Laboratory work 3
Identification of the inorganic cations

Analytical classification of cations is based on separation of analytical group cations by the action of group reagents. A *group reagent* acts on a mixture of ions in a known order and chain. The group reagent must meet the following requirements:

1) deposition of cations completely numerically;
2) in order to carry out the analysis correctly, the obtained precipitate should dissolve easily;
3) the excess amount of the reagent should not interfere with the determination of other ions in the solution.

Depending on the type of reagent used in the analysis, the following sequences of classification of cations are known:

1) acid-base;
2) sulfide;
3) ammonia-phosphate.

Analytical classification of cations is directly related to the chemical properties of elements and their location in Periodic system, their structure, physico-chemical characteristics. All these classifications are based on experiments in analytical chemistry.

The acid-base sequence is classified depending on the solubility of metal chlorides, sulfates, and hydroxides. By acid-base classification, cations are grouped into six groups (Table 9).

Table 9 - Acid-base classification of cations

Groups	Cations	Group reagent	Characterization of products
I	NH_4^+, Na^+, K^+, Li^+	-	-
II	Ag^+, Pb^{2+}, Hg_2^{2+}	HCl	MCl, MCl_2 insoluble in diluted acids
III	$Ba^{2+}, Ca^{2+}, Sr^{2+}$	H_2SO_4	MSO_4 insoluble in acids and alkalis
IV	$Al^{3+}, Cr^{3+}, Zn^{2+}, Sn^{2+}, Sn\ (IV), As\ (III, V)$	Excess of NaOH	M(OH)n soluble in the excess of NaOH
V	$Fe^{2+}, Fe^{3+}, Bi^{3+}, Mn^{2+}$ $Mg^{2+}, Sb\ (III, V)$	NaOH	M(OH)n insoluble in the excess of NaOH
VI	$Cu^{2+}, Hg^{2+}, Ni^{2+}, Co^{2+}$ Cd^{2+}	Excess of $NH_3 \cdot H_2O$	M(OH)n soluble in the excess of $NH_3 \cdot H_2O$

Laboratory work 3.1
Identification of the inorganic cations of the first and second groups

Goal of the work: to get acquainted with the acid-base classification of cations, to get acquainted with the analytical reactions of cations of the I, II analytical groups and the properties of the precipitates obtained.

Procedure

Perform the reactions in Tables 10 and 11 to get familiar with the analytical reactions of the cations of the first and second groups. Identify the cations in the mixture given by the instructor according to Table 12. Fill the table below for each performed reaction.

Cation	Reaction equation and conditions	Observation and conclusion

Table 10 - Cations of the analytical group I, *no group reagent*

Cation	Reactions to perform in the lab	Reactions for theoretical study
NH_4^+	1. Reaction with Nessler's reagent $K_2[HgI_4]$	1. Reaction with $NaHC_4H_4O_6$
	2. Reaction with NaOH during heating	2. Reaction with $Na_3[Co(NO_2)_6]$
Na^+	Microcrystalloscopic reaction with zincuranyl acetate $Zn(UO_2)_3(CH_3COO)_8$	-
K^+	Reaction with $Na_3[Co(NO_2)_6]$	Reaction with $NaHC_4H_4O_6$ or $H_2C_4H_4O_6$

Reactions

Identification of NH_4^+ ion

1. Nessler's reagent forms an orange precipitate with ammonium ions in an alkaline medium:

$$NH_4Cl + 2K_2[HgI_4] + 4KOH = [OHg_2NH_2]I \downarrow + 7KI + KCl + 2H_2O$$

1-2 drops of Nessler's reagent are added to the solution containing 1-2 drops of ammonium ions. An orange precipitate is formed. If there is a residue of ammonium ions in the solution, the color changes to yellow.

2. Reaction with sodium (potassium) hydroxide. Specific reaction. If ammonium salts in the solution are affected by alkali and heated, ammonia is released in the form of gas.

$$NH_4^+ + OH^- = NH_3 \uparrow + H_2O$$

A few drops of NaOH (KOH) are added to the solution containing 1-2 drops of ammonium ions and heated in a water bath. The released ammonia can be detected by changing the color of the universal indicator or litmus paper.

Identification of Na^+ ion

Microcrystalloscopic reaction. Sodium ion forms bright yellow tetrahedral or octahedral crystals with zincuranyl acetate at pH 7:

$$CH_3COONa + Zn(UO_2)_3(CH_3COO)_8 = NaZn(UO_2)_3(CH_3COO)_9$$

1 drop of the sodium ion containing solution is placed on a dry and clean glass plate, 1 drop of reagent is added to it, and the two solutions are gently mixed with a glass rod. After some time, the shape of the formed crystal is determined by a microscope.

Identification of K^+ ion

Sodium (III) hexanitrocobaltate forms a yellow precipitate with potassium ions at pH 4-5:

$$2KCl + Na_3[Co(NO_2)_6] = K_2Na[Co(NO_2)_6] \downarrow + 2NaCl$$

Add 2-3 drops of reagent to a solution containing 2-3 drops of potassium ions and heat it in a water bath. A yellow precipitate is formed. If the solution is acidic, add CH_3COONa. In an alkaline medium, a dark brown $Co(OH)_3$ precipitate is formed, which prevents the identification of potassium ions.

Table 11 - Cations of the analytical group II, *group reagent - HCl*

Cation	Reactions to perform in the lab	Reactions for theoretical study
Ag^+	1. Reaction with HCl and dissolving the obtained AgCl in $NH_3 \cdot H_2O$	1. Reaction with Na_2HPO_4
	2. Reaction with K_2CrO_4	2. Reaction with KI or KBr
	3. Reaction with $NaOH$	3. Reaction with $(NH_4)_2S$ or H_2S
Pb^{2+}	1. Reaction with HCl and dissolving in hot water	1. Reaction with Na_2HPO_4
	2. Reaction with H_2SO_4 and dissolving the obtained salt in 30% solution of	

	CH_3COONH_4	
	3. Reaction with $K_2Cr_2O_7$ or K_2CrO_4	2. Reaction with $NaOH$ and $NH_3 \cdot H_2O$
	4. Reaction with KI	
Hg_2^{2+}	1. Reaction with HCl and the effect of NH_4OH	1. Reaction with $NaOH$
	2. Reaction with K_2CrO_4	2. Reaction with KI
		3. Reaction with $(NH_4)_2S$ or H_2S
		4. Reaction with Na_2HPO_4
		5. Reaction with metallic copper

Identification of Ag^+ ion

1. Hydrochloric acid reacts with silver ions to form a curd-like white precipitate:

$$Ag^+ + Cl^- = AgCl \downarrow$$
$$AgCl \downarrow + 2NH_3 = [Ag(NH_3)_2]Cl$$

Add 2-3 drops of 2M HNO_3 solution and 3-4 drops of 2M HCl to 2-3 drops of silver solution. A white precipitate is formed. Separate the precipitate in a centrifuge, wash and treat with 4-5 drops of concentrated NH_3 solution. The precipitate dissolves.

2. Potassium chromate forms brick-red precipitate with Ag^+ ion:

$$2Ag^+ + CrO_4^{2-} = Ag_2CrO_4 \downarrow$$

Add 2-3 drops of potassium chromate to 2-3 drops of silver solution. The reaction should be carried out at a pH ~ 7. The brick-red precipitate formed is soluble in nitric acid and ammonia, although less soluble in CH_3COOH.

3. Sodium (potassium) hydroxide reacts with Ag^+ ion and gives a brown precipitate of Ag_2O. It is formed by the decomposition of unstable silver hydroxide that is immediately formed from the initial reaction:

$$Ag^+ + OH^- = AgOH \downarrow$$
$$2AgOH \downarrow = Ag_2O \downarrow + H_2O$$

Add 2-3 drops of sodium hydroxide to 2-3 drops of silver solution. The precipitate dissolves in ammonia in the presence of ammonium salt!

Identification of Pb^{2+} ion

1. Hydrochloric acid reacts with lead ion to form a white precipitate:

$$Pb^{2+} + 2Cl^{-} = PbCl_2 \downarrow$$

Add 2 drops of 2M HCl solution to 2-3 drops of lead ions in a test tube. A white precipitate is formed. Separate it in a centrifuge, heat to boiling with a few drops of distilled water. The precipitate dissolves, and after the solution cools down, it precipitates again.

2. Sulfuric acid can be used as a reagent. Resulting $PbSO_4$ precipitate dissolves in 30% NH_4Ac:

$$2PbSO_4 \downarrow + 2CH_3COO^{-} = [Pb(CH_3COO)_2 \cdot PbSO_4] + SO_4^{2-}$$

Add 2-3 drops of 2M H_2SO_4 to 1-2 drops of lead solution. Observe the formation of a white crystalline precipitate. Centrifuge it and treat with 4-5 drops of 30% NH_4Ac+HAc solution and heat. The precipitate dissolves.

3. Reaction with potassium dichromate or chromate. A yellow precipitate is formed when potassium dichromate or chromate is added to a weak or acetic acid lead solution:

$$2Pb(NO_3)_2 + K_2Cr_2O_7 + H_2O + 2CH_3COONa =$$
$$= 2PbCrO_4 \downarrow + 2KNO_3 + 2CH_3COOH + 2NaNO_3$$

Add 2-3 drops of 2M CH_3COOH, 2-3 drops of CH_3COONa and 2-3 drops of $K_2Cr_2O_7$ to 1-2 drops of lead solution. A yellow precipitate forms. It is centrifuged and 2-3 drops of 2M NaOH are added to the precipitate. The precipitate dissolves.

4. Reaction with potassium iodide. Lead ion forms a yellow precipitate with iodide ions. The precipitate dissolves well when heated and falls again after cooling:

$$Pb^{2+} + 2I^{-} = PbI_2 \downarrow$$

Add 2 drops of 2M CH_3COOH and 2-3 drops of KI to 1-2 drops of lead solution. A yellow precipitate is formed. After heating and cooling, a golden-yellow precipitate falls in the form of shiny leaves.

Identification of Hg_2^{2+} ion

1. Hydrochloric acid reacts with Hg_2^{2+} ions to form a white precipitate of Hg_2Cl_2 (calomel):

$$Hg_2(NO_3)_2 + 2HCl = Hg_2Cl_2 \downarrow + 2HNO_3$$
$$Hg_2Cl_2 + 2NH_4OH = [NH_2Hg_2]Cl + NH_4Cl + 2H_2O$$
$$[NH_2Hg_2]Cl = [NH_2Hg]Cl \downarrow + Hg \downarrow$$

Add 2 drops of 2M HCl to 1-2 drops of mercury (I) solution. A white precipitate is formed. It is centrifuged, washed and treated with 4-5 drops of concentrated NH_3 solution. Under the influence of ammonia, the calomel precipitate turns black, that is, a mixture of Hg and $HgNH_2Cl$ is formed.

2. Potassium chromate forms red Hg_2CrO_4 precipitate with mercury (I) ion.

Add 2 drops of 2M potassium chromate solution to 2-3 drops of monovalent mercury solution in a test tube. A red precipitate is formed.

Control test. Identification of cations of I and II groups

Goal of the work: to separate and identify group I and II cations in the given solution.

Preliminary control. Place 1 drop of the test solution on a piece of indicator paper. Redness of the paper indicates the acidity of the medium and the possibility of the presence of ammonium ions in the solution, while blueness of the paper indicates the alkalinity of the medium and may indicate the presence of alkali or potassium and sodium salts formed by a weak acid.

Table 12 – Qualitative analysis of the control solution for the presence of cations of I and II group (P – precipitate, S - solution)

<table>
<tr><td colspan="4">$NH_4^+, Na^+, K^+, Ag^+, Pb^{2+}, Hg_2^{2+}$
+ **HCl (2M)**</td></tr>
<tr><td colspan="3">**P1.** $AgCl, Hg_2Cl_2, PbCl_2$
+ **H_2O, t°**</td><td rowspan="3">**S1.** NH_4^+, Na^+, K^+

Partial identification:
1. Na^+
2. NH_4^+
If NH_4^+ has been identified, the S1 solution should be dried in a crucible. Dissolve the residue in distilled water
3. K^+</td></tr>
<tr><td colspan="2">**P2.** $AgCl, Hg_2Cl_2$
+ **NH_4OH (6M)**</td><td rowspan="2">**S2.** Pb^{2+}
+ $\boldsymbol{K_2Cr_2O_7}$
+ $\boldsymbol{KI}$</td></tr>
<tr><td>**P3.** $HgNH_2Cl$</td><td>**S3.**
$[Ag(NH_3)_2]^+$</td></tr>
</table>

Questions for self-control

1. Why potassium cation cannot be detected in strong acid and base medium?
2. Why is it necessary to remove the ammonium cation first to determine the potassium ion?
3. Name the ways to remove NH_4^+ ion from the solution.
4. What phenomena are observed when $AgCl, Hg_2Cl_2, PbCl_2$ mixture is treated with ammonia solution?
5. What is observed when the mixture of $AgCl, AgBr, AgI$ salts is treated with ammonia solution?

6. How to separate silver ion from mercury (I) ion? What role does nitric acid play in the identification of silver ion?

7. Suggest ways to separate precipitates of $AgCl$ and $PbCl_2$.

8. What reagents can change $PbSO_4$ precipitate into a solution.

9. If the sample contains a) potassium salt, b) sodium salt, how will the color of the flame change?

10. Make a chain of analysis of cations:
   a) $Ag^+, Pb^{2+}, K^+, NH_4^+$
   b) $Hg_2^{2+}, Pb^{2+}, Na^+, NH_4^+$.

Laboratory work 3.2
Identification of the inorganic cations of the third and fourth groups

Goal of the work: to get acquainted with the acid-base classification of cations, to get acquainted with the analytical reactions of cations of the III, IV analytical groups and the properties of the precipitates obtained.

Procedure

Perform the reactions in Tables 13 and 14 to get familiar with the analytical reactions of the cations of the third and fourth groups. Identify the cations in the mixture given by the instructor according to Table 15. Fill the table below for each performed reaction.

Cation	Reaction equation and conditions	Observation and conclusion

Table 13 - Cations of the analytical group III, *group reagent – H_2SO_4*

Cation	Reactions to perform in the lab	Reactions for theoretical study
Ba^{2+}	1. Reaction with H_2SO_4	1. Reaction with Na_2HPO_4
	2. Reaction with $(NH_4)_2CO_3$	2. Reaction with $(NH_4)_2C_2O_4$
	3. Reaction with $K_2Cr_2O_7$	
Sr^{2+}	1. Reaction with H_2SO_4	
	2. Reaction with reaction with gypsum water	
Ca^{2+}	1. Reaction with H_2SO_4	1. Reaction with Na_2HPO_4
	2. Reaction with $(NH_4)_2CO_3$	2. Reaction with $K_4[Fe(CN)_6]$
	3. Reaction with $(NH_4)_2C_2O_4$	

Reactions

Identification of Ba^{2+} *ion*

1. Barium ion reacts with sulfuric acid giving a white precipitate insoluble in acids. Therefore, the formed $BaSO_4$ precipitate is converted into $BaCO_3$, which is soluble in mineral and acetic acid:

$$BaCl_2 + H_2SO_4 = BaSO_4 \downarrow + 2HCl$$

Add 2-3 drops of 2M H_2SO_4 solution to 1-2 drops of the barium ion solution. A white crystalline precipitate is formed. Centrifuge the precipitate, add saturated sodium carbonate to the precipitate separated from the solution, heat it, again separate the precipitate in the centrifuge and add a new portion of sodium carbonate. In the same way, repeat the experiment 3-4 times. Dissolve the formed $BaCO_3$ precipitate in CH_3COOH.

2. Ammonium carbonate reacts with Ba^{2+} ion and gives a white precipitate ($BaCO_3$):

$$BaCl_2 + (NH_4)_2CO_3 = BaCO_3 \downarrow + 2NH_4Cl$$

Add 2-3 drops of 2M $(NH_4)_2CO_3$ to 1-2 drops of a solution containing barium ions. A white precipitate is obtained.

3. Potassium dichromate gives a crystalline yellow precipitate with barium ions in acetic acid medium:

$$2BaCl_2 + K_2Cr_2O_7 + H_2O + 2CH_3COONa = 2BaCrO_4 \\ \downarrow + 2KCl + 2CH_3COOH + 2NaCl$$

Add 3-4 drops of CH_3COONa and 1-2 drops of potassium dichromate to 1-2 drops of the barium ion solution. Heat the test tube in a water bath. Yellow barium chromate is formed.

Identification of Sr^{2+} *ion*

1. Sulfuric acid reacts with strontium ion and gives a white precipitate insoluble in acids. Therefore, the formed $SrSO_4$ precipitate turns into $SrCO_3$, which is soluble in mineral and acetic acid:

$$SrCl_2 + H_2SO_4 = SrSO_4 \downarrow + 2HCl$$

Add 2-3 drops of 2M H_2SO_4 solution to 1-2 drops of a solution containing strontium ion. A white crystalline precipitate is formed. The carbonization process is repeated several times as for the barium ion.

2. Gypsum water (saturated solution of $CaSO_4 \cdot 2H_2O$) forms a crystalline white precipitate with strontium ions.

Add an equal amount of gypsum water to 1-2 drops of the solution containing strontium ions, the wall of the test tube should be rubbed with a glass rod and heated in a water bath for 10 minutes. Sludge is formed.

Identification of Ca^{2+} ion

1. Reaction with sulfuric acid:

$$CaCl_2 + H_2SO_4 = CaSO_4 \downarrow + 2HCl$$

a) Microcrystallographic reaction. Take a drop of calcium solution on the glass surface, add a drop of 2M H_2SO_4 to it, and mix the drops with a stick. After some time, observe the formed crystals under a microscope (especially around the droplet, the crystals are needle-shaped).

b) To obtain calcium sulfate, add 2-3 drops of ethyl alcohol and 2-3 drops of 2M H_2SO_4 to 1-2 drops of a solution containing calcium, a precipitate is formed.

2. Ammonium carbonate reacts with calcium ions and gives a white precipitate ($CaCO_3$):

$$CaCl_2 + (NH_4)_2CO_3 = CaCO_3 \downarrow + 2NH_4Cl$$

Add 2-3 drops of 2M $(NH_4)_2CO_3$ to 1-2 drops of a solution containing calcium ions. A white crystalline precipitate is obtained.

3. Ammonium oxalate forms a crystalline precipitate with calcium ion:

$$CaCl_2 + (NH_4)_2C_2O_4 = CaC_2O_4 \downarrow + 2NH_4Cl$$

Add 2-3 drops of reagent to 1-2 drops of calcium ion solution and mix. A white precipitate forms. Divide the precipitate into two halves and add 2M HCl solution to one and 2M CH_3COOH to the other. What is the change?

Table 14 - Cations of the analytical group IV, *group reagent – excess of NaOH*

Cation	Reactions to perform in the lab	Reactions for theoretical study
Al^{3+}	1. Reaction with $NaOH$	1. Reaction with Na_2HPO_4
	2. Reaction with $NH_3 \cdot H_2O$	2. Reaction with $(NH_4)_2CO_3$ or Na_2CO_3
	3. Reaction with alizarin	3. Reaction with $(NH_4)_2S$
	1. Reaction with $NaOH$	1. Reaction with Na_2HPO_4

Cr^{3+}		2. Reaction with $NH_3 \cdot H_2O$
	2. Reaction with $NaOH + H_2O_2$	3. Reaction with $(NH_4)_2S$
		4. Reaction with $(NH_4)_2CO_3$
	3. Obtaining of H_2CrO_6	5. Reaction with $KMnO_4$
		6. $(NH_4)_2S_2O_8 + HNO_3 + AgNO_3 \rightarrow H_2Cr_2O_7$
Zn^{2+}	1. Reaction with $NaOH$	1. Reaction with Na_2HPO_4
	2. Reaction with $NH_3 \cdot H_2O$	2. Reaction with $(NH_4)_2CO_3$
		3. Reaction with H_2S
	3. Reaction with dithizone	4. Reaction with $K_4[Fe(CN)_6]$
		5. Reaction with $K_3[Fe(CN)_6]$

Identification of Al^{3+} ion

1. Sodium (potassium) hydroxide reacts with Al^{3+} ion and forms a white precipitate at pH 4-7.8. The formed $Al(OH)_3$ dissolves in an excess of the reagent:

$$Al^{3+} + 3OH^- = Al(OH)_3 \downarrow$$
$$Al(OH)_3 \downarrow + OH^- = [Al(OH)_4]^-$$

Add 2M sodium hydroxide dropwise to 2-3 drops of aluminum-containing solution until a precipitate forms. Addition of excess alkali dissolves the precipitate.

2. Ammonium hydroxide reacts with Al^{3+} ion and forms $Al(OH)_3\downarrow$ which is less soluble.

Add 2M ammonium hydroxide dropwise to 2-3 drops of the solution containing aluminum until a white precipitate is formed. In an excess of alkali, the precipitate partially dissolves.

3. Reaction with alizarin.

Put 1-2 drops of aluminum solution on the filter paper and keep the paper in ammonia vapor for 1-2 minutes. Ammonia vapor forms aluminum hydroxide with a watery mark. Add alizarin to the solution in the filter and hold again in ammonia vapor. The mark becomes purple, add 1-2 drops of acetic acid and dry it, the color of the mark changes to bright red.

Identification of Cr^{3+} ion

1. Sodium (potassium) hydroxide reacts with Cr^{3+} ion and gives purple-gray or green-gray $Cr(OH)_3$ precipitate, formed precipitate has amphoteric property.

Add 2M sodium hydroxide dropwise to 2-3 drops of chromium-containing solution until a $Cr(OH)_3\downarrow$ precipitate is formed. In excess of alkali, the color of the solution changes to bright green.

2. Oxidation of Cr^{3+} cation by H_2O_2:

$$2[Cr(OH)_6]^{3-} + 3H_2O_2 = 2CrO_4^{2-} + 2OH^- + 8H_2O$$

Add 3-4 drops of 2M NaOH and 2-3 drops of 3% H_2O_2 solution to the solution of 2-3 drops of chromium (III) in a test tube and heat until the color of the solution changes from green ($[Cr(H_2O)_6]^{3+}$ (aquacomplex color) to yellow (color of chromate ion).

3. Formation of H_2CrO_4. In order to obtain chromic acid from chromate ions, the medium should be acidic and the solution should be obtained in a cool place:

$$CrO_4^{2-} + H_2O_2 + 4H^+ = H_2CrO_4 + 2H_2O$$

Add 5 drops of hydrogen peroxide, 4-5 drops of amyl alcohol to 2-3 drops of K_2CrO_4 solution, mix thoroughly and add H_2SO_4 drop by drop. The organic layer is colored blue.

Identification of Zn^{2+} ion

1. Sodium (potassium) hydroxide reacts with Zn^{2+} ion to form a white precipitate $Zn(OH)_2\downarrow$ with amphoteric properties.

Add carefully 2M sodium hydroxide drop by drop to 2-3 drops of a solution containing zinc until a precipitate forms. In the excess of alkali, the precipitate dissolves.

2. Ammonium hydroxide reacts with Zn^{2+} ion to give a white precipitate of $Zn(OH)_2$, which dissolves in an excess amount of the reagent and forms a $[Zn(NH_3)_4]^{2+}$ complex.

Add slowly 2-3 drops of zinc-containing solution dropwise to 2M ammonium hydroxide until a precipitate forms. In excess of the reagent, the precipitate dissolves.

3. Reaction with dithizone.

Add 2-3 drops of sodium hydroxide and 5-6 drops of dithizone in CCl_4 solution to the zinc-containing solution until a few drops of the precipitate disappear. Shake the test tube several times and mix. The organic layer is colored red-purple.

Control test. Identification of cations of I-III groups

The goal of the work: to separate and identify group I-III cations in the given solution.

Preliminary control. Place 1 drop of the test solution on a piece of indicator paper. Redness of the paper indicates the acidity of the medium and the possibility of the presence of ammonium ions in the solution, while blueness of the paper indicates the alkalinity of the medium and may indicate the presence of alkali or potassium and sodium salts formed by a weak acid.

Table 15 – Qualitative analysis of the control solution for the presence of cations of I-III groups (P – precipitate, S - solution)

<table>
<tr><td colspan="7">$NH_4^+, Na^+, K^+, Ag^+, Pb^{2+}, Hg_2^{2+}, Ca^{2+}, Sr^{2+}, Ba^{2+}$
+ HCl (2M) + H_2SO_4 (2M)</td></tr>
<tr><td colspan="5">**P1.**
$AgCl, PbCl_2, Hg_2Cl_2, PbSO_4, BaSO_4, SrSO_4, (CaSO_4)$
+ H_2O, t°</td><td colspan="2">**S1.** $NH_4^+, Na^+, K^+, Ca^{2+}$
+C_2H_5OH, t°</td></tr>
<tr><td colspan="4">**P2.** $AgCl, Hg_2Cl_2, PbSO_4, BaSO_4, SrSO_4$
+ 30% NH_4Ac, t°</td><td rowspan="10">**S2.**
Pb^{2+}</td><td rowspan="10">**P10.**
$CaSO_4$</td><td rowspan="10">**S9.**
NH_4^+, Na^+, K^+
Partial identification:
1. Na^+
2. NH_4^+
If NH_4^+ has been identified, the S1 solution should be dried in a crucible. Dissolve the residue in distilled water
3. K^+</td></tr>
<tr><td colspan="3">**P3.** $AgCl, Hg_2Cl_2, BaSO_4, SrSO_4$
+ NH_4OH (6M)</td><td rowspan="9">**S3.**
$PbAc_2 \cdot PbSO_4$</td></tr>
<tr><td colspan="2">**P4.**
$Hg, HgNH_2Cl, BaSO_4$
+ HNO_3 (6M), t°</td><td>**S4.**
$[Ag(NH_3)_2]$</td></tr>
<tr><td colspan="2">**P5.** $BaSO_4, SrSO_4$
+ saturated Na_2CO_3, t°</td><td>**S5.** Not studied</td></tr>
<tr><td colspan="3">**P6.** $BaCO_3, SrCO_3$
+ HAc (6M)</td></tr>
<tr><td colspan="3">**S6.** Sr^{2+}, Ba^{2+}
+ $K_2Cr_2O_7$ + NaAc (pH 5), t°</td></tr>
<tr><td rowspan="4">**P7.**
$BaCrO_4$</td><td colspan="2">**S7.** Sr^{2+} (excess of $Cr_2O_7^{2-}$)
+ saturated Na_2CO_3, t°</td></tr>
<tr><td colspan="2">**P8.** $SrCO_3$
+ HAc (6M)</td></tr>
<tr><td colspan="2">**S8.** Sr^{2+}
+ $(NH_4)_2SO_4$</td></tr>
<tr><td colspan="2">**P9.** $SrSO_4$</td></tr>
</table>

Questions for self-control

1. If solution contains Pb^{2+} cation, how is Ba^{2+} cation can be identified?

2. Why is barium chromate formed when barium salts react with potassium dichromate?

3. Why do barium, strontium, calcium sulfates dissolve in concentrated sulfuric acid?

4. In what solvent do barium, strontium, calcium sulfates, carbonates and oxalates dissolve? What are the reasons for the precipitate dissolution?

5. Explain the process of carbonization of barium, strontium, calcium sulfates.

6. Explain the separation methods of group II and III cations.

7. Write specific and characteristic reactions for the cations of groups I, II and III.

8. Which of the above three groups of cations is poisonous and harmful?

9. What kind of buffer solution can be used to keep the acidity of the medium stable, the pH should be equal to: a) 8-10; b) 4-6; c) 3-5.

10. Make a chain of analysis of cations:

a) $Pb^{2+}, Hg_2^{2+}, Ca^{2+}, Ba^{2+}, Na^{+}, K^{+}$

b) $Ag^{+}, Pb^{2+}, Ca^{2+}, Sr^{2+}, Ba^{2+}, Na^{+}, NH_4^{+}$.

Control test. Identification of cations of III-IV groups

Goal of the work: to separate and identify group III-IV cations in the given solution.

Procedure

Identify the cations in the mixture given by the instructor according to Table 16. Fill the table below for each performed reaction.

Cation	Reaction equation and conditions	Observation and conclusion

Table 16 – Qualitative analysis of the control solution for the presence of cations of III-IV groups (P – precipitate, S - solution)

<table>
<tr><td colspan="6">$Ca^{2+}, Sr^{2+}, Ba^{2+}, Al^{3+}, Cr^{3+}, Zn^{2+}$
+ H_2SO_4 (1M)</td></tr>
<tr><td colspan="2">**P1.** $SrSO_4, BaSO_4$
+ saturated Na_2CO_3, t°</td><td colspan="4">**S1.** $Ca^{2+}, Al^{3+}, Cr^{3+}, Zn^{2+}$
+ C_2H_5OH, t°</td></tr>
<tr><td colspan="2">**P2.** $SrCO_3, BaCO_3$
+ HAc (6M)</td><td rowspan="5">**P4.** $CaSO_4$</td><td colspan="3">**S5.** $Al^{3+}, Cr^{3+}, Zn^{2+}$
+ NaOH (6M) + H_2O_2, t°</td></tr>
<tr><td colspan="2">**S3.** Sr^{2+}, Ba^{2+}
+ $K_2Cr_2O_7$ + NaAc</td><td colspan="3">**S6.** $AlO_2^{-}, ZnO_2^{2-}, CrO_4^{2-}$
+ NH_4Cl (solid), t°</td></tr>
<tr><td rowspan="3">**P3.** $BaCrO_4$</td><td rowspan="3">**S4.** Sr^{2+}</td><td rowspan="3">**P5.** $Al(OH)_3$</td><td colspan="2">**S7.** CrO_4^{2-}, $[Zn(NH_3)_4]^{2+}$
+ Na_2CO_3, t°</td></tr>
<tr><td>**P6.** $Zn_2(OH)_2CO_3$
+ HCl</td><td rowspan="2">**S8.** CrO_4^{2-}</td></tr>
<tr><td>**S9.** Zn^{2+}</td></tr>
</table>

Questions for self-control

1. Give an example of reactions that determine the amphoteric property of aluminum, chromium, zinc hydroxides.

2. How do $BaCrO_4$, $CaCO_3$, $SrCO_3$ dissolve?

3. What reagent can be used to hide foreign ions when aluminum is identified with alizarin?

4. What favorable conditions should be created for obtaining chromic acid?

5. Make a chain of analysis of cations:
   a) $AgNO_3$, $SrCl_2$, $K_2Cr_2O_7$, Na_2SO_3, HAc
   b) $Ba(NO_3)_2$, $Sr(NO_3)_2$, $K_2Cr_2O_7$, HAc
   c) $AgNO_3$, $AlCl_3$, $ZnCl_2$, $NH_3 \cdot H_2O$.

Laboratory work 3.3
Identification of the inorganic cations of the fifth and sixth groups

Goal of the work: to get acquainted with the acid-base classification of cations, to get acquainted with the analytical reactions of cations of the V, VI analytical groups and the properties of the precipitates obtained.

Procedure

Perform the reactions in Tables 16 and 17 to get familiar with the analytical reactions of the cations of the fifth and sixth groups. Identify the cations in the mixture given by the instructor according to Table 18. Fill the table below for each performed reaction.

Cation	Reaction equation and conditions	Observation and conclusion

Table 16 - Cations of the analytical group V, *group reagent – NaOH*

Cation	Reactions to perform in the lab	Reactions for theoretical study
Fe^{2+}	1. Reaction with $NaOH, NH_3 \cdot H_2O$	1. Oxidation of Fe^{2+} to Fe^{3+}
	2. Reaction with $K_3[Fe(CN)_6]$	2. Reaction with $(NH_4)_2CO_3, Na_2CO_3$
Fe^{3+}	1. Reaction with $NaOH, NH_3 \cdot H_2O$	1. Reaction with $(NH_4)_2CO_3, Na_2CO_3$
	2. Reaction with NH_4CNS	2. Reaction with NaAc
	3. Reaction with $K_4[Fe(CN)_6]$	3. Reaction with Na_2HPO_4
		4. Reduction of Fe^{3+} to Fe^{2+}
Mg^{2+}	1. Reaction with $NaOH$	1. Reaction with Na_2CO_3
	2. Reaction with Na_2HPO_4	
Mn^{2+}	1. Reaction with $NaOH + H_2O_2$	1. Reaction with $(NH_4)_2CO_3, Na_2CO_3$
	2. Reaction with $NaBiO_3$	2. Reaction with Na_2HPO_4
	3. Reaction with PbO_2	3. Reaction with $NH_3 \cdot H_2O$

Reactions

Identification of Fe^{2+} ion

1. Sodium (ammonium) hydroxide reacts with Fe^{2+} ion and gives a white precipitate $Fe(OH)_2$, which oxidizes over time and changes to a muddy green color. The precipitate dissolves in mineral acids and does not dissolve in alkalis:

$$Fe^{2+} + 2OH^- = Fe(OH)_2 \downarrow$$
$$4Fe(OH)_2 \downarrow + O_2 + 2H_2O = 4Fe(OH)_3 \downarrow$$

Add 2M sodium hydroxide to 2-3 drops of a solution containing iron (II) ions. Iron (II) hydroxide is formed as a precipitate. Ammonia also precipitates $Fe(OH)_2$, although the precipitation process is not complete.

2. Reaction with potassium (III) hexacyanoferrate:

$$3FeSO_4 + 2K_3[Fe(CN)_6] = Fe_3[Fe(CN)_6]_2 \downarrow + 3K_2SO_4$$

Add 1-2 drops of HCl solution and 2-3 drops of $K_3[Fe(CN)_6]$ to 1-2 drops of a solution containing iron (II) ions. A blue precipitate called "Turnbull's blue" is formed.

Identification of Fe^{3+} ion

1. Sodium (ammonium) hydroxide reacts with Fe^{3+} ion and gives brown-red $Fe(OH)_3$. The precipitate dissolves in mineral acids and does not dissolve in alkalis.

Add 2M sodium (ammonium) hydroxide to 2-3 drops of a solution containing iron (III) ions. Iron (III) hydroxide is formed as a precipitate. Note the solubility of the precipitate in hydrochloric acid and alkali.

2. Reaction with thiocyanate ions:

$$FeCl_3 + NH_4SCN = [Fe(SCN)]Cl_2 + NH_4Cl$$

Add 1-2 drops of NH_4SCN solution to 1-2 drops of a solution containing iron (III) ions. The color of the solution becomes red.

3. Reaction with potassium (II) hexacyanoferrate:

$$4FeCl_3 + 3K_4[Fe(CN)_6] = Fe_4[Fe(CN)_6]_3 \downarrow + 12KCl$$

Add 1-2 drops of HCl and 2-3 drops of $K_4[Fe(CN)_6]$ solution to 1-2 drops of a solution containing iron (III) ions. A blue precipitate called "Berlin azure" is formed.

Identification of Mg^{2+} ion

1. Sodium hydroxide forms an amorphous white precipitate with magnesium ion. The precipitate dissolves in mineral acids and ammonium salts.

Add 2M sodium hydroxide to 2-3 drops of a solution containing magnesium ions. A precipitate of magnesium hydroxide is formed. If there are ammonium salts in the solution, no precipitate is formed.

2. Sodium hydrogen phosphate in the presence of magnesium ion and ammonia (NH_3) gives a crystalline white precipitate at pH=9:

$$MgCl_2 + Na_2HPO_4 + NH_3 = MgNH_4PO_4 \downarrow + 2NaCl$$

At pH > 10, $Mg(OH)_2$ and $Mg_3(PO_4)_2$ are formed.

Add 2-3 drops of 2M HCl, 1 drop of Na_2HPO_4 and 2M NH_3 dropwise to 1-2 drops of a solution containing magnesium ions, while stirring. It is necessary to observe the smell and the medium (pH = 9). A white crystalline precipitate is formed.

Identification of Mn^{2+} ion

1. Sodium hydroxide forms a white precipitate $Mn(OH)_2$ with manganese ion. The precipitate is soluble in mineral acids and insoluble in alkali. The precipitate turns brown under the influence of air, that is, Mn^{2+} is oxidized to Mn (IV). If the reaction takes place in the presence of hydrogen peroxide, a dark brown precipitate of $MnO(OH)_2$ is formed:

$$Mn^{2+} + 2OH^- + H_2O_2 = MnO(OH)_2 \downarrow + H_2O$$

Divide the manganese solution into two test tubes. Add 2M sodium hydroxide to the 1st test tube. A white precipitate is formed. In the 2nd test tube, add 2M sodium hydroxide and 2-3 drops of 3% H_2O_2 solution. A dark brown precipitate of $MnO(OH)_2$ is obtained.

2. Oxidation reaction of Mn^{2+} ion with sodium bismuthate takes place in nitric acid medium:

$$2Mn^{2+} + 5NaBiO_3 + 14H^+ = 2MnO_4^- + 5Bi^{3+} + 7H_2O$$

Add 1 drop of concentrated nitric acid, 3-4 drops of water and a small amount of dry sodium bismuthate to 1 drop of manganese ion (nitrate or sulfate). The color of the solution should be bright red.

3. Oxidation reaction of Mn^{2+} ion with lead dioxide takes place by heating in acidic environment:

$$2Mn^{2+} + 5PbO_2 + 4H^+ = 2MnO_4^- + 5Pb^{2+} + 2H_2O$$

Put a small amount of PbO_2 in a test tube and add 1 mL of HNO_3 to it, heat it until boiling, add 1 drop of manganese salt solution and heat it again. The color of the solution should be bright red.

Table 17 - Cations of the analytical group VI, *group reagent – excess of* $NH_3{\cdot}H_2O$

Cation	Reactions to perform in the lab	Reactions for theoretical study
Cu^{2+}	1. Reaction with $NH_3 \cdot H_2O$	1. Reaction with Na_2HPO_4
	2. Reaction with $K_4[Fe(CN)_6]$	2. Reaction with $NaOH$
	3. Reaction with $Na_2S_2O_3$	3. Reaction with KI
	4. Reaction with metals	
Ni^{2+}	1. Reaction with $NH_3 \cdot H_2O$	1. Reaction with Na_2HPO_4
		2. Reaction with $NaOH$
	2. Reaction with dimethylglyoxime (Chugaev's reagent)	3. Reaction with $K_4[Fe(CN)_6]$
		4. Reaction with Na_2CO_3
Co^{2+}	1. Reaction with $NH_3 \cdot H_2O$	1. Reaction with Na_2HPO_4
	2. Reaction with NH_4CNS	2. Reaction with $NaOH$
		3. Reaction with $(NH_4)_2S$
	3. Reaction with KNO_2	4. Reaction with $K_4[Fe(CN)_6]$
Cd^{2+}	1. Reaction with $NH_3 \cdot H_2O$	1. Reaction with $NaOH$
		2. Reaction with $(NH_4)_2S$

Identification of Cu^{2+} ion

1. If a small amount of ammonia is added to copper ions, it precipitates in the form of a green basic salt, which dissolves in an excess amount of the reagent. In this case, a deep blue colored ammonia complex is formed:

$$2CuSO_4 + 2NH_4OH = (CuOH)_2SO_4 \downarrow + (NH_4)_2SO_4$$
$$Cu^{2+} + 4NH_4OH = [Cu(NH_3)_4]^{2+} + 4H_2O$$

Add ammonium solution to 2-3 drops of copper (II) ion solution until pH > 9. The appearance of blue color indicates the presence of copper ions.

2. Reaction with potassium (II) hexacyanoferrate:

$$2CuSO_4 + K_4[Fe(CN)_6] = Cu_2[Fe(CN)_6] \downarrow + 2K_2SO_4$$

Add 1-2 drops of the reagent solution to 2-3 drops of the solution containing copper (II) ion (pH ≤ 7). A brown-red precipitate is formed.

3. Sodium thiosulfate decolorizes copper in an acidic medium, and if the solution is slightly heated, the complex easily decomposes and precipitates:

$$2Cu^{2+} + 2S_2O_3^{2-} + 4OH^- = Cu_2S\downarrow + S\downarrow + 4H^+ + 2SO_4^{2-}$$

Add 1-2 drops of the reagent solution to 2-3 drops of the solution containing copper (II) ion. Heat the resulting solution. A black-brown precipitate consisting of a mixture of sulfur and Cu_2S is obtained.

4. Some metals, such as aluminum, iron and zinc, reduce copper (II) ion:

$$3Cu^{2+} + 2Al = 3Cu + 2Al^{3+}$$

Put a grain of metal in the solution of copper (II) in a test tube. After a few minutes, it is observed that the copper in red color is released on the metal surface.

Identification of Ni^{2+} ion

1. Ammonia forms a green basic salt $(NiOH)_2SO_4$ with nickel ions, which dissolves in an excess of ammonia:

$$2NiSO_4 + 2NH_4OH = (NiOH)_2SO_4 + (NH_4)_2SO_4$$
$$Ni^{2+} + 6NH_4OH = [Ni(NH_3)_6]^{2+} + 6H_2O$$

Add an excess amount of ammonia to 2-3 drops of nickel solution, a bright blue nickel complex is formed.

2. Reaction with dimethylglyoxime. Dimethylglyoxime is used as a selective reagent for nickel. In an ammoniacal medium, the nickel inner complex gives a light-red precipitate in the form of dimethylglyoximate.

Add 1-2 drops of 1% dimethylglyoxime and 1-2 drops of 2M NH_3 to 1-2 drops of nickel solution. A bright red precipitate is formed.

Identification of Co^{2+} ion

1. Ammonia with cobalt first gives a blue basic salt $(CoOH)_2SO_4$, which dissolves in an excess amount of ammonia and turns into a brown-yellow complex:

$$2CoSO_4 + 2NH_4OH = (CoOH)_2SO_4 + (NH_4)_2SO_4$$
$$Co^{2+} + 6NH_4OH = [Co(NH_3)_4]^{2+} + 6H_2O$$

Add an excess of ammonia to 1-2 drops of cobalt solution until a brown-yellow complex is formed.

2. Ammonium (potassium) thiocyanate forms a blue, well soluble complex salt with cobalt (II) solution:

$$Co^{2+} + 4CNS^- = [Co(CNS)_4]^{2-}$$

Add 1-2 drops of cobalt solution to dry ammonium (potassium) thiocinate, dry ammonium fluoride and 5-7 drops of isoamyl alcohol. The organic layer is colored blue.

3. Potassium nitrite. In an acidic medium, KNO_2 reacts with cobalt (II) cations and gives a yellow potassium hexanitrocobaltate precipitate:

$$NO_2^- + CH_3COOH = HNO_2 + CH_3COO^-$$
$$Co^{2+} + 2HNO_2 = Co^{3+} + 2NO\uparrow + H_2O$$
$$Co^{3+} + 6NO_2^- = [Co(NO_2)_6]^{3-}$$
$$3K^+ + [Co(NO_2)_6]^{3-} = K_3[Co(NO_2)_6]\downarrow$$

Add 2 drops of 2M CH_3COOH, 2 drops of CH_3COONa and dry KNO_2 to 1-2 drops of cobalt (II) solution. Heat the mixture in a water bath for a few minutes. A yellow precipitate $K_3[Co(NO_2)_6]$ is formed.

Control test. Identification of cations of IV-VI groups

Goal of the work: to separate and identify group IV-VI cations in the given solution.

Table 18 – Qualitative analysis of the control solution for the presence of cations of IV-VI groups (P – precipitate, S - solution)

<table>
<tr><td colspan="7">$Al^{3+}, Cr^{3+}, Zn^{2+}, Mg^{2+}, Mn^{2+}, Fe^{2+}, Fe^{3+}, Cu^{2+}, Ni^{2+}, Co^{2+}$
(preliminary identification of Fe^{2+} and Fe^{3+})
+ NaOH (6M) + H_2O_2, t°</td></tr>
<tr><td colspan="4">**P1.**
$Fe(OH)_3, H_2MnO_3, Mg(OH)_2, Cu(OH)_2, Ni(OH)_2, C$
+ HNO_3 + H_2O_2, t°</td><td colspan="3">**S1.** $AlO_2^-, ZnO_2^{2-}, CrO_4^{2-}$
+ NH_4Cl (s), t°</td></tr>
<tr><td colspan="4">**S2.** $Mg^{2+}, Mn^{2+}, Fe^{3+}, Cu^{2+}, Ni^{2+}, Co^{2+}$
+ Na_2CO_3 (s) + NH_4OH (s), t°</td><td>**P7.**
$Al(OH)_3$
+ HCl (2M)</td><td colspan="2">**S10.**
$CrO_4^{2-}, [Zn(NH_3)_4]^{2+}$
+ Na_2CO_3, t°</td></tr>
<tr><td colspan="2">**P2.**
$FeOHCO_3, MnCO_3, Mg(OH)_2C$
+ HNO_3 (2M), t°</td><td colspan="2" rowspan="3">**S3.** $[Cu(NH_3)_4]^{2+}$,
$[Ni(NH_3)_6]^{2+}$,
$[Co(NH_3)_6]^{2+}$
+ H_2SO_4(6M)
+ $Na_2S_2O_3$ (s), t°</td><td rowspan="4">**S11.**
Al^{3+}</td><td>**P8.**
$Zn(OH)_2CO_3$
+ HCl (2M)</td><td rowspan="4">**S12.**
CrO_4^{2-}</td></tr>
<tr><td colspan="2">**S4.** $Mg^{2+}, Mn^{2+}, Fe^{3+}$
+ $(NH_4)_2HPO_4$ + NH_4OH + NH_4Cl (s)</td><td rowspan="3">**S13.** Zn^{2+}</td></tr>
<tr><td colspan="2">**P3.**
$MnNH_4PO_4, MgNH_4PO_4, FePO$
+ HAc, t°</td></tr>
<tr><td>**P4.**
$FePO_4$</td><td>**S5.** Mg^{2+}, Mn^{2+}
+ HNO_3 + $KBrO_3$</td><td>**P6.**
Cu_2S, S</td><td>**S8.**
Co^{2+}, Ni^{2+}</td></tr>
</table>

+ HCl, t°			**+ HNO_3 (6M)**	*Partial identification*			
S6. Fe^{3+}	**P5.** H_2MnO_3	**S7.** Mg^{2+}					
			S9. Cu^{2+}				

Questions for self-control

1. What role does hydrogen peroxide play for group V cations in systemic analysis?

2. $Fe(OH)_3$, $Mg(OH)_2$ and $Cu(OH)_2$ precipitates are treated with ammonia and ammonium chloride and heated. In this case, which ions are in solution and which ions are precipitated?

3. How are cobalt and nickel identified when they are together?

4. Give an example of oxidation-reduction reactions during the determination of group IV-VI cations.

5. Is $MgNH_4PO_4$ soluble in acids? What products can be formed depending on the strength of the acid?

6. Give examples of complexing reactions used in the separation of aluminum and iron, cobalt and nickel.

7. Under what conditions can cobalt (II) ion be determined using potassium nitrite?

8. What conditions should be used during the extraction of chromic acid?

9. Why does an excess amount of chloride ion interfere with the determination of manganese ion during permanganate formation?

10. Why is it important to identify Fe^{2+} ion first during the identification of cations of IV-VI groups?

Laboratory work 3.4

Identification of the inorganic cations in a given solution

Goal of the work: to get acquainted with the acid-base classification of cations, to identify the cations in the mixture given by the instructor.

Procedure

Identify the cations in the mixture given by the instructor according to Table 19. Fill the table below for each performed reaction.

Cation	Reaction equation and conditions	Observation and conclusion

In order to analyze the mixture of cations of I -VI groups by this method, it is necessary to separate individual samples beforehand. To do this, determine the acidity of the medium, pay attention to the color of the solution, and identify

NH_4^+, Fe^{2+}, Fe^{3+} ions first. If the substance under study consists of two phases, it is necessary to separate the precipitate and the solution.

Questions for self-control

1. When separating Ba^{2+} ion from Sr^{2+} and Ca^{2+} ions with $K_2Cr_2O_7$ solution, why is sodium acetate added to the solution under study?
2. What factors affect the solubility of sparingly soluble compounds?
3. At which of pH values (2.0; 7.0; 8.0; 9.0) is the solubility of $Co(OH)_2$ good and bad?
4. At which of pH values (2.0; 3.0; 5.0) is the solubility of $CaCO_3$ good and bad?
5. Why is magnesium hydroxide soluble in NH_4Cl, but $Fe(OH)_3$ is insoluble?
6. The solubility of which of these compounds depends on the acidity of the medium: $AgBr$, $PbCl_2$, CaC_2O_4, Hg_2Cl_2, $SrCO_3$?
7. Give examples of coordination compounds used in the process of ion identification, hiding ions, dissolving a precipitate, changing the acid-base or oxidation-reduction properties of compounds.
8. What ligand can hide iron (III) when determining Co(II) ion with ammonium thiocyanate?
9. Why does an excess amount of chloride ion interfere with the determination of manganese ion during permanganate formation?
10. Build an analysis chain of cations:
    1) $Pb^{2+}, K^+, Fe^{3+}, Mn^{2+}, Ni^{2+}$
    2) $Ag^+, Ba^{2+}, Al^{3+}, Mn^{2+}, Cd^{2+}$
    3) $Ca^{2+}, Zn^{2+}, Mg^{2+}, Fe^{3+}, Na^+$
    4) $Ba^{2+}, Cd^{2+}, Ca^{2+}, Ag^+, Cr^{3+}$
    5) $Ag^+, Pb^{2+}, Ba^{2+}, Na^+, Fe^{3+}, Mg^{2+}$
    6) $Hg_2^{2+}, Ba^{2+}, K^+, Fe^{3+}, Cu^{2+}, Ni^{2+}$
    7) $Mg^{2+}, Zn^{2+}, Cu^{2+}, Fe^{3+}, Pb^{2+}, NH_4^+$
    8) $Na^+, Pb^{2+}, Hg_2^{2+}, Sr^{2+}, Fe^{3+}, Fe^{2+}, Co^{2+}$
    9) $Ba^{2+}, Al^{3+}, Cr^{3+}, Mn^{2+}, Fe^{2+}, Cu^{2+}, Ni^{2+}$
    10) $Ca^{2+}, Cr^{3+}, Zn^{2+}, Mg^{2+}, Cu^{2+}, Ni^{2+}, K^+, NH_4^+$

Table 19 – Qualitative analysis of the control solution for the presence of inorganic cations (P – precipitate, S - solution)

<table>
<tr><td colspan="14">$NH_4^+, Na^+, K^+, Ag^+, Pb^{2+}, Hg_2^{2+}, Ca^{2+}, Sr^{2+}, Ba^{2+}, Al^{3+}, Cr^{3+}, Zn^{2+}, Mg^{2+}, Mn^{2+}, Fe^{2+}, Fe^{3+}, Cu^{2+}, Ni^{2+}, Co^{2+}$
+ HCl (2M) + H_2SO_4 (1M)</td></tr>
<tr><td colspan="5">**P1.** $AgCl, PbCl_2, Hg_2Cl_2, PbSO_4, SrSO_4, BaSO_4, (CaSO_4)$
+ HNO_3 + H_2O_2, t°</td><td colspan="9">**S1.** $NH_4^+, Na^+, K^+, Ca^{2+}, Al^{3+}, Cr^{3+}, Zn^{2+}, Mg^{2+}, Mn^{2+}, Fe^{2+}, Fe^{3+}, Cu^{2+}, Ni^{2+}, Co^{2+}$
+ C_2H_5OH, t°</td></tr>
<tr><td colspan="4">**P2.** $AgCl, Hg_2Cl_2, PbSO_4, SrSO_4, BaSO_4$
+ HAc, t°</td><td rowspan="9">**S2.**
Pb^{2+}</td><td rowspan="9">**P9.**
$CaSO_4$</td><td colspan="8">**S8.** $NH_4^+, Na^+, K^+, Al^{3+}, Cr^{3+}, Zn^{2+}, Mg^{2+}, Mn^{2+}, Fe^{2+}, Fe^{3+}, Cu^{2+}, Ni^{2+}, Co^{2+}$
+ NaOH (6M) + H_2O_2, t°</td></tr>
<tr><td colspan="3">**P3.** $AgCl, Hg_2Cl_2, SrSO_4, BaSO_4$
+ NH_4OH (6M)</td><td rowspan="8">**S3.**
$PbAc_2 \cdot PbSO_4$</td><td colspan="5">**P10.** $Fe(OH)_3, H_2MnO_3, Mg(OH)_2, Cu(OH)_2, Ni(OH)_2, Co(OH)_3$
+ HNO_3 + H_2O_2, t°</td><td colspan="3">**S9.** $AlO_2^-, ZnO_2^{2-}, CrO_4^{2-}$
+ NH_4Cl (s), t°</td></tr>
<tr><td colspan="2">**P4.** $Hg, HgNH_2Cl, SrSO_4, BaSO_4$
+ HNO_3 (6M), t°</td><td rowspan="7">**S4.**
$[Ag(NH_3)_2]^+$</td><td colspan="5">**S10.** $Mg^{2+}, Mn^{2+}, Fe^{3+}, Cu^{2+}, Ni^{2+}, Co^{2+}$
+ Na_2CO_3 (s) + NH_4OH (s), t°</td><td>**P16.**
$Al(OH)_3$
+ HCl (2M)</td><td colspan="2">**S18.**
$CrO_4^{2-}, [Zn(NH_3)_4]^{2+}$
+ Na_2CO_3, t°</td></tr>
<tr><td rowspan="2">**P5.** $SrSO_4, BaSO_4$
+ HCl, t°</td><td rowspan="2">**S5.** waste</td><td colspan="3" rowspan="2">**P11.** $FeOHCO_3, MnCO_3, Mg(OH)_2CO_3$
+ HNO_3 (2M), t°</td><td colspan="2" rowspan="2">**S11.** $[Cu(NH_3)_4]^{2+}, [Ni(NH_3)_6]^{2+}, [Co(NH_3)_6]^{2+}$
+ H_2SO_4(6M) + $Na_2S_2O_3$ (s), t°</td><td rowspan="6">**S19.**
Al^{3+}</td><td>**P17.**
$Zn(OH)_2CO_3$
+ HCl (2M)</td><td rowspan="6">**S20.**
CrO_4^{2-}</td></tr>
<tr><td rowspan="5">**S21.** Zn^{2+}</td></tr>
<tr><td colspan="2">**P6.** $SrSO_4, BaSO_4$
+ saturated Na_2CO_3, t°</td><td colspan="3">**S12.** $Mg^{2+}, Mn^{2+}, Fe^{3+}$
+ $(NH_4)_2HPO_4$ + NH_4OH + NH_4Cl (s)</td><td>**P12.**
Cu_2S, S
+ HNO_3 (6M)</td><td rowspan="4">**S13.**
Co^{2+}, Ni^{2+}</td></tr>
<tr><td colspan="2">**P7.** $SrCO_3, BaCO_3$
+ HAc (6M)</td><td colspan="3">**P13.**
$MnNH_4PO_4, MgNH_4PO_4, FePO_4$
+ HAc, t°</td><td rowspan="3">**S14.** Cu^{2+}</td></tr>
<tr><td colspan="2">**S6.** Sr^{2+}, Ba^{2+}
+ $K_2Cr_2O_7$ + NaAc</td><td>**P14.**
$FePO_4$
+ HCl, t°</td><td colspan="2">**S15.**
Mg^{2+}, Mn^{2+}
+ HNO_3 + $KBrO_3$</td></tr>
<tr><td>**P8.** $BaCrO_4$</td><td>**S7.** Sr^{2+}</td><td>**S16.**
Fe^{3+}</td><td>**P15.**
H_2MnO_3</td><td>**S17.**
Mg^{2+}</td></tr>
</table>