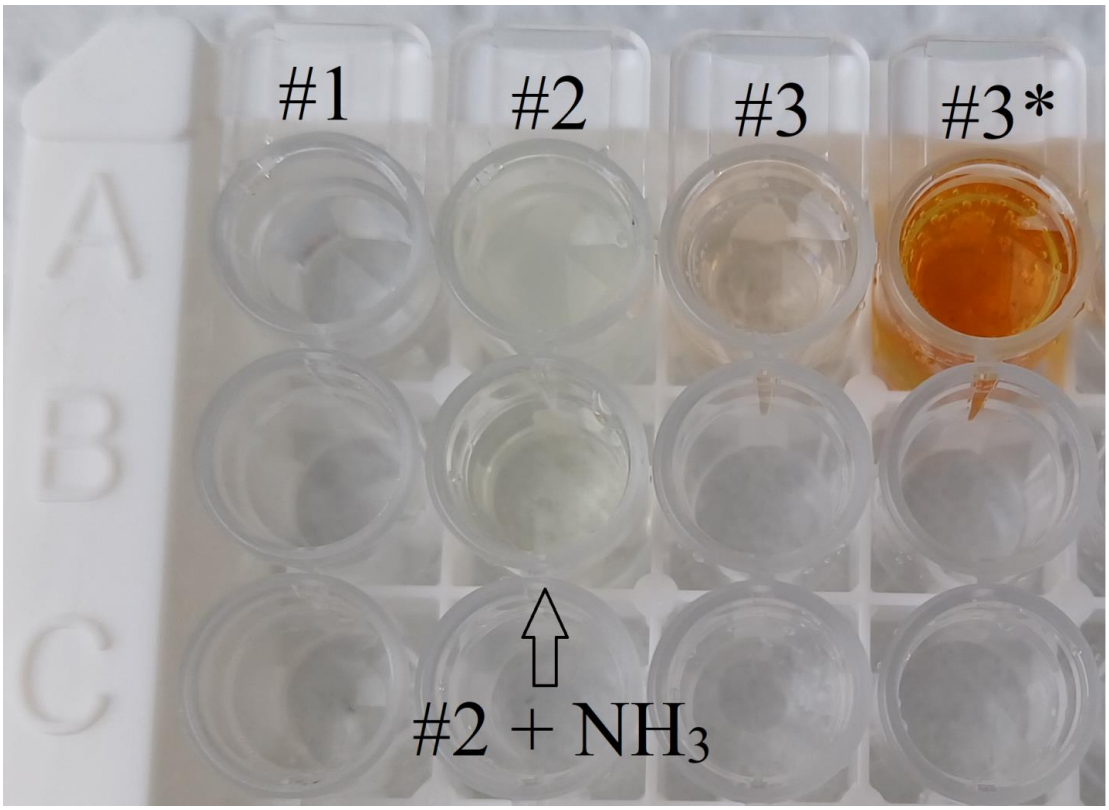
If s moles of **AgHal** are dissolved, molar concentration of other substances as follows at the equilibrium: NH_3 – (5.64 – 2s) M, $Ag(NH_3)_2^+$ – s M, Hal^- – s M. We can calculate s by using equilibrium constant as follows:

$$K = \beta \cdot K_{sp} = \frac{s^2}{(5.64 - 2s)^2}.$$

Solving quadratic equation for each **Hal** gives us the following results:

	Cl	Br	I
$\boldsymbol{\beta \cdot K_{sp}}$	$4.43 \cdot 10^{-3}$	$1.34 \cdot 10^{-5}$	$2.13 \cdot 10^{-9}$
s, M	0.331	0.0205	$2.60 \cdot 10^{-4}$

Q4. Results of qualitative reactions are as follows:



#	Mixture content	Observations
1	70 µL of solution **A** + 70 µL of $BaCl_2$	no changes
2	70 µL of solution **A** + 70 µL of $AgNO_3$	white precipitate is formed, which is soluble in NH_3 solution (#2 + NH_3)
3	70 µL of solution **A** + 70 µL of $NaNO_2$ + 70 µL of HCl	coloring the solution yellowish (due to nitrosylation of amino acid)
3*	70 µL of solution KI + 70 µL of $NaNO_2$ + 70 µL of HCl	coloring the solution brown (it is provided for distinguish from #3)

A correctly filled table looks as follows:

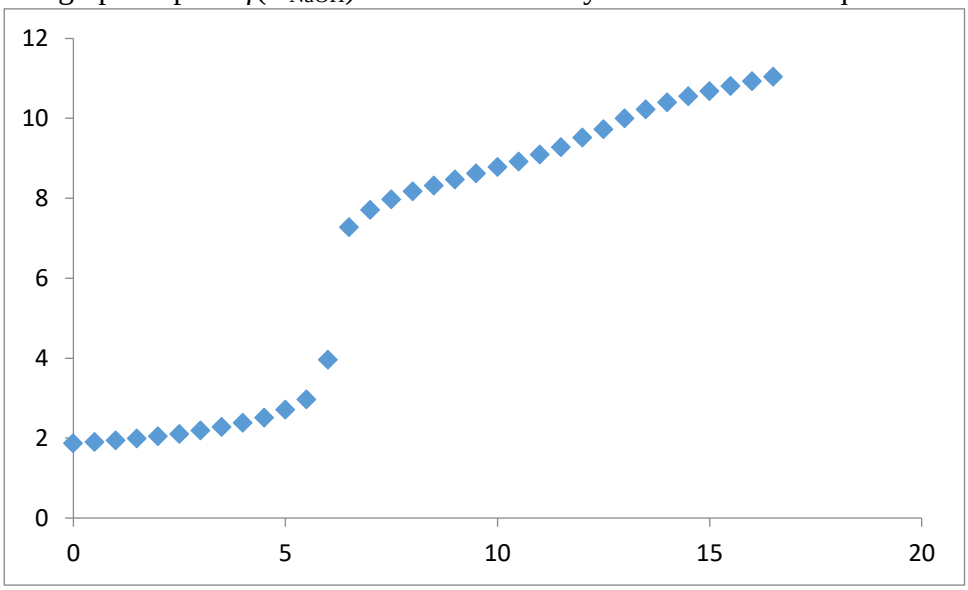
Reaction number	Reaction mixture	Precipitate formed	Colour of precipitate	Precipitate solubility in NH_3	Colour of resulting solution
1	70 µL of solution **1** + 70 µL of $BaCl_2$	□ Yes **X** No	-	-	colorless
2	70 µL of solution **1** + 70 µL of $AgNO_3$	**X** Yes □ No	white	**X** Yes □ No	colorless
3	70 µL of solution **1** + 70 µL of HCl + 70 µL of $NaNO_2$	-	-	-	yellowish

Q5. From qualitative reactions we can conclude that, X^{n-} is Cl^-.

Q6. Result of potentiometric titration of solution **A** with 0.182 M NaOH solution by adding 0.5 mL probes of the titrant:

V_{NaOH}	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5
pH	1.87	1.90	1.94	1.99	2.05	2.10	2.19	2.28	2.38	2.51
V_{NaOH}	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5
pH	2.71	2.97	3.96	7.28	7.71	7.97	8.17	8.32	8.47	8.62
V_{NaOH}	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5
pH	8.78	8.92	9.09	9.28	9.52	9.73	10.00	10.22	10.40	10.55
V_{NaOH}	15.0	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5
pH	10.68	10.81	10.93	11.04	-	-	-	-	-	-

We can draw the graph of pH = $f(V_{NaOH})$ function to clearly demonstrate the equivalence points:



There are two pH jumps: the first one is big at 6.0-6.5 mL range, the second is smoother at 12.5-13.0 mL range.

V_{NaOH}	0.0	□	0.5	□	1.0	□	1.5	□	2.0	□	2.5	□	3.0	□	3.5	□	4.0	□	4.5
V_{NaOH}	4.5	□	5.0	□	5.5	□	6.0	**X**	6.5	□	7.0	□	7.5	□	8.0	□	8.5	□	9.0
V_{NaOH}	9.0	□	9.5	□	10.0	□	10.5	□	11.0	□	11.5	□	12.0	□	12.5	**X**	13.0	□	13.5
V_{NaOH}	13.5	□	14.0	□	14.5	□	15.0	□	15.5	□	16.0	□	16.5	□	17.0	□	17.5	□	18.0
V_{NaOH}	18.0	□	18.5	□	19.0	□	19.5	□	20.0	□	20.5	□	21.0	□	21.5	□	22.0	□	22.5

Q7. For a more precise titration, it is convenient to select the first jump, as it's more precise than the 2nd one. Potentiometry results for the 6.0-6.5 mL range of NaOH by adding 0.1 mL probes of the titrant are shown below:

V_{NaOH}	6.0	6.1	6.2	6.3	6.4	6.5
pH	4.36	6.42	6.91	7.15	7.32	7.45

So, the 1st equivalence point is at **6.0-6.1 mL** range due to it shows the highest pH change.

Q8. The salt contains **2 acidic protons**.

Q9-10. Using 6.1 mL volume for the 1st equivalence point, we calculate the molar mass of the salt as follows:

$$M = \frac{1.0040}{0.182 \cdot 6.1 \cdot 10^{-3} \cdot \frac{250}{50}} \approx 181 \text{ g/mole.}$$

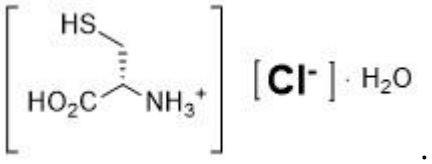
This value is sum of different parts of the salt:

$$181 = M_R + 110.5 + 18m \rightarrow M_R + 18m = 70.5.$$

During potentiometry the pH jump of neutralization of group $-NH_3^+$ is not observed in an aqueous solution due to the fact that it is a very weak acid ($pK_a > 10$). So, side chain (–R) contains another acidic group, which has higher pK_a value than –COOH group. The only possible variant that occurs in canonical amino acids is –SH group [Histidine is not suitable due to the high molar mass of the side group ($M_R \approx 81 > 70.5$), low pK_a value (the graph of pH = $f(V_{NaOH})$ shows it need to be higher than 8) and the cation in his case will have a charge of "2+"]. So, amino acid is **cysteine**, –R is **$-CH_2SH$**. Than we calculate integer m:

$$m = \frac{70.5 - 47}{18} = 1.30 \approx 1.$$

So, the unknown salt is **cysteine hydrochloride monohydrate**:



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Problem 36. Khodja Nasreddin's secret message

Q1. The final image in a 96-well plate after completion of titration according to the method given in the text of the problem as Figure 6.1:

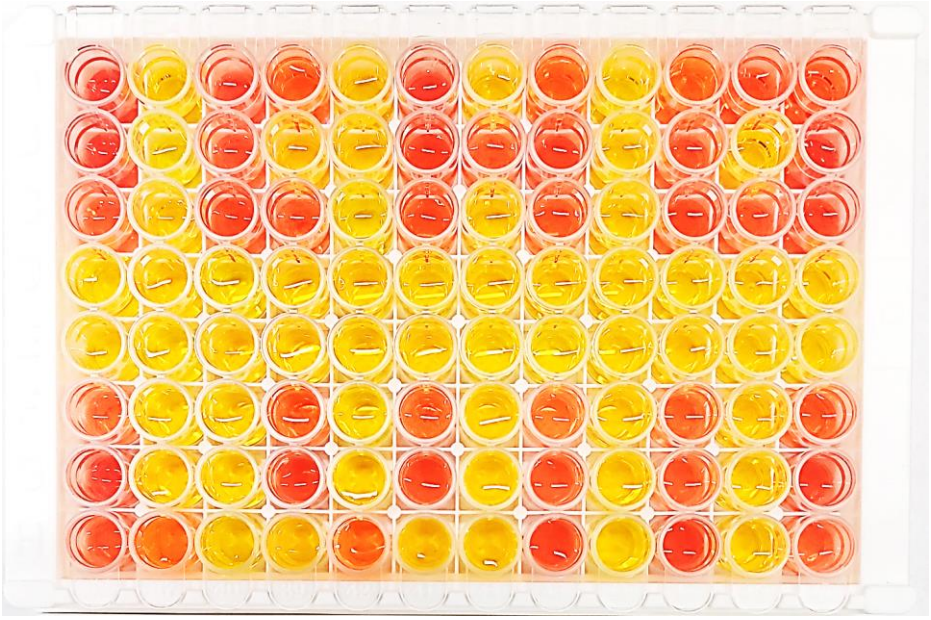

Figure 6.1.

The pattern looks as "ICHO LVIII" (LVIII stands for 58 in Roman numerals), which means "The 58th International Chemistry Olympiad". It is important to consider that incorrect titration of even one solution will lead to damage to the entire drawing.

There is an alternative approach. To do this, you first "titrate" each solution **I-VIII**, then determine how many wells there are and what color each will be during the "titration". Results of "titrations" of 100 μL of solutions **I-VIII** with 0.05 M NaOH or 0.05 M HCl by increasing the volume of the titrant solution by 20 μL and moving to the next well until color of the solution changes as Figure 6.2:

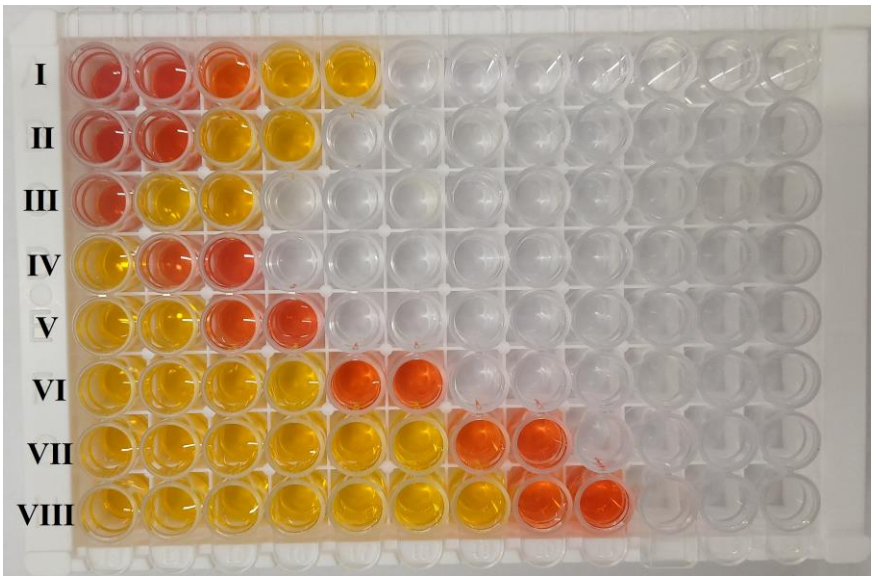

Figure 6.2.

From the results it can be understood that in the case of solution **I**, the equivalent point occurs in the 4th well and from the 5th well it will be necessary to begin "titrating" solution **IV** as indicated in the "titration" sequence in the problem condition etc. For each solution **I-VIII** it looks as Figure 6.3:

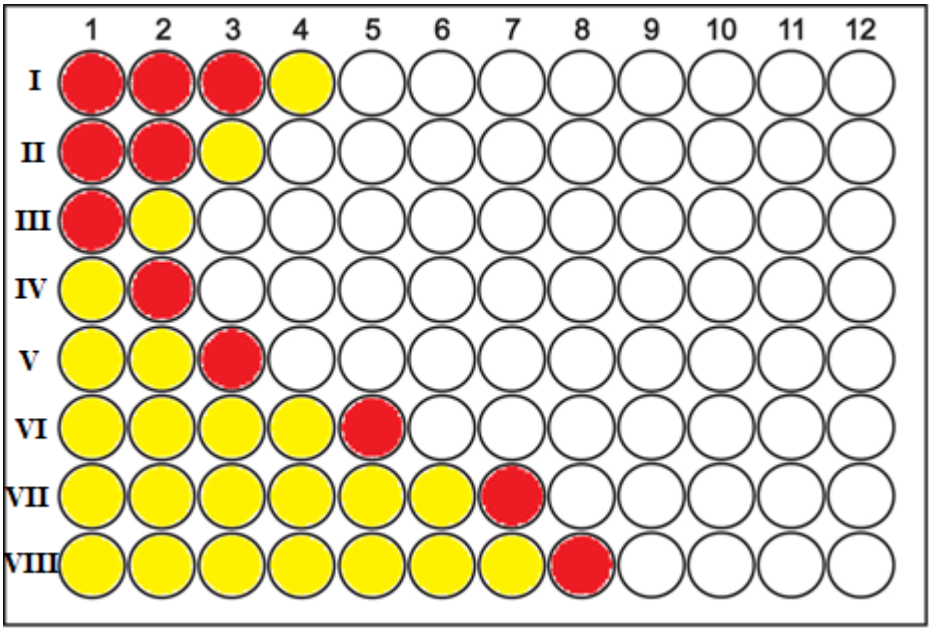

Figure 6.3.

According to **Table 1**, "titration" of the first 2 solutions (**I** and **IV**) recreates Figure 6.4:

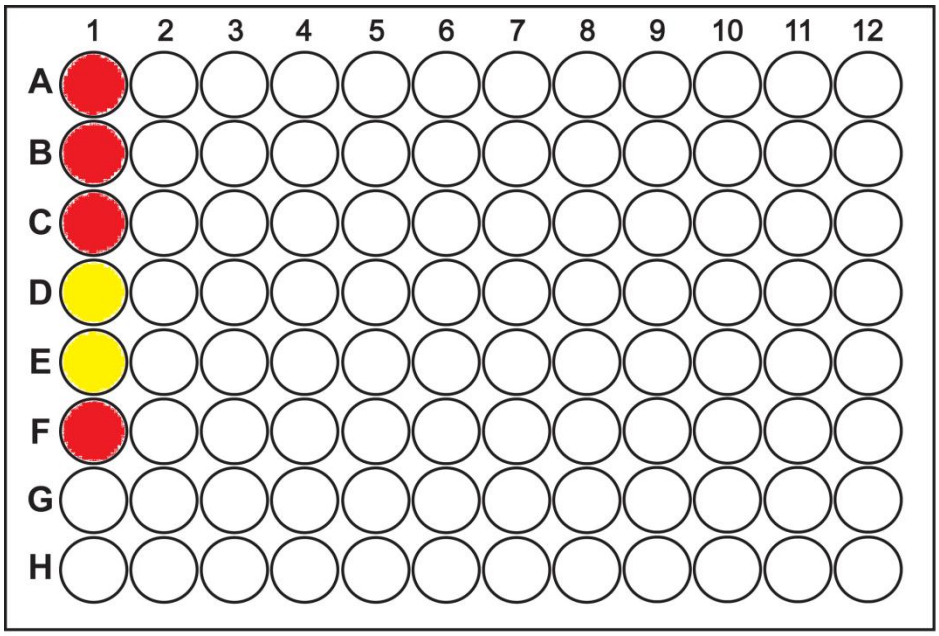

Figure 6.4.

When we continue “titration” with the third solution (**II**), we get Figure 6.5:

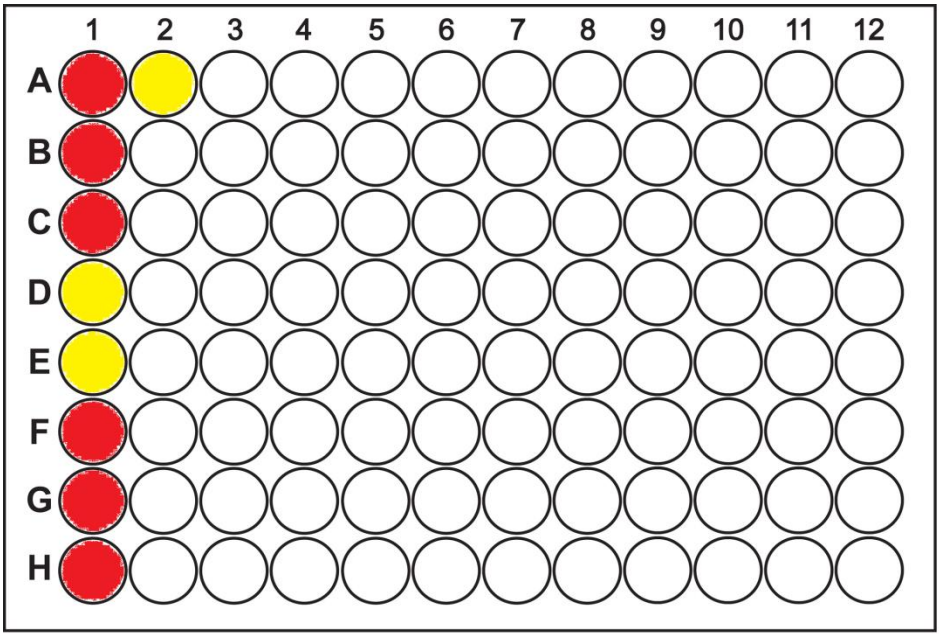

Figure 6.5.

Finally, after complete “titration” according to **Table 1**, we obtain the Figure 6.6:

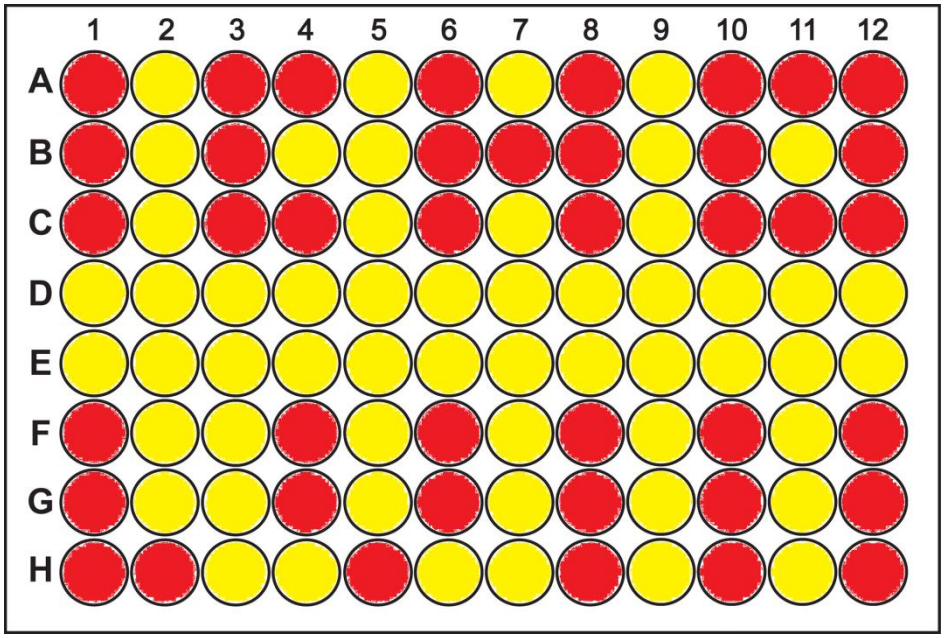

Figure 6.6.

Q2. During “titration” the following reaction occurs:

$$HCl + NaOH = NaCl + H_2O.$$

The concentration of solutions can be calculated using the following equation:

$$c_{HCl}V_{HCl} = c_{NaOH}V_{NaOH}.$$

Calculated concentration of solutions **I–VIII** by using the above formula as follows:

Solution	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**
Substance	HCl	HCl	HCl	NaOH	NaOH	NaOH	NaOH	NaOH
Calculated concentration ranges, M	0.03-0.04	0.02-0.03	0.01-0.02	0.01-0.02	0.02-0.03	0.04-0.05	0.06-0.07	0.07-0.08
Prepared concentration, M	0.035	0.025	0.015	0.015	0.025	0.045	0.065	0.075

Note: Lab assistants should normalize concentrations of solutions **I-VIII** as in Figure 6.3.

Q3. Towards the end of the "titration", in well F12 (indicated by the red arrow), the "titration" of solution **IV** ends and in well G12 (indicated by the green arrow), the "titration" of solution **II** begins:

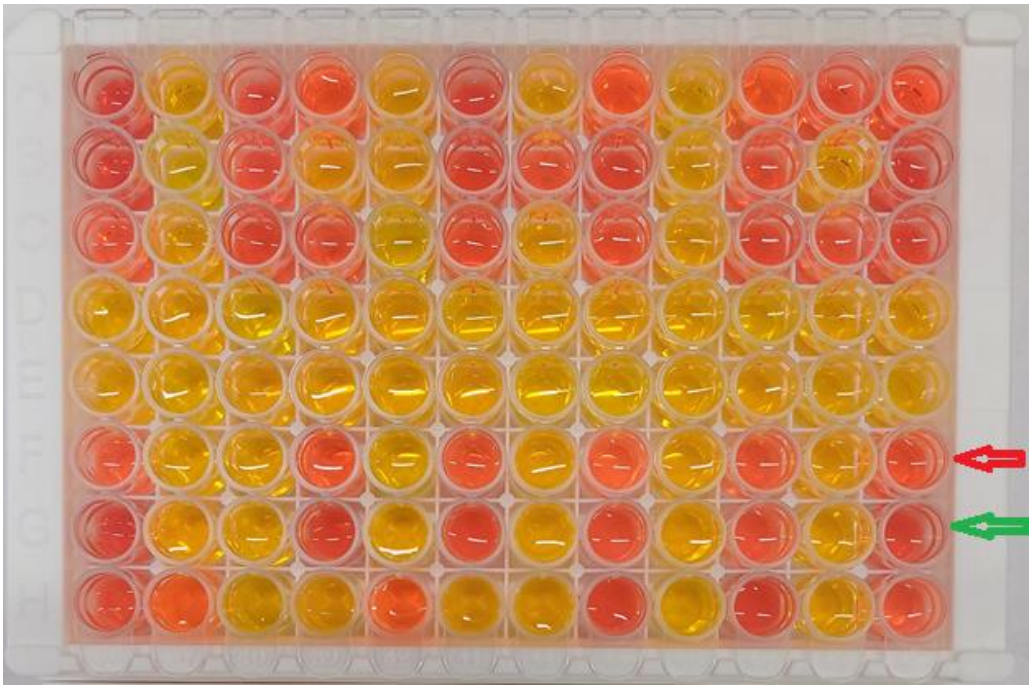

Figure 6.7.

As can be seen from the Figure 6.7, the last two wells (G12 and H12) need to be red. This will only be possible if solution **II** is replaced with solution **I**.