The Stereochemistry of 1,2,5,6-Tetrabromocyclooctane

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Abstract

1,2,5,6-Tetrabromocyclooctane (TBCO) is a less common brominated flame retardant used in textiles, paints and plastics. Very little is known about its presence in the environment. TBCO exists as two diastereomers which can be separated under HPLC conditions but their individual stereochemistries have not been established. We have separated the diastereomers and determined their stereochemistry by means of x-ray crystallography. Under LC conditions, the first eluting isomer was named alpha-TBCO (α-TBCO), a meso compound whose steric structure is denoted in its preferred IUPAC name, (1*R*,2*R*,5*S*,6*S*)-1,2,5,6-tetrabromocyclooctane. The later eluting compound, named beta-TBCO (β-TBCO) or *rac*-(1*R*,2*R*,5*R*,6*R*)-1,2,5,6-tetrabromocyclooctane, is a racemate.

1.0 Introduction

1,2,5,6-Tetrabromocyclooctane (TBCO), also known as Saytek-BC-48™ (Albermarle), is a commercial product that may be viewed as an important brominated flame retardant (BFR) since its use is revealed in many patents (see for example[1-3]). TBCO appears to be used as an additive flame retardant in textiles, paints and plastics.[4]

Only one study that we know of has reported the analysis of TBCO, and this was in Styrofoam.[5] However, it appears that there has been no report of the analysis or detection of TBCO in the environment. Therefore, very little is known about its presence in the environment.

TBCO exists as two diastereomers which can be separated under HPLC conditions. We have labeled the first eluting isomer as alpha-TBCO (α-TBCO) and the later eluting isomer as beta-TBCO (β-TBCO). The stereochemistries of these diastereomers have not been previously reported. Trans diaxial addition of bromine across both cis double bonds of 1,5-cylcooctadiene can only give two products, a meso compound ((1*R*,2*R*,5*S*,6*S*)-1,2,5,6-tetrabromocyclooctane) and a racemate (*rac*-(1*R*,2*R*,5*R*,6*R*)-1,2,5,6-tetrabromocyclooctane) (see Figure 1). An x-ray crystallographic study was previously done[6] on one isomer of TBCO. Unfortunately, it is not known if the structural determination was carried out on α- or β-TBCO.

The objective of the present work was to elucidate the stereochemistry of α- and β-TBCO.

2.0 Experimental

2.1 Separation and purification of α- and β-TBCO

α- and β-TBCO were purified from a technical mixture of TBCO (Saytek-BC-48™) by a combination of crystallization and HPLC separation techniques. α–TBCO (**1**): Mp 133-133.5°C, with sublimation starting at ~115°C; δ_H (22°C, $CDCl_3$) 4.57 (br m, 4H), 2.54 (m, 4H), 2.43 (m, 4H). β- TBCO (**2**): Mp 133-135°C, with sublimation starting at ~95°C; δ_H (22°C, $CDCl_3$) 4.76 (m, 4H), 2.82 (m, 4H), 2.12 (m, 4H). Technical TBCO has a melting point of 102-124°C.

2.2 High Resolution Gas Chromatography/Low Resolution Mass Spectrometry (HRGC/LRMS)

Analyses were performed on a Shimadzu GC/MS-QP2010 using a J&W 30m DB-5 column (0.25 mm ID, 0.25 µm film). All injections were done in splitless mode. All experiments were done with the following GC conditions: helium carrier gas flow at 1.0 ml/minute, injector temperature at 170°C, temperature program set to the following parameters: initial oven temperature at 80°C, hold for 5 minute, ramp at 50°C/minute to 200°C, hold for 5.5 minutes, ramp at 10°C/minute to 325°C, hold for 20 minutes. Spectra (50 to 1000 u) were obtained in positive ion, electron impact mode (EI+).

2.3 LCMS

LCMS experiments were conducted on a Waters Acquity Ultra Performance LC interfaced to a Micromass Quattro micro API (triple quad mass spectrometer). Separations were performed on an Acquity UPLC BEH C_{18} column (1.7 um, 2.1 x 100 mm). A typical LC method started at 77% (80:20 MeOH: ACN) and 23% water (both with 10 mM NH_4OAc) at a flow rate of 200 µL/minute. The program was then ramped to 85% (80:20 MeOH: ACN) over 10 minutes and held for 3 minutes before returning to initial conditions. Data were collected in SIM mode by monitoring the Br^- anion (m/z 79 and 81) under negative electrospray ionization conditions (capillary voltage 3kV, cone voltage 12V).

2.4 ^{1}H-NMR Experiments

^{1}H-NMR analyses were performed on a 400 MHz Bruker instrument using deuterochloroform (CDN Isotopes) as the solvent and TMS as an internal standard.

3.0 Results and Discussion

3.1 X-ray structure determination of α- and β-TBCO

The products, α- and β-TBCO, were isolated by a combination of crystallization and HPLC separation techniques. Crystals suitable for x-ray structure determination for both α- and β-TBCO were grown from isopropanol/methanol. The results clearly indicate that α-TBCO has the meso structure **1** (see Figure 2) and β-TBCO has the racemic structure **2** (see Figure 3). Our work now shows that the previous x-ray study[6] was done on α-TBCO.

It is interesting to note that the overall molecular shapes of α- and β-TBCO differ significantly. Indeed, we have noticed obvious differences in solubilities between the two isomers, analogous to what has been observed for the isomers of the closely related BFR, hexabromocyclododecane (HBCD).[7-9] These differences may lead to a variation in environmental behavior between the two diastereomers, as is currently being found for the HBCD isomers.

3.2 NMR of α- and β-TBCO

The meso structure of α-TBCO (**1** in Figure 1) has one plane and one C2*v* axis of symmetry. This results in all CHBR and CH_2 moieties within the structure being equivalent and thus a very simple ^{1}H NMR spectrum (see Figure 4a). However, the geminal protons in the CH_2 groups are non-equivalent due to different magnetic environments above and below the ring. The racemic structure in β-TBCO (**2** in Figure 1) has two C2*v* axes of symmetry and this also leads to a simple ^{1}H NMR spectrum (see Figure 4b). Careful analysis and comparison of the NMR spectra of α- and β-TBCO did not allow us to determine the stereochemistry of the compounds. However, as indicated above, X-ray structure determinations provided the means of elucidating their stereochemistry unequivocally.

3.3 Analysis of α- and β-TBCO by GC/MS

Some isomeric brominated ring compounds, such as α-, β- and γ-HBCD, cannot be separated when analyzed by gas chromatography (GC) because they interconvert at temperatures > 160°C[10,11] and give a single broad peak. Not surprisingly, the same issue arises when one attempts to analyze α- and β-TBCO by GC. The individual TBCO isomers give signals with identical retention times indicating that a fast thermal interconversion between the isomers is probably occurring.

3.4 Analysis of α- and β-TBCO by LCMS

LCMS analysis of the individual TBCO isomers gave signals with different retention times. Thus, the interconversion of these isomers is not a problem during LC analysis. However, the molecular ion for both diastereomers is difficult to detect using LCMS analysis with electrospray ionization. They can be detected when the bromide ion (Br^-) is monitored under SIM conditions. Other ionization techniques such as APCI are being investigated in the hope that a method can be developed that can more positively analyze for TBCO.

4. Conclusions

The stereochemistries of the α- and β-TBCO diastereomers, **1** and **2**, have been elucidated by x-ray structure determination to be (1*R*,2*R*,5*S*,6*S*)-1,2,5,6-tetrabromocyclooctane and *rac*-(1*R*,2*R*,5*R*,6*R*)-1,2,5,6-tetrabromocyclooctane, respectively.

References

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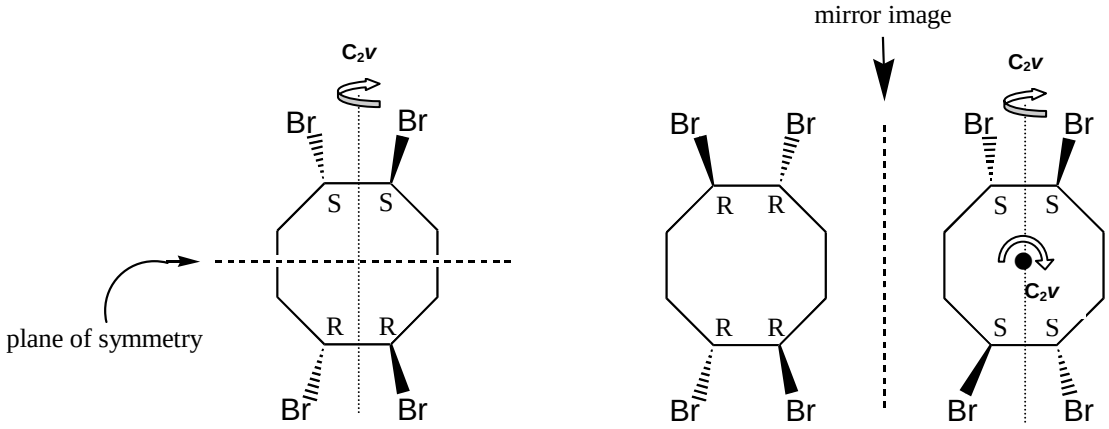

1 (α-TBCO) **2 (β-TBCO)**

α-TBCO = (1*R*,2*R*,5*S*,6*S*)-1,2,5,6-tetrabromocyclooctane

β-TBCO = *rac*-(1*R*,2*R*,5*R*,6*R*)-1,2,5,6-tetrabromocyclooctane

Figure 1. Structures and nomenclature for α- and β-TBCO

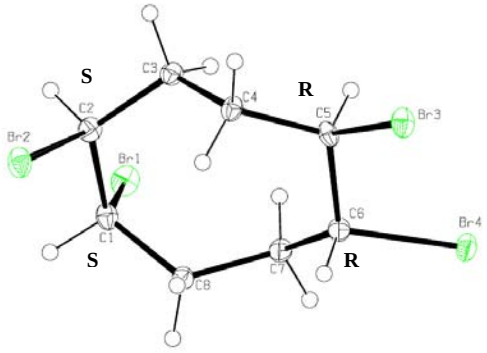

Figure 2. Ortep diagram for α-TBCO

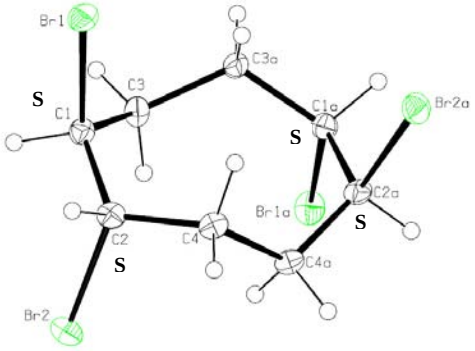

Figure 3. Ortep diagram for β-TBCO

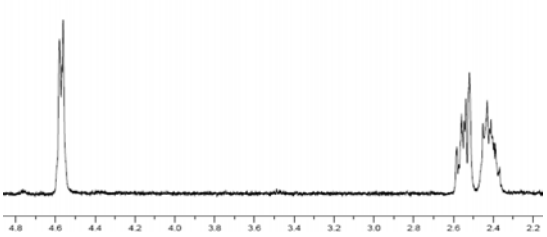

Figure 4a. ^{1}H NMR of α-TBCO

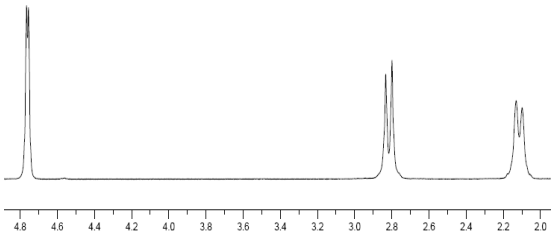

Figure 4b. ^{1}H NMR of β-TBCO