Boron Volatilization and Its Isotope Fractionation during Evaporation of Boron Solution

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Evaporation experiments were undertaken to determine the volatility of parts-per-million concentrations of boron in water and dilute HCl in the presence and absence of equimolar mannitol and/or cesium. Multiple 10 mL aliquots prepared identically were evaporated to various extents or just to dryness and heated 10–20 min after reaching dryness under filtered air at 60 °C. Boron was only retained quantitatively in water during evaporation and after reaching dryness in the presence of equimolar mannitol and cesium. Boron was retained quantitatively in dilute HCl solution during evaporation, without mannitol or cesium. But it could be retained when the dilute HCl just reached dryness and thereafter only in the presence of equimolar mannitol. Isotopic measurements of the evaporating solutions and residues indicate that the heavier isotope, [11]B, is preferentially lost from the near-neutral and acidic solutions examined. The results are pertinent for procedures requiring preconcentration of boron.

Volatilization of boron from boron solution during evaporation was first noted many years ago.[1] It is a very serious problem for boron isotopic studies because sample solutions often must be partially evaporated in order to concentrate boron prior to mass spectrometric analysis. The volatilization of boron can be reduced by adding substances which form complexes with boric acid in acidic solution. Levi and Curti[2] observed that mannitol reduces the volatilization of boron from acidic solution during evaporation because of formation of a mannitol–boron complex. Since then, mannitol has been commonly adopted to suppress the volatilization of boron during evaporation of boron solution, especially in boron isotopic studies.

Ishikawa and Nakamura[3] investigated the volatilization and isotopic fractionation of boron during evaporation of hydrofluoric and hydrochloric acid solutions and concluded that the degree of volatilization and isotope fractionation decreased with increasing mannitol/boron mole ratio. The volatilization of boron was completely suppressed when the ratio was more than unity. The volatilization of boron in the presence of mannitol was also studied by Leeman et al.[4] They found that no significant boron loss or isotopic fractionation occurred during evaporation of aqueous boron solutions with mannitol/boron ratios exceeding 0.5, whereas an isotopic shift −2.4‰ and incomplete recovery were observed with a molar ratio of 0.2. Leeman et al.[4] suggested that samples evaporated with heat should be removed from the heat source promptly upon desiccation.

In an earlier study, Kuwada et al.[5] indicated that the addition of mannitol alone cannot prevent boron loss during solution evaporation. These investigators indicated that, when both mannitol and sodium acetate were added to a sample solution before evaporation, the loss of boron was very small and constant. Because of this apparent inconsistency and to test boron volatilization in dilute acid solution, a new study was deemed necessary. In the present study, a series of experiments was carried out to determine the efficacy of various combinations of mannitol and cesium carbonate in preventing boron volatilization and isotopic fractionation for neutral and acidic solutions during evaporation and after drying.

EXPERIMENTAL METHODS

Reagents and Standards. Low-boron water for the experiments was obtained by passing Millipore water through a column loaded with Amberlite IRA 743 boron-specific resin. The boron blank of the resulting water, determined by azomethine-H colorimetric method, was less than 0.6 ng of B/mL.

Concentrated HCl (instrument grade, 6 ppb B lot assay) was diluted to 2 M with low-boron water. A 1.82 wt % solution of mannitol was prepared using low-boron water. Next, 75.3 mg of Cs_2CO_3 (99.994% pure) was dissolved in 5 mL of low-boron water to form a solution containing 12.3 mg of Cs/mL. At these concentrations, the addition of 1 mL of the mannitol or Cs_2CO_3 solution to a solution containing 1 mg of boron results in a nearly equimolar proportion of boron and mannitol or cesium. Spectroscopic-grade graphite (obtained from the National Institute of Standards and Technology [NIST]) and 80% ethanol/20% water were mixed to give a 40 mg of graphite/g slurry. Working solutions were prepared by diluting concentrated (1 mg of B/g) normal and isotopic standard solutions made from reagent H_3BO_3 and NIST Standard Reference Material 951 boric acid.

Evaporation Apparatus and Procedures. Most evaporation experiments were carried out in a vacuum oven, through which filtered air was passed, at a temperature of 60 ± 0.5 °C. Using an electric air pump, air was forced at low pressure into the oven through four KOH-impregnated cellulose fiber filters in series and a 0.4 μm polycarbonate membrane. Solutions were prepared in polypropylene vials, each containing 20 or 48.2 μg of boron and

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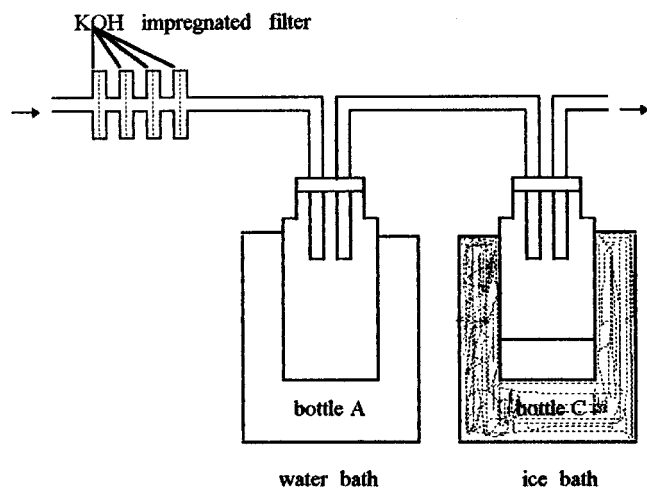
Figure 1. Schematic diagram of the experimental apparatus for the determination of the isotopic composition of volatilized and residual boron upon evaporation to dryness of aqueous boron solution and dilute HCl solution containing boron.

some combination of HCl, mannitol, and/or cesium carbonate. The vials were evaporated in the oven and immediately removed when the volume of solution was reduced to desired volume or dryness. When the solution or dry residue was cool, the concentration of boron was measured by the azomethine-H colorimetric method. Sample solutions which were intentionally evaporated without mannitol and cesium carbonate had these chemicals added in equimolar proportion to the measured boron content prior to filament loading for mass spectrometric analysis.

Another evaporation experiment, using the apparatus shown in Figure 1, was carried out to determine the concentration and isotopic composition of boron in both the residual solution or dry residue and extracted vapor. Air was forced through four KOH-impregnated Whatman No. 41 filters into bottle A, which contained 30 mL of boron solution. Bottle A was placed in a water bath with a constant temperature of 60 ± 0.5 °C. Solutions containing about 50 μg of boron without or with 10 mL of 2 M HCl were evaporated to dryness. The vapor from bottle A was condensed in bottle C, which was situated in ice. Bottle C initially contained 10 mL of water to which mannitol had been added in equimolar proportion to the expected boron collection amount to prevent secondary volatilization of boron. For runs evaporated to dryness, 1 mL of low-boron water was added to bottle A after evaporation to dissolve any dry residue. Small fractions of the resulting solution in bottle A and the condensate in bottle C were used for measurement of boron content. The remainder was evaporated, in the presence of equimolar mannitol and cesium carbonate, to reduce the volume of solution until a boron concentration of about 1 mg/mL was reached. The solution was then subjected to mass spectrometric analysis.

Measurement Procedures. Boron concentrations were measured using the azomethine-H spectrophotometric method described by Kiss,[6] with slight modification. One milliliter of boron-containing sample solution, 2 mL of buffer solution (containing 250 g of ammonium acetate, 15 g of EDTA, and 125 mL of glacial acetic acid [instrument grade, 1 ppb B lot assay], diluted to 400 mL), and 2 mL of azomethine-H solution (containing 0.45 g of azomethine-H and 1 g of ascorbic acid dissolved in 100 mL

of water) were sequentially added into a quartz cuvette. After thorough mixing, the solution was allowed to stand for 30 min. The absorbance of the boron−azomethine-H complex at 420 nm was measured using a Turner 330 spectrophotometer and calibrated with standards. The external precision (2σ) of the azomethine-H method used here was determined to be 2%.

A 30 cm radius, 90° sector NBS design mass spectrometer was used for boron isotope analysis. The procedure for isotope analysis used was the same as that reported by Xiao et al.[7] For mass spectrometry, the samples were loaded on single outgassed tantalum filaments. First, 3 μL of graphite slurry was spread across the whole top of the filament. Next, approximately 1 μg of sample boron solution containing equimolar mannitol and cesium (as Cs_2CO_3) was loaded. The solution was dried by heating the filament at 1.2 A current for 5 min. The internal precisions of the boron isotope analyses for all samples and NIST SRM 951 were better than 0.2‰ (2σ). The isotopic composition of boron in samples is expressed as a permil deviation relative to NIST SRM 951 boric acid standard:

$$\delta^{11}B \ (‰) = [[(^{11}B/^{10}B)_{sample}/(^{11}B/^{10}B)_{SRM\ 951}] - 1] \times 1000$$

The isotopic fractionation factor (α) was calculated as follows:

$$\alpha = (^{11}B/^{10}B)_{vapor}/(^{11}B/^{10}B)_{residue}$$

RESULTS AND DISCUSSION

Volatility of Boron in Near-Neutral, Acidic, and Alkaline Solutions in the Presence and Absence of Mannitol. Retention of boron in partially evaporated and evaporated solutions containing various combinations of dilute HCl, Cs_2CO_3, and mannitol is listed in Table 1 and plotted against the residual evaporated solution weights in Figure 2. It was considered especially important to determine the volatility of boron in evaporating 0.1 M HCl solution because of the utility of this solution for eluting boron from Amberlite IRA 743 boron-specific resin.[8] The following points are evident from the table and figure.

(1) The loss of boron was negligible (complete recovery within the precision of the measurement) when the residual weight of solution was at least 0.31 g for water, 0.007 g in the presence of equimolar cesium, and 0.005 g for 0.1 M HCl solution. In the presence of equimolar mannitol, the loss of boron was negligible for water when the residual solution weight was at least 0.075 g and was negligible for the solution with Cs_2CO_3 and 0.1 M HCl solution, even when evaporated to dryness (Figures 2 and 3).

(2) In the absence of mannitol, the retention of boron in water evaporated to small volume was lower than that in 0.1 M HCl and Cs_2CO_3 solutions (Figure 2A,C,E). Significant loss of boron from the latter solutions was observed only when they were evaporated to dryness (Figure 3).

(3) The positive effect of mannitol on the retention of boron in all three types of solutions is most evident in the solutions evaporated to small weight or to dryness (Figures 2 and 3, Table 1). Cesium by itself showed a similar ability to retain boron (Figure 3B), though it was not quite as effective as mannitol. Since

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Table 1. Retention of Boron during Evaporation

	solution (g)		added boron (μg)	added mannitol[a] (μL)	added Cs$_2$CO$_3$[b] (μL)	added HCl[c] (mL)	recovered boron μg	recovered boron %
no.	initial	final						
1–1	10.3	1.49	20.06	0	0	0	20.2	101
1–2	10.0	0.97	20.01	0	0	0	20.7	103
1–3	10.1	0.49	20.10	0	0	0	19.9	99.0
1–4	10.1	0.31	20.03	0	0	0	19.8	98.9
1–5	10.2	0.060	19.93	0	0	0	18.4	92.3
1–6	10.2	0.053	20.08	0	0	0	18.7	93.1
1–7	10.2	0.043	19.99	0	0	0	19.3	96.5
1–8	10.3	0.024	20.10	0	0	0	19.2	95.5
1–9	10.1	0.007	19.93	0	0	0	14.9	74.8
1–10	10.0	0.005	20.06	0	0	0	14.2	70.8
1–11	10.2	just dry	19.54	0	0	0	12.5	64.0
1–12	10.2	dry for 10 min	19.57	0	0	0	10.7	54.7
1–13	10.0	dry for 20 min	19.56	0	0	0	14.8	75.7
2–1	10.3	1.45	20.05	20	0	0	20.6	103
2–2	10.2	0.96	19.86	20	0	0	19.9	100
2–3	10.2	0.48	19.86	20	0	0	19.6	98.7
2–4	10.2	0.24	19.91	20	0	0	19.5	97.9
2–5	10.3	0.075	19.90	20	0	0	19.6	98.5
2–6	10.0	0.059	19.90	20	0	0	19.1	96.0
2–7	10.0	0.052	19.94	20	0	0	18.8	94.3
2–8	10.2	0.018	19.91	20	0	0	17.8	89.4
2–9	10.4	0.004	19.93	20	0	0	18.8	94.3
2–10	10.3	0.001	19.80	20	0	0	18.8	94.9
2–11	10.1	just dry	19.25	20	0	0	17.7	91.9
2–12	10.3	dry for 10 min	19.25	20	0	0	16.9	87.8
2–13	10.2	dry for 20 min	19.24	20	0	0	18.4	95.6
3–1	9.9	1.58	19.06	0	30	0	19.0	99.7
3–2	9.9	0.95	19.12	0	30	0	19.3	101
3–3	10.2	0.50	19.16	0	30	0	18.7	97.6
3–4	10.1	0.29	19.03	0	30	0	19.6	103
3–5	10.4	0.084	19.03	0	30	0	18.9	99.3
3–6	10.6	0.055	19.02	0	30	0	19.0	99.9
3–7	10.7	0.028	19.03	0	30	0	19.0	99.8
3–8	10.6	0.012	19.00	0	30	0	18.9	99.5
3–9	10.3	0.007	19.04	0	30	0	18.8	98.7
3–10	10.3	0.003	19.07	0	30	0	18.5	97.0
3–11	10.1	just dry	19.46	0	30	0	17.9	92.0
3–12	10.4	dry for 10 min	19.50	0	30	0	18.6	95.4
3–13	10.5	dry for 10 min	19.48	0	30	0	18.4	94.5
4–1	10.4	1.47	19.25	0	0	9.0	19.8	103
4–2	10.3	0.95	19.30	0	0	9.0	19.7	102
4–3	10.5	0.48	19.20	0	0	9.0	19.4	101
4–4	10.4	0.099	19.24	0	0	9.0	19.4	101
4–5	10.0	0.074	19.16	0	0	9.0	18.8	98.1
4–6	10.1	0.056	19.18	0	0	9.0	19.3	101
4–7	10.1	0.029	19.14	0	0	9.0	18.9	98.7
4–8	10.2	0.006	19.12	0	0	9.0	19.5	102
4–9	10.3	0.005	19.16	0	0	9.0	18.9	98.6
4–10	10.4	just dry	19.28	0	0	9.0	17.5	90.8
4–11	9.9	dry for 10 min	19.35	0	0	9.0	12.4	64.1
4–12	10.1	dry for 10 min	19.43	0	0	9.0	13.4	69.0
5–1	10.3	1.49	19.04	20	30	0	19.1	100
5–2	10.3	0.98	19.06	20	30	0	18.8	98.6
5–3	10.3	0.42	19.02	20	30	0	19.3	101
5–4	10.6	0.24	19.00	20	30	0	19.5	103
5–5	10.3	0.071	19.01	20	30	0	19.0	99.9
5–6	10.3	0.047	19.01	20	30	0	19.4	102
5–7	10.3	0.035	18.97	20	30	0	19.3	102
5–8	10.2	0.009	18.95	20	30	0	18.8	99.2
5–9	9.9	just dry	20.30	20	30	0	19.6	96.6
5–10	10.3	dry for 10 min	20.26	20	30	0	20.0	98.7
5–11	10.1	dry for 20 min	20.32	20	30	0	20.0	98.4
6–1	10.4	1.48	20.54	20	0	9.0	20.5	99.8
6–2	10.4	0.98	20.04	20	0	9.0	19.6	97.8
6–3	10.0	0.49	20.44	20	0	9.0	20.1	98.3
6–4	10.4	0.30	20.38	20	0	9.0	20.3	99.6
6–5	10.4	0.11	20.04	20	0	9.0	19.9	99.3
6–6	10.5	0.053	20.48	20	0	9.0	19.8	96.7
6–7	10.4	0.030	20.42	20	0	9.0	20.1	98.4
6–8	10.5	0.010	20.50	20	0	9.0	20.1	98.0
6–9	10.1	0.006	20.47	20	0	9.0	19.7	96.2
6–10	10.0	just dry	19.24	20	0	9.0	19.2	99.8
6–11	10.4	dry for 10 min	19.29	20	0	9.0	19.5	101
6–12	10.4	dry for 20 min	19.29	20	0	9.0	19.6	102

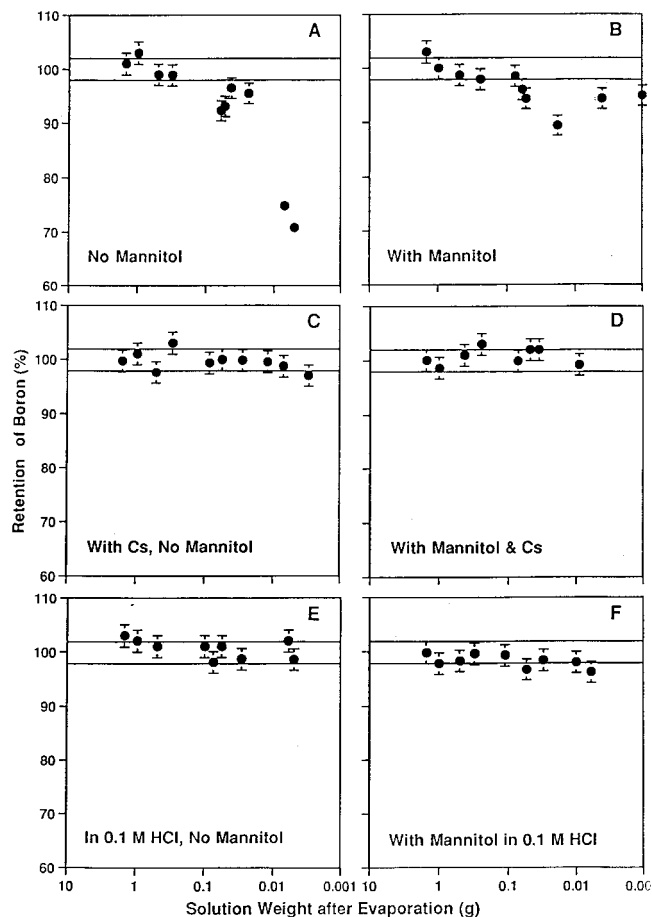[a] 1.82% mannitol solution. [b] 12.3 mg/mL Cs$_2$CO$_3$ solution. [c] 0.1 M HCl solution.

Figure 2. Comparison of the retention of boron in evaporating water, aqueous Cs$_2$CO$_3$, and 0.1 M HCl solutions in the absence and presence of equimolar mannitol. The uncertainty brackets at each data point reflect the 2σ external precision of the concentration measurement. Horizontal lines at 98 and 102% give the $\pm 2\sigma$ range for full retention of boron.

the presence of cesium on the filament is necessary for the isotopic measurement of boron using the Cs$_2$BO$_2^+$ method, the experimental observations listed above suggest that it is advantageous to add both mannitol and Cs$_2$CO$_3$ to near-neutral to acidic solutions before concentration by evaporation. The mechanisms of boron retention in solution with mannitol and in alkaline solution have been discussed by Ishikawa and Nakamura[3] and Cogbill and Yoe.[9]

The data of Feldman[1] indicated that boron in acidic solution was more easily volatilized during evaporation to dryness than in neutral solution and that substantial boron loss occurs from HCl solution even early in the evaporation. Ishikawa and Nakamura[3] suggested that boron in acidic solution was more easily volatilized during evaporation to dryness than in neutral or alkaline solutions. The results of the present study indicate that boron is lost more easily from neutral solution than from dilute acid or base solution. This apparent contradiction is probably due to the different HCl concentrations used. Solutions of 33% and 6 M HCl were used by Feldman[1] and Ishikawa and Nakamura,[3] respectively. Boron in concentrated hydrochloric acid may be lost as gaseous boron chloride, but boron in dilute hydrochloric acid (0.1 M) may not produce a significant quantity of gaseous boron chloride.

Isotopic Shift of Residual Boron during Evaporation of Boron-Bearing Solution. The isotopic compositions of boron

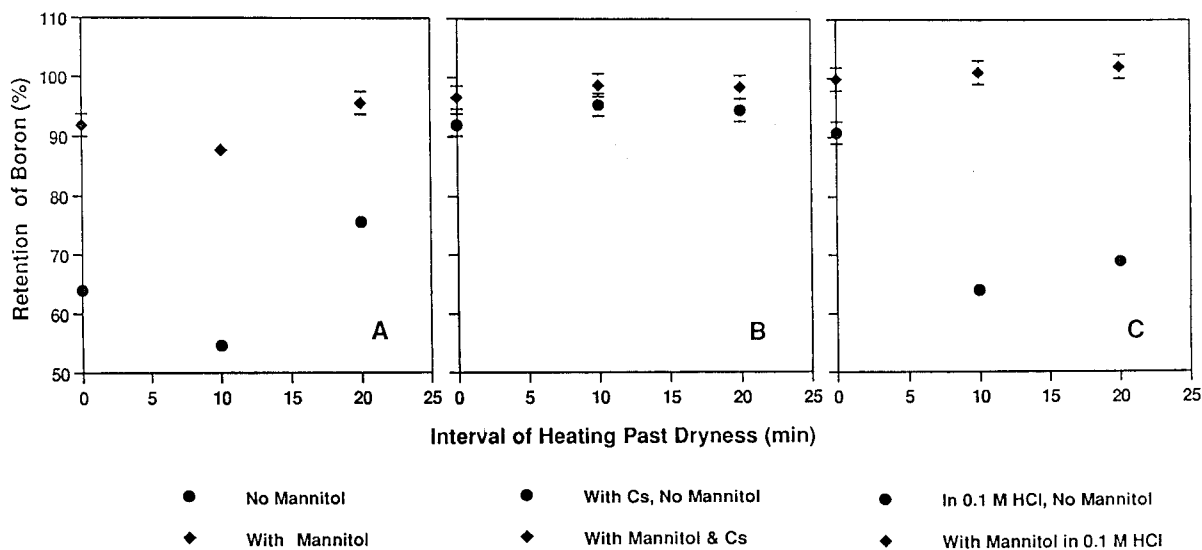(9) Cogbill, E. C.; Yoe, J. H. *Anal. Chem.* **1957**, *29*, 1251–1258.

Figure 3. Comparison of the retention of boron in residues left heated beyond dryness. Evaporated solutions are described in the caption of Figure 2.

Table 2. Isotopic Shifts of Boron in Residue during Evaporation of Boron Solution Containing 48.2 μg of Boron

water	added, mL Cs₂CO₃ (12.3/mL Cs)	added, mL HCl (0.1 M)	added, mL mannitol (1.82%)	pH	residue volume (μL)	isotopic shift of B (‰) (2σ)
10	0	0	0	6.33	50	−1.29 (8)
10	0	0	0	6.33	0	−1.89 (5)
10	0.048	0	0	8.87	50	−0.44 (10)
10	0.048	0	0	8.87	0	−1.21 (9)
0	0	10	0	1.0	0	−0.37 (19)
10	0	0	0.048	6.05	50	−0.21 (7)
10	0	0	0.048	6.05	0	0.07 (11)
10	0.048	0	0.048	8.49	50	−0.12 (15)
10	0.048	0	0.048	8.49	0	−0.32 (13)
0	0	10	0.048	1.0	0	−0.32 (11)
0	0	10	0.048	1.0	0	−0.38 (9)

Figure 4. Isotopic shifts of the residual boron upon evaporation to 50 μL and dryness of various solutions in the presence and absence of equimolar mannitol.

in residues obtained by evaporation of solution containing NIST SRM 951 boric acid are shown in Table 2 and plotted in Figure 4. These data indicate an enrichment of ^{10}B in the residue in all cases. In the absence of mannitol, the largest isotopic shifts (−1.3 and −1.9‰) were observed when boron-bearing water was evaporated, whereas a smaller isotopic shift (−0.4‰) was observed when HCl solution containing boron was evaporated to dryness.

These results are consistent with the observations about boron volatilization described above. In the absence of mannitol, substantial losses of boron occurred from water solution, whereas volatilization of boron was slight from acid solution.

In the presence of mannitol, isotopic shifts (−0.2 and 0.1‰) during evaporation of boron-bearing water were at or within the 2σ internal precision of the isotopic measurement. When compared to the larger shifts in the absence of mannitol, these negligible shifts suggest that the presence of mannitol effectively reduces the isotopic shift of boron. In the presence of mannitol, small isotopic shifts (−0.3 and −0.4‰) can be observed during evaporation to dryness of boron-bearing 0.1 M HCl solution. These shifts are the same as those that occurred with the evaporation of boron-bearing 0.1 M HCl solution in the absence of mannitol.

In the absence of mannitol, the shifts are smaller from evaporated dilute HCl solution than from plain water, apparently
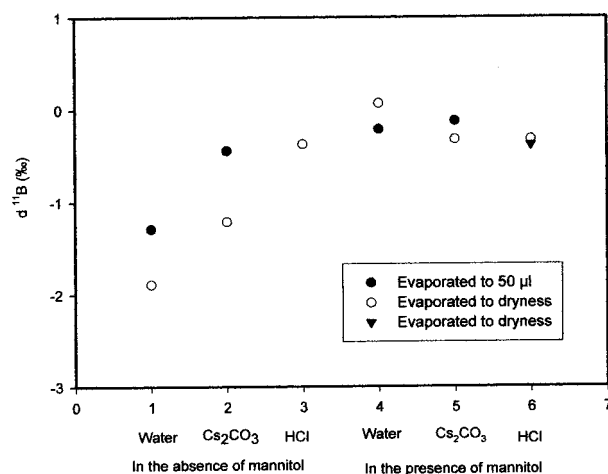
indicating that dilute HCl reduces the isotopic fractionation of boron. This result apparently conflicts with observations made by Ishikawa and Nakamura;[3] however, as noted above, their experiments were carried out using 6 M HCl solution. Boron is present as $B(OH)_3$ and $B(OH)_4^-$ dilute boron solution. The proportions of $B(OH)_3$ and $B(OH)_4^-$ are controlled by the pH of the solution. The fraction of $B(OH)_3$ in boron solution of pH 1 is nearly 100%. No isotopic fractionation of boron should occur during evaporation of boron solution with pH 1 if boron is volatilized only as $B(OH)_3$.

The results in Table 2 show that the presence of Cs_2CO_3 in solution also effectively reduces the isotopic shift of boron during evaporation if the solution is not evaporated to dryness. The isotopic shifts (−0.1 and −0.3‰) of boron in the residue after evaporation of Cs_2CO_3 and mannitol-containing solution to 50 μL or dryness are lower than those (−0.4 and −1.2‰) for solutions containing Cs_2CO_3 alone. The effect was most pronounced when solution was evaporated to dryness. Although boron loss was less than 5%, an isotopic fractionation of −1.2‰ was observed when the solution containing Cs_2CO_3 without mannitol was evaporated to dryness.

Table 3. Isotopic Fractionation of Boron between the Residue and Vapor during Evaporation of SRM 951 Boron Solution Containing 48.2 μg of Boron to Dryness

added				boron concent		δ [11]B (‰) (2σ)		
boron (μg)	water (mL)	HCl, 2 M (mL)	acidity of solution	residue (μg)	vapor (μg)	residue	vapor	α^a
51.9	10	0	pH 6.33	48.9	4.4	−1.48 (8)	4.87 (10)	1.0064
48.4	0	10	2 M HCl	39.9	7.0	−2.21 (15)	1.83 (16)	1.0040

^{a} Isotopic fractionation factor defined as $(^{11}B/^{10}B)_{vap}/(^{11}B/^{10}B)_{res}$.

Isotopic Fractionation of Boron between Residue and Vapor during Evaporation of Boron Solution. The isotopic compositions of boron in residue and vapor collected during evaporation of solution containing NIST SRM 951 are shown in Table 3. The data show an enrichment of [11]B in the vapor. This result (and data in Table 2) is consistent with the observations of Leeman et al.[4] and Ishikawa and Nakamura[3] that acidic solution evaporation residues lacking full retention of boron are depleted in [11]B. The isotopic fractionation of boron between residue and vapor (Table 3) is evidently related to the chemical composition of the boron solution. The isotopic fractionation of boron during evaporation of boron-bearing water is larger than that during evaporation of boron-bearing 2 M HCl solution. This may be due to different mechanisms of isotopic fractionation.

The isotopic fractionation of boron between residue and vapor during evaporation of aqueous boron solution might be controlled by the relative abundance of trigonally and tetrahedrally coordinated boron in each phase. Kakihana et al.[10] predicted an equilibrium isotopic fractionation of 1.0177 at 60 °C between trigonal and tetrahedral boron species in aqueous solution. The measured isotopic fractionation between solution and vapor of 1.0064 is much smaller than that predicted for the aqueous species. For equilibrium fractionation, this would imply that the proportions of three- to four-coordinated boron sites in solution and vapor are different. As stated earlier, the proportion of $B(OH)_3$ to $B(OH)_4^-$ in a dilute aqueous solution of boron is a function of pH. In the present evaporation experiments, the pH of the solutions changed with extent of evaporation, resulting in a shift of the fractions of $B(OH)_3$ and $B(OH)_4^-$ in solution. Consequently, the isotopic composition of boron in vapor could not be accurately calculated on the basis of the equilibrium isotopic fractionation of boron between aqueous $B(OH)_3$ and $B(OH)_4^-$.

The calculated isotopic fractionation of boron between residue and vapor during evaporation of 3 M HF solution was reported by Ishikawa and Nakamura[3] to be 1.011. These authors concluded that the fractionation was controlled by a Rayleigh-type distillation. In the present study, boron in 2 M HCl solution may have been volatilized as BCl_3. As described by Ishikawa and Nakamura,[3]

Rayleigh isotopic distillation can be expressed as follows:

$$\ln R = (\alpha - 1) \ln f + \ln R_0$$

where R_0 and R are the [11]B/[10]B ratios in the initial solution and the final residue, α is the kinetic isotopic separation coefficient, and f is the remaining boron. In the present study, $R_0 = 4.0582$, $R = 4.0492$, and $f = 0.824$. The isotopic fractionation of boron between the residue and vapor calculates as 1.011, which is exactly the same as that reported by Ishikawa and Nakamura[3] for HF solution. But the measured isotopic fractionation, 1.0040, is much smaller than the calculated isotopic fractionation. This suggests that a more complex fractionation process may have affected the vapor isotopic ratio. Perhaps vapor boron was only partially collected in the condenser, or secondary evaporation occurred from the condenser. An experimental study on evaporation of seawater[11] shows that a small quantity of boron would be lost after the cold condenser.

CONCLUSIONS

The volatilization of boron during evaporation of boron-bearing water, acid solution, and alkaline solution was observed. The results show that the presence of equimolar mannitol can reduce but not completely suppress the volatilization of boron. A significant negative shift of the residual boron isotopic composition was observed in this study when mannitol was not present in neutral solution. In the absence of mannitol, no significant isotopic fractionation of boron was observed during evaporation of boron-bearing dilute HCl solution to dryness, though boron loss was obvious. An opposite effect was observed for evaporation of boron-bearing alkaline solution. In the presence of mannitol, the isotopic fractionation of boron is negligible (within the precision of the isotopic measurement) during evaporation of boron-bearing water, but small negative isotopic shifts were observed during evaporation of boron-bearing dilute HCl and alkaline solution. Based on the results from the present study, the optimum procedure for retention of boron during evaporative concentration (at 60 °C) of the acid solutions eluted from boron-specific resin is the addition of equimolar mannitol and cesium.

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