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Competition between Isomerization and Addition in the Sonication of Vinyl Sulfones in the Presence of Bromotrichloromethane

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Abstract. (E)- and (Z)-vinyl sulfones isomerise under ultrasound irradiation in carbon tetrachloride in the presence of bromoform or bromotrichloromethane to give an E/Z equilibrium mixture via bromine radicals. Furthermore, the bromine radicals formed add to the C=C double bond (presumably of the Z isomer) to form *vic*-dibromo compounds. In pure $CBrCl_3$ this addition reaction reaches a 99% yield. In tetrahydrofurane/CBr_4 (or $CBrCl_3$) no isomerization is observed since the bromine radicals react probably with the THF. The addition is also favoured by highly efficient energy transmission.

Ultrasound is able to generate free radicals by sonolysis of carbon halogen bonds [1]. Among these, the carbon-halogen bond in halomethanes is especially prone to undergo homolysis :

$$CBrCl_3 \xrightarrow{)))} Br^{\bullet} + {}^{\bullet}CCl_3 \qquad \text{(Eq.)}$$

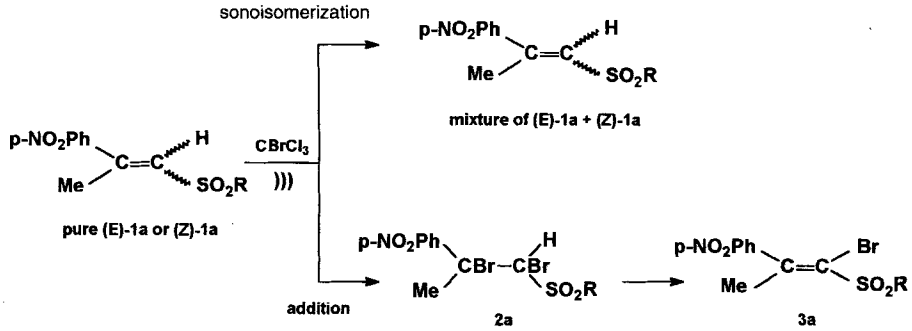
Bromine atoms are capable to initiate further chemical transformations such as *cis-trans* isomerizations of olefines. Only few examples of sonoisomerizations are reported in the literature. The maleate/fumarate conversion was performed in water in the presence of bromine and alkyl bromides [2], respectively, or carbon tetrachloride and mediated by bromoform [3]. More recently, the *cis-trans*-1,2-dichloroethylene isomerization was also studied in carbon tetrachloride/R-Br [4].

In a preliminary communication [5] we reported that in the case of (E)- and (Z)-1-(methylsulfonyl)-2-(4-nitrophenyl)-propene **1a** the sonoisomerization in presence of bromotrichloromethane is accompanied by a competitive addition reaction giving the dibromo compound **2a** (scheme 1). This reaction was never mentioned in previous reports. Therefore, we extended this investigation to other vinyl sulfones with a variation of the irradiation parameters and the conditions which are able to affect the ratio between isomerization and addition.

Results and Discussion

Sonication at 20 kHz with a 9.5 mm probe

In the pure solvents, THF or CCl_4, we did not observe any isomerization or other reactions of the pure (E)- or (Z)-isomer **1a**.



Scheme 1

Using bromoform or bromotrichloromethane as co-solvents in THF, the sonication of the vinyl sulfones **1a** gave no detectable isomerization. This is properly due to fast side reactions caused by the attack of Br$^{\bullet}$ on the solvent, which has also been observed in the absence of the vinyl sulfone **1a** when THF/$CHBr_3$ or THF/$CBrCl_3$ are sonicated. The structures of the products have not yet been determined.

In CCl_4, with 1-10 eq. of bromoform relative to vinyl sulfone **1a** some isomerization occurs. However, side reactions due to bromoform sonolysis result in by-products as shown by complex ^{1}H-NMR spectra. Thus, bromotrichloromethane according to the above equation appears as a better candidate for inducing isomerizations with minimal disturbing side reactions. It was checked that no isomerization or other reactions take place in CCl_4/$CBrCl_3$ without sonication in the dark. Because of the relative selectivity of this system (solvent and initiator), it was used for all the following experiments.

Starting from the less stable (Z)-isomer, we found the following results: if the ratio (Z)-**1a**:$CBrCl_3$ is 1 molar eq., the (E)-isomer is not detectable within a reaction time of 2 h. The isomerization from (Z) to (E) becomes noticeable in the presence of higher amounts of bromotrichloromethane, 10 and 150 eq., which give 30 and 40% (E)-**1a**, respectively, and no addition product **2a** is observed. Isomerization becomes a rapid process when $CBrCl_3$ is used in 1700 eq. in carbon tetrachloride (CCl_4/$CBrCl_3$ 50:50 v/v). Under these conditions, the reaction mixture consists after 2h of 70% of the (E)-isomer accompanied by 12% of the addition product **2a** as summarized in table 1.

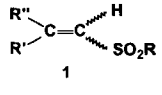
Starting from the more stable (E)-**1a** and using the same conditions, a maximum amount of 15% of the less stable (Z)-**1a** is observed after 2h.

After sonication of (Z)-**1a** or (E)-**1a** for 2h, the (E):(Z) ratio is comparable (table 1) indicating that it represents an equilibrium under the conditions applied. However, this equilibrium is only transient since after 2h, the competitive addition reaction becomes important and the dibromo compound **2a** is formed in increasing amounts at the expenses of the (Z)-**1a** to reach about 40% after 3h.

Compound **2a** is difficult to purify because of rapid HBr elimination to restore the conjugate system giving the vinylic compound **3a**. The structure of **2a** was independently confirmed by direct addition of bromine to (E)-**1a** and (Z)-**1a**, followed by elimination of HBr. The ^{1}H-NMR spectra of the addition and the elimination products **2a** and **3a** (cf. experimental), respectively, are identical to those obtained from the sonochemical reaction products, indicating the same stereoisomeric composition.

Changing the reaction medium has very important consequences on the evolution of the reaction. Sonication of (E)- or (Z)-**1a** in pure bromotrichloromethane yields 99% dibromo compound **2a** after 2h. The rates from each isomer are different as evidenced by an experiment run with a 50/50 mixture of (E) and (Z) compounds. The final composition consists of 20% of unreacted (E)-**1a** and 80% of addition product **2a**. A practically identical composition is found from the addition (without sonication) of bromine in CCl_4 to the same (E)/(Z) mixture.

In order to investigate the influence of the substituents at the double bond, we have synthesized various vinyl sulfones **1b–e** (scheme 2).



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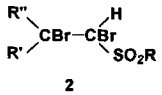

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	R	R'	R''
1b, 2b	Me	H	p-NO_2Ph
1c, 2c	Ph	Me	p-NO_2Ph
1d, 2d	Me	Ph	p-NO_2Ph
1e, 2e	Me	CF_3	Ph

Scheme 2

The results (table 2) indicate for the compounds **1a–d** that the addition is not importantly influenced by the substituents. But, it is shown from this table that in the case of the less stable (Z)-isomer, the isomerization is decreased if R' is more bulky (**1b**, **1a**, **1d**). The presence of a trifluoromethyl group in compound **1e** has changed the priority for the (E) and (Z) nomenclature. Furthermore, the effect of this electron withdrawing substituent seems to be more pronounced on the isomerization compared to that of the methyl one in **1a**.

Table 1 Sonoisomerization (Z)-**1a** to (E)-**1a** (left) and (E)-**1a** to (Z)-**1a** (right) as well as formation of **2a** in CCl_4/$CBrCl_3$ 50:50 (v/v)

time [h]	(Z)-1a[a]	(E)-1a[a]	2a[a]	time [h]	(E)-1a[a]	(Z)-1a[a]	2a[a]
0	100	0	0	0	100	0	0
0.5	69	31	0	0.5	100	0	0
1	34	61	5	1	93	4	3
2	18	70	12	2	70	15	15
2 b)	56	40	4	2 b)	90	3	7
3	3	55	42	3	59	3	38

[a] Determined by NMR [6] [b] in the presence of 1 eq. galvinoxyl per mole of **1a**

Table 2 Sonoisomerization from the less stable isomer of **1** (left) and from the more stable isomer of **1** (right) as well as formation of **2** in CCl_4/$CBrCl_3$ 50:50 (v/v), 2h

compound	(Z)-1:(E)-1:2	(E)-1:(Z)-1:2
1b [7]	0:80:20	96:4:0
1a [8a]	18:70:12	70:15:15
1c	22:58:20	83:5:12
1d [9]	–	60:22:18

compound	(E)-1:(Z)-1:2	(Z)-1:(E)-1:2
1e	54:46:0	100:0:0

Sonication at 20 kHz using other probes and an ultrasonic bath

Considering the energy differences between the (E)- and (Z)-isomers being larger for compound **1b**, this pair was chosen for a study of the sonochemical parameters (table 3). Sonication of (Z)-**1b** using a larger probe (cf. run 2 and 3) leads to an increased isomerization and practically no addition (except very few in run 3). Starting from (E)-**1b**, no isomerization or addition is observed within 30 min. sonication time.

Sonication with a 19 mm probe forces the reaction towards the dibromo adduct **2b**. The (Z)-isomer completely disappears and 80% addition product is found. The (E)-isomer does not isomerize, but a week addition occurs giving 14% of adduct **2b**. The results displayed in table 3 illustrate the importance of energy transmission. The more efficient reactions occur at a low energy density given by a large emitting surface. This efficiency is easily visualised by colour changes due to bromine production. Using a cleaning bath, the solution remains colourless whereas the solution becomes more and more coloured from run 2 to 4 reaching a deep orange colour in run 4.

Sonication at 850 kHz

Sonication for 2 h of the (E)- or (Z)-isomer **1a** and **1b**, respectively, gives neither isomerization nor addition product **2a** or **2b** in $CCl_4/CBrCl_3$ 50:50 (v/v).

Mechanistic Aspects

These results raise an interesting mechanistic problem. It was assumed by previous workers that these halogen mediated sonoisomerizations proceed via the reversible addition of the halogen atom to the double bond, rotation around the single bond of the β-haloradical which releases the halogen in the final step [1–3].

However, the following remarks with respect to the addition mechanism in the formation of compound **2** should be made. It is known that under some conditions, the addition of halogens can proceed via a radical pathway [10]. In our experiments, no allylic bromination could be detected. On the other hand, the bromine atoms are rather prone to dimerize to the bromine molecule, which can add to the olefinic bond to give the dibromo adduct. If this addition proceeds via a bromonium intermediate, the ratio of the diastereomeric *vic*-dibromo compounds should be different for the addition to the (E)- and (Z)-isomer. However, bromination of stilbenes was shown to proceed via a β-bromo carbocationic intermediate, leading to a mixture of the *vic*-dibromo adducts, irrespective of the initial geometric isomer [11a]. The same result is obtained from the addition of bromine to **1** and from the sonochemical experiments. But, this would also be expected via a radical pathway.

The large volume of bromotrichloromethane results in a large amount of $Br^{\bullet}$ formed according to the equation above. Consequently, bromine is formed in important amounts, as revealed by the intense orange colour of the reaction mixture, it could be envisaged that compounds **2** result from an electrophilic addition of bromine to the double bond, generating the β-bromocarbocation. Isomerization can result if the bromine cation is released or addition of the bromide ion occurs leading to the addition compounds [cf. 11]. The decreased reactivity of the double bond substituted by an electron withdrawing group such as CF_3 (compound **1e**) could support this interpretation.

Sonication of (Z)-**1a** and (E)-**1a**, respectively, in the presence of 1 molar eq. of galvinoxyl results in a decrease both of the addition and the isomerization (table 1). But, the decreasing effect can be due to the partial trapping or other change introduced in the very first step of the process, the sonocleavage of $CBrCl_3$.

Thus, the mechanism of the formation of compound **2** is still open. Radical (initiated by formation of $Br^{\bullet}$) and ionic pathway (initiated by evolution of bromine) or duality of both mechanisms are possible under our conditions.

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Experimental

The vinyl sulfones **1a–e** were prepared via WITTIG-HORNER reaction performed under ultrasonic irradiation following reference [8]. Compounds **1c** and **1e** have not yet been described. They were obtained in 57% and 54% yield, respectively.

Table 3 Variation of the sonochemical conditions (starting from (Z)-**1b** (left) and from (E)-**1b** (right) and formation of the dibromo adduct **2b** in $CCl_4/CBrCl_3$ 50:50 (v/v), 30 min)

run	)))	electrical power [W]	energy density [W/cm^2]	(Z)-1b:(E)-1b:2b	(E)-1b:(Z)-1b:2b
1	**bath**			100:0:0	100:0:0
2	**probe 4 mm**	45	358	84:16:0	100:0:0
3	**probe 9.5 mm**	45	63	60:38:2	100:0:0
4	**probe 19 mm**	100	35	0:20:80	86:0:14

Compounds **2a** and **3a** were prepared as follows: Bromine (3 eq., 57.6 mg in 4 ml carbon tetrachloride) is dropped into a CH_2Cl_2-solution (10 ml) of 86.8 mg (Z)-**1a**. After standing for 2 h at r.t. in the dark the solvent is evaporated. One part of the resulting residue **2a** is used for analysis and the other for circular preparative t.l.c. (Harrision Research Chromatotron 8924, Merck silica gel containing gypsum, CH_2Cl_2/AcOEt 9:1) which quantitatively yields compound **3a** (m.p. 153 °C). Compounds **2b–d** were identified by NMR and not pure isolated. ^{1}H-NMR (300 MHz, $CDCl_3$, δ ppm) and analytical results:

1-(Phenylsulfonyl)-2-(4-nitrophenyl)-propene (**1c**)

(E)-isomer: 2.58 (d, 3H, CH_3), 6.65 (s, 1H, =CH, $^3J_{H/H}$ = 1.3 Hz), aromat.: 7.53 (m, 2H, ortho p-NO_2Ph), 8.22 (m, 2H, meta p-NO_2Ph), 7.99 (m, 2H, ortho SO_2Ph), 7.60 (m, 2H, meta SO_2Ph), 7.66 (m, 1H, para SO_2Ph); (Z)-isomer: 2.18 (d, 3H, CH_3), 6.59 (d, 1H, =CH, $^3J_{H/H}$ = 1.5 Hz), aromat.: 7.31 (m, 2H, ortho p-NO_2Ph), 8.19 (m, 2H, meta p-NO_2Ph), 7.63 (m, 2H, ortho SO_2Ph), 7.45 (m, 2H, meta SO_2Ph), 7.59 (m, 1H, para SO_2Ph); $C_{15}H_{13}NO_4S$, Calcd.: C 59.40 H 4.32 N 4.62 S 10.57, Found: C 59.25 H 4.30 N 4.59 S 10.79.

1-(Methylsulfonyl)-2-phenyl-3,3,3-trifluoro-propene (**1e**)

(E)-isomer: 3.20 (s, 3H, SO_2CH_3), 6.80 (s, 1H, =CH), aromat.: 7.39–7.51 (m, 5H); (Z)-isomer: 2.71 (s, 3H, SO_2CH_3), 7.13 (d, 1H, CH, $^3J_{H/F}$ = 0.9 Hz)), aromat.: 7.41–7.53 (m, 5H); $C_{10}H_9F_3O_2S$, Calcd.: C 48.00 H 3.63 S 12.81, Found: C 48.08 H 3.63 S 12.99.

1-(Methylsulfonyl)-1,2-dibromo-2-(4-nitrophenyl)-propane (**2a**)

Major diastereomer, 95%: 2.64 (s, 3H, CH_3), 3.11 (s, 3H, SO_2CH_3), 5.57 (s, 1H, -CH), aromat.: 7.86 (d, 2H, ortho), 8.24 (d, 2H, meta); $C_{10}H_{11}Br_2NO_4S$, Calcd.: C 29.95 H 2.76 N 3.49 S 7.99, Found: C 30.21 H 2.86 N 3.57 S 7.82; minor diastereomer, 5%: 2.63 (s, 3H, CH_3), 3.20 (s, 3H, SO_2CH_3), 5.49 (s, 1H, -CH), aromat.: 7.82 (d, 2H, ortho), 8.24 (d, 2H, meta).

1-(Methylsulfonyl)-1,2-dibromo-2-(4-nitrophenyl)-ethane (**2b**)

Major diastereomer, 79%: 3.29 (s, 3H, SO_2CH_3), 5.92 (d, 1H, -CH), 4.93 (d, 1H, -CH-SO_2-), aromat.: 7.75 (d, 2H, ortho), 8.25 (d, 2H, meta); minor diastereomer, 21%: 2.93 (s, 3H, SO_2CH_3), 5.90 (d, 1H, -CH), 5.35 (d, 1H, -CH-SO_2-), aromat.: 7.82 (d, 2H, ortho), 8.24 (d, 2H, meta).

1-(Phenylsulfonyl)-1,2-dibromo-2-(4-nitrophenyl)-propane (**2c**)

Major diastereomer, 78%: 2.70 (s, 3H, CH_3), 5.68 (s, 1H, -CH); minor diastereomer, 22%: 2.69 (s, 3H, CH_3), 5.48 (s, 1H, -CH).

1-(Methylsulfonyl)-1,2-dibromo-2-(4-nitrophenyl)-2-phenyl-ethane (**2d**)

Major diastereomer, 68%: 3.13 (s, 3H, SO_2CH_3), 3.84 (s, 1H, -CH); minor diastereomer, 32%: 2.63 (s, 3H, CH_3), 3.25 (s, 3H, SO_2CH_3), 3.84 (s, 1H, -CH).

1-(Methylsulfonyl)-1-bromo-2-(4-nitrophenyl)-propene (**3a**)

One isomer: 2.62 (s, 3H, CH_3), 3.26 (s, 3H, SO_2CH_3), aromat.: 7.38 (d, 2H, ortho), 8.28 (d, 2H, meta); after comparison with the NMR shifts [8] of (E)-**1a** : 2.62 (3H, CH_3), 3.10 (3H, SO_2CH_3) and (Z)-**1a** : 2.26 (3H, CH_3), 2.81 (3H, SO_2CH_3), we have assigned to **3a** the (Z)-configuration; $C_{10}H_{10}BrNO_4S$, Calcd.: C 37.52 H 3.15 N 4.37 S 10.01, Found: C 37.60 H 3.34 N 4.46 S 10.05

Sonication

Conditions: 21.7 mg vinyl sulfone **1** in 30 ml solvent (3 mmol/l), Ar atmosphere, 20 °C, darkness [12], sonication time: 2 h if not otherwise mentioned
20 kHz cleaning bath: thermostated bath Sonoclean S-1000; reactor: 50 ml Erlenmeyer-flask
20 kHz probe: Braun Labsonic U
- 4 mm or 9.5 mm probe, 45W electrical input, reactor: thermostated glass cylinder (diameter 35 mm, depth 80 mm)
- 19 mm probe, 100 W electrical input, reactor: thermostated glass cylinder (diameter 35 mm, depth 70 mm)

850 kHz: Ultraschalltechnik Meinhardt K 80/5 generator (100W electrical input) and thermostated bath with focus transducer; reactor: 50 ml Erlenmeyer-flask

References

[1] (a) K. S. Suslick, Ultrasound: Its chemical, physical, and biological effects; VCH: Weinheim, 1988; p.146;
(b) I. Rosenthal, M. M. Mossoba, P. Riesz, J. Magn. Res. **45** (1981) 359

[2] (a) I. E. Elpiner, A. V. Sokolskaya, M. A. Margulis, Nature **208** (1965) 945;
(b) M. A. Margulis, L. M. Grundel, Russ. J. Phys. Chem. **56** (1982) 2987

[3] (a) T. Lepoint, F. Mullie, N. Voglet, D. H. Yang, J. Vandercammen, J. Reisse, Tetrahedron Lett. **33** (1992) 1055;
(b) J. Reisse, D. H. Yang, M. Maeck, J. Vandercammen, E. Vander Donckt, Ultrasonics **30** (1992) 397

[4] (a) T. Caulier; J. Vandercammen, L. Broeckaert, J. Reisse, Proc. 3rd Meeting of the European Society of Sonochemistry, Figueira da Foz (Portugal), 28.03.-01.04.1993, p. 120;
(b) T. Caulier, M. Maeck; J. Reisse, Proc. 4th Meeting of the European Society of Sonochemistry, Blankenberge (Belgium), 18.09.-22.09.1994, p. 51

[5] D. Peters, F. Pautet, H. El Fakih, H. Fillion, J.L. Luche, R. Miethchen, Proc. 4th Meeting of the European Society of Sonochemistry, Blankenberge (Belgium), 18.09.–22.09.1994, p. 77

[6] Each set of experiments is run twice. Dispersion of the measurements fall within a 2% margin. The solutions are evaporated after sonication and the ^{1}H-NMR spectra (300 MHz) are recorded.

[7] (a) W. Wegner, C. Courault, K.-D. Schleinitz, Z. Chem. **23** (1983) 54;
(b) W. Wegner, D. Palm, H. Beerbaum, K.-D. Schleinitz, Z. Chem. **20** (1980) 337

[8] (a) H. El Fakih, F. Pautet, H. Fillion, J. L. Luche, Tetrahedron Lett. **33** (1992) 4909;
(b) H. El Fakih, F. Pautet, D. Peters, H. Fillion, J. L. Luche, Synth. Commun. **24** (1994) 3225

[9] H. Fillion, M.H. Péra, J.L. Rappat, C. Luu Duc, J. Heterocycl. Chem. **15** (1978) 753

[10] R. M. Dessau, J. Am. Chem. Soc. **101** (1979) 1344
[11] (a) G. Bellucci, R. Bianchini, C. Chiappe, R. Stanley Brown, H. Slebocka-Tilk, J. Am. Chem. Soc. **113** (1991) 8012
(b) G. Bellucci, C. Chiappe, F. Marioni, J. Am. Chem. Soc. **109** (1987) 4515
[12] Photoisomerization of vinyl sulfones has been observed: M. A. A. M. El Tabei, N. V. Kirby, S. T. Reid, Tetrahedron Lett. **21** (1980) 565. We found isomerization even in presence of daylight. Therefore, all products were carried out in appropriate protection against light.

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