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Abstract

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On the Possibility of Separating Boron Isotopes by Chemical Exchange

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Separation of isotopes by means of isotope-exchange reactions (the method of chemical exchange) is perhaps the most effective method for separating isotopes of light elements; it has already led to the deep separation of appreciable quantities of the isotopes of hydrogen, oxygen, nitrogen, carbon, and sulfur ([1–3]). The present communication describes the separation of boron isotopes by chemical exchange.

We proposed the isotope-exchange reaction:

$$B^{10}F_3 + A \cdot B^{11}F_3 \rightleftarrows B^{11}F_3 + A \cdot B^{10}F_3, \tag{1}$$

where A is anisole $C_6H_5OCH_3$, and $A \cdot BF_3$ is the liquid complex compound (complex) of anisole with boron fluoride. We note that this complex decomposes quantitatively according to the reaction ([4]):

$$A \cdot BF_3 \underset{\sim 20^\circ}{\overset{\sim 100\text{–}150^\circ}{\rightleftarrows}} A + BF_3. \tag{2}$$

Reaction (1) may be suitable for the separation of boron isotopes if its equilibrium constant α differs from unity. The question of the existence of reaction (1) and of the magnitude of its equilibrium constant was resolved by us experimentally, by means of a "stepwise" experiment, as follows ([5,14]). A portion of the anisole–boron fluoride complex was divided in half, and the boron fluoride released by heating from one half of the complex was passed very slowly, in the form of small bubbles (with the aid of a glass filter), through the second half of the complex (the first step of the experiment). Then this second half was in turn divided in half, and again the boron fluoride released from one half of the complex was passed through its other half (the second step of the experiment), and so on. The experiment consisted of 9 such steps. The isotopic composition, i.e., the ratio $(B^{10}/B^{11})_{\text{final}}$ for the boron fluoride released from the last portion of the complex, was determined mass-spectrometrically ([5,6]). According to our calculations, the boron-isotope separation coefficient obtained as a result of the "stepwise" experiment,

$$S = (B^{10}/B^{11})_{final}/(B^{10}/B^{11})_{initial},$$

under the condition that $|\alpha - 1| \leqslant 0.01^*$, is determined with quite sufficient accuracy by the expression $S = \alpha^{4.5}$.

In this way it was shown that isotope-exchange reaction (1) actually exists, that its equilibrium constant is $\alpha = 1.013 \pm 0.005$, and that the isotope B^{10} is concentrated in the anisole–boron fluoride complex, i.e., in the liquid phase. Reaction (1) is, apparently, the first isotope-exchange reaction described in the literature based on complex–

* Precisely this order of magnitude of $|\alpha - 1|$ is expected for the equilibrium constant of reaction (1).

formation, whose equilibrium constant differs markedly from unity.

In order to demonstrate the possibility of deep separation of boron isotopes by means of reaction (1), a countercurrent process (5, 14) was used, analogous to the well-known processes for the chemical separation of carbon and nitrogen isotopes (3). The scheme of the apparatus for carrying out the process is shown in Fig. 1. Here the solid arrows indicate the motion of the liquid complex $A{\cdot}BF_3$, and the dashed arrows the motion of gaseous BF_3. The complex from reservoir 1 flows downward through column 3, 205 cm long and with an internal diameter of 2.1 cm. The column is filled with Fenske-type glass rings; ring diameter 2.5 mm, thickness 0.7 mm. The complex flowing out of column 3 is decomposed partially in furnace 4 and completely in furnace 5. The liberated boron trifluoride rises through column 3 against the stream of complex and is absorbed by anisole in reservoir 2. The spent anisole from furnace 5 enters reservoir 6. The complex $A \cdot BF_3$, enriched in the isotope B^{10}, accumulates in the lower part of column 3; samples of the complex are periodically withdrawn, and the boron trifluoride liberated from them is analyzed on a mass spectrometer.

Fig. 1

In the apparatus described, four experiments were carried out with different rates v of feeding the complex into column 3. The results of experiment No. 2 ($v = 2$ ml/min) are presented in Table 1 and shown graphically in Fig. 2.

Fig. 2

It is seen from Table 1 that equilibrium separation of the isotopes is attained in 6–8 h. Taking $S = 1.22$ and $\alpha = 1.013$, we obtain that our column is equivalent to 15.5 theoretical plates, i.e., that the height equivalent to a theoretical plate is 13 cm.

Table 1

Results of experiment No. 2

Time t, hours	0	1	2	4	6.65	9.75	12	17
Separation coefficient S	1.000	1.123	1.123	1.199	1.220	1.216	1.216	1.220
Content of B^{10} in the sample, at.%	18.98	20.83	20.96	21.93	22.22	22.17	22.17	22.22

Analysis of the results of the operation of the countercurrent apparatus described shows that the method we have proposed for the separation of boron isotopes is fully suitable for industrial use. It undoubtedly surpasses other methods of boron isotope separation described in the literature: separation by means of a high-intensity mass spectrometer (7-9), by thermal diffusion of boron trifluoride (10, 13, 15). When it is necessary to obtain large quantities of boron trifluoride with a B^{10} content above 90%, our method also surpasses the method of separating boron isotopes by distillation of boron trifluoride (12).

This method can be applied not only with the use of the boron trifluoride-anisole complex, but also with other complex compounds of boron trifluoride.

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Note: Figure translations are in progress. See original paper for figures.