

Short Report

Hydrobromination of Alkenes with $\text{PBr}_3/\text{SiO}_2$: a Simple and Efficient Regiospecific Preparation of Alkyl Bromides

Antonio M. Sanseverino and Marcio C.S. de Mattos*

Departamento de Química Orgânica, Instituto de Química, Universidade Federal do Rio de Janeiro, CP 68545, 21945-970, Rio de Janeiro - RJ, Brazil

A reação de diversos alquenos com 0,4 equiv. mol de $\text{PBr}_3/\text{SiO}_2$ em diclorometano à temperatura ambiente forneceu os brometos de alquila com regiospecificidade Markovnikov em 50 - 100% de rendimento e tempos curtos de reação. O isopreno a - 8 °C nestas mesmas condições forneceu somente o 1-bromo-3-metil-2-buteno em 54%

The reaction of several alkenes with 0.4 mol equiv. $\text{PBr}_3/\text{SiO}_2$ in dichloromethane at room temperature gave the alkyl bromides with Markovnikov regiospecificity in 50 - 100% yield and short reaction time. Isoprene at - 8 °C in these conditions gave 1-bromo-3-methyl-2-butene only (54%).

Keywords: alkenes, bromides, electrophilic addition, regiospecificity, silica

Introduction

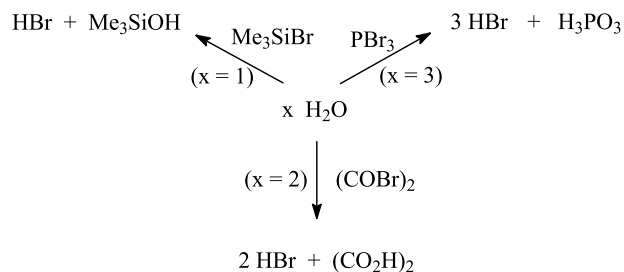
Surface mediated reactions are of great utility in organic synthesis, and in many cases the products are obtained in better yields and improved selectivities than in a homogeneous media in solution¹⁻³. The reagents or catalysts can be supported¹⁻³ or unsupported in these reactions⁴.

Organic halides are important compounds in organic synthesis, where functional group interconversions mediated by substitution reactions (radical or ionic) are of great utility⁵. HBr adds readily to most alkenes predominantly with Markovnikov regioselectivity^{6,7}. However, unless the substrate is rigorously purified (alkenes readily absorb oxygen from the air) and the reaction media is isolated from light and air to avoid formation of small amounts of peroxides, competing radical-chain addition to give the anti-Markovnikov products occurs⁸. As the generation and transfer of the hygroscopic gas HBr is inconvenient and difficult to perform stoichiometrically^{6,7}, alternate methodologies for performing hydrobromination of alkenes are of great interest.

Kropp and co-workers showed that oxalyl bromide or bromotrimethylsilane undergo hydrolysis on the surface of silica gel to generate HBr *in situ*⁷, which produces alkyl

or alkenyl bromides in high yields *via* highly Markovnikov additions to carbon-carbon double or triple bonds⁶. This methodology has the advantage of not requiring anhydrous conditions nor generation of toxic and corrosive gaseous HBr.

Surprisingly, although Kropp studied the reaction of $(\text{COBr})_2$ and $\text{Me}_3\text{SiBr}/\text{SiO}_2$ with 1-octene only⁷, no study was done with PBr_3 . This latter reagent is easily available and cheaper than the previous ones⁹ and also more efficient in terms of the stoichiometry of the reaction, as only one mol equiv. of PBr_3 would generate 3 mol equiv. of HBr in its reaction with water (Scheme 1). Furthermore, PBr_3 is more useful in terms of atom economy¹⁰ than $(\text{COBr})_2$ and Me_3SiBr .



Scheme 1.

In previous communications we showed that the hydrohalogenation of (*R*)-limonene with $\text{SOCl}_2/\text{SiO}_2$ ¹¹ and

* e-mail: mmattos@iq.ufrj.br

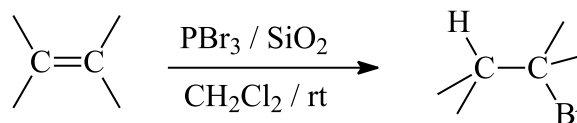
$\text{PBr}_3/\text{SiO}_2$ ¹² produces chemo- and regioselectively the respective α -terpinyl halides. Now we studied the scope of the hydrobromination of alkenes with $\text{PBr}_3/\text{SiO}_2$ and communicate our results.

Results and Discussion

The reaction of styrene (10 mmol) with PBr_3 (0.4 mol equiv.) was studied in the presence of SiO_2 (5 g) in CH_2Cl_2 in an open flask at room temperature (rt). The reaction led to a quantitative yield of 1-bromo-1-phenylethane, with purity greater than 99% (by HRGC- High Resolution Gas Chromatography) in only 20 min. A control experiment was also made in the absence of SiO_2 where 1 mol equiv. of water was added to the reaction media. The results indicate that the presence of SiO_2 is really important, as in its absence the reaction was not complete in the same reaction time (88%, crude yield).

Based on the above results we made a systematic study of the reaction of diverse alkenes and 0.4 mol equiv. of $\text{PBr}_3/\text{SiO}_2$ and the results are shown in Scheme 2 and Table. In all cases only the Markovnikov addition products were obtained and no trace of the regioisomeric anti-

Markovnikov bromides were detected using all analytical techniques (HRGC, ^1H and ^{13}C NMR). The alkyl bromides were obtained in 50 - 79% isolated yield (> 95 - 99% purity by HRGC) and were characterised by physical¹³ and spectroscopic data.



Scheme 2.

Interestingly, under similar conditions, isoprene at - 8 °C underwent exclusively 1,4-addition to afford the corresponding monobromide in 54% isolated yield and greater than 99% purity by HRGC. The reaction time was considerably shorter than the reported literature method, which takes 5 h or more to give the product¹⁴. Onemore, there is no need of anhydrous conditions nor generating dry gaseous HBr as reported¹⁴.

In summary, the reaction of alkenes with $\text{PBr}_3/\text{SiO}_2$ in CH_2Cl_2 is an easy and efficient way to prepare alkyl

Table. Alkyl bromides from the reaction of alkenes with $\text{PBr}_3/\text{SiO}_2$ in CH_2Cl_2 .

| alkene | alkyl bromide | t (min) | yield ^a (%) | bp (°C) (lit. bp ¹³) | selected analytical data |
|--------|---------------|-----------------|------------------------|----------------------------------|---|
| | | 60 ^b | 50 | 144 (144) | ¹ H NMR: δ 0.91 (t, <i>J</i> 6.60 Hz, 3H); 1.35-1.46 (m, 4H); 1.71 (d, <i>J</i> 6.68 Hz, 3H, $\text{CH}_3\text{-CH}_2\text{Br}$); 1.76-1.83 (m, 2H); 4.13 (m, <i>J</i> 6.68 Hz, 1H, CHBr) ppm. ¹³ C NMR: δ 14.1; 22.2; 26.6; 30.1; 41.0; 52.0 ppm. |
| | | 20 ^b | 79 | 157 (158) | ¹ H NMR: δ 1.39-1.77 (m, 8H); 1.83 (s, 3H); 2.09 (d, <i>J</i> 7.00 Hz, 2H) ppm. ¹³ C NMR: δ 23.7; 25.4; 35.5; 43.2; 71.9 ppm. <i>m/z</i> (%): 97 ($\text{M}^+ - \text{Br}$, 100%); 81 (8%); 55 (65%); 41 (13%). |
| | | 20 ^b | 53 | 166 (166.2) | ¹ H NMR: δ 1.33-1.59 (m, 4H); 1.75-1.85 (m, 4H); 2.13-2.28 (m, 2H); 4.20 (m, 1H, CHBr) ppm. ¹³ C NMR: δ 25.2; 26.0; 37.7; 53.7 ppm. <i>m/z</i> (%): 164 ($\text{M}^+ + 2$, 1%); 162 (M^+ , 1%); 83 (100 %); 67 (5%); 55 (50%); 41 (16%). |
| | | 20 ^b | 100 | 200 (202-203) | ¹ H NMR: δ 2.04 (d, <i>J</i> 6.90 Hz, 3H); 5.21 (q, <i>J</i> 6.94 Hz, 1H, CHBr); 7.34 (m, 5H) ppm. ¹³ C NMR: δ 26.8; 49.5; 126.8; 128.3; 128.7; 143.3 ppm. <i>m/z</i> (%): 186 ($\text{M}^+ + 2$, 0.8%); 184 (M^+ , 0.8%); 169 (0.4%); 171 (0.4%); 105 (100%); 79 (15%); 77 (15%). |
| | | 25 ^c | 54 | 131 (131) | ¹ H NMR: δ 1.71 (s, 3H); 1.76 (s, 3H); 3.99 (d, <i>J</i> 8.42 Hz, 2H, CH_2Br); 5.49 (t, <i>J</i> 8.42 Hz, 1H, $=\text{CH-CH}_2\text{Br}$) ppm. ¹³ C NMR: δ 18.1; 25.9; 29.9; 120.9; 140.3 ppm. IR: ν 3031; 2975; 2933; 2916; 2857; 1644; 1378; 1202; 840 cm^{-1} . |

^a all yields refer to pure products; ^b rt; ^c - 8 °C

bromides with Markovnikov regioselectivity. Furthermore, our methodology avoids the need of drying chemicals, rigorous exclusion of moisture, light, and oxygen from the reaction media, and manipulation/generation of dry toxic and corrosive gaseous HBr.

Experimental

Isoprene was distilled prior to use, and the other alkenes were used as received. SiO_2 (Aldrich, 270-70 MESH, 60 Å) was used as received¹⁵, PBr_3 (Merck), and other chemicals were also used as received. ^1H and ^{13}C NMR were acquired on a Bruker AC-200 (200 MHz and 50 MHz, respectively) spectrometer in CDCl_3 solutions with TMS as internal standard. IR spectra were recorded on a Perkin-Elmer 1600 FT-IR spectrometer (KBr film). Analyses by HRGC were performed on a HP-5890-II gas chromatograph with FID by using a 28 m (length), 0.25 mm (ID) and 0.50 μm (phase thickness) RTX-5 silica capillary column and H_2 (flow rate 50 $\text{cm}^3 \text{ s}^{-1}$) as carrier gas (split 1:10). Oven temp.: 70 °C then 8 °C/min to 300 °C, injector temp.: 260 °C, detector temp.: 280 °C.

General procedure for the preparation of alkyl bromides

To a stirred suspension of the appropriated alkene (10 mmol) and SiO_2 (5 g) in CH_2Cl_2 (25 cm^3), a solution of PBr_3 (4 mmol) in CH_2Cl_2 (10 cm^3) was added for 10 min at rt. After completed addition, the suspension was stirred for several minutes (see Table) and then filtered. The SiO_2 was washed with CH_2Cl_2 (15 cm^3), the combined liquid was washed with 10% NaHCO_3 (until no more gas was liberated), brine (2 x) and the organic extract was dried (Na_2SO_4). The solvent was evaporated in a rotatory evaporator at reduced pressure to give the pure alkyl bromide.

1-Bromo-3-methyl-2-butene

A 50 ml flask with CH_2Cl_2 (25 cm^3) was charged with isoprene (10 mmol). SiO_2 (5 g) was added slowly followed by a solution of PBr_3 (3.3 mmol) in CH_2Cl_2 (10 cm^3), added for 10 min with stirring at - 8 °C (bath temperature). The suspension was stirred for additional 5 min and for 10 min

at rt and then worked as above to produce pure 1-bromo-3-methyl-2-butene.

Acknowledgements

AMS thanks CNPq for a fellowship. We thank W. Bruce Kover and Joel Jones Jr. for helpful discussions.

References

1. Clark, J.H.; Macquarrie, D.J. *Chem. Soc. Rev.* **1996**, 25, 303.
2. McKillop, A.; Young, D.W. *Synthesis* **1979**, 401.
3. McKillop, A.; Young, D.W. *Synthesis* **1979**, 481.
4. Foti, C.J.; Fields, J.D.; Kropp, P.J. *Org. Lett.* **1999**, 1, 903 and references cited therein.
5. Christie, S.D.R. *J. Chem. Soc., Perkin Trans. 1* **1999**, 737 and references cited therein.
6. Kropp, P.J.; Daus, K.A.; Crawford, S.D.; Tubergen, M.W.; Kepler, K.D.; Craig, S.L.; Wilson, V.P. *J. Am. Chem. Soc.* **1990**, 112, 7433.
7. Kropp, P.J.; Daus, K.A.; Tubergen, M.W.; Kepler, K.D.; Wilson, V.P.; Craig, S.L.; Baillargeon, M.M.; Breton, G.W. *J. Am. Chem. Soc.* **1993**, 115, 3071.
8. Mayo, F.R.; Walling, C. *Chem. Rev.* **1940**, 27, 351.
9. $(\text{COBr})_2$ and Me_3SiBr are considerably more expensive than PBr_3 , ca. 3.7 and 3.4 times, respectively. Moreover PBr_3 is also sold as a 1 M solution in CH_2Cl_2 (*Aldrich Catalog of Fine Chemicals*, 1997).
10. Trost, B.M. *Science* **1991**, 254, 1471.
11. de Mattos, M.C.S.; Sanseverino, A.M. *Synth. Commun.* **2000**, 30, 1975.
12. Sanseverino, A.M.; de Mattos, M.C.S.; Kover, W.B. *J. Chem. Res. (S)* **2000**, 346.
13. Lide, D.R. (Ed.) *Handbook of Chemistry and Physics*, 78th ed.; CRC Press; Boca Raton, 1997-1998.
14. Vogel, A.I. *Textbook of Practical Organic Chemistry*, 5th ed.; Singapore; Longman, 1996; pp. 575-576.
15. The water content (ca. 15% w/w) was determined by heating in a domestic microwave oven until constant weight.

Received: October 14, 2000

Published on the web: July 7, 2001