

# Reactions of haloarenes, haloheteroarenes and dihalobenzenes with triphenylstannyl anions in DMSO and acetonitrile

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## Abstract

We studied different haloarenes, haloheteroarenes and dihalobenzenes with  $\text{Ph}_3\text{Sn}^-$  ions in DMSO or acetonitrile ( $\text{CH}_3\text{CN}$ ) as solvents, in the dark or under irradiation to determine whether the halogen metal exchange (HME) reaction or the  $\text{S}_{\text{RN}}1$  process prevails. With *p*-chloroanisole the photostimulated reaction is sluggish in DMSO. There is an HME reaction with 2- and 3-chlorothiophene. Bromoarenes (*p*-bromoanisole, *p*-dibromobenzene and 1-bromonaphthalene) and *p*-iodoanisole react with  $\text{Ph}_3\text{Sn}^-$  ions faster by an HME mechanism than by the  $\text{S}_{\text{RN}}1$  process. In the photostimulated reaction of 1-chloronaphthalene, 2-chloro and 3-chloropyridines with  $\text{Ph}_3\text{Sn}^-$  ions in DMSO, the substitution products are obtained in 72, 82 and 93% yields, respectively. With *p*-dichlorobenzene the di-substitution product is obtained in 90% yield. All these reactions occur by the  $\text{S}_{\text{RN}}1$  mechanism. Yields improve when the reactions are carried out in DMSO rather than in  $\text{CH}_3\text{CN}$ . © 1999 Elsevier Science S.A. All rights reserved.

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## 1. Introduction

The reaction of triorganostannyl ions as nucleophiles with haloarenes has long been known, and the products obtained depend on the nucleophile, solvent and on reaction conditions. Thus, the reaction of sodium trimethyltin ( $\text{Me}_3\text{SnNa}$ ) with halobenzenes (chloro, bromo and iodo) in tetraglyme gives phenyltrimethyltin ( $\text{Me}_3\text{SnPh}$ ) and variable amounts of the reduction product benzene together with diphenyldimethyltin ( $\text{Ph}_2\text{SnMe}_2$ ) and tetramethyltin ( $\text{Me}_4\text{Sn}$ ). From trapping experiments and solvent effects it has been proposed that the reaction occurs by a halogen metal exchange (HME) in a solvent cage. The formation of the by-products  $\text{Ph}_2\text{SnMe}_2$  and  $\text{Me}_4\text{Sn}$  has been ascribed to the decomposition of  $\text{Me}_3\text{SnNa}$  into  $\text{MeNa}$  and dimethylstannylene [1]. The reaction of *o*-dibro-

mobenzene with  $\text{Me}_3\text{SnNa}$  yields the disubstitution product *o*-bis(trimethylstannyl)benzene in 42%, but part of the intermediate *o*-bromophenyl anion decomposes into benzyne, which then is trapped with furan to give the corresponding Diels–Alder adduct [2].

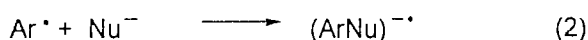
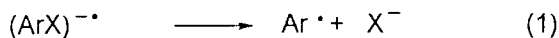
The reaction of *o*-, *m*- and *p*-bromotoluenes with  $\text{Bu}_3\text{SnLi}$  in THF affords the straightforward substitution product, but with *p*-chloro and *p*-fluorotoluenes cine substitution products are formed, indicating that a benzyne mechanism operates. When radical traps were added, more cine substitution products were obtained, and in the presence of lithium metal, the yield of the ipso products increased. According to these results the reaction should occur at least in part, by a radical mechanism [3].

We have described previously the photostimulated reactions of haloarenes with  $\text{Me}_3\text{SnNa}$  and  $\text{Ph}_3\text{SnNa}$  [4] and other nucleophiles derived from tin [5] in liquid ammonia that give good to excellent yields of nucleophilic substitution products by the  $\text{S}_{\text{RN}}1$  mechanism [6]. This mechanism is a chain process, whose main steps are presented in Scheme 1.

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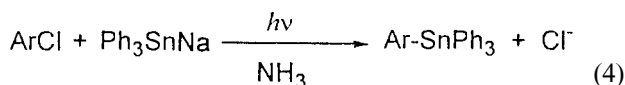
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Scheme 1.

Overall, Eqs. (1)–(3) depict a nucleophilic substitution in which radical and radical anions are intermediates. This chain process requires an initiation step. In a few systems, spontaneous electron transfer (ET) from the nucleophile to the substrate has been observed. When the ET does not occur spontaneously, it can be induced by light stimulation [6].

The photostimulated reactions of chloroarenes (ArCl) with  $\text{Ph}_3\text{Sn}^-$  ions give the substitution products in high yields (70–100%) (Eq. (4)) [4], whereas variable results are obtained with ArBr [4].



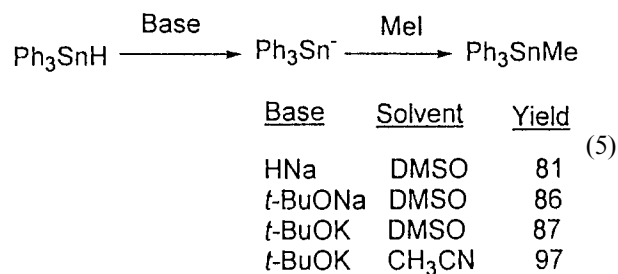
Ar=*p*-tolyl, 1-naphthyl, 2-quinoly

Thus, *p*-bromotoluene (*p*-BrTo) gave the substitution product *p*-tolyltriphenyltin in 62% yield, but with *p*-dibromobenzene, there is a fast HME reaction to give PhBr, and after irradiation the disubstitution product is obtained in only 22% yield, together with tetraphenyltin, which arises from the reaction of the PhBr formed and  $\text{Ph}_3\text{Sn}^-$  ions. With no photostimulation, *p*-dibromobenzene and  $\text{Ph}_3\text{Sn}^-$  ions afforded 96% yield of PhBr. With ArI as substrates, the main reaction with  $\text{Ph}_3\text{Sn}^-$  ions was the HME.

Now we report on the reactions of several haloarenes, heteroarenes and dihalobenzenes with  $\text{Ph}_3\text{Sn}^-$  ions under photostimulated as well as in the dark in DMSO and acetonitrile ( $\text{CH}_3\text{CN}$ ) in order to compare the reactivity in these solvents [7]. The competing HME and  $\text{S}_{\text{RN}}1$  pathways in DMSO and  $\text{CH}_3\text{CN}$  will be confronted with results obtained in liquid ammonia. These studies can be of interest not only from the mechanistic point of view, but also as a synthetic route to organotin and organoditin compounds with mixed organic ligands. The increasing importance of organostannane compounds in recent years comes from their suitability as substrates for the palladium catalyzed reactions, such as the Stille reaction [8].

## 2. Results and discussion

In order to know the yield of formation of  $\text{Ph}_3\text{Sn}^-$  ions in DMSO and  $\text{CH}_3\text{CN}$ , we studied the reactions of different bases with triphenyltin hydride ( $\text{Ph}_3\text{SnH}$ ), and the resulting  $\text{Ph}_3\text{Sn}^-$  ions were trapped with methyl iodide and quantified [9]. The results are in Eq. (5).



From these results, we synthesized  $\text{Ph}_3\text{Sn}^-$  ions with *t*-BuOK in DMSO and in  $\text{CH}_3\text{CN}$ .

In the treatment of aromatic halides with this nucleophile, they behaved in different ways. Some of them reacted very sluggishly in the dark or under irradiation. Others reacted in the dark to give the reduction product by an HME reaction, and others were completely unreactive in these experimental conditions. However, they reacted under irradiation to give the substitution product by the  $\text{S}_{\text{RN}}1$  mechanism.

### 2.1. Reactions of aromatic halides with $\text{Ph}_3\text{Sn}^-$ ions in the dark

The reaction of *p*-BrTo in liquid ammonia (2 h of irradiation) renders the substitution product in 62% yield. When *p*-IAN was used (1 h of irradiation) only 20% of the substitution product was obtained [4]. In this case the HME is faster than the  $\text{S}_{\text{RN}}1$  reaction [10]. The reactions of *p*-BrAn and *p*-IAN in the dark or under irradiation lead only to dehalogenation products in DMSO (Table 1, Experiments 1–2). The fact that ArBr reacts in liquid ammonia by the  $\text{S}_{\text{RN}}1$  mechanism, but in DMSO it does so by an HME process may be due to the ca. 60°C difference between liquid ammonia (–33°C) and DMSO (r.t.), which suffice to overcome the barrier for the activation energy in the HME process.

With 1-bromonaphthalene, only traces of the substitution product were obtained, the main product being naphthalene both in  $\text{CH}_3\text{CN}$  and DMSO. In order to know if this dehalogenation occurs with radicals as intermediates, we did the reaction under the same experimental conditions, but with the addition of galvinoxyl. However, the result was the same, indicating that the dehalogenation occurs by an HME (Table 1, Experiments 3–5).

The reaction of 2-chlorothiophene with  $\text{Ph}_3\text{Sn}^-$  gives only the reduction product, either in the dark or under

Table 1  
HME reactions of haloarenes, haloheteroarenes and dihalobenzenes with  $\text{Ph}_3\text{SnK}$  ions in DMSO<sup>a</sup>

Experiment	Substrate <sup>b</sup>	Time (h)	Ar-H, Yield, (%) <sup>c</sup>
1	<i>p</i> -BrAn	1	58 <sup>d</sup>
2	<i>p</i> -IAn	0.5	90
3	1-BrNaph	1	72
4	1-BrNaph	1 <sup>e</sup>	56
5 <sup>f</sup>	1-BrNaph	1	69
6	2-ClTiop	4	76
7	3-ClTiop	17 <sup>g</sup>	57
8	<i>m</i> -DCB	7	3
9	<i>o</i> -DCB	7	48
10	<i>o</i> -DCB	7	52
11	<i>p</i> -DBB	7	93 <sup>h</sup>

<sup>a</sup> In dark conditions. Substrate concentration 0.051 M;  $\text{Ph}_3\text{SnK}$  concentration 0.061 M.

<sup>b</sup> *p*-Haloanisole: *p*-XAn; 1-bromonaphthalene: 1-BrNaph; 2- and 3-chlorothiophene: 2- and 3-ClTiop; *m*-dichlorobenzene: *m*-DCB; *o*-dichlorobenzene: *o*-DCB; *p*-dibromobenzene: *p*-DBB.

<sup>c</sup> Determined by GLC.

<sup>d</sup> The reactions with *o*- and *m*-bromo anisoles give the same results.

<sup>e</sup> In  $\text{CH}_3\text{CN}$ .

<sup>f</sup> Galvinoxyl was added (30 mol.%).

<sup>g</sup> At 50°C. At room temperature and 10 h there is no reaction.

<sup>h</sup> The reduction product was benzene.

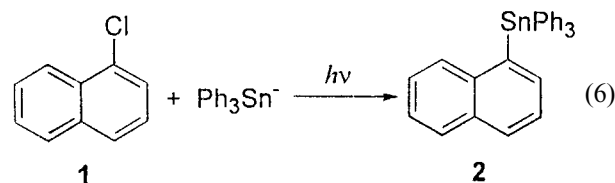
irradiation. 3-Chlorothiophene does not react (10 h, r.t.), but in 17 h at 50°C, 57% of dehalogenation was found (Table 1, Experiments 6–7).

*p*-Dichlorobenzene does not react in the dark, but it reacts under irradiation (vide infra). Different results were found when *m*-dichlorobenzene was used, that was completely unreactive upon irradiation (7 h) in DMSO and  $\text{CH}_3\text{CN}$ . With *o*-dichlorobenzene as substrate, it was dehalogenated partially in DMSO. With *p*-dibromobenzene only benzene was formed (96% yield) (Table 1, Experiments 8–11).

## 2.2. Reactions of aromatic halides with $\text{Ph}_3\text{Sn}^-$ ions under irradiation

All the substrates that did not react in the dark were irradiated to know if they can react by the  $\text{S}_{\text{RN}}1$  mechanism. There is no reaction of  $\text{PhCl}$  and  $\text{Ph}_3\text{Sn}^-$  ions in the dark neither under irradiation ( $h\nu$ , DMSO, 8 h). With *p*-chloroanisole (*p*-ClAn) there is no reaction in the dark (24 h), but under irradiation (8 h) it affords 10% of the substitution product. The yield increases up to 30% in 24 h under the same experimental conditions. With *t*-BuONa used as a base, only 21% yield of *p*-AnSnPh<sub>3</sub> is obtained (Table 2, Experiments 1–2). These results indicate that *t*-BuOK gives better yields than when  $\text{Na}^+$  is the counter ion. The reaction of *p*-chlorotoluene (*p*-ClTo) in liquid ammonia (2 h of irradiation) affords the substitution product in 75% yield, indicating that chloroarenes react in this solvent, and much more slowly in DMSO.

There is no reaction of 1-chloronaphthalene (**1**) in the dark (4 h) in DMSO, but under irradiation (4 h) the substitution product **2** was obtained in 72% yield (Eq. (6)). The photostimulated reaction was inhibited by *p*-DNB, a very well-known inhibitor of  $\text{S}_{\text{RN}}1$  reactions [6] (Table 2, Experiments 3–5).



Also there was no reaction in the dark when  $\text{CH}_3\text{CN}$  is used as solvent, and under irradiation it gives **2** in low yields; the reduction product naphthalene being obtained in 10% yield. The photostimulated reaction was inhibited by *p*-DNB (Table 2, Experiments 6–8). The hydrogen abstraction by aryl radicals from  $\text{CH}_3\text{CN}$  is slightly faster than the abstraction of hydrogen from DMSO [11]. For instance, 1-naphthyl radicals react 2.3 times faster with  $\text{CH}_3\text{CN}$  than with DMSO, and for that reason naphthalene was found as product in the former solvent. Despite this fact, it has been found that

Table 2

$\text{S}_{\text{RN}}1$  reactions of haloarenes, haloheteroarenes and dihalobenzenes under irradiation with  $\text{Ph}_3\text{SnK}$  ions in DMSO and  $\text{CH}_3\text{CN}$ <sup>a</sup>

Experiment	Substrate <sup>b</sup>	Solvent	Conditions (h)	Ar-SnPh <sub>3</sub> , Yield (%) <sup>c</sup>
1	<i>p</i> -ClAn	DMSO	$h\nu$ , 8	10
2	<i>p</i> -ClAn	DMSO	$h\nu$ , 24	30 <sup>d</sup>
3	<b>1</b>	DMSO	Dark, 4	0
4	<b>1</b>	DMSO	$h\nu$ , 4	72
5	<b>1</b>	DMSO	$h\nu$ , 4 <sup>e</sup>	31
6	<b>1</b>	$\text{CH}_3\text{CN}$	Dark, 4	0
7	<b>1</b>	$\text{CH}_3\text{CN}$	$h\nu$ , 4	55 <sup>f</sup>
8	<b>1</b>	$\text{CH}_3\text{CN}$	$h\nu$ , 4 <sup>e</sup>	34 <sup>g</sup>
9	<b>3a</b>	DMSO	Dark, 6	4
10	<b>3a</b>	DMSO	$h\nu$ , 6	82
11	<b>3a</b>	DMSO	$h\nu$ , 6 <sup>e</sup>	39
12	<b>3a</b>	$\text{CH}_3\text{CN}$	Dark, 6	0
13	<b>3a</b>	$\text{CH}_3\text{CN}$	$h\nu$ , 6	73
14	<b>3b</b>	DMSO	Dark, 5	0
15	<b>3b</b>	DMSO	$h\nu$ , 6	93
16	<b>5</b>	DMSO	Dark, 7	32 <sup>h</sup>
17	<b>5</b>	DMSO	$h\nu$ , 7	90 <sup>h</sup>
18	<b>5</b>	DMSO	$h\nu$ , 7 <sup>e</sup>	59 <sup>h</sup>
19	<b>5</b>	$\text{CH}_3\text{CN}$	$h\nu$ , 7	44 <sup>h,i</sup>

<sup>a</sup> Substrate concentration 0.051 M;  $\text{Ph}_3\text{SnK}$  concentration 0.061 M.

<sup>b</sup> *p*-Chloroanisole: *p*-ClAn.

<sup>c</sup> Determined by GLC.

<sup>d</sup> In the dark (24 h) there is no reaction. With  $\text{Na}^+$  as counter ion the yield was 21% (24 h).

<sup>e</sup> *p*-DNB was added (20 mol.%).

<sup>f</sup> Naphthalene (10%).

<sup>g</sup> Naphthalene (9%).

<sup>h</sup> Disubstitution product **6**.

<sup>i</sup> Isolated yield.



straction reaction by aryl radicals from  $\text{CH}_3\text{CN}$  competes with the coupling reaction with  $\text{Ph}_3\text{Sn}^-$  ions.

## 4. Experimental

### 4.1. General methods

Irradiation was conducted in a reactor equipped with four 250 W UV lamps emitting maximally at 350 nm (Philips model HPT, water-refrigerated).

### 4.2. Materials

Reagents were available commercially and were used as received, unless otherwise indicated.  $\text{Ph}_3\text{SnH}$  was prepared by the reaction of  $\text{Ph}_3\text{SnCl}$  (Fluka) and  $\text{LiAlH}_4$  as reported [14]. DMSO and  $\text{CH}_3\text{CN}$  were vacuum distilled from  $\text{CaH}_2$  and stored with molecular sieves. The products were quantified by glc with the internal standard method, compared with an authentic sample. *p*-Anisyltriphenyltin [15], *p*-bis(triphenylstannyl)benzene [16], 2-pyridyltriphenyltin [17] and 3-pyridyltriphenyltin [17] were synthesized by known methods.

### 4.3. Photostimulated reaction of **1** with $\text{Ph}_3\text{SnK}$ in DMSO

The following procedure is representative of all the reactions. The reactions were carried out in a two-necked 50 ml, round-bottomed flask equipped with a nitrogen inlet, and a magnetic stirrer, and the outlets were sealed with septa. Then, 0.78 mmol of  $\text{Ph}_3\text{SnH}$  in 10 ml of degassed DMSO was added by syringe followed by *t*-BuOK (0.8 mmol). Then a solution of 0.082 ml (0.6 mmol) of **1** in 1 ml of DMSO was added. The solution was irradiated 4 h under continuous stirring. The reaction was quenched by the addition of methyl iodide in excess and 10 ml of water, and then extracted with diethyl ether. The products were quantified by GLC with the internal standard method (72% yield), compared with an authentic sample synthesized by a known procedure [18].

### 4.4. Reaction of **1** with $\text{Ph}_3\text{SnK}$ in DMSO in the dark

The procedure was similar to that for the previous reaction. In this case, however, the reaction flask was wrapped with aluminium foil.

### 4.5. Photostimulated reaction of **1** with $\text{Ph}_3\text{SnK}$ in DMSO in the presence of *p*-DNB

The procedure was similar to that for the previous reaction, except that in this case 20 mol.% of *p*-DNB

was added to the solution of the nucleophile before substrate addition.

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