

Review Article

Simplifying Classical Qualitative Mixture Analysis Through Green and Sustainable Innovations

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Abstract

Inorganic mixture analysis remains one of the most intricate and intellectually stimulating exercises in chemistry education. It demands not only technical precision but also a deep conceptual understanding of solubility equilibria, complex formation, and redox behaviour. This study presents a comprehensive evaluation of the persistent challenges faced by students during classical mixture analysis and introduces several innovative strategies designed to simplify experimental procedures while fostering sustainability in the laboratory. The proposed modifications emphasize the intelligent selection of chemically compatible salts to avoid unwanted precipitation or redox interference, ensuring that mixtures remain stable and analytically meaningful. Equally important is the replacement of toxic reagents such as hydrogen sulphide (H_2S) with safer and environmentally benign substitutes that maintain analytical reliability without compromising safety. Further improvements include the reuse of sodium carbonate extract residues for cation detection, effectively converting laboratory waste into a valuable analytical resource. The adoption of semi-micro techniques and spot testing significantly reduces reagent consumption, waste generation and operational costs, thereby supporting both economic efficiency and ecological responsibility. Safer qualitative procedures for borate and fluoride analysis such as turmeric paper and ferric thiocyanate decolorization tests offer reliable, user-friendly and non-toxic alternatives to traditional methods. Collectively, these modifications promote greener, more efficient and pedagogically effective laboratory practices. By aligning classical qualitative inorganic analysis with modern principles of green chemistry, this work not only enhances analytical accuracy and conceptual understanding but also instils in learners a deeper awareness of sustainability and environmental responsibility within chemical education.

Keywords

Inorganic Qualitative Analysis, Green Chemistry, Semi-micro and Spot Tests, *Green Analytical Methods*, and *Sustainable Practices*

1. Introduction

Qualitative inorganic analysis remains one of the most challenging yet conceptually rewarding experiments in practical chemistry curricula. It provides students with a comprehensive understanding of fundamental principles such as solubility equilibria, complex formation and redox behavior,

all of which underpin analytical chemistry. Despite its pedagogical richness, the experiment continues to be a source of frustration for many learners who often encounter difficulty in obtaining correct and reproducible results. The complexity of sequential reactions, intricate separation procedures, and the

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demand for logical reasoning at every decision point make this experiment both intellectually demanding and technically exacting [1, 2].

In traditional pedagogy, qualitative analysis is taught through a well-established group separation scheme, wherein cations are systematically identified through the addition of selective reagents. However, this method presents several recurring challenges. Unplanned side reactions, such as hydrolysis or oxidation-reduction processes, may occur when chemically incompatible ions coexist, leading to erroneous results. Likewise, carryover effects from incomplete precipitations or washing can propagate errors into subsequent groups, diminishing accuracy and reproducibility. Students also struggle with ambiguous visual endpoints for instance, colloidal precipitates or subtle color changes that can easily be misinterpreted [3]. These procedural and interpretative difficulties often result in rote memorization rather than conceptual understanding, undermining the very purpose of laboratory training.

Another dimension of concern is the environmental and safety impact of conventional inorganic analysis. The traditional use of hydrogen sulphide (H_2S) gas, strong acids, and other sulphur containing reagents introduces significant toxicity, odour and waste management challenges. This reliance on hazardous chemicals limits experimental accessibility and raises concerns about occupational safety and environmental compliance [4]. In the context of global sustainability initiatives, such as the United Nations' Sustainable Development Goal 12 (Responsible Consumption and Production), it has become imperative for chemical education to align laboratory practices with the principles of green chemistry [5-13].

Over the past two decades, several researchers have developed greener and safer alternatives to conventional qualitative schemes. Sidhwani and Chowdhury [4] pioneered a method that eliminates H_2S and other sulphur-based reagents, replacing them with less toxic substitutes while preserving analytical selectivity. Their later works extended this philosophy to anion analysis, emphasizing the use of mild acids, semi-micro techniques, and low-volume reagents [14]. Subsequent studies proposed the reuse of sodium carbonate residues, the adoption of spot-test methodologies, and the rational selection of compatible cation-anion pairs to prevent unwanted side reactions during mixture preparation [15, 16]. Together, these innovations reflect a paradigm shift from reagent-intensive, toxic procedures toward eco-efficient, learner-cantered laboratory design.

Beyond chemical substitution, researchers in chemistry education have highlighted the cognitive aspects of mixture analysis. Students must navigate between macroscopic observations and microscopic reasoning by linking colour changes and precipitate formation to ionic species and equilibria. This representational challenge contributes significantly to conceptual misunderstanding [1]. Modern educational frameworks therefore advocate for scaffolded and inquiry-based designs, where decision maps, predictive

flowcharts, and reflective questions guide learners through the logical reasoning behind each step [3]. Visualization tools, such as computer-aided simulations and digital models of equilibria, further strengthen this conceptual linkage [17].

The present study builds on these advances by identifying common difficulties encountered during qualitative inorganic analysis and proposing practical modifications that improve efficiency, accuracy, and sustainability. Emphasis is placed on (I) chemically compatible mixture preparation, (II) optimized separation strategies using low-volume reagents, and (iii) integration of green laboratory practices to minimize waste and hazards. By merging traditional analytical rigor with sustainable innovation, this work aims to simplify mixture analysis, enhance student understanding, and promote environmentally responsible chemical education.

2. Making of Mixture

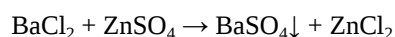
The process of mixture preparation marks the very beginning of qualitative analysis and requires careful thought and planning. The success of the entire experiment largely depends on how intelligently the mixture is designed. Preparing a mixture that can be analyzed logically and systematically, without leading to confusion or experimental difficulty, is an art as well as a scientific exercise.

The preparation of a mixture should never be arbitrary. Randomly combining two or more salts without considering their chemical compatibility can lead to undesirable outcomes such as precipitation, complex formation, hydrolysis or oxidation-reduction reactions even before the analysis begins. Such unintended reactions may alter the composition of the mixture and produce misleading or inconsistent results.

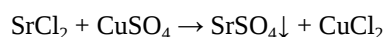
Hence, the preparation of a suitable mixture demands a sound understanding of the chemical behaviour of the constituent ions. Factors such as solubility, common ion effects, group separation principles and possible interferences must be taken into account.

At first glance, many mixtures may appear perfectly suitable for analysis. However, a closer examination often reveals hidden incompatibilities or chemical interactions that can complicate the analytical process. Therefore, a thoughtful and informed selection of salts is essential to ensure that the mixture remains stable and provides meaningful results during systematic qualitative analysis.

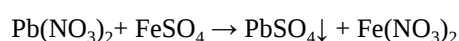
a) $(\text{BaCl}_2 + \text{ZnSO}_4)$

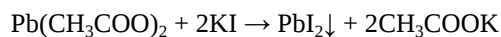
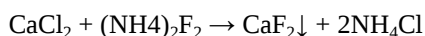
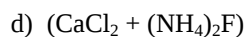


b) $(\text{SrCl}_2 + \text{CuSO}_4)$



c) $(\text{Pb}(\text{NO}_3)_2 + \text{FeSO}_4)$





Yet, there exists one common issue among all these mixtures as none of them yield a clear solution when treated with concentrated hydrochloric acid. Consequently, the preparation of the original solution (O.S.) becomes impossible, thereby hindering the subsequent analysis of cations. This problem arises due to the dissociation of salts in aqueous medium, which often leads to double decomposition or ion-exchange reactions between the components of the mixture. As a result, insoluble products or precipitates are formed, preventing the formation of a homogeneous solution.

In the Mixture 1, for instance, the salts undergo mutual interaction immediately upon dissolution, producing a precipitate through a double decomposition reaction. This not only alters the composition of the mixture but also makes qualitative analysis unreliable and, in many cases, unfeasible.

The white precipitate of barium sulphate formed in the first mixture is insoluble in concentrated hydrochloric acid, a fact well recognized from the confirmatory test for the sulphate ion. Similarly, in mixtures 2, 3, and 4, the corresponding white precipitates of strontium sulphate, lead sulphate, and calcium fluoride are produced, while in mixture 5, a yellow precipitate of lead (II) iodide is obtained. As a result of these reactions, the metal ions that form insoluble compounds are no longer available in the solution phase and, therefore, cannot be detected in their respective analytical groups. This leads to incomplete or erroneous analysis.

The solution to this problem is straightforward: while preparing mixtures, due consideration must be given to possible mutual reactions between the constituent salts. Arbitrary selection of components without understanding their chemical compatibility often results in precipitation and analytical difficulties.

To aid in the selection of suitable salt combinations, the following table summarizes some of the common cases of insoluble compound formation encountered during mixture preparation. However, this precaution may be relaxed in advanced situations where students are specifically trained in the analysis of insoluble compounds and can interpret such systems with confidence.

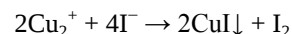
Table 1. Common cases of insoluble compound during mixture preparation and their corresponding cation-anion combinations.

S. No.	Anion	Cation	Insoluble Product
1.	SO_4^{2-}	$\text{Ba}^{2+}, \text{Sr}^{2+}, \text{Pb}^{2+}$	MSO_4 (M=Ba, Sr, Pb)
2.	F^-	Ca^{2+}	CaF_2

S. No.	Anion	Cation	Insoluble Product
3.	Br^-, I^-	$\text{Pb}^{2+}, \text{Ag}^+$	PbX_2, AgX (X=Br, I)
4.	Cl^-	Ag^+	AgCl

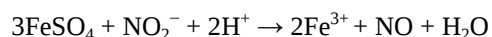
Apart from the issues arising from precipitation and insolubility, certain mixtures may also undergo mutual redox reactions, which render specific combinations unsuitable for qualitative analysis. This problem is particularly significant when one of the components is a transition metal ion capable of exhibiting variable oxidation states.

For instance, a mixture containing a copper (II) salt and an iodide is unsuitable because copper (II) ions oxidize iodide ions to free iodine, while they themselves are reduced to copper (I):



This reaction not only produces a white precipitate of cuprous iodide (CuI) but also liberates iodine, leading to a brown coloration. Consequently, both ions are altered, and their detection during systematic analysis becomes impossible.

Similarly, a mixture containing a ferrous salt and a nitrite undergoes a slow oxidation-reduction process, gradually turning brown on standing. In this reaction, the nitrite ion oxidizes a portion of Fe^{2+} to Fe^{3+} , while itself being reduced to nitric oxide (NO). The liberated NO then combines with unoxidized Fe^{2+} ions to form the nitrosyl ferrous complex, the same brown-colored species observed in the brown ring test for nitrates:



Such reactions not only alter the oxidation state of the analyte ions but also produce misleading colours, which can confuse the observer and lead to incorrect interpretations during analysis.

An interesting observation was also noted in the case of the mixture $(\text{NH}_4)_2\text{CO}_3 + \text{FeCl}_3$. Here, a redox and hydrolysis process occurs simultaneously. The carbonate ion hydrolyzes in the presence of the strongly acidic ferric chloride solution, leading to the formation of basic ferric carbonate and ammonium chloride. The resulting reddish-brown precipitate gives a false impression of ferric hydroxide formation even before any analytical test is performed. This again highlights the importance of understanding the chemical compatibility of the salts chosen for mixture preparation.

The examples given in following table demonstrate that the presence of oxidizing or reducing ions in the same mixture can lead to mutual redox interactions, producing colored species, precipitates, or decomposition products even before analysis begins. Such reactions alter the oxidation states of the ions and lead to false or missing group results during qualitative cation analysis.

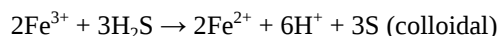
At first glance, the mixture appeared satisfactory; however, upon passing hydrogen sulphide (H_2S) during the detection of Group II cations, a persistent yellow suspension was observed

which could neither be filtered nor centrifuged effectively. Students initially assumed the formation of cadmium sulphide (CdS), but further examination revealed that this was not the case.

Table 2. Common redox-incompatible salt combinations and their effects on qualitative cation analysis.

S. No.	Salt Combination	Chemical Equation / Process	Observation	Analytical Consequence
1	$\text{CuSO}_4 + \text{KI}$	$2\text{Cu}^{2+} + 4\text{I}^- \rightarrow 2\text{CuI}\downarrow + \text{I}_2$	White precipitate of CuI and liberation of brown iodine vapor/solution	Cu^{2+} reduced to Cu^+ ; both Cu^{2+} and I^- missed in analysis
2	$\text{FeSO}_4 + \text{NaNO}_2$	$3\text{Fe}^{2+} + \text{NO}_2^- + 2\text{H}^+ \rightarrow 2\text{Fe}^{3+} + \text{NO} + \text{H}_2\text{O}$	Solution turns brown due to formation of nitrosyl ferrous complex	Fe^{2+} partly oxidized to Fe^{3+} ; misleading brown coloration
3	$(\text{NH}_4)_2\text{CO}_3 + \text{FeCl}_3$	$\text{Fe}^{3+} + \text{CO}_3^{2-} + \text{H}_2\text{O} \rightarrow \text{Fe}(\text{OH})_3\downarrow + \text{CO}_2$	Reddish-brown precipitate of basic ferric carbonate/hydroxide	Mixture appears decomposed; Fe^{3+} lost before analysis
4	$\text{SnCl}_2 + \text{HgCl}_2$	$\text{SnCl}_2 + 2\text{HgCl}_2 \rightarrow \text{SnCl}_4 + 2\text{HgCl}\downarrow$	Formation of gray mercury precipitate	Hg^{2+} reduced to Hg ; mixture unsuitable for systematic analysis
5	$\text{FeSO}_4 + \text{KMnO}_4$	$5\text{Fe}^{2+} + \text{MnO}_4^- + 8\text{H}^+ \rightarrow 5\text{Fe}^{3+} + \text{Mn}^{2+} + 4\text{H}_2\text{O}$	Purple color disappears; solution turns light brown	Mn (VII) reduced; Fe^{2+} oxidized thus both ions altered
6	$\text{CuCl}_2 + \text{Na}_2\text{S}_2\text{O}_3$	$2\text{Cu}^{2+} + 2\text{S}_2\text{O}_3^{2-} \rightarrow \text{Cu}_2\text{S}_2\text{O}_3\downarrow + \text{S}_4\text{O}_6^{2-}$	Solution turns milky; blackish residue	Thiosulfate decomposes, Cu^{2+} reduced thus false observations

The actual reason for this observation was that ferric ions (Fe^{3+}) present in the mixture oxidized hydrogen sulphide, leading to the liberation of colloidal sulphur according to the reaction:



The finely divided sulphur thus formed imparted a yellow coloration and remained suspended in the solution, giving a misleading impression of CdS precipitation.

It is important to recall that, prior to the precipitation of Group III cations, concentrated nitric acid is deliberately added to oxidize ferrous (Fe^{2+}) ions to ferric (Fe^{3+}) after boiling off excess H_2S . However, if ferric salts are already present in the original mixture, this oxidation step becomes counterproductive, as Fe^{3+} will prematurely oxidize H_2S , disturbing the analytical sequence.

The inevitable conclusion, therefore, is that while preparing mixtures, ferrous salts should be preferred over ferric salts. This ensures that H_2S performs its intended role in precipitating Group II cations without undergoing unwanted oxidation, thereby maintaining the integrity and reliability of the systematic analysis.

3. Interfering Anions and Their Removal: A Green Chemistry Approach

Certain anions such as borate, fluoride, oxalate, and phos-

phate are well known to interfere with the systematic analysis of cations. These ions are salts of weak acids and, as long as the medium remains acidic (for example, in the presence of concentrated hydrochloric acid), they largely remain undissociated and therefore do not interfere with the cation analysis. However, when the medium becomes alkaline - beginning from Group III onwards - these anions dissociate, leading to the formation of precipitates or complexes that hinder the proper detection of cations.

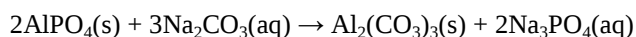
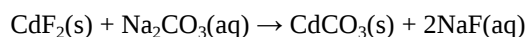
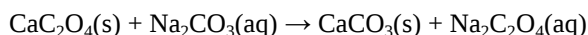
Traditionally, these interfering anions are removed after Group II analysis by repeated evaporation with concentrated hydrochloric or nitric acid. However, this classical method suffers from several drawbacks:

- It involves the consumption of large volumes of corrosive acids. For instance, in a class of 60 students, nearly one litre of concentrated acid is used.
- The fumes evolved during evaporation cause significant indoor air pollution and health hazards.
- Evaporation with nitric acid may convert certain metal salts into insoluble oxides, creating further analytical difficulties.
- Phosphate removal using reagents such as zirconium nitrate introduces toxic and environmentally unsafe materials.

To address these limitations, a green chemistry improvisation can be adopted that entirely eliminates the need for separate removal of interfering anions. During the anion analysis, the sodium carbonate extract of the mixture is prepared by boiling it with excess sodium carbonate solution, which

converts all anions into their soluble sodium salts, while the metal ions are precipitated as carbonates in the residue. Conventionally, this residue is discarded; however, if it is utilized for the subsequent cation analysis, the step of removing interfering radicals becomes unnecessary, as they have already been separated in the extract.

The process can be represented by the following reactions:



By employing this method, the residue which would otherwise be rejected is effectively reused for cation detection. This approach offers multiple benefits:

- It minimizes the consumption of acids and other hazardous chemicals.
- It reduces air pollution and exposure to toxic fumes in the laboratory.
- It conserves heat energy, as no evaporation step is required.
- It reduces waste generation and exemplifies the principles of green chemistry by converting laboratory waste into a useful resource.

Hence, the reuse of the sodium carbonate extract residue represents a sustainable and eco-friendly modification in classical qualitative analysis, maintaining analytical accuracy while ensuring environmental safety.

4. Steps to Reduce Consumption of Chemicals and Cost Incurred

The escalating cost of laboratory chemicals poses a major challenge to science education and research. It has therefore become imperative to devise strategies that minimize chemical consumption and waste generation without compromising the quality and reliability of analytical results. Moreover, since many of these chemicals are toxic and proper effluent treatment facilities are often unavailable, it is our collective responsibility to adopt sustainable and environmentally conscious laboratory practices.

In qualitative mixture analysis, a large number of reagents and acids are routinely employed. Hence, efforts to optimize their usage can have a significant environmental and economic impact. One such step, already discussed earlier, is the reuse of the residue from sodium carbonate extract for cation analysis, a modification that eliminates the need for acid based removal of interfering anions and promotes the principles of green chemistry.

Another highly effective measure involves reducing the scale of analysis by shifting from macro to semi-micro methods. In conventional (macro) analysis, test tubes of 20 ml

capacity are used, and approximately 5 ml of test solution is required for each step. In contrast, semi-micro analysis utilizes 5 ml capacity test tubes, requiring only about 1 ml of analyte per test. This modification results in a fivefold reduction in the consumption of chemicals and reagents. Additionally, the use of smaller quantities shortens reaction times and enhances the speed of analysis, while also reducing the consumption of fuel (LPG), thereby conserving natural resources.

Although an initial investment is needed for the semi-micro analysis kits, it is a one-time expenditure that offers long-term benefits in terms of cost savings, environmental sustainability and operational efficiency which truly justifying the adage “*spend today and smile tomorrow.*”

4.1. Spot Tests: A Sustainable and Economical Alternative

Spot tests represent another practical approach to minimizing chemical use. These tests require only a few drops of the reagent, yet they provide clear and reliable results. Their advantages include:

- Economic efficiency: Significant reduction in reagent cost and wastage.
- Environmental protection: Lower air and water pollution.
- Operational speed: Rapid detection due to smaller sample size.
- Energy conservation: Reduced heating requirements.
- Safety: Lower exposure to corrosive and toxic reagents.
- Reduced toxicity: Minimal use of hazardous substances.
- Lower stress and fatigue: Simplified procedures enhance comfort and confidence in laboratory work.

Spot tests can be conveniently performed on grooved porcelain tiles, micro (ignition) tubes, or even filter paper. The white background of grooved tiles allows easy visualization of color changes. For white precipitates or turbid reactions that are difficult to perceive against a white surface, black grooved tiles are preferred. These can be economically fabricated from discarded granite tiles obtained from construction waste. Alternatively, white tiles can be modified by painting selected grooves black with enamel paint or a permanent marker. Transparent watch glasses placed over black paper also serve as an effective substitute.

Importantly, there is no need for costly specialized reagents while most conventional qualitative tests can be performed in spot form using only a few drops of the same solutions.

Examples of Spot Tests

a. Anion Tests

- Nitrate: Brown ring test.
- Chloride, Bromide, Iodide: Silver nitrate test (*use black tile for chloride and bromide*).
- Nitrite: Dye test using sulphanilic acid and

o-naphthylamine.

- iv. Sulphate, Sulphite: Barium chloride test (*black tile for better contrast*).
- v. Fluoride, Oxalate: Calcium chloride test (*black tile*).

Note: Silver nitrate is a costly reagent (approximately ₹3,000 for 25 g). Performing the halide test as a spot test drastically reduces its consumption and expense.

b. Cation Tests

- i. Potassium: Sodium cobaltinitrite test
- ii. Lead: Potassium chromate and potassium iodide tests
- iii. Copper, Iron: Potassium ferrocyanide test
- iv. Iron (III): Ammonium thiocyanate test
- v. Manganese: Sodium bismuthate test
- vi. Nickel: Dimethylglyoxime (DMG) test
- vii. Barium: Potassium chromate test
- viii. Strontium: Ammonium sulphate test (*black tile*)
- ix. Calcium: Ammonium oxalate test (*black tile*)

4.2. Spot Tests on Filter Paper

For gaseous reactions or volatile products, spot tests may be performed on small strips (2 × 2 cm) of Whatman No. 1 filter paper. A small drop of the detecting reagent—such as acidified potassium dichromate for sulphite, lead acetate for sulphide, or Nessler's reagent for ammonium—is placed on the paper using a fine capillary. The paper is then held at the mouth of the test tube containing the reaction mixture to detect the evolved gas.

The spot test for ammonium using Nessler's reagent deserves special attention, as the reagent contains mercury, a highly toxic metal. Performing this test in spot form substantially reduces mercury use and exposure, contributing to safer and greener laboratory practices.

Adopting semi-micro techniques and spot test methodologies not only minimizes chemical consumption and laboratory costs but also aligns teaching and research laboratories with the principles of green and sustainable chemistry. These approaches reduce environmental hazards, conserve resources, enhance analytical speed and promote safety by transforming conventional mixture analysis into a more efficient, economical and eco-friendly exercise.

5. Less Common But Highly Effective and Eco-friendly Tests

The growing emphasis on green chemistry and sustainable laboratory practices has encouraged the development of analytical methods that minimize the use of toxic, corrosive, and flammable reagents. Several conventional tests in qualitative inorganic analysis can be replaced by safer and equally reliable alternatives. Two such examples are the borate and fluoride tests.

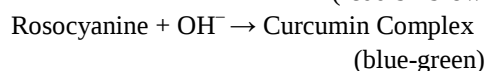
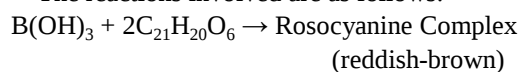
(a) *Borate Test*

The conventional test for borate ions (BO_3^{3-}) involves heating the sample with methyl or ethyl alcohol and concen-

trated sulphuric acid. This method poses significant safety and environmental concerns, as methyl alcohol is highly toxic and both alcohols are flammable, while concentrated sulphuric acid is corrosive and hazardous to handle.

A safer and eco-friendly alternative is the turmeric paper test, which is simple, inexpensive, and non-toxic. This modified spot test is performed using self-prepared turmeric paper, obtained by impregnating small strips of filter paper with a suspension of raw turmeric powder and drying them. When an acidified solution of borate is applied to the turmeric paper, a reddish-brown coloration develops due to the formation of the rosocyanine complex between boric acid and curcumin (the active constituent of turmeric). On treatment with an alkali, the colour turns blue to greenish-black, and the change is reversible upon acidification.

The reactions involved are as follows:



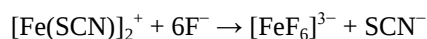
It should be noted that ferric salts may interfere with the test by imparting their own color; however, the alkaline color change characteristic of the borate reaction is not observed in their presence, allowing differentiation.

This modified procedure eliminates the use of hazardous reagents while maintaining sensitivity and reliability, making it an ideal green analytical method.

(b) *Fluoride Test*

An additional, highly convenient test for fluoride ions (F^-) is based on the discoloration of ferric thiocyanate complex. The test is performed by adding a drop of potassium thiocyanate (KSCN) or ammonium thiocyanate (NH_4SCN) solution to a drop of ferric chloride (FeCl_3) solution, producing the characteristic blood-red colour of ferric thiocyanate.

When a drop of an acidified fluoride solution is added, the red colour is discharged because fluoride ions replace thiocyanate ligands, forming the colourless ferric fluoride complex:



This reaction serves as a simple, sensitive, and clean qualitative test for fluoride, avoiding the use of glass-etching reactions or toxic reagents like HF. The test also aligns with micro-scale analytical principles, using only a few drops of reagent and generating negligible waste.

6. Scheme of Cation Analysis Without H_2S

The use of hydrogen sulphide (H_2S) in qualitative analysis, although classical, presents serious health and safety hazards due to its high toxicity, unpleasant odour, and potential for air pollution. A modified H_2S free scheme of cation analysis has

therefore been developed to eliminate its use entirely, while preserving group separation and detection accuracy.

In this modified classification, cations are divided into four

groups, each precipitated and identified using non-toxic and eco-friendly reagents. Specific group reagents replace H_2S and related sulphide generating agents. For instance:

Table 3. Modified Scheme of Cation Analysis (without H_2S).

Group	Cations	Group Reagent	Precipitated As
0	NH_4^+ , K^+	-	-
I	Pb^{2+} , Ag^+	Dilute HCl	Insoluble chlorides
II	Ba^{2+} , Sr^{2+} , Ca^{2+} , Pb^{2+} (Incompletely precipitated in Group I)	Saturated Na_2SO_4 solution / alcohol	Insoluble sulphates
III A	Fe^{3+} , Mn^{2+} , Mg^{2+}	10% NaOH after treatment with H_2O_2	Insoluble hydroxides
III B	Cu^{2+} , Cd^{2+} , Co^{2+} , Ni^{2+}	Ammonia solution	Soluble ammine complexes
IV	Al^{3+} , Zn^{2+} , Sn^{2+} , Cr^{3+}	10% NaOH after treatment with H_2O_2	Soluble hydroxo complexes and CrO_4^{2-}

This revised approach provides several advantages:

- This classification eliminates the use of toxic H_2S gas at all stages.
- The oxidation treatment with H_2O_2 ensures correct group separation of amphoteric and transition metal ions.
- The method is eco-friendly, safe and efficient, suitable for both educational and analytical laboratories.

7. Some Useful Points

The following hints are derived from practical observations and long-term laboratory experience. They serve as valuable guidelines for students and teachers to improve efficiency, accuracy, and confidence in qualitative mixture analysis.

These tips are not intended to replace systematic group analysis, but rather to complement and guide it by offering diagnostic clues, safety insights, and time-saving practices.

7.1. Direct and Selective Tests

Certain tests are sufficiently sensitive and selective to be performed directly on the mixture without preliminary group separation.

Examples include:

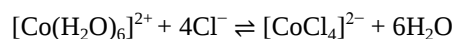
- The thiocyanate test for Fe^{3+} (formation of blood-red ferric thiocyanate complex).
- The dimethylglyoxime (DMG) test for Ni^{2+} (formation of red Ni-DMG complex).
- The sodium bismuthate test for Mn^{2+} (formation of purple permanganate).

Such direct detections provide useful hints about the possible presence of specific cations; however, they should not

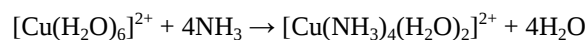
substitute the systematic group analysis required for accurate confirmation.

7.2. Colour Changes and Diagnostic Clues

A color change from pink to blue (or vice versa) during preparation of the original solution indicates the presence of Cobalt (II). This is due to equilibrium between the pink hex-aquacobalt (II) complex and the blue tetrachlorocobaltate (II) complex, especially when hydrochloric acid is added.



The appearance of a deep blue coloration upon addition of ammonia solution suggests the presence of copper (II) ions, resulting from the formation of tetraamminecopper (II) complex:



7.3. Observations Related to Gas Evolution

- When the mixture contains Ba^{2+} , Sr^{2+} , Ca^{2+} or Pb^{2+} , the effervescence of CO_2 from carbonates may be faint or absent upon addition of dilute H_2SO_4 because insoluble sulphates are formed. Using dilute HCl instead gives clearer results.
- Some carbonates react slowly with dilute acids; adding a small amount of anhydrous sodium carbonate during mixture preparation improves gas evolution and consistency.

7.4. Handling Watery Mixtures

Mixtures containing nitrates or acetates often appear watery

due to water of hydration or decomposition. This can be avoided by incorporating anhydrous sodium carbonate during mixture preparation, which absorbs excess moisture and maintains suitable consistency.

7.5. Efficiency in Group Analysis

- To save time and chemicals, it is advisable to perform preliminary tests on small portions of the sample. For example, before proceeding to Group II, pass H_2S through a small portion of the test solution and then dilute to check for Cd^{2+} .
- If no precipitate appears even after dilution, the portion can be discarded, and analysis can directly proceed to Group III. This reduces H_2S consumption, exposure, and time.
- If the mixture is white, concentrated nitric acid treatment before testing for Group III may be omitted, as iron salts are absent in white mixtures.

7.6. Ensuring Complete Precipitation

Each cation must be completely precipitated within its designated group to prevent interference in higher groups. This is particularly crucial for Pb^{2+} and Co^{2+} , which, if incompletely removed, can cause misleading results in subsequent steps.

7.7. Testing for Potassium and Ammonium

- Potassium should be tested in Group 0, immediately after ammonium, using the same original mixture.
- By the time the analysis reaches Group VI, the solution becomes excessively diluted, making potassium detection difficult.

7.8. Handling the Sodium Carbonate Extract

- Before testing for anions, the sodium carbonate extract must be acidified.
- If not acidified, insoluble carbonates of barium, calcium, or silver may form with reagents such as BaCl_2 , AgNO_3 , or CaCl_2 , giving false white precipitates.
- Though nitrates are water-soluble, it is preferable to perform the brown ring test using the acidified sodium carbonate extract, as this minimizes interference.
- In mixtures containing soluble Ba^{2+} , Sr^{2+} , or Pb^{2+} , the direct addition of FeSO_4 to the aqueous extract can yield a white precipitate, obscuring the brown ring formation.

7.9. Additional Practical Tips

- Always perform a blank test for chloride using distilled water, since traces of chloride are often present in laboratory water supplies.

- A substitute for lime water in CO_2 detection is barium chloride solution, which also turns milky when carbon dioxide is passed through it.
- Whenever possible, use smaller sample portions for preliminary tests to reduce reagent consumption, waste generation and experimental time.

8. Conclusion

The systematic modifications proposed in this study collectively demonstrate that qualitative inorganic analysis can be conducted with reduced complexity, cost, and environmental impact without compromising analytical accuracy. The careful selection of chemically compatible salts ensures stability of mixtures, while avoidance of redox incompatible combinations prevents misleading results. The substitution of toxic and corrosive reagents with eco-friendly alternatives, coupled with the reuse of sodium carbonate extract residues, effectively incorporates the principles of green chemistry into classical analysis.

Furthermore, the adoption of semi-micro and spot test methodologies minimizes reagent use, enhances laboratory safety, and provides rapid and reliable results. Innovative tests such as the turmeric paper test for borate and the ferric thiocyanate decolorization test for fluoride demonstrate that safe, sustainable and sensitive alternatives can successfully replace hazardous traditional methods.

Reframing the classical scheme within a green and logical context transforms mixture analysis into a dynamic learning process that nurtures chemical reasoning, environmental consciousness and analytical thinking by marking a shift toward safer and more sustainable laboratory practices.

Abbreviations

O.S.	Original Solution
H_2S	Hydrogen Sulphide
HCl	Hydrochloric Acid
HNO_3	Nitric Acid
Na_2CO_3	Sodium Carbonate
Na_2SO_4	Sodium Sulphate
NaOH	Sodium Hydroxide
H_2O_2	Hydrogen Peroxide
KSCN NH_4SCN	Potassium Thiocyanate / Ammonium Thiocyanate
FeCl_3	Ferric Chloride
KMnO_4	Potassium Permanganate
FeSO_4	Ferrous Sulphate
NH_4^+	Ammonium Ion
CO_2	Carbon Dioxide
CdS	Cadmium Sulphide
DMG	Dimethylglyoxime

Author Contributions

Vikas Singh is the sole author. The author read and approved the final manuscript.

Conflicts of Interest

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