Formation of σ-Anionic Complexes in Reactions between 5-Nitrothiazole, 6-Nitrobenzothiazole and Tetrabutylammonium Borohydride

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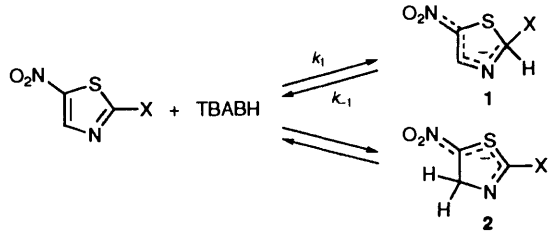
The title reactions were performed in toluene, tetrahydrofuran (THF) and dimethylsulfoxide. ^{1}H NMR spectral data from the reaction mixtures in Me_2SO and in THF indicate that each substrate affords only one respective σ-anionic complex. Kinetic data on formation of the complexes indicate that the attack of the nucleophile and stability of the complexes are affected greatly by changing the solvent. In agreement with our previous findings, in Me_2SO the rate of formation of the complexes from both substrates considered is lower than that observed in less polar solvents (toluene and THF). The explanation of this trend includes comparison of charge dispersion in the transition state with respect to the initial state and the possibility of changes in the hydride ion carrier when the solvent is changed.

Borohydrides are useful reagents in organic syntheses [1] but their properties have not been widely investigated from the quantitative point of view. Reactions of formation of σ-anionic complexes from activated aromatic derivatives and nucleophiles have been extensively studied.[2] Recently,[3] we reported some quantitative data on reactions between polynitrobenzenes and tetrabutylammonium borohydride (TBABH) to form σ-anionic complexes[4] in various solvents.

Our interest concerns the reactivity of thiazole derivatives,[5] and in particular of nitrothiazoles, toward nucleophiles.[6,7] The strong activation of position 2 of the thiazole ring by the nitro-group bonded in position 5 has been discussed.[5,8] We have investigated previously[9] the reactions of 5-nitro-2-methoxythiazole and of 5-nitrothiazole with sodium methoxide to yield σ-anionic adducts.

To collect further information about the reactivity of borohydrides and of thiazole derivatives, we are now reporting the reactions of 5-nitrothiazole (NTZ), 6-nitrobenzothiazole (NBTZ) and TBABH in dimethylsulfoxide, tetrahydrofuran (THF) and in toluene.



X = H (**a**); ^{2}H (**b**); OMe (**c**); Cl (**d**); Br (**e**)

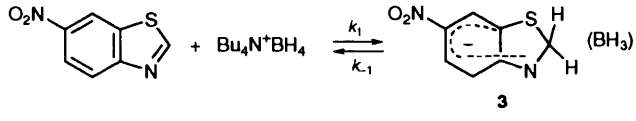
Scheme 1

Results

When a solution of TBABH (1×10^{-2} mol dm^{-3}) in deuteriodimethylsulfoxide ($[^2H_6]Me_2SO$) or in deuteriotetrahydrofuran ($[^2H_8]THF$) is added to a solution (in $[^2H_6]Me_2SO$ or in $[^2H_6]THF$) of NTZ (1.1×10^{-2} mol dm^{-3}), a dark-red colour develops immediately. ^{1}H NMR spectra quickly recorded after mixing indicate the presence of only one new compound. The structure of this compound is ascertained by ^{1}H NMR chemical shifts (in comparison with previous data of related compounds) and by ^{1}H NMR data of the mixtures of 5-nitro[2-^{2}H]thiazole (NTZD) and TBABH. ^{1}H NMR spectral data are collected in Table 1 and they agree with the structure of the Meisenheimer-like compounds **1** of Scheme 1.

The hydride ion attacks position 2 of NTZ. The same ^{1}H NMR spectrum is obtained under both experimental conditions $[NTZ]_0 > [TBABH]_0$ and $[NTZ]_0 < [TBABH]_0$ ($[\,]_0$ indicates the values of the initial concentration of the reagents).

Similar behaviour is observed when a solution of TBABH (1×10^{-2} mol dm^{-3}) in $[^2H_6]Me_2SO$ or in $[^2H_8]THF$ is added to a solution (in $[^2H_6]Me_2SO$ or in $[^2H_8]THF$) of NBTZ: a red colour develops immediately. The ^{1}H NMR spectrum indicates the presence of only one new compound. ^{1}H NMR spectral data are also collected in Table 1 and they agree with structure **3** of Scheme 2. In particular the singlet at δ 5.1 (see Table 1) of area 2 is referred to the protons bonded at C-2 of the thiazole ring. If the sp^3 carbon were in the homocyclic ring, a singlet of area 1 should be observed for 2-H. This kind of signal was never detected.



Scheme 2

We also checked the behaviour of 5-nitro-2-methoxythiazole, but in the (dark-red coloured) mixtures of this compound and TBABH in $[^2H_6]Me_2SO$, we were unable to obtain ^{1}H NMR evidence for the presence of σ-complexes (**1c** and **2c**). The ^{1}H NMR spectrum shows the presence of several signals probably related also to products of ring-opening reactions.

In addition, for the reaction mixtures in $[^2H_6]Me_2SO$ of 5-nitro-2-chlorothiazole or 5-nitro-2-bromothiazole and TBABH, ^{1}H NMR spectra do not provide evidence of the presence of NTZ or related σ-complexes. TBABH is unable, at least under our experimental conditions, to yield products of direct substitution, probably because other processes (such as Meisenheimer-like complex formation in position 4 followed by ring-opening reactions) take place. It is known that the attack of the nucleophile on position 4 of NTZ derivatives may be followed by fast ring opening[5,10] which is probably the first step in the formation of tars for the 2-substituted NTZs considered here.

The NTZ–TBABH mixtures obtained under both experimental conditions $[NTZ]_0 > [TBABH]_0$ and $[NTZ]_0 < [TBABH]_0$ show the same UV–VIS spectra. This fact agrees with the conclusion obtained from inspection of the mixtures by ^{1}H NMR spectroscopy. Consequently the colour development

Table 1 ^{1}H NMR spectral data and NTZ, NTZD, NBTZ and their σ-anionic complexes with TBABH (internal reference TMS)

Compound	Solvent	δ_{H-2}	δ_{H-4}
NTZ	$[^2H_6]Me_2SO$	9.40 (1 H, s)	8.89 (1 H, s)
NTZ	$[^2H_8]THF$	9.12 (1 H, s)	8.68 (1 H, s)
NTZD	$[^2H_6]Me_2SO$[a]	9.41 (s)	8.88 (s)
NTZD	$[^2H_8]THF$[a]	9.13 (s)	8.66 (s)
NBTZ	$[^2H_6]Me_2SO$	9.73 (1 H, s)	9.23 (1 H, d);[b] 8.2–8.3 (2 H, m)[c]
NBTZ	$[^2H_8]THF$	9.46 (1 H, s)	9.08 (1 H, d);[b] 8.1–8.4 (2 H, m)[c]
1a	$[^2H_6]Me_2SO$	4.95 (2 H, s)	7.67 (1 H, s)
1a	$[^2H_8]THF$	4.92 (2 H, s)	7.70 (1 H, s)
1b	$[^2H_6]Me_2SO$[d]	4.92 (s)	7.66 (s)
1b	$[^2H_8]THF$[d]	4.93 (s)	7.70 (s)
3	$[^2H_6]Me_2SO$	5.10 (2 H, s)	6.3 (1 H, m); 7.6–7.8 (2 H, m)
3	$[^2H_8]THF$	5.10 (2 H, s)	6.2 (1 H, m); 7.4–7.5 (2 H, m)

[a] Relative intensities of signals H-4 : H-2 = 1 : 0.2. [b] H-7. [c] H-4 and H-5. [d] Relative intensities of signals H-4 : H-2 = 1 : 1.2.

Table 2 Reactions between NTZ and TBABH in various solvents, at 21 °C

Solvent = Me_2SO (λ = 390 nm[a])										
$[NTZ]_0 = 8.9 \times 10^{-5}$ mol dm^{-3}										
$10^3 \times [TBABH]_0$ mol dm^{-3}	0.958	1.05	1.39	1.79	2.02	2.13	2.61	2.75		
$10^3 \times k_{obs}$ s^{-1}	1.35	1.32	1.69	2.26	2.59	2.71	3.07	3.31		
$[TBABH]_0 = 1.3 \times 10^{-4}$ mol dm^{-3}										
$10^3 \times [NTZ]_0$ mol dm^{-3}	1.57	2.17	2.54	2.82						
$10^3 \times k_{obs}$ s^{-1}	2.34	3.20	3.71	4.02						
Solvent = toluene (λ = 390 nm[a])										
$[NTZ]_0 = 8.0 \times 10^{-5}$ mol dm^{-3}										
$10^3 \times [TBABH]_0$ mol dm^{-3}	1.96	2.48	3.30	4.46	5.27	5.61	6.48	6.71	7.50	8.15
$10^3 \times k_{obs}$ s^{-1}	2.70	3.01	3.74	4.73	5.32	5.56	6.03	6.25	6.66	7.05
Solvent = THF (λ = 398 nm[a])										
$[NTZ]_0 = 1.3 \times 10^{-4}$ mol dm^{-3}										
$10^3 \times [TBABH]_0$ mol dm^{-3}	2.02	2.40	3.04	3.64	4.03	4.45	4.73			
$10 \times k_{obs}$ s^{-1}	0.770	0.819	0.953	1.08	1.19	1.25	1.32			
$[NTZ]_0 = 1.3 \times 10^{-4}$ mol dm^{-3}; $[TBAB]$[b] $= 7.6 \times 10^{-3}$ mol dm^{-3}										
$10^3 \times [TBABH]_0$ mol dm^{-3}	1.98	2.63[c]	3.35	3.71	4.24	4.90[c]	5.55	5.70	6.72	7.20[c]
$10^2 \times k_{obs}$ s^{-1}	5.20	7.30	7.36	8.10	8.86	11.1	12.1	12.5	14.2	15.0
$[NTZ]_0 = 1.2 \times 10^{-4}$ mol dm^{-3}; $[TBABH]_0 = 1.6 \times 10^{-3}$ mol dm^{-3}										
$10^3 \times [TBAB]$[a] mol dm^{-3}	—	2.41	3.96	12.7						
$10^2 \times k_{obs}$ s^{-1}	6.17	6.06	5.95	5.15						

[a] Used in the determination. [b] TBAB = tetrabutylammonium bromide. [c] Tetradodecylammonium bromide, [TDAB] = 7.4×10^{-3} mol dm^{-3}.

may hardly be ascribed to the presence of impurities or to other processes, such as the reaction of the dimsyl anion arising from Me_2SO. In principle, the colour development in Me_2SO may be explained by the presence of a σ-anionic complex arising from a reaction of the methylsulfinate anion of Me_2SO.

$$CH_3\text{–}SO\text{–}CH_3 \rightleftharpoons CH_3\text{–}SO\text{–}CH_2^- + H^+$$

The ^{1}H NMR spectrum shows the presence of only the reported σ-anionic complexes: no other species are detectable either in the presence of 1 equiv. of water which probably shifts the equilibrium of formation of the methylsulfinyl anion toward Me_2SO. Kinetic constants (s^{-1}) were calculated from analytical data using the first-order equation and they are collected in Table 2 in Me_2SO, toluene and THF. Table 2 also collects kinetic data obtained in the presence of TBAB or of TDAB.

Table 3 collects data for NTBZ and TBABH and Table 4 reports the effect of the addition of Me_2SO to reactions between NTZ and TBABH in toluene.

k_{obs} (s^{-1}) Values, obtained under pseudomonomolecular conditions, are enhanced on increasing the initial value of the concentration of the reagent used in excess as required by the eqn. (1),[2] where $[R]_0$ is the initial concentration of the reagent

$$k_{obs} = k_{-1} + k_1[R]_0 \quad (1)$$

used in excess. k_1 and k_{-1} Values (calculated by the least-squares method) and $K = k_1/k_{-1}$ are collected in Table 5 together with some significant parameters.

As generally observed when equilbria like those of Schemes 1 and 2 are shifted strongly toward the σ-anionic complexes, the k_{-1} value is low and cannot be accurately determined (as indicated by high values of standard deviations). This is the case of reactions, here reported, in Me_2SO. However, the fact that very close values of k_1 and k_{-1} were calculated under both experimental conditions $[NTZ]_0 > [TBABH]_0$ and $[NTZ]_0 < [TBABH]_0$ (see Table 5) indicates this method as reliable for an approximate comparison of the differences in stability of the reported complexes. Other methods (previously reported also by us[3]) to evaluate K values cannot be used under the present experimental conditions (see Experimental section). Attempts to reveal the presence in the reaction mixtures of NBTZ and TBABH of products of ring-opening processes[10] by adding to the reaction mixtures methyl iodide (or benzyl bromide) afforded starting NBTZ and compounds **4**. In particular, when the reaction mixture of NBTZ and TBABH (in Me_2SO) after long reaction times, is poured into a water–methanol mixture, and in the presence of methyl iodide, a yellow

Table 3 Reactions between NBTZ and TBABH in various solvents, at 21 °C

Solvent = Me_2SO (λ = 506 nm[a])							
$[NBTZ]_0 = 4.1 \times 10^{-5}$ mol dm^{-3}							
$10^2 \times [TBABH]_0$ mol dm^{-3}	1.91	2.10	2.39	2.76	3.02	3.43	3.68
$10^4 \times k_{obs}$ s^{-1}	0.964	1.06	1.21	1.40	1.51	1.60	1.74
$[NBTZ]_0 = 4.1 \times 10^{-5}$ mol dm^{-3} (λ = 292 nm[b])							
$10^3 \times [TBABH]_0$ mol dm^{-3}	2.52	2.93	3.81	5.15			
$10^4 \times k_{obs}$ s^{-1}	0.12	0.13	0.161	2.25			
Solvent = THF (λ = 491 nm[a])							
$[TBABH]_0 = 4.2 \times 10^{-5}$ mol dm^{-3}							
$10^3 \times [NBTZ]_0$ mol dm^{-3}	0.416	1.06	1.68	2.13	3.19	3.70	4.25
$10^3 \times k_{obs}$ s^{-1}	1.99	3.33	5.20	6.09	9.13	9.37	11.0
$[TBABH]_0 = 4.2 \times 10^{-5}$ mol dm^{-3} [TBAB] = 1.25×10^{-3} mol dm^{-3}							
$10^3 \times [NBTZ]_0$ mol dm^{-3}	0.841	1.68	2.64	3.17			
$10^3 \times k_{obs}$ s^{-1}	1.86	3.16	5.27	6.32			

[a] Used in the determination. [b] Used in the determination by following the disappearance of the starting material.

Table 4 Reactions between NTZ and TBABH in toluene and in the presence of Me_2SO

$[NTZ]_0 = 5.4 \times 10^{-4}$ mol dm^{-3}; $[TBABH]_0 = 1.07 \times 10^{-3}$ mol dm^{-3}							
$[Me_2SO]_0$ % (by vol.)	0.0[a]	10.0	20.0	30.0	32.5	35.0	40.0
$10^3 \times k_{obs}$ s^{-1}	21.6	11.0	7.90	6.80	6.17	5.81	5.70

$[Me_2SO]_0$ % (by vol.)	45.0	50.0	75.0	85.0	95.0	100
$10^2 \times k_{obs}$ s^{-1}	5.30	4.21	2.83	2.66	2.13	2.16[a]

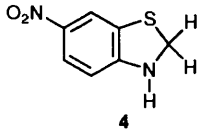
[a] Extrapolated value from data of Table 2.

Table 5 Kinetic and equilibrium constants for the reactions between NTZ, NBTZ and TBABH at 21 °C

Substrate	Solvent[a]	k_1[b]/s^{-1} mol^{-1} dm^3	k_{-1}[b]/s^{-1}	K/mol^{-1} dm^3	r[c]	n[d]
NTZ	Toluene	7.2 ± 0.2	(1.4 ± 0.1) × 10^{-2}	5.2 × 10^2	0.996	10
NTZ	THF	20.8 ± 0.6	(3.3 ± 0.2) × 10^{-2}	6.3 × 10^2	0.998	7
NTZ	THF[e]	19.8 ± 0.8	(9.0 ± 3) × 10^{-2}	2.2 × 10^3	0.996	7
NTZ	Me_2SO	1.14 ± 0.05	(2.01 ± 0.05) × 10^{-4}	5.7 × 10^3	0.995	8
NTZ	Me_2SO[f]	1.36 ± 0.04	(2.29 ± 1) × 10^{-4}	5.9 × 10^3	0.999	4
NBTZ	THF[g]	2.36 ± 0.091	(1.05 ± 0.2) × 10^{-3}	2.1 × 10^3	0.996	7
NBTZ	THF[g,h]	1.95 ± 0.1	(1 ± 2) × 10^{-4}[i]	1.9 × 10^4	0.997	4
NBTZ	Me_2SO	(4.29 ± 0.2) × 10^{-3}	(1.73 ± 0.6) × 10^{-5}	2.5 × 10^2	0.993	7

[a] $[TBABH]_0 > [NTZ]_0$, unless otherwise indicated. [b] Errors are standard deviations. [c] Correlation coefficient. [d] Number of points. [e] In the presence of TBAB, [TBAB] = 7.6 × 10^{-3} mol dm^{-3}. [f] $[TBABH]_0 < [NTZ]_0$. [g] $[TBABH]_0 < [NBTZ]_0$. [h] In the presence of TBAB, [TBAB] = 1.25×10^{-3} mol dm^{-3}. [i] Approximate value.

solid precipitates. Structure **4** may be attributed to this solid on the basis of the spectroscopic properties (see Experimental section).



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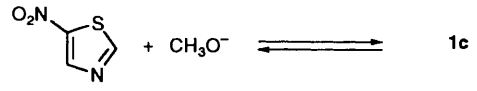
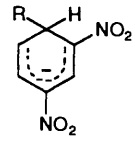
When dilute sulfuric acid is added to the reaction mixtures immediately after reaching the infinite time, the UV–VIS spectrum reveals only the presence of starting thiazole derivatives.

Discussion

The ability of NTZ to support negative charge is very high. For the equilibrium in Scheme 3 (in methanol) we found[9] K = 7×10^2 dm^3 mol^{-1}, a value near that reported in Table 5 for the reaction of TBABH. The stability of the σ-anionic complex **5a** obtained from 1,3-dinitrobenzene and sodium methoxide was evaluated at 10^{-6} dm^3 mol^{-1}.[11]



Scheme 3



5a R = CH_3O
b R = H

The stability of the σ-anionic complex **5b** obtained from 1,3-dinitrobenzene and TBABH is 6 × 10^3 dm^3 mol^{-1} both in THF and Me_2SO[3].

Usually the aza activation toward S_NAr reactions is roughly comparable with the nitro-activation. The stability of the σ-complex NTZ–TBABH parallels the stability of the complex 1,3-dinitrobenzene–TBABH. On the contrary, the stability of the respective σ-anionic complexes with sodium methoxide shows a very wide aza:nitro ratio (*ca.* 10^8). One can conclude that the usual idea that negative charge delocalization explains

the relative stability of σ-anionic complexes needs to be revisited. There are clearly important parameters, external to the intrinsic power of the substrate, that support the negative charge.

As observed previously,[6] methanol may play an important role in enhancing the reactivity of aza activated substrates. When the negative charge is from TBABH, the relative power of the substrate to support the negative charge is less important, probably because the residual boron derivative is involved in stabilizing the σ-complex, probably by an interaction between aza nitrogen and BH_3. This interaction may explain the formation of **4** when the reaction is quenched with a proton donor system (see Experimental section). This fact was well observed for the stability of the σ-complexes of 1,3-dinitrobenzene and 1,3,5-trinitrobenzene with TBABH: the σ-complex of trinitrobenzene is as stable as the σ-complex of dinitrobenzene (or slightly less stable).

The reported comparison indicates that the reactivity of TBABH is governed by parameters other than the more usual nucleophiles: the presence of BH_3 and strong interactions with the solvents may explain the considerable differences observed.

In principle, it is possible that the nucleophile attacks NTZ derivatives in position 2 or in position 4 of the thiazole ring, yielding σ-complexes 1 or 2 respectively (Scheme 1). Recently,[9] we reported that the reactions of 2-X-5-nitrothiazole with sodium methoxide (in methanol) afford the σ-complex in position 2 when X = H and in position 4 when X = OCH_3. In homocyclic nitro-methoxy derivatives the attack of the nucleophile on an unsubstituted carbon is a faster process[2,12] than the attack on a substituted carbon because steric hindrance depresses the rate of the attack on the substituted carbon. It is important to observe that complex **1c** of Scheme 1 was obtained from NTZ and sodium methoxide (in methanol) and is a stable complex, but under the present experimental conditions in the mixture of the reactions between 2-methoxy-5-nitrothiazole and TBABH in Me_2SO it, like complex **2c**, was not observed.

The unsubstituted NTZ reacts with TBABH at C-2 which may be the more activated centre.[13] When C-2 bears substituents (methoxy, halogen) the hydride ion prefers the slow attack on unsubstituted C-4, but the attack on this position is followed by ring-opening reactions,[10] with consequent formation of tars in fast steps. Probably the nucleophile is scarcely prone to attack on position 4 of NTZ and may offer some steric (or electronic) hindrance.

Comparison between sodium methoxide and TBABH affords the same conclusions. Considering the reactions between 5-nitro-2-halogenothiazole and sodium methoxide, a considerable amount of substition product (5-nitro-2-methoxythiazole and its σ-anionic adduct) was observed in the reaction mixtures also in the presence of an excess of sodium methoxide. When 5-nitro-2-halogenothiazoles reacted with TBABH, in the reaction mixtures the substitution product (NTZ) (or its σ-complexes) was not observed. Even if the reported observations are from a qualitative point of view, it must be noted that TBABH is a nucleophile which is more sensible than sodium methoxide to the steric hindrance of the reaction centre.

This explanation implies that the H^- cannot be considered a naked hydride ion (which is the most polarizable nucleophile and obviously less bulky), but that there is a carrier bonded to it. Steric hindrance also strongly reduces the carbonyl reactivity in the reaction of reduction of aldehydes and ketones with borohyrides.[14]

The effect of changing the solvent deserves some comment. The reactivity order of k_1 (see Table 5) for NTZ is: THF > TOL (toluene) > Me_2SO ($k_1^{Me_2SO}:k_1^{TOL}:k_1^{THF}$ = 1:6:18). The ratio $k_1^{THF}:k_1^{Me_2SO}$ = 465 was calculated for NBTZ. The same trend was observed for reactions between 1,3-dinitrobenzene and TBABH in the same solvents.[3] On this basis, initial additions of Me_2SO depress k_{obs} values (see Table 4). Usually Me_2SO is a powerful solvent in enhancing the reactions of anionic nucleophiles (the present trend is unusual in nucleophilic aromatic substitution reactions). Generally this fact is explained by the high polarity of Me_2SO which stabilizes charge separation from neutral reagents[15] and by the ability of Me_2SO to solvate the counter ion of anionic nucleophiles. In the present case the k_1 value is scarcely affected by changes of polarity of medium: addition of tetraalkylammonium bromides in THF (see Table 5) produces feeble changes on k_1. k_{-1} Is poorly depressed by salt addition. An increase of medium polarity slightly reduces the rate of attack of the nucleophile when the charge is less delocalized in the starting reagents than the transition state toward the products of the reactions.[16,17] However, simple changes in the polarity of the medium hardly explain the lack of the usual enhancement of reactivity of the anionic nucleophiles related to use of Me_2SO. As observed previously,[3] poor reactivity in Me_2SO may be explained by considering the possibility that Me_2SO acts as a bulk carrier of the hydride ion. It is of interest to emphasize that often the reactivities in Me_2SO of anionic nucleophiles are compared with reactivities in protic solvents (alcohols) which are highly prone to solvate the negative charge of the nucleophile. Consequently the ability of Me_2SO to enhance the nucleophilic power of anionic nucleophiles may be overestimated with respect to aprotic solvents.

The stability of σ-anionic complexes is reported to be enhanced by dipolar aprotic solvents.[2,18] In the present case (see Table 5) the trend $K_{TOL} < K_{THF} < K_{Me_2SO}$ is observed but the increase of polarity produces a moderate stabilization of σ-complex ($K_{TOL}:K_{THF}:K_{Me_2SO}$ = 1:1.2:11). This trend agrees with the effect of the addition of tetraalkylammonium bromide: in THF the increase to medium polarity produces a feeble decrease in the K value: $K_{TBAB}:K$ = 1:2.9.

Apparently, the effect of benzocondensation is unexpected: $k_1^{NTZ}:k_1^{NBTZ}$ = 275 in Me_2SO. Usually benzothiazole derivatives are more reactive towards nucleophilic reagents than thiazole derivatives: for the methoxy-dehalogenation $k^{2\text{-chlorobenzothiazole}}:k^{2\text{-chlorothiazole}}$ = 416;[19,7] for thiophenoxy-dehalogenation $k^{2\text{-chlorobenzothiazole}}:k^{2\text{-chlorothiazole}}$ = 422;[19] for alkoxy substitution of 2-nitrothiazole and of 2-nitrobenzothiazole with sodium methoxide and sodium *tert*-butoxide,[6] $k^{2\text{-nitrobenzothiazole}}:k^{2\text{-nitrothiazole}}$ are 2×10^3 and 2.8×10^3, respectively. Similar behaviour was reported for benzocondensation of the pyridine system: for the methoxy dehalogenation reaction the ratio $k^{2\text{-chloroquinoline}}:k^{2\text{-chloropyridine}}$ = 655 (ref. 20) was reported. On the contrary, when the thiazole ring is activated directly by the nitro group, the ratio $k^{benzothiazole}:k^{thiazole}$, favours the thiazole derivative as for thiophenoxydehalogenation in MeOH: $k^{6\text{-nitro-2-chlorobenzothiazole}}:k^{5\text{-nitro-2-chlorothiazole}}$ = 0.0020.[19,7] The high reactivity of NTZ in comparison with the reactivity of NBTZ may be attributed to the electron-withdrawing power of the nitro group which is more able to support the negative charge on the small-sized pentaatomic heterocycle than on the benzocondensed system.

This ratio confirms that the reactivity of TBABH is a particular instance of the usual nucleophilic attack on aromatic activated carbon and well agrees with previous findings. Usually 1,3,5-trinitrobenzene is more activated than 1,3-dinitrobenzene toward nucleophilic reagents, but it is slower than 1,3-dinitrobenzene toward TBABH.

Experimental

NTZ, 2-methoxy-5-nitrothiazole, 2-chloro(bromo)-5-nitrothiazole and NBTZ were prepared and purified according to literature.[7,9,21] TBABH (Fluka) was a commercial sample purified by recrystallization from AcOEt. Toluene, THF,

Me_2SO, were commercial specimens purified by usual procedures.[22]

6-Nitro-2,3-dihydrobenzothiazoline **4**. To a solution of NBTZ (0.40 g in 10 cm^3 of Me_2SO), TBABH (0.55 g) in 5 cm^3 of Me_2SO is added under vigorous stirring. Immediately the reaction mixture becomes dark-red. After a few minutes the reaction mixture was poured into 20 cm^3 of methanol–ice–methyl iodide mixture. A yellow solid precipitated. Yield = 90%. M.p. 163–164 °C (from methanol). $\lambda_{max}(Me_2SO)$ = 434 nm ($\log \varepsilon$ = 4.622); M^+ = 182 *m/z*; $\delta_H(CDCl_3)$ 5.11 (s, 2 H, 2-H), 6.50 (m, 1 H, 4-H), 7.8–7.9 (m, 2 H, 5-H and 6-H) and 4.75 (br s, 1 H, N–H, D_2O exch.); $\delta_H([^2H_6]Me_2SO)$ 5.10 (s, 2 H, 2-H), 6.52 (m, 1 H, 4-H) and 7.7–7.9 (m, 3 H, 5- H, 6-H and N-H).

^1H *NMR*. Spectra were recorded with a Varian Gemini 200 MHz spectrometer. The signals reported in Table 4 were assigned on the basis of chemical shifts by comparison with literature information.[2] $[^2H_6]Me_2SO$, $[^2H_8]THF$ (Carlo Erba) were used without purification.

Kinetics. Kinetic runs were performed by following the appearance of σ complexes with UV–VIS Perkin-Elmer (model Lambda 5) spectrophotometer or (as appropriate) with a stopped-flow spectrophotometer (Hi-Tech. Scientific) with a spectrascan accessory. All the runs followed first-order kinetics to a high percent of conversion. Addition of acetic acid to the reaction mixtures produces colour fading. The wavelength used in the kinetic determinations was chosen to minimize the absorbance values of starting materials. In all other cases, k_{obs} reproducibility was ± 3%.

Attempts to obtain *K* values from absorbance values of the reaction mixtures at infinite reaction time, failed: the reproducibility of the absorbance value was unsatisfactory, probably because of the poor stability of the solutions at infinite time.[3]

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