

Synthesis of Bismuths (III) Compounds for Medical Applications

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Abstract

Syntheses of bismuth compounds having useful properties for medical applications: neutral and basic bismuth nitrate, tartrate, gallate, subsalicylate, phosphate, oxochloride, oxocarbonate, and bismuth-potassium-ammonium citrate are reported. For synthesis of highly pure and reactive compounds it is recommended that hydrolysis and heterogeneous solid-solution reactions be used.

INTRODUCTION

Highly pure and reactive bismuth compounds, namely, neutral and basic bismuth nitrates, as well as basic bismuth carbonate, salicylate, tartrate, gallate, tribromophenoxide, and citrate, have found wide medical applications in Russia and abroad [1–4]. These compounds are used as substances for syntheses of various pharmaceuticals: vicalin, vicair, xeroform, dermatol, bismoverol, bijochinol, de-nol, tribimol, telen, desmol, pylorid, *etc.* The new bismuth-containing drugs such as de-nol and its analog tribimol produced by Gist Brocades (The Netherlands), Wave International and Edder Pharmaceuticals (India), Yamanouchi Europe (Japan), as well as desmol produced by INC Laboratories (USA), are the most effective antiulcer drugs.

Colloid subcitrate is the pharmacologically active part of de-nol; in desmol, this is bismuth subsalicylate. Apart from de-nol, pylorid has recently begun to be widely used in medical practice; its pharmacologically active part is bismuth ranitidine-citrate produced by Glaxo Wellcome Operations (Great Britain) and Tritec (USA). This compound combines the antisecretory effects of ranitidine with gastroprotective and bactericidal properties of bismuth compounds affecting *Helicobacter pylori*. Ta-

ble 1 lists bismuth compounds and their useful medical applications.

Bismuth compounds are obtained from Bi 1 grade metal (State Standard 10928) with a bismuth content of up to 97.7 % and the maximal percent of metal impurities: lead 2.0, zinc $5 \cdot 10^{-3}$, iron $5 \cdot 10^{-3}$, antimony $5 \cdot 10^{-3}$, copper $1 \cdot 10^{-2}$, silver $1.8 \cdot 10^{-1}$, arsenic $3 \cdot 10^{-4}$, and tellurium $1 \cdot 10^{-4}$. The synthetic procedure is based on precipitation of bismuth compounds from nitrate solutions. The existing scheme of synthesis suffers from a number of disadvantages: isolation of toxic nitrogen oxides at the stage of the preparation of bismuth-containing nitrate solutions, difficulties in preparing products of required purity during hydrolytic processing, and prolonged purification process.

The aim of the present work is to overview the available literature data on syntheses of several most widely applicable bismuth (III) compounds, choosing simple and ecologically clean synthetic procedures.

PREPARATION OF BISMUTH SALT SOLUTIONS

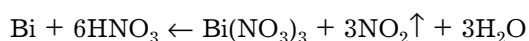
A solution of bismuth (III) nitrate is generally obtained by dissolving metal granules in nitric acid, or by pouring a melt of metallic bismuth in an acid solution with stirring [5, 6].

TABLE 1

Medical compositions based on bismuth

Bismuth salts	Medical applications
Inorganic salts: carbonate phosphate silicate basic carbonate basic nitrate	These salts react slowly with the hydrochloric acid of stomach, covering the mucous membrane of the latter. Major applications: antiulcer agent for treatment of gastric and duodenal ulcer, gastritis, dyspepsia, and functional disorders of large intestine, stomach, and duodenum; protective and soothing agent in ointment form for treatment of inflamed skin.
Aliphatic carboxylates: butylthiolaurate camphorate citrate dipropylacetate ethylcamphorate potassium (sodium) tartrate succinate	Antibacterial drugs used for treatment of tonsillitis, infectious quinsy, syphilis.
Aromatic salts: iodosubgallate salicylate basic gallate trobromophenoxide tannate	Internal astringent and absorbing agents protecting the mucous membrane of the gastrointestinal tract. Also used as antiseptics and medicine for treatment of gastroenteritis, diarrhea, dermatitis, and hemorrhoid.

The starting concentration of nitric acid is 7.4–8.8 mol/l. Dissolution follows the scheme



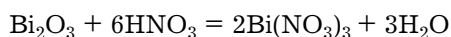
To decompose nitrogen oxides liberated during the solution process the use of carbamide [7] or hydrogen peroxide [8] or oxygen feeding to the solution zone [9] was recommended. Addition of hydrogen peroxide (an expensive oxidant) (4.1–9.3 %) or carbamide (~5 %) to a nitric acid solution suppresses the atmospheric release of nitrogen oxides, but considerably lowers the rate of bismuth solution. The solution process of metallic bismuth in nitric acid while feeding oxygen has been studied [9]; it was shown that dilute (~1.5 mol/l) acid should be used before bismuth hydrolysis forming oxohydroxonitrate has started. However, bismuth concentration should not be higher than 60 g/l.

To prepare bismuth salt solutions from metallic bismuth we suggested that bismuth should be preliminarily converted to bismuth oxide and then dissolved in mineral acids [10]. This can be done by adding 20–30 %

bismuth (III) oxide to a metallic bismuth melt at 300–400 °C, subsequently elevating the temperature to 550–650 °C. Due to this, the metal is dispersed, yielding agglomerates sized up to 3 mm. As a result, the reaction surface of metallic bismuth increases, and bismuth is more readily oxidized with atmospheric oxygen by the scheme



Conversion of the metal to oxide form lowers the amount of nitric acid needed for preparing bismuth nitrate solutions by a factor of two. This also makes it possible to avoid atmospheric release of toxic nitrogen oxides. The solution process follows the scheme



SYNTHESIS OF BASIC BISMUTH (III) NITRATE

More than 20 basic bismuth (III) nitrates have been considered in the literature. Previously, the compound used in medicine was formulated

as $5\text{Bi}_2\text{O}_3 \cdot 4\text{N}_2\text{O}_5 \cdot 9\text{H}_2\text{O}$. The composition of the compound is $4\text{Bi}(\text{NO}_3)(\text{OH})_2 \cdot \text{BiO}(\text{OH})$ (Sigma, USA) or $\text{BiONO}_3 \cdot \text{H}_2\text{O}$ (Aldrich, USA). According to monograph [1], this is a mixture of $\text{Bi}(\text{NO}_3)(\text{OH})_2$, BiONO_3 , and $\text{BiO}(\text{OH})$. USP 26-NF21 and the Register of Pharmaceuticals of Russia [12] ascribed it a composition $\text{Bi}_5\text{O}(\text{OH})_9(\text{NO}_3)_4$ (CAS 1304-85-4), stating that this is a mixture of BiONO_3 , $\text{Bi}(\text{NO}_3)(\text{OH})_2$, and BiOOH . However, X-ray diffraction studies indicated that the pharmacopoeial drug is an individual compound, namely, bismuth oxohydroxonitrate $[\text{Bi}_6\text{O}_5(\text{OH})_3](\text{NO}_3)_5 \cdot 3\text{H}_2\text{O}$ crystallizing in the monoclinic crystal system [13, 14]. According to Lazarini [13], the cation of the compound is formed from two cellular groups $[\text{Bi}_6\text{O}_5(\text{OH})_3]^{5+}$ symmetrically bonded by two bridging oxygen atoms to NO_3^- anions and water molecules. The molecular mass of the compound is 1748.97, while mass fraction of Bi_2O_3 is 79.93 %, which satisfies the requirements of the pharmacopoeial article FS 42-2374-98.

When bismuth is precipitated from nitrate solutions by adding alkaline reagents (ammonia, caustic soda, and sodium or ammonium carbonates), the degree of bismuth precipitation R depends significantly on pH of the medium and reaction temperature and is almost independent of the nature of the alkaline reagent. The degree of Bi precipitation increases with pH of the solution; at pH 0.8–1 and reaction temperature 20–25 °C, it reaches 93–97 % (residual concentration of Bi in solution is 5–10 g/l). At elevated temperatures quantitative precipitation of Bi takes place at lower values of pH; thus at 60 °C (pH 0.8–1) R is 97–99 % (residual concentration of Bi is 2–5 g/l). Lowering the acidity of the solution to pH 3 permits one to attain complete ($R = 99.99$ %) precipitation of bismuth (residual concentration is ~0.05 g/l). Studies on hydrolytic processing of bismuth-containing nitric acid solutions indicated that at elevated temperatures (≥ 50 °C) hydrolysis yields an easily filtered-off coarse-crystalline precipitate of basic bismuth nitrate $[\text{Bi}_6\text{O}_4(\text{OH})_4](\text{NO}_3)_6 \cdot \text{H}_2\text{O}$, which can be effectively separated from the solution containing impurity metals. Recrystallization of the above hydrolysis product into $[\text{Bi}_6\text{O}_5(\text{OH})_3](\text{NO}_3)_5 \cdot 3\text{H}_2\text{O}$ takes place when the product is washed with a

nitric acid solution with $\text{pH} \geq 1$ or with water. This procedure permits one to remove impurity metals adsorbed during hydrolysis and the substances trapped by microcrystals during crystallization.

It was recommended [15] that basic pharmacopoeial bismuth be prepared from metallic bismuth by hydrolytic purification of bismuth by adding water or ammonium carbonate to the nitrate solution (pH 0.55–1.0, temperature at least 50 °C), subsequently washing the precipitate with water and drying the product at 80–120 °C.

SYNTHESIS OF BISMUTH (III) COMPOUNDS BY PRECIPITATION FROM NITRATE SOLUTIONS

Bismuth (III) compounds are generally synthesized by hydrolytic processing of nitric acid solutions of metallic bismuth [5, 6, 16–18]. Therefore, studies on direct precipitation of bismuth (III) compounds having useful medical applications from nitrate solutions is of interest from practical viewpoint.

Bismuth (III) citrate is used in antiulcer drug production and for nutrient media in bacterial drug production. Studies on bismuth precipitation from nitrate solutions by adding aqueous trisubstituted sodium citrate at a temperature of (60 ± 1) °C revealed that the degree of bismuth (III) precipitation R increased considerably with the concentration of sodium citrate. Thus addition of a small amount of citrate ions to the system (molar ratio of citrate ions to bismuth is $n = 0.15$) leads to $R = 49.3$ % versus 22.1 % obtained when the nitrate solution of bismuth (III) solution was diluted with water to the same volume. The citrate ions are almost completely bound to bismuth (III) in the precipitate, their residual concentration in solution being up to 0.001 g/l. When n increases to 1.1, the degree of bismuth (III) precipitation reaches 99.5 %; the B: Cit molar ratio in the precipitate is 1.02 with 47.6 % Cit and 51.89 % Bi. According to X-ray phase analysis data, the precipitated product is a compound with a composition $\text{BiC}_6\text{H}_5\text{O}_7$. Bismuth (III) citrate $\text{BiC}_6\text{H}_5\text{O}_7$ may be synthesized in laboratory conditions and on an industrial scale; it was recommended [19]

to perform synthesis by precipitation from bismuth (III) nitrate solutions by adding a solution of citric acid at pH 0.1–0.7 and at a temperature of $(60 \pm 10)^\circ\text{C}$. Thermal decomposition of bismuth (III) citrate occurs above 200°C , permitting the drying of this compound at elevated temperatures.

Basic bismuth (III) gallate is employed for the preparation of the dermatol drug. Studies on precipitation of basic bismuth gallate from nitric acid solutions indicated that the degree of bismuth precipitation depends heavily on the added quantity of gallate ions, but is practically independent of the sequence of addition [20]. The *R* index is minimum when the molar ratio of gallate ions to bismuth in solution is $n = 0.5$; when $n = 1$, $R = 95\%$. The *R* index increases to 99.6% for $n = 1.1$ (residual concentration of bismuth(III) in solution is 0.16 g/l). Residual concentration is up to 0.08 g/l when $n = 2.0$ and higher. It was established that bismuth is precipitated in the form of oxogallate monohydrate $\text{C}_6\text{H}_2(\text{OH})_3\text{COOBiO} \cdot \text{H}_2\text{O}$. The specific surface of the product varies from 1.5 to $25.0\text{ m}^2/\text{g}$ depending on the reaction temperature and pH of the solution, due to which the pharmaceutical compositions possess high therapeutic activity.

Studies on the effect of tartaric acid concentration on the degree of bismuth precipitation from nitrate solutions indicated that at $(23 \pm 1)^\circ\text{C}$ bismuth precipitation was minimum when the molar ratio of tartrate ions to bismuth was $n = 0.25$, but increased to 98.8% when $n = 5$. At $(60 \pm 1)^\circ\text{C}$ the degree of bismuth precipitation was constant and independent of the tartaric acid concentration until n reached 3. Then the degree of bismuth precipitation increased with n , reaching 91.1% for $n = 5$. At higher temperatures, the degree of bismuth precipitation decreased. In the absence of tartrate ions, basic nitrates $[\text{Bi}_6\text{O}_4(\text{OH})_4](\text{NO}_3)_6 \cdot 4\text{H}_2\text{O}$ (23°C) and $[\text{Bi}_6\text{O}_4(\text{OH})_4](\text{NO}_3)_6 \cdot \text{H}_2\text{O}$ (60°C) formed in the system (X-ray phase analysis data). When the initial molar ratio of tartrate ions to bismuth n was 1, the precipitates contained (%) 49 Bi, 9.74 C, 1.42 H, and 2.46 N; the molar ratio of bismuth (III) to the tartrate and NO_3^- ions in the precipitate was 1 : 1.1 and 1 : 1.2, respectively. Therefore, one can assume that

the compound precipitating under the given conditions is $\text{Bi}(\text{NO}_3)(\text{C}_4\text{H}_4\text{O}_6) \cdot 3\text{H}_2\text{O}$, which was reported in the literature as one of the possible products [21]. When n was 2 (23°C) or 3 (60°C) or higher, the precipitate was the bismuth ditartrate complex $[\text{Bi}(\text{C}_4\text{H}_4\text{O}_6)(\text{C}_4\text{H}_5\text{O}_6)] \cdot 3\text{H}_2\text{O}$, crystallizing in the orthorhombic crystal system and constructed as a 3D net with bridging and chelate bonds of polydentate hydroxycarboxylate ligands [22]. This is confirmed by the data of chemical and X-ray phase analyses.

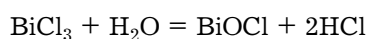
It was recommended that bismuth ditartrate $[\text{Bi}(\text{C}_4\text{H}_4\text{O}_6)(\text{C}_4\text{H}_5\text{O}_6)] \cdot 3\text{H}_2\text{O}$ should be synthesized by precipitation from bismuth-containing nitrate solutions by adding tartaric acid with a molar ratio of tartrate ions to Bi(III) of at least 2, H^+ concentration of $0.4\text{--}0.5\text{ mol/l}$, and reaction temperature $(22 \pm 3)^\circ\text{C}$ [23]. Bismuth precipitation by sodium tartrate led to sodium-containing tartrates with pharmaceutical applications.

Bismuth phosphate was recommended for use as an active component of antiulcer drugs. Bismuth phosphate may be synthesized from the industrial nitrate solutions (440 g/l Bi , 120 g/l free HNO_3) by adding a bismuth-containing solution (0.2 l) to the solution (0.8 l) with a concentration of 0.56 M $(\text{NH}_4)_3\text{PO}_4$ and 1 M nitric acid at 60°C while stirring for 1 h, subsequently washing the precipitate two times with water at 60°C and drying it in air. According to the data of [24], the crystal structure of bismuth phosphate has a composition $\text{BiPO}_4 \cdot 0.67\text{H}_2\text{O}$; it has channels running parallel to the *c* axis and containing water molecules. The water molecules are directly coordinated to the bismuth atoms and stabilize the trigonal form. The trigonal modification of bismuth phosphate is considered to be metastable [24]. After having been kept for two months at ambient temperature, the trigonal form can spontaneously lose crystallization water, irreversibly transforming into bismuth phosphate of monazite structural type.

Bismuth oxochloride BiOCl is used in medicine as a filler in polymer production for manufacturing blood vessels, as a radiographic contrast medium, as a pearlescence agent in lipstick or nail varnish, eyeshade, and face powder. The crystal structure of BiOCl was

reported in [25]. In the crystal structure, each bismuth atom coordinates four oxygen and four chlorine atoms at distances of 2.316 and 3.059 Å, respectively, forming a decahedron. The decahedra, in turn, are linked through the O–Cl bond into infinite layers along the *a* and *b* axes.

The basic procedure for synthesizing bismuth oxochloride is dissolving bismuth oxide in hydrochloric acid. Subsequent dilution of the resulting solution with water to a volume 10 to 25 times larger than the initial volume leads to hydrolysis forming bismuth oxochloride according to the scheme



In industrial conditions, bismuth oxochloride is generally obtained by hydrolysis of a solution of bismuth nitrate in the presence of an alkali metal chloride. Studies on bismuth precipitation from chloride-containing solutions by adding an alkaline reagent or water showed [26] that the extent of bismuth precipitation is strongly dependent on pH of the solution and on the reaction temperature, but is virtually independent of the nature of the alkali reagent. At pH ranging from 0 to 3 bismuth is precipitated in the form of oxochloride BiOCl. Electron micrographs of the hydrolysis products indicated that bismuth oxochloride obtained at $(25 \pm 5)^\circ\text{C}$ by adding alkali reagents or water to a hydrochloric solution has an aggregate structure. Aggregates of micron-sized microcrystals have a planar prismatic form with poor morphology. If bismuth oxochloride is precipitated at an elevated temperature $(90 \pm 5)^\circ\text{C}$ by adding water to a bismuth-containing solution, the product is represented by aggregates of platelike crystals with a milky pearl luster sized $\sim 2\ \mu\text{m}$ in the basal plane and $\sim 0.2\ \mu\text{m}$ thick. When the order of addition is reversed (the bismuth-containing solution is added to water), the product is represented by aggregates of thin-plate crystals with a metallic luster sized 20–100 μm in the basal plane and 0.1–0.3 μm thick.

When bismuth oxocarbonate, oxochloride, oxogallate, citrate, and tartrate are precipitated from the nitrate solutions, impurity metals such as lead and silver are coprecipitated [19, 20, 26–29] together with

bismuth. That is why synthesis of high purity compounds needs the use of a high purity metal or preliminary purification of bismuth from contaminants.

SYNTHESIS OF BISMUTH (III) COMPOUNDS USING SOLID – SOLUTION REACTIONS

Hydrolytic treatment of bismuth-containing nitrate solutions allows effective purification of bismuth from major impurity metals in the course of bismuth precipitation in the form of oxohydroxonitrate $[\text{Bi}_6\text{O}_5(\text{OH}_3)](\text{NO}_3)_5 \cdot 3\text{H}_2\text{O}$. This makes it possible to use solid – solution reactions in synthesis of high purity bismuth compounds for medical purposes.

Bismuth (III) nitrate pentahydrate $\text{Bi}(\text{NO}_3)_3 \cdot 5\text{H}_2\text{O}$ is used in medicine for the production of bismuth-containing pharmaceuticals. Synthesis of this substance involves evaporation of nitrate solutions [5, 6], leading to atmospheric release of nitrogen oxides in large quantities. Data on reactions of bismuth oxohydroxonitrate (BOHN) $[\text{Bi}_6\text{O}_4(\text{OH})_4](\text{NO}_3)_6 \cdot \text{H}_2\text{O}$ with nitric acid solutions of varying concentrations indicate [27] that reactions with relatively dilute (0.1–2 mol/l) solutions (reaction temperature 20–25 $^\circ\text{C}$) lead to the product $[\text{Bi}_6\text{O}_4(\text{OH})_4](\text{NO}_3)_6 \cdot 4\text{H}_2\text{O}$ of the partial conversion of BOHN. Reactions with highly concentrated (4–7 mol/l) solutions yield $[\text{Bi}_6(\text{H}_2\text{O})(\text{NO}_3)_4(\text{OH})_4](\text{NO}_3)_5$. When the concentration of nitric acid is increased further (≥ 9.0 mol/l), bismuth (III) nitrate pentahydrate $\text{Bi}(\text{NO}_3)_3 \cdot 5\text{H}_2\text{O}$ is formed. Thus bismuth (III) nitrate pentahydrate, which is useful in syntheses of inorganic and organic bismuth compounds, may be prepared by treatment of BOHN with a nitric acid solution with a concentration of ≥ 1.7 mol/l pure acid avoiding the stage of evaporation of bismuth-containing nitrate solutions. The reaction is exothermic, due to which the starting BOHN is completely converted to $\text{Bi}(\text{NO}_3)_3 \cdot 5\text{H}_2\text{O}$. The final reaction temperature should be $\leq 25^\circ\text{C}$. At a temperature of $>25^\circ\text{C}$ bismuth precipitation is no more than 80 %. Thus synthesis of bismuth (III) nitrate pentahydrate from metallic bismuth involving preliminary oxidation of the latter to oxide, further hydrolytic purification of Bi, and

conversion of basic bismuth (III) nitrate obtained as a result of purification to the final product avoids atmospheric release of toxic nitrogen oxides at the stage of the preparation of a bismuth-containing solution. This procedure also avoids evaporation of the bismuth-containing nitric acid solution, also liberating nitrogen oxides.

Studies on the interaction of bismuth oxohydroxynitrate with ammonium carbonate and bicarbonate solutions indicated [28] that pH of the pulp increases with the concentration of ammonium carbonate in the system; accordingly, the nitrate ion to bismuth ratio in the precipitate decreases, while the carbonate ion to bismuth ratio increases; *i.e.*, nitrate ions are replaced by carbonate. When bismuth oxohydroxynitrate $[\text{Bi}_6\text{O}_5(\text{OH})_3](\text{NO}_3)_5 \cdot 3\text{H}_2\text{O}$ reacts with ammonium carbonate solutions at $\text{pH} \geq 8.0$, the nitrate ions are substituted by carbonate, forming bismuth oxocarbonate $(\text{BiO})_2\text{CO}_3$. Conversion of BOHN to oxocarbonate starts already at $\text{pH} \geq 2.0$ and occurs without preliminary hydrolysis in contrast to reactions with aqueous ammonia, forming oxohydroxynitrates with a lower nitrate ion to bismuth ratio, and without the stage of hydroxide formation.

It is also recommended to synthesize high purity bismuth(III) oxogallate monohydrate $\text{C}_2\text{H}_2(\text{OH})_3\text{COOBiO} \cdot \text{H}_2\text{O}$ and bismuth (III) tartratohydrotartrate trihydrate $[\text{Bi}(\text{C}_4\text{H}_4\text{O}_6)(\text{C}_4\text{H}_5\text{O}_6)] \cdot 3\text{H}_2\text{O}$ by a reaction of solid oxohydroxynitrate with gallic or tartaric acid solutions. In the case of gallic acid solutions, synthesis of basic bismuth gallate at 60°C requires that the mixture should be stirred for at least 18 h. As the reaction temperature increases to 90°C , the stirring time is reduced to 4 h. The gallate ion to bismuth ratio in the precipitate is 1.0, and the nitrate ion to bismuth ratio is up to 0.02; the acid and bismuth concentration in the solution is 0.36 mol/l and 0.012 g/l, respectively.

It was shown [29] that highly pure bismuth (III) tartratohydrotartrate trihydrate may be obtained by treatment of bismuth (III) oxohydroxynitrate trihydrate with a tartaric acid solution at a reaction temperature of $(20 \pm 3)^\circ\text{C}$, molar ratio of tartrate ions to bismuth of 2.1, and hydrogen ion concentration of 0.2–0.6 mol/l.

A synthetic procedure has been developed to prepare bismuth-potassium-ammonium

citrate (“viskalcitrate”) – a substance for home production of highly effective antiulcer drugs such as de-nol, tribimol, and pylorid. The technique involves synthesis of pharmacopoeial basic bismuth nitrate, its conversion to citrate by treating it with a citric acid solution, further dilution of bismuth citrate in aqueous potassium hydroxide in the presence of citric acid and ammonia, dilution with water, and spray drying or crystallization [30]. In this process, nitric acid consumption is reduced by a factor of two, and atmospheric release of toxic nitrogen oxides is eliminated. Bismuth is effectively purified from impurity metals by its precipitation in the form of oxohydroxynitrate $[\text{Bi}_6\text{O}_5(\text{OH})_3](\text{NO}_3)_5 \cdot 3\text{H}_2\text{O}$, and a highly reactive product is obtained. Moreover, one can avoid the use of ethanol at the stage of drug pelletization.

CONCLUSIONS

1. Bismuth (III) nitrate solutions may be prepared by preliminary oxidation of metallic bismuth with atmospheric oxygen, which reduces the consumption of nitric acid by factor of two and eliminates atmospheric release of toxic nitrogen oxides.

2. Conditions for bismuth purification from impurity metals during precipitation from nitrate solutions have been determined. Pure final product is obtained in oxohydroxynitrate form $[\text{Bi}_6\text{O}_5(\text{OH})_3](\text{NO}_3)_5 \cdot 3\text{H}_2\text{O}$ by hydrolytic precipitation of bismuth from the given solutions by adding water or an ammonium carbonate solution at $\text{pH} 0.55\text{--}1.0$ and a temperature of at least 50°C .

3. In the course of precipitation of bismuth oxogallate, oxocarbonate, oxochloride, and tartrate from the industrial nitrate solutions, impurity metals such as lead and silver are coprecipitated together with bismuth (III). For synthesis of pure compounds, therefore, metallic bismuth of high purity should be taken, or bismuth should be preliminarily purified from contaminants by precipitation in oxohydroxynitrate form.

4. An attractive approach to synthesis of highly pure bismuth (III) compounds is interaction of solid bismuth oxohydroxynitrate with solutions of acids and alkali reagents,

which was demonstrated for neutral bismuth (III) nitrate, oxocarbonate, oxogallate, and tartrate.

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