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EXPANDED BENCHTOP PROTOCOL FOR THE COLORMETRIC TITRATION OF BORON CHLORIDE AND BROMIDE

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Abstract

Expansion and modification upon previous uses of N,N-dimethylaniline (DMA) as a colorimetric titrant for boron tribromide now allows for the quantification of boron trichloride. This technique is now a general method for titration of BX_3 (X = Cl, Br). In CH_2Cl_2, the initial complex exhibits an increasingly blue color before reaching a sharp yellow endpoint upon addition of catalytic quantities of Lewis acid.

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Introduction

Boron trihalide (BX_3) reagents play an important role in organic synthesis.[1-5] Their strong Lewis acid character allows for diverse chemistry from the classic ether cleavage reaction (established in 1942) to more modern alkyne-activated annulations.[2,3,5] Like organolithiums and Grignard reactions, the use of BX_3 reagents requires precise knowledge of the concentration of the reagent. However, unlike organometallic reagents, where numerous titration methods are available, benchtop quantification protocols for BX_3 reagents are scarce (Figure 1).[6-8] Additionally, BX_3 reagents are commonly purchased as a solution and degrade rapidly to produce boric acid and HX. Therefore, a fast and reliable benchtop titration method is needed to ensure correct stoichiometric addition of Lewis acid to substrate.

Recently, we and others reported the first colorimetric protocol for titrating boron tribromide.[9] This methodology uses DMA, which in a CH_2Cl_2 solution is colorless. Upon addition of BBr_3 (1 equivalent) the solution turns blue indicating a 1:1 DMA-BBr_3 adduct. Upon addition of catalytic amounts of the Lewis acid, the solution reaches a yellow endpoint. While this approach works well for boron tribromide, it did not prove a reliable method for other boron-based Lewis acids, namely boron trichloride due to weak or unobservable color changes.

Yet, BCl_3 is well known for its C-O bond cleavage reactions, but recently is employed to activate alkynes towards electrophilic addition.[10-14] Additionally, BCl_3 is known to borylate arenes in the presence of catalytic quantities of $AlCl_3$.[15] The polarizability of the boron-chlorine bonds found in BCl_3 combined with its versatility as both a catalyst and source of chlorine in reactions explain the utility of this reagent.

Our interest in the boron trihalide class of reagents stems from developing a deeper understanding of ether cleavage as well as expanding the scope of annulation reactions to generate larger fused rings motifs.[2] Due to the continued and expanding interest in BX_3 (X = Cl, Br), we sought to expand our prior method for titrating boron tribromide. The modified technique increases the concentration of DMA, thus expanding this technique from quantifying only BBr_3 to now include BCl_3 solutions. Additionally, the modified protocol exhibits reliable and reproducible results across both reagents.

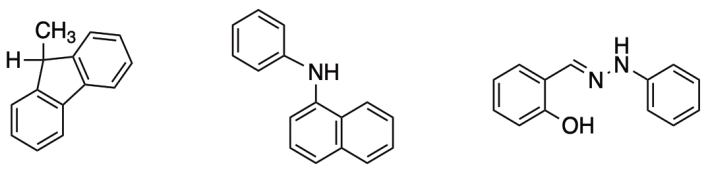


Figure 1: Commonly employed organometallic titrants.

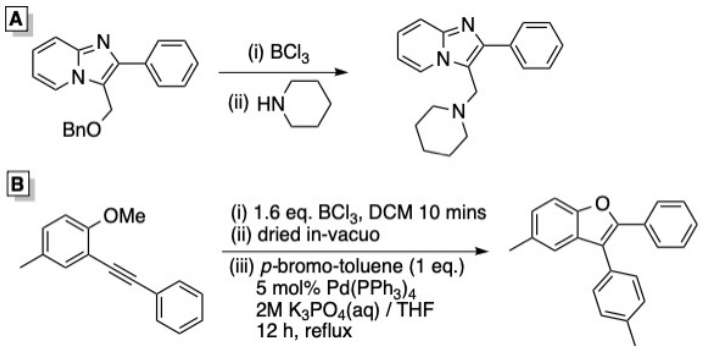
Experimental Methods

General Procedures

Boron trihalides are highly corrosive and should be handled under inert atmosphere. 1.0 M BCl_3 and BBr_3 in CH_2Cl_2 and N,N-dimethylaniline (≥99.5% purity) were purchased from Sigma-Aldrich. Anhydrous CH_2Cl_2 was obtained from a solvent system. Additional concentrations of BCl_3 and BBr_3 were prepared by adding the appropriate amount of 1.0 M solution by syringe to an oven-dried, septum-capped 10-mL volumetric flask under inert (nitrogen or argon) atmosphere, and diluting with anhydrous CH_2Cl_2.

Titration Protocol

An oven-dried reaction vessel charged with a magnetic stirbar was placed under an inert atmosphere. N,N-dimethylaniline (0.1 mL, 0.789 mmol) and anhydrous CH_2Cl_2 (0.5 mL) were added to the vessel. The BCl_3 solution was placed under inert atmosphere and drawn into a gastight syringe and was subsequently added dropwise to the reaction vessel. The color changed from clear to increasingly blue (or pink as noted in Table 1, entry 5) until reach-



Scheme 1: BCl_3 efficiently cleaves C-O bonds[11] and active alkynes toward electrophilic cyclization.[14]

ing a distinct yellow endpoint upon addition of one drop of BCl_3 solution (Figure 2). The volume of BCl_3 solution added was used to calculate the concentration of the solution, using a 1:1 molar ratio of N,N¬-dimethylaniline to BCl_3.

Results and Discussion

The titration is carried out at a concentration of 0.16 M DMA / CH_2Cl_2 solution (**1**) and the solution is placed under an inert atmosphere. Our initial trials focused on CH_2Cl_2 since this solvent in commonly used for C-O bond cleavage and annulation reactions. The addition of one equivalent of BCl_3 results in a blue solution due to the Lewis acid-base interaction (**2**). Upon addition of catalytic quantities of BCl_3, the solution quickly reaches a yellow endpoint presumably due to the loss of the BCl_3-DMA adduct and subsequent borylation of DMA's aromatic ring (**3**).[16]

The results of the titration methods are highlighted in Table 1. To test the limits of this methodology, several different concentrations of BCl_3 ranging from 0.1 M to 1.0 M were titrated (Table 1, entries 1-5). Each solution was run in triplicate to confirm consistency and reproducibility. Each trial performed saw an increasingly intense blue color as more BCl_3 was added, with the exception of 0.25 M, which turned pink, until a sharp yellow endpoint was reached with the addition of one drop of BCl_3 solution. The group is further exploring the seemingly concentration dependent pink color noted in the 0.25 M trial, although the variation in initial solution color did not impact the accuracy of the titration method or the fact that the addition of catalytic quantities of BCl_3 created a yellow solution. At too low of a concentration, demonstrated by Entry 5 of Table 1, the concentration of the BCl_3 solution could not be determined through visible color change, indicating there is a lower limit for the application of this protocol.

Titration of BCl_3 in heptane initially produced a cloudy pale blue solution before forming a thick white precipitate which prevented the appearance of the yellow endpoint. However, precipitation did not occur when a 1 M BCl_3 in m-xylenes was titration; rather this solution produced clear blue midpoints and a vibrant yellow endpoint.

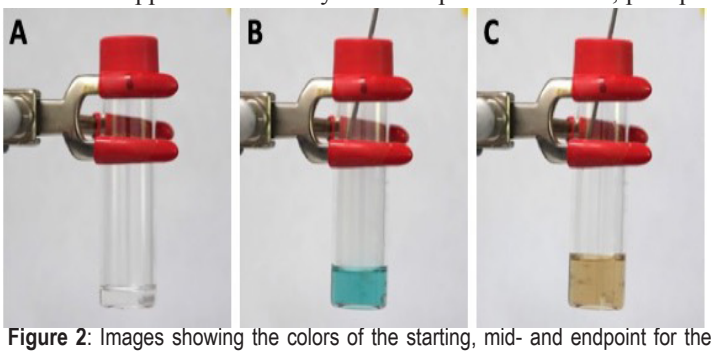
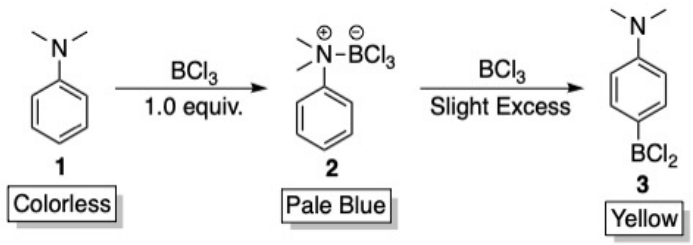


Figure 2: Images showing the colors of the starting, mid- and endpoint for the titration of BCl3.



Scheme 1: Progress of color changes as a function of BCl_3 addition. (see Figure 2 for images the starting, mid- and endpoints).

Furthermore, and not surprisingly, the increase in concentration of DMA, which allows for BCl_3 titration, does not affect quantification of BBr_3 as shown in Table 2. The original and modified procedure show good agreement in their observed molarity at the 1 M and 0.25 M concentrations. Unfortunately, however, the use of DMA as a titrant, does not allow for BF_3 etherate quantification regardless of the concentration of the titrant.

In summary, modification of a previously reported protocol that uses DMA as a titrant for BBr_3, now allows for quantification of BCl_3 solutions. This methodology is easily conducted from inexpensive commercially available materials and provides a clear color changes and defined endpoint.

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Table 1. Titrations of boron trichloride solutions.

Entry	Expected Molarity	Solvent	Number of trials	Observed Molarity
1	1 M	CH_2Cl_2	n = 3	0.98±0.02
2	0.66 M	CH_2Cl_2	n = 3	0.63±0.03
3	0.33 M	CH_2Cl_2	n = 3	0.32±0.01
4	0.25 M	CH_2Cl_2	n = 3	0.22±0.04
5	0.10 M	CH_2Cl_2	n = 2	N/A
6	1 M	heptane	n = 3	N/A
7	1 M	m-xylene	n = 4	0.97±0.02

Table 2. Titration of boron tribromide solutions

Entry	Expected Molarity	Concentration of DMA	Number of trials	Observed Molarity
1	1 M	0.53	n = 3	0.98±0.08
2	1 M	1.6 M	n = 3	1.0± 0.06
3	0.25 M	0.53	n = 3	0.24±0.05
4	0.25 M	1.6 M	n = 3	0.25±0.01

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