Triorganostannylation of Halo- and Dihaloadamantanes and 5-Chloro-2-adamantanone in Liquid Ammonia by the $S_{RN}1$ Mechanism. Relative Reactivity of Nucleophiles and Bridgehead Halides

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The reactions of 1-bromo-, 1-iodo-, 2-bromo-, 1,3-dibromo-, and 1,4-dibromoadamantane with Me_3Sn^- ions were studied in liquid ammonia. The photostimulated reaction of 1-haloadamantane (1-XAd, X = Br, I) or 2-BrAd with Me_3Sn^- ions gave in a few minutes excellent yields of the substitution products. The 1,3-dibromo- and 1,4-dibromoadamantane with Me_3Sn^- ions also reacted very fast under irradiation to give the disubstitution product in good yields. In competition experiments, 1-ClAd is 5.3 times more reactive than 5-chloro-2-adamantanone (**9**) toward Me_3Sn^- ions in liquid ammonia. When the nucleophile is the Ph_2P^- ion, 1-ClAd reacts 2.4 times faster than **9**. This is the first time that no redox catalysis was observed when the bridgehead compound bears a carbonyl group as a π acceptor. On the other hand, the nucleophile Me_3Sn^- ion was ca. >1000 times more reactive than Ph_3Sn^- ions toward 1-adamantyl radicals, in contrast to the behavior of aryl radicals, where both nucleophiles have the same reactivity.

Introduction

The formation of tetraalkyltin compounds by the reaction of alkyl halides with alkali-metal triorganotin compounds has long been known, and the products obtained depend on the leaving group, the nucleophile, solvent, and the reaction conditions, and it has been proposed that they react by S_N2, electron transfer (ET) or halogen−metal exchange (HME) mechanisms.[1]

The reactivity of the bridgehead halides with different nucleophiles depends on the strain energy, the nature of the leaving group, the nucleophiles, and the solvent. Bridgehead halides have a high-energy barrier for a polar mechanism due to strain factors, and some of these halides have been found to react by the ET mechanism.[2] The mechanism of radical nucleophilic substitution, or $S_{RN}1$, is one of the reactions that proceed by ET reaction. In the initiation step, when there is no spontaneous ET from the nucleophile to the substrate, the process can be catalyzed by photostimulation[2] or by $FeBr_2$ in DMSO,[3] The alkyl radical $R^\bullet$ thus formed couples with the Nu^- to yield a radical anion $(RNu)^{\bullet-}$ (eq 1), which by an intermolecular dissociative ET[4] to the substrate gives the substitution product and the radical $R^\bullet$, that propagates the chain propagation cycle (eq 2).

$$R^\bullet + Nu \rightarrow (RNu)^{-\bullet} \qquad (1)$$

$$(RNu)^{-\bullet} + RX \rightarrow RNu + R^\bullet + X^- \qquad (2)$$

1-Iodoadamantane (1-IAd) as well as other bridgehead halides are known to react with Ph_2P^-, PhS^-, $PhSe^-$, $PhTe^-$ ions or carbanions by the $S_{RN}1$ mechanism.[2] Carbonylation of 1-XAd has been suggested to occur by the $S_{RN}1$ mechanism.[5] A nonchain $S_{RN}1$ process has been proposed by the photostimulated reaction in MeCN of 1-IAd with arenethiolate ions.[6]

It has been reported that trimethylstannylation of 1-BrAd, 2-BrAd, or 1-IAd with $NaSnMe_3$ in THF proceeds predominantly by a free radical process.[1a,7]

We have previously described the photostimulated reaction of Me_3Sn^- ions with 1-ClAd and 2-ClAd in liquid ammonia, which afforded substitution products in very good yields of substitution by the $S_{RN}1$ mechanism.[8]

1,3-Dihaloadamantanes, upon reaction with $NaSnMe_3$ in THF, afford 1,3-dehydroadamantane (propellane) and 1,3-bis(trimethylstannyl)adamantane, depending on the halogen leaving groups.[9] The 1,3-dibromoadamantane gave 52% of disubstitution product by the $S_{RN}1$ mecha-

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(1) (a) Smith, G. F.; Kuivila, H. G.; Simon, R.; Sultan, L. *J. Am. Chem. Soc.* **1981**, *103*, 833−839. (b) Ashby, E. C.; Su, W. Y.; Pham, T. N. *Organometallics* **1985**, *4*, 1493−1501. (c) Ashby, E. C.; DePriest, R. N.; Su, W. Y. *Organometallics* **1984**, *3*, 1718−1727. (d) San Filippo, J., Jr.; Silbermann, J. *J. Am. Chem. Soc.* **1981**, *103*, 5588−5590.

(2) For reviews see: (a) Rossi, R. A.; Pierini, A. B.; Palacios, S. M. *Advances in Free Radical Chemistry*; Tanner, D. D., Ed.; Jai Press: Greenwich, CT, 1990; p 193; *J. Chem. Ed.* **1989**, *66*, 720. (b) Rossi, R. A.; Pierini, A. B.; Peñéñory, A. B. *The Chemistry of Functional Groups*; Patai, S., Rappoport, Z., Eds.; Wiley: Chichester, 1995; Supl. D2, Chapter 24, p 1395.

(3) (a) Nazareno, M A.; Rossi, R. A. *J. Org. Chem.* **1996**, *61*, 1645−1649. (b) Murguía, M. C.; Rossi, R. A. *Tetrahedron Lett.* **1997**, *38*, 1355−1358. (c) Murguía, M. C.; Ricci, C. G.; Cabrera, M. I.; Luna, J. A.; Grau, R. J. *J. Mol. Catal. A. Chem.* **2001**, *165*, 113−120.

(4) Savéant, J. M. *Advanced Electron-Transfer Chem.* **1994**, *4*, 53, and references therein.

(5) Brunet, J.; Sidot, C.; Caubere, P. *J. Org. Chem.* **1981**, *46*, 3147−3149.

(6) Ahbala, M.; Hapiot, P. K.; Houmam, A.; Jouini, M.; Pinson, J.; Savéant, J. M. *J. Am. Chem. Soc.* **1995**, *117*, 11488−11498.

(7) (a) Kuivila, H. G.; Smith, G. F. *J. Org. Chem.* **1980**, *45*, 2919−2921. (b) Duddeck, H.; Islam, M. R. *Chem. Ber.* **1984**, *117*, 565−574.

(8) Santiago, A. N.; Stahl, A. E.; Rodriguez, G. L.; Rossi, R. A. *J. Org. Chem.* **1997**, *62*, 4406−4411.

(9) Adcock, W.; Clark, C. I. *J. Org. Chem.* **1993**, *58*, 7341−7349.

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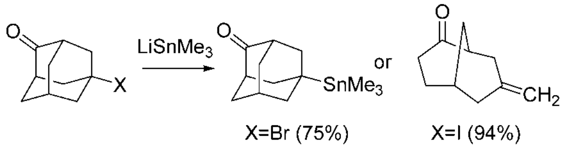
nism, and 32% of propellane. When one halogen is iodine (such as X = Br, Y = I or X = Y = I) with $LiSnMe_3$ or $NaSnMe_3$, in THF, the formation of propellane is the predominant product. The electrochemical reduction of 1,3-dihaloadamantanes demonstrated that the process to give the propellane did not involve the intermediacy of radical anions.[10] The photostimulated reaction of 1,3-dihaloadamantanes with carbanions in DMSO,[11] or with Ph_2P^- ions in liquid ammonia,[12] gave products by the $S_{RN}1$mechanism, and no propellane was formed.

In the 1,4-dihaloadamantanes the formation of propellane is not possible. A series of 1,4-dihaloadamantanes react with $LiSnMe_3$ in THF to give disubstitution products. The formation of the disubstitution products in the case of the chloro bromide and chloro iodide derivatives constitutes an evidence for the chain nature of the radical mechanism, since the chloro tin compounds are relatively inert toward this nucleophile. These reactions gave the disubstitution products with the isomers *E* and *Z* in equal amounts, indicating that there is no π-facial selectivity, except with 1,4-dibromoadamantane, in which a modest π-facial selectivity was found. It was proposed that this is an $S_{RN}1$ reaction.[13,14]

Substitution of 9-bromotriptycene by $LiSnMe_3$ in THF was demonstrated to occur through a carbanion pathway that predominates (ca. 80%) over the radical path (ca. 20%). Similarly, several 9,10-dihalotriptycenes react with $LiSnMe_3$ to afford mainly monosubstitution with retention of halogen and disubstitution, also by a competition of polar and radical pathways.[14] On the other hand, 9-bromotriptycene reacts in liquid ammonia under irradiation with Ph_2P^- and Ph_2As^- ions by the $S_{RN}1$ mechanism.[15]

The reaction of $LiSnMe_3$ with 1-fluoro-4-iodobicyclo[2.2.2]octane gave only the monosubstitution product with retention of fluorine.[16] The disubstitution product was observed for the reaction of 1,4-dihalobicyclo[2.2.2]octane by the $S_{RN}1$ mechanism.[16,17] The 1-bromobicyclo[2.2.1]heptane reacts with $LiSnMe_3$ in THF by the radical pathway, and the1-iodo derivative has been proposed to react by the radical and HME pathways.[18] In the reaction of $LiSnMe_3$ with various 1,4-dihalobicyclo[2.2.1]heptanes, a polar mechanism can compete effectively with free radical chain processes.[18]

5-Bromo-2-adamantanone reacts with $LiSnMe_3$ in THF to afford the substitution product (75%) by a radical path; however, the iodo derivative furnishes the fragmentation product by a polar reaction (eq 3).[14] Changing the C=O group by $C=CH_2$ precludes the fragmentation, and both derivatives (X = Br, I) give the substitution product.[14]



(3)

The reactions of Me_3Sn^- ions with aryl chlorides in liquid ammonia gave very good yields of stannanes by the $S_{RN}1$ mechanism, but the aryl bromides or iodides react by the HME reaction.[19] To establish if bromo- or iodoadamantanes react by the ET process, or HME in liquid ammonia, we have studied the photostimulated reaction of several halo- and dihaloadamantanes with Me_3Sn^- ions. In addition, we studied the photostimulated reactions of 5-chloro-2-adamantanone because this substrate offers the possibility to observe or not intramolecular redox catalysis by the carbonyl group.[20,21] We have also investigated the relative reactivities of Ph_3Sn^- and Me_3Sn^- toward 1-adamantyl radicals, and the relative reactivity of 1-ClAd and 5-chloro-2-adamantanone toward Me_3Sn^- and Ph_2P^- ions.

Table 1. Reaction of Haloadamantanes with Me_3Sn^- Ions in Liquid Ammonia[a]

expt	substrate[b]	conditions (min)	substrate recovered, %	X^-,[c] %	substitution product (%)
1	1-BrAd	dark (2)	80	<5	- - -
2	1-BrAd	$h\nu$ (2)	- -	82	80[d]
3[e]	1-BrAd	$h\nu$ (2)	83	<5	- - -
4	1-BrAd	dark (60)	55	37	32[f]
5[g]	1-BrAd	$FeSO_4$ (60)	30	45	43[f]
6	1-IAd	$h\nu$ (2)	7	74	74[f]
7	1-IAd	dark (2)	35	55	40[f,h]
8[e]	1-IAd	dark (2)	82	2	- - -
9	1-IAd	$h\nu$ (15)	- -	75	70[f]
10[g]	1-IAd	$FeSO_4$ (3)	4	88	48[f,i]
11[j]	2-BrAd	$h\nu$ (4)	1	80	80[l]
12[j]	2-BrAd	dark (4)	75	<5	<2[l]
13[e,j]	2-BrAd	$h\nu$ (4)	*k*	<5	<2[l]

[a] Me_3Sn^- ions were prepared from $ClSnMe_3$ and sodium metal in liquid ammonia. The concentration was 4.00×10^{-3} M, unless otherwise indicated. [b] The concentration was 3.33×10^{-3} M. [c] Determined potentiometrically, taking into account the chloride ions from the preparation of the nucleophile. [d] Quantified by GLC and the internal standard method with 1-IAd as reference. [e] *p*-DNB (10 mol %) was added. .[f]Quantified by GLC and the internal standard method with 1-chloronaphthalene as reference. [g] $FeSO_4$ (54 mol %). [h] Adamantane was quantified (5%). [i] Adamantane was quantified (13%). [j] The concentration of Me_3Sn^- ions was 3.33×10^{-3} M. [k] Not quantified. [l] Quantified by GLC and the internal standard method with 4-bromoanisole as reference.

Results and Discussion

Reactions of 1- and 2-Haloadamantanes with Me_3Sn^- Ions in Liquid Ammonia. 1-BrAd fails to undergo reaction with Me_3Sn^- ions in liquid ammonia in the dark (2 min). However, it reacted under photostimulation to give high yields of $1\text{-}AdSnMe_3$ in only 2 min. This photostimulated reaction was inhibited by *p*-dinitrobenzene (*p*-DNB), a good electron acceptor. Under dark conditions, prolonging reaction times (60 min) can result in moderate yields (32%) of the substitution product (Table 1, expts 1−4). These results indicate

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[10] Adcock, W.; Clark, C. I.; Houmam, A.; Krstic, A. R.; Pinson, J.; Savéant, J. M.; Taylor, D. K.; Taylor, J. F. *J. Am. Chem. Soc.* **1994**, *116*, 4653−4659.

[11] Lukach, A. E.; Santiago, A. N.; Rossi, R. A. *J. Org. Chem.* **1997**, *62*, 4262−4265.

[12] Lukach, A. E.; Santiago, A. N.; Rossi, R. A. *J. Phys. Org. Chem.* **1994**, *7*, 610−614.

[13] Adcock, W.; Clark, C. I.; Trout, N. A. *Tetrahedron Lett.* **1994**, *35*, 297−300.

[14] Adcock, W.; Clark, C. I.; Trout, N. A. *J. Org. Chem.* **2001**, *66*, 3362−3371.

[15] Palacios, S. M.; Santiago, A. N.; Rossi, R. A. *J. Org. Chem.* **1984**, *49*, 4609−4613.

[16] Adcock, W.; Iyer, V. S.; Kitching, W.; Young, D. *J. Org. Chem.* **1985**, *50*, 3706−3710.

[17] Santiago, A. N.; Iyer, V. S.; Adcock, W.; Rossi, R. A. *J. Org. Chem.* **1988**, *53*, 3016−3020.

[18] (a) Adcock, W.; Clark, C. I. *J. Org. Chem.* **1995**, *60*, 723−724. (b) Adcock, W.; Gangodawila, H. *J. Org. Chem.* **1989**, *54*, 6040−6047.

[19] Yammal, C. C.; Podesta, J. C.; Rossi, R. A. *J. Org. Chem.* **1992**, *57*, 5720−5725.

[20] Santiago, A. N.; Takeuchi, K.; Ohga, Y.; Nishida, M.; Rossi, R. A. *J. Org. Chem.* **1991**, *56*, 1581−1584.

[21] Lukach, A. E.; Morris, D. G.; Santiago, A. N.; Rossi, R. A. *J. Org. Chem.* **1995**, *60*, 1000−1004.

that 1-BrAd reacts with Me_3Sn^- ions by the $S_{RN}1$ mechanism.

It has been shown that $FeSO_4$ induced the $S_{RN}1$ reactions in liquid ammonia with carbanions as nucleophiles;[22] so we were prompted to study the behavior of this catalyst with Me_3Sn^- ions as nucleophile.

1-BrAd reacts in the dark with Me_3Sn^- ions in 1 h to give 32% yield of 1-AdSnMe_3, and when the reaction was induced by $FeSO_4$, 43% of 1-AdSnMe_3 was observed (Table 1, expts 4 and 5). Thus, these results indicate that $FeSO_4$ slightly induces the reaction.

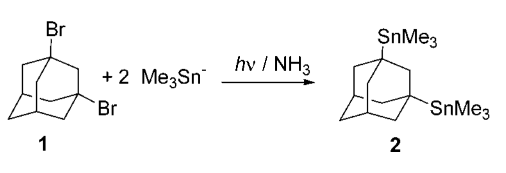
There was slow reaction of 1-IAd with Me_3Sn^- ions after 2 min in the dark, reaction that is accelerated under irradiation in the same time to give 1-AdSnMe_3. The dark reaction was totally inhibited by *p*-DNB. In reactions carried out at longer irradiation times, no change was observed in the yields. In the reaction of 1-IAd with Me_3Sn^- ions after 3 min in the dark and induced by $FeSO_4$ (54 mol %), no change was observed (Table 1, expts 6−10).

We have previously reported that 1-ClAd reacts more slowly with Me_3Sn^- ions and after 30 min of irradiation gives 1-AdSnMe_3 by $S_{RN}1$ mechanism.[8] Thus, the halogen nucleofugality for 1-XAd is $I = Br > Cl$, similar to that observed with other nucleophiles.[15]

The 2-BrAd reacted under photostimulation with Me_3Sn^- ions to give high yields of 2-AdSnMe_3 after 4 min. Addition of *p*-DNB inhibited this reaction. There was no reaction in the dark (Table 1, expts 11−13). These results are in agreement with that the 1-position is more reactive than the 2-position, as already reported, where 1-BrAd is 1.4 times more reactive than 2-BrAd toward Ph_2P^- ions, while 1-ClAd is 12 times more reactive than 2-ClAd with Me_3Sn^- ions.[8]

Reactions of 1,3-Dibromoadamantanes or 1,4-Dibromoadamantanes with Me_3Sn^- Ions. The $S_{RN}1$ reactions of substrates with two leaving groups with nucleophiles afford either the monosubstitution or disubstitution product depending on the structure of the substrate, the nature of the nucleofugal groups and their separation, or the nucleophile.

The photostimulated reaction of 1,3-dibromoadamantane (**1**) with Me_3Sn^- ions in liquid ammonia gave the disubstitution product (59% yield) after two min, and only traces of the monosubstitution product or 1-BrAd were found. This reaction slowed in the dark and the disubstitution product was found in 31% yield. The dark reaction was almost completely inhibited by adding *p*-DNB (Table 2, expts 1−3) (eq 4).



(4)

No propellane was found in these reactions. Propellane is trapped with NH_4Cl to give 1-ClAd.[9] When the photostimulated reaction of **1** with Me_3Sn^- ions was quenched with NH_4Cl, no traces of 1-ClAd were found.

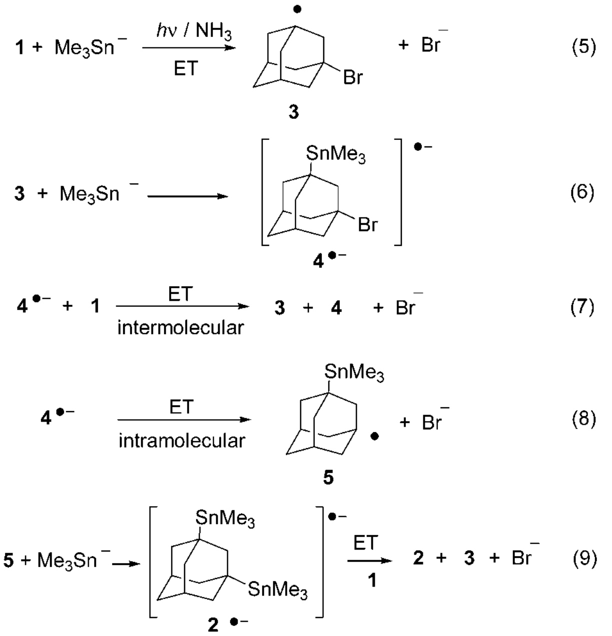
On the other hand, the photostimulated reaction of **1** in excess with Me_3Sn^- ions rendered the disubstitution product **2** and recovered 50% of **1**. The monobromo substitution product was not formed, indicating that this product is not an intermediate in the reaction (Table 2, expt 4).

Table 2. Reaction of Dibromoadamantanes with Me_3Sn^- Ions in Liquid Ammonia

expt	substrate M × 10^3	Me_3Sn^-,[a] M × 10^3	conditions (min)	substrate recovered, %	Br^-,[b] %	substitution product (%)
1	**1**, 3.33	8.00	*hν* (2)	- -	82	**2**, 59[c]
2	**1**, 3.33	8.00	dark (2)	36[d]	38	**2**, 31[c]
3[e]	**1**, 3.33	8.00	dark (2)	96[f]	<2	<1
4	**1**, 3.33	1.67	*hν* (1)	50	22	**2**, 21[c]
5	**6**, 1.67	4.00	*hν* (3)	*g*	84	**7**, 60[h]
6[e]	**6**, 1.67	4.00	*hν* (3)	64	20	**7**, 12[h]
7	**6**, 1.67	4.00	dark (3)	52	17	**7**, 6[h]
8	**6**, 3.33	1.67	*hν* (1)	*g*	17	**7**, >4[i]

[a] Prepared with $ClSnMe_3$ and sodium metal in liquid ammonia. [b] Determined potentiometrically, considering two bromines per molecule. [c] Quantified by GLC and the internal standard method with $AsPh_3$ as reference. [d] AdH (1%) and 1-BrAd (13%) were quantified. [e] *p*-DNB (10 mol %) was added. [f] Adamantane (1%) and BrAd (1%) were quantified. [g] Not quantified. [h] Yield of isolated product. [i] Four monobromo substitution products isomers **8** were formed (relative yields of 9%, 21%, 25%, and 45% by GLC, considering the same molar response), with an overall 25% yield.

Scheme 1



These results suggest that **1** reacted by the $S_{RN}1$ mechanism, as shown in Scheme 1. When **1** receives one electron, it fragments at the C−Br bond to give a radical intermediate **3** (eq 5), which reacts with Me_3Sn^- ions to form the radical anion $\mathbf{4}^{\bullet-}$ eq 6). This radical anion $\mathbf{4}^{\bullet-}$ can, by ET to the substrate, afford the monosubstitution product **4** (eq 7), or by intramolecular ET to the second C−Br bond will form a radical **5** (eq 8), which by coupling with Me_3Sn^- ions will afford the radical anion of the disubstitution product $\mathbf{2}^{\bullet-}$, which by an ET reaction affords the disubstitution compound **2** (eq 9).

Substitution product **4** was not found, indicating that when the radical anion $\mathbf{4}^{\bullet-}$ was formed, the intramolecular ET to the σ^* MO of the C−Br bond is faster than the intermolecular ET.

On the other hand, a mixture of isomers (*E* and *Z*) of 1,4-dibromoadamantane (**6**) reacts with Me_3Sn^- ions in liquid ammonia in three min under irradiation to give

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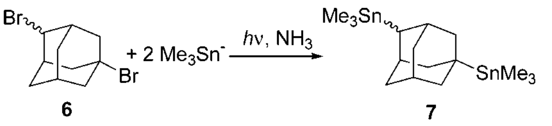
[22] (a) Galli, C.; Bunnett, J. F. *J. Org. Chem.* **1984**, *49*, 3041−3042. (b) Galli, C.; Gentili, P. *J. Chem. Soc., Perkin Trans. 2* **1993**, 1135−1140. (c) van Leeuwen, M.; McKillop, A. *J. Chem. Soc., Perkin Trans.1* **1993**, 2433−2440.

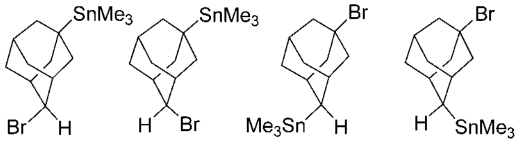
the *E* and *Z* disubstitution products **7** (60% isolated yield) in 45% and 55% relative yields, respectively, and only mere traces of 2-BrAd were found. This reaction was slow in the dark, and the disubstitution product was found in 6% yield. The photostimulated reaction was inhibited by *p*-DNB (Table 2, expts 5−7) (eq 10).



(10)

The photostimulated reaction of **6** in excess with Me_3Sn^- ions renders the disubstitution product **7** in low yield (>4%), and the four monobromo substitution products **8** isomers (Chart 1) were formed in an overall yield of 25%, with a relative yields of 9%, 21%, 25%, and 45% (determined by GLC-mass spectra, considering the same molar response). The formation of these products indicates that in this case they are intermediates for the formation of **7** (Table 2, expts 8).

Chart 1. Monobromo-Substituted Isomers of Product 8



8a **8b** **8c** **8d**

These results indicate that **6** also reacts with Me_3Sn^- ions by the $S_{RN}1$ mechanism, but when radical anions $\mathbf{8}^{\bullet-}$ are formed, the intermolecular ET to **6** to give **8** as intermediates, is faster than the intramolecular ET to the σ^* MO of the C−Br bond, in contrast to the behavior of **1**, in which the intramolecular ET is faster than the intermolecular ET. A similar order of intramolecular vs intermolecular ET-efficiency has been observed in THF, with faster intramolecular ET for 1,3-dihaloadamantanes than for the 1,4 isomers.[13]

The fact that in the photostimulated reaction of a mixture of (*E*) and (*Z*) isomers of 1,4-dibromoadamantane with $NaSnMe_3$, the (*E*) and (*Z*) distribution products are obtained in 45% and 55% yields, respectively, indicates that there is a small π-facial selectivity when the radical intermediate couples with $NaSnMe_3$. Similar results were found in THF.[14]

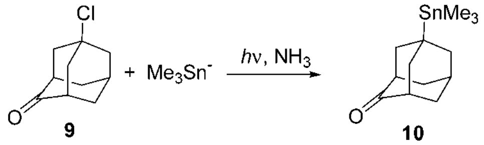
Reactions of 5-Chloro-2-adamantanone (9) with Me_3Sn^- and Ph_2P^- Ions in Liquid Ammonia: Relative Reactivities of 1-ClAd and 9 toward Me_3Sn^- and Ph_2P^- Ions. When substrates that react slowly by ET reactions are substituted by a carbonyl group, their radical anions can be formed and facilitate the ET pathway (intramolecular redox catalysis) with Ph_2P^- ions as nucleophile. For example, it has been shown that while 3,3-dimethylbicyclo[2.2.2]oct-1-yl and bicyclo[2.2.1]hepta-1-yl chlorides do not react with Ph_2P^- ions under irradiation by the $S_{RN}1$ mechanism, the 2-oxo and 3-oxo derivatives react very fast under the same experimental conditions.[20,21]

The photostimulated reaction of Me_3Sn^- ions with 1-ClAd in liquid ammonia afforded substitution products in good yields (95%) by the $S_{RN}1$ mechanism.[8] However, 5-chloro-2-adamantanone (**9**) reacted with Me_3Sn^- ions under photostimulation to give 5-trimethylstannanyl-2-adamantanone (**10**) in only 40% yields in 1 h (eq 11). Similar experiments were conducted at varying concentrations of nucleophile and irradiation time, but similar results were obtained (Table 3, expts 1−3). This reaction did not occur in the dark. The photostimulated reaction was inhibited by *p*-DNB (Table 3, expts 4−5).

Table 3. Reaction of 5-Chloro-2-adamantanone (9) with Me_3Sn^- Ions in Liquid Ammonia

expt	**9**, M × 10^3	Me_3Sn^-,[a] M × 10^3	conditions (min)	X^-,[b] %	**10**,[c] yield %
1	3.33	4.00	*hν* (30)	24	18
2	3.33	4.00	*hν* (60)	*d*	40
3[e]	1.67	6.00	*hν* (120)	*d*	50
4	1.67	6.00	dark (120)	<5[f]	- - -
5[g]	1.67	6.00	*hν* (120)	<5	8

[a] Prepared with $ClSnMe_3$ and sodium metal in liquid ammonia. [b] Determined potentiometrically, taking into account the chloride ions from the preparation of the nucleophile. [c] Quantified by GLC and the internal standard method with $AsPh_3$ as reference. [d] Not quantified. [e] Quenched with methyl iodide, and **9** was quantified in 32% yield. No other products were formed. [f] Substrate **9** was recovered unchanged. [g] *p*-DNB (10 mol %) was added.



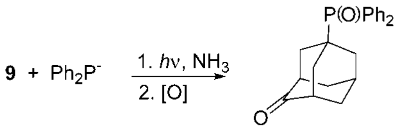
9 **10**

(11)

The decrease of reactivity of **9** could depend on the distance between the donor and the acceptor, or to the nucleophilic addition of the nucleophile to the carbonyl group, forming a substrate bearing a negative charge.

The addition of nucleophile to the carbonyl group may be determined by increasing the concentrations of the nucleophile and trapping the intermediate of the addition. When the reaction was performed with Me_3Sn^- ions in excess, and quenched with MeI in order to trap any adduct formed, no other product was formed (Table 3, expt 3).

The photostimulated reaction of 1-ClAd with Ph_2P^- ions in liquid ammonia gave only 40% of chloride ions,[15] and in the same experimental conditions, **9** (1.67 10^{-3} M) reacts with Ph_2P^- ions (1.67 10^{-3} M) in 3 h of irradiation to give the substitution product **11** in 11% yields, quantified as the oxide (eq 12).



11

(12)

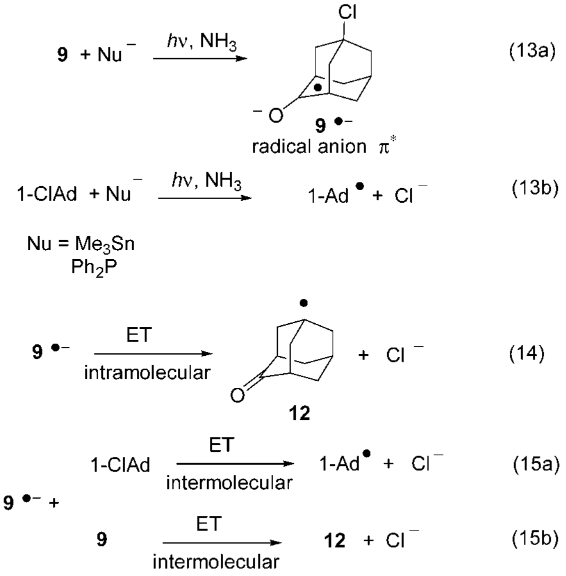
This nucleophile gave redox catalysis with 1-chloro-3,3-dimethyl-2-oxobicyclo[2.2.2]octane and 1-chloro-2-oxo- and 1-chloro-3-oxobicyclo[2.2.1]heptanes, and no addition of the nucleophile was observed.[20,21] The intramolecular ET in these systems occurs at the α and β positions of the carbonyl group to the C−Cl bond. When the acceptor is in γ position with respect to the donor, as in the case of **9**, the intramolecular ET from the carbonyl group to the C−Cl bond is either very slow or does not take place whatsoever. These results are similar to those found with **6** as substrate, where the intramolecular ET at three σ bonds did not occur in significant amount, but occurs with substrate **1**, with only two σ bonds.

Table 4. Competition Experiments of 1-ClAd and 9 with Me_3Sn^- and Ph_2P^- Ions

expt	1-ClAd, M × 10^3	**9**, M × 10^3	nucleophile, M x 10^3	products,[a] yields % 1-AdNu	**10** or **11**	$k_{1\text{-ClAd}}/k_9$
1[b]	3.33	3.33	Me_3Sn^-, 2.67	31.4	**10**, 6.70	5.28
2[b]	3.33	3.33	Me_3Sn^-, 2.67	32.3	**10**, 7.02	5.26
						5.3 ± 0.1 (average)
3[c]	1.67	1.67	Ph_2P^-, 2.0	8.60	**11**, 3.85	2.45
4[c]	3.33	3.33	Ph_2P^-, 2.0	18.9	**11**, 8.33	2.41
						2.4 ± 0.1 (average)

[a] Quantified by GLC and the internal standard method, with $AsPh_3$ as reference. [b] Irradiation time 60 min. [c] Irradiation time 110 min.

Scheme 2



In independent reactions, apparently the rate of reaction of **9** with Me_3Sn^- ions is slower than the rate of the parent compound 1-ClAd. To compare the reactivity of **9** and 1-ClAd, the relative reactivity was studied by competition experiments.[23] In these competition experiments the relative reactivity depends on the rate of the ET from any of the radical anion intermediates to the substrates. By these competition reactions, 1-ClAd is 5.3 times more reactive than **9** (1.0) toward Me_3Sn^- ions (Table 4, expts 1 and 2). By competition experiments we found that the relative reactivity of 1-ClAd (2.4) is higher than **9** (1.0) toward Ph_2P^- ions. This is the first case where the carbonyl group does not catalyze the $S_{RN}1$ reactions using Ph_2P^- ions as nucleophile with a substrate bearing a carbonyl group as substituent (Table 4, expts 3 and 4).

These results suggest that in these competition experiments, there is a competition between intramolecular and intermolecular ET reactions (Scheme 2). When the substrate **9** receives one electron, a radical anion π^* $\mathbf{9}^{\bullet-}$ is formed (eq 13a). On the other hand, when 1-ClAd receives an electron, it gives straightforwardly 1-$Ad^\bullet$ radicals (eq 13b).

Table 5. Reaction of 1-BrAd with Ph_3Sn^- Ions in Liquid Ammonia

expt	1-BrAd, M × 10^3	Ph_3Sn^-,[a] M × 10^3	conditions (min)	Br^-,[b] %	1-AdSnPh$_3$, yield %
1	6.67	8.00	hν (10)	65	>3[c]
2	3.33	8.00	hν (150)	80	65[d,e]
3	3.33	8.00	dark (150)	35	- -[f]
4[g]	3.33	8.00	dark (150)	<1	- -
5	1.33	20.0[h]	hν (60)	84	82[i]

[a] Prepared with $ClSnPh_3$ and sodium metal in liquid ammonia. [b] Determined potentiometrically. [c] AdH (40%) was quantified. [d] Quantified by GLC and the internal standard method, with 1-IAd as reference. [e] AdH (30%) was quantified and traces of 1-Ad_2 were detected as product. [f] AdH (38%) and 1-BrAd (51%) were quantified. [g] DTBN (10 mol %) was added. [h] Together with 1.67×10^{-3} M of Me_3Sn^- ions. [i] The only substitution product was 1-AdSnMe$_3$. AdH was detected but not quantified.

The radical anion $\mathbf{9}^{\bullet-}$ gives the radical **12** by intramolecular ET to the C−Cl bond (eq 14), which by reaction with the nucleophile finally affords the substitution products. Radical anion $\mathbf{9}^{\bullet-}$ can also give intermolecular ET reactions to the competing 1-ClAd and to **9** itself to produce radicals 1-$Ad^\bullet$ and **12** to continue the chain propagation steps (eqs 15). These competing reactions of eqs 15 gave finally an overall decrease in the reactivity of **9**.

Therefore, the intramolecular redox catalysis was dependent on the distance of the carbonyl group. In the reaction of Me_3Sn^- and Ph_2P^- ions with **9**, no intramolecular redox catalysis occurs because the carbonyl group is in a γ position, in contrast to what is observed when the carbonyl group is in the α or β positions.[20,21] There is a precedent that the phenyl ring in 1-chloro-2-methyl-2-phenylpropane increases the rate of reaction with Ph_2P^- ions by the $S_{RN}1$ mechanism, compared with the parent neopentyl chloride, by an intramolecular redox catalysis. With an extra bond between the phenyl ring and the C−Cl bond, as in 1-chloro-2,2-dimethyl-3-phenylpropane, it reacts more slowly than neopentyl chloride. Although the latter compound also has a phenyl ring, its lower reactivity is ascribed to a decrease in the rate of the intramolecular ET by elongation of the chain in one methylene unit.[24]

Reactions of 1-BrAd with Ph_3Sn^- Ions in Liquid Ammonia. Relative Reactivities of Me_3Sn^- and Ph_3Sn^- Ions toward 1-Adamantyl Radicals. There was a slow reaction of 1-BrAd with Ph_3Sn^- ions after 10 min under photostimulation to give AdH (40%) but it reacted at longer irradiation times and with twice the concentration of the nucleophile, to give AdH (28%) and 1-AdSnPh$_3$ (52%). A trace of dimer 1-bisadamantyl (1-Ad_2) was detected (Table 5, expts 1 and 2). In the dark, this reaction gives AdH in 38% yield. This dark reaction was inhibited by adding di-*tert*-butyl nitroxide, a known radical trap (Table 5, expts 3 and 4).

These results indicate that this nucleophile is able to initiate the photostimulated reaction, but couples with 1-$Ad^\bullet$ radical more slowly than Me_3Sn^- ions. To compare the reactivity of Me_3Sn^- and Ph_3Sn^- ions toward 1-BrAd, we studied the relative reactivity by competition reactions. In the photostimulated reaction of 1-BrAd with Me_3Sn^- and Ph_3Sn^- ions (with a ratio of 1:12), 1-AdSnMe$_3$ was the only product formed. These results show

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(23) The equation used in the relative reactivity determination of pairs of substrate vs a nucleophile is: k_1/k_2 = ln([substrate 1]0/[substrate 1]*t*)/ln([substrate 2]0/[substrate 2]*t*) where [substrate 1]0 and [substrate 2]0 are initial concentrations and [substrate 1]*t* and [substrate 2]*t* are concentration at time *t* of both substrates; see Bunnett, J. F. In *Investigation of Rates and Mechanisms of Reactions*, 3rd ed.; Lewis, E. S., Ed.; Wiley-Interscience: New York, 1974; part 1, p 159.

(24) Duca, J. S.; Gallego, M. H.; Pierini, A. B.; Rossi, R. A. *J. Org. Chem.* **1999**, *64*, 2626−2629.

that Me_3Sn^- ions are at least 1000 times more reactive than Ph_3Sn^- ions toward 1-Ad$^•$ radicals (Table 5, expt 5).

Conclusions

In the photostimulated reaction of several halo and dihaloadamantanes with Me_3Sn^- ions in liquid ammonia it is possible, by the $S_{RN}1$ mechanism, to achieve the synthesis of mono- and disubstitution products in very good yields. The monosubstitution or disubstitution products can be obtained with chlorine, bromine, and iodine as leaving groups, and no evidence of HME was found. Thus, tin substitution via $S_{RN}1$ reaction has shown to be the more important reaction for these haloadamantanes in liquid ammonia, in contrast with the results of 1,3-dihaloadamantane in THF as solvent.[9]

The presence of a carbonyl group on substrates that otherwise react slowly by ET reactions with Ph_2P^- ions can facilitate the ET pathway. However, it was found that the intramolecular redox catalysis depends on the distance between the carbonyl group and the C−Cl bond. For instance, in the reaction of **9** with Me_3Sn^- or Ph_2P^- ions, no intramolecular redox catalysis occurs.

The photostimulated reaction of 1-BrAd with Ph_3Sn^- ions in liquid ammonia is a new case in the aliphatic systems where the coupling reaction is not diffusion-controlled, and 1-Ad$^•$ radicals are more selective than Ar$^•$-radicals. Thus, Me_3Sn^- ions are at least 1000 times more reactive than Ph_3Sn^- ions toward 1-Ad$^•$ radicals. These results are different from those reported in aromatic systems where $NaSnMe_3$, $NaSnPh_3$, and $NaPPh_2$ react with *p*-anisyl radicals at the same rate and probably at the diffusion-controlled rate.[19]

Experimental Section

General Methods. NMR spectra were recorded on a Bruker AC-200 nuclear magnetic resonance spectrometer. Mass spectral measurements were obtained with a Shimadzu GCMS QP5050 GC-17A gas chromatograph mass spectrometer. Gas chromatographic analyses were performed on a Hewlett-Packard 5890 Series II instrument with a flame-ionization detector and a data system Hewlett-Packard 3396 Series II, using HP5 (5% methyl silicone, 0.5 m × 0.53 mm) column. Irradiation was conducted in a reactor equipped with two 400-W UV lamps emitting maximally at 350 nm (Philips Model HPT, water-refrigerated). Column chromatography was performed on silica gel (70−270 mesh ASTM). Potentiometric titration of halide ions was performed in a pH meter (Orion model 420A), using an Ag/Ag^+ electrode and $AgNO_3$ as standard. Melting points were obtained with a Büchi 510 apparatus and are not corrected.

Materials. 1- and 2-BrAd, 1-IAd, 1,3- and 1,4-dibromoadamantanes, Me_3SnCl, Ph_3SnCl, and Ph_3P were commercially available and used as received. 5-Chloro-2-adamantanone was obtained by chlorination of 5-hydroxy-2-adamantanone (Aldrich) (1 g) using thionyl chloride (20 mL). Recrystallization from hexane gave pure 5-chloro-2-adamantanone (0.9 g, 80% yield); mp 195−197 °C.

Photostimulated Reactions of 1-Halo-, 2-Halo-, 1,3-, and 1,4-Dibromoadamantanes or 5-Chloro-2-adamantanone with Me_3Sn^- Ions in Liquid Ammonia. The following procedure is representative of these reactions. To 300 mL of distilled ammonia were added Me_3SnCl (1.2 mmol) and then Na metal (2.6 mmol, 20% excess) in small pieces, until total decoloration between two consecutive additions, and 20 min after the last addition, when no more solid was present, Me_3Sn^- ions were ready for use (lemon yellow solution). The haloadamantane (1 mmol) dissolved in 1 mL of anhydrous ether was added to the solution, and the reaction mixture was irradiated. Then, the reaction was quenched with an excess of ammonium nitrate, and the ammonia was allowed to evaporate. The residue was dissolved with water and then extracted with diethyl ether. The products were isolated by column chromatography. In the other experiments the products were quantified by CGL using the internal standard method.

Ferrous Ion-Induced Reaction of 1-BrAd with Me_3Sn^- Ions in Liquid Ammonia. To the lemon yellow solution of Me_3Sn^- ions in liquid ammonia was added $FeSO_4$ (0.54 mmol) which was previously dried at 100 °C for 6 h in a vacuum. After five min, 1-BrAd (1 mmol) dissolved in 1 mL of anhydrous ether was added. Then, the reaction was quenched with an excess of ammonium nitrate, and the ammonia was allowed to evaporate. The residue was dissolved with water and then extracted with diethyl ether. The products were quantified by GLC using the internal standard method.

Photostimulated Reaction of 1-BrAd with Ph_3Sn^- Ions in Liquid Ammonia. The procedure was similar to that for the previous reactions, except that Ph_3SnCl was used to form the nucleophile. The residue was dissolved with water and then extracted with chloroform. The products were quantified by GLC using the internal standard method.

Reaction with Me_3Sn^- Ions in the Dark. The procedure was similar to that for the previous reaction, except that the reaction flask was wrapped with aluminum foil.

Inhibited Reaction with Me_3Sn^- Ions. The procedure was similar to that for the previous reaction, except that *p*-DNB or di-*tert*-butyl nitroxide were added to the solution of nucleophile prior to substrate addition.

Isolation and Identification of the Products. 1-AdSnMe$_3$: isolated as a white solid after column chromatography on silica gel, eluted with petroleum, and identified by comparison with an authentic sample.[8]

2-AdSnMe$_3$: isolated as a white solid after column chromatography on silica gel, eluted with petroleum ether, and identified by comparison with an authentic sample.[8]

1,3-Bis(trimethylstannyl)adamantane: isolated as a white solid after radial chromatography on silica gel, eluted with petroleum ether. ^{13}C NMR ($CDCl_3$) δ: −13.09, 29.60, 30.09; 37.85, 42.17, 46.39, and was identified by comparison with the literature.[9] Mp: 104−106 °C. (lit.[9] 95−97 °C).

(*E*),(*Z*)-1,4-Bis(trimethylstannyl)adamantane: isolated as a white solid after radial chromatography on silica gel, eluted with petroleum ether. ^1H NMR ($CDCl_3$) δ: −0.18 to 0.18 (36H, m); 1.83−2.03 (14H, m); ^{13}C NMR ($CDCl_3$) δ: −13.17, −9.72, −9.59, 28.07, 28.61, 29.06, 29.44, 32.76, 32.92, 36.59, 40.14, 40.77, 40.87, 42.50, 45.18. MS (EI+) *m/z* (%): 299 (14.2), 269 (4.6), 165 (100.0), 150 (7.9), 135 (17.4), 119 (1.7), 105 (3.3), 91 (10.2), 79 (12.7), 67 (2.0), 55 (2.3), 41(3.7) and 299 (21.2), 165 (100.0), 150 (6.8), 135 (14.4), 119 (1.7), 105 (3.1), 91 (9.3), 79 (16.0), 67 (1.7), 55 (2.0), 41(3.8) and identified by comparison with the literature.[25]

5-(Trimethylstannyl)-2-adamantanone: isolated as a white solid after radial chromatography on silica gel, eluted with petroleum ether−diethyl ether (50:50). ^1H NMR ($CDCl_3$) δ: 0.016 (9H, t), 1.57−2.57 (13H, m). ^{13}C NMR ($CDCl_3$) δ: −12.66, 26.89, 28.13, 39.08; 40.74, 44.41, 48.40, 218.14. MS (EI+) *m/z* (%): 314 (M^+, 43.0), 299 (72.1), 165 (100.0), 149 (71.1), 135 (33.3), 121 (46.9), 105 (12.0), 93 (63.1), 79 (76.0), 67 (22.4), 55 (24.6), 41(22.2). Identified by comparison with the literature.[26] Mp: 81.5−83.5 °C (lit.[26] 81−82 °C).

1-AdSnPh$_3$: isolated as a white solid after column chromatography on silica gel, eluted with petroleum ether. IR (KBr) ν: 3063 m, 3049 m, 3019 w, 2985 w, 2899 vs, 2845 s, 1479 m, 1448 m, 1427 vs, 1341 m, 1301 m, 1250 w, 1176 vw, 1073 vs, 1043 m, 1022 mw, 997 mw, 968 w, 924 vw, 697 vs and was identified by comparison with bibliography.[27] ^{13}C NMR ($CDCl_3$): 29.31, 29.70, 37.58, 43.23, 127.91, 128.35, 128.64,

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(25) Adcock, W.; Lunsmann, D.; Trout, N. A. *J. Org. Chem.* **1998**, *63*, 7231−7235.

(26) Xie, M.; le Noble, W. J. *J. Org. Chem.* **1989**, *54*, 3836−3839.

(27) Roberts, R. M. G. *J. Organomet. Chem.* **1973**, *63*, 159−165.

128.74, 137.36, 137.64, 137.96, 138.70. MS (EI+) *m*/*z* (%): 351 (100), 197 (25.5), 152 (4.9), 135 (93.3), 120 (14.4), 107 (15.5), 93 (33.8), 79 (48.2), 78 (34.1), 77 (26.6), 67 (19.9), 55 (12.8), 41 (12.7); mp: 157−159 °C (lit.[28] 154 °C).

Competition Experiments. Relative Reactivity of 1-ClAd and 9 toward Me_3Sn^- Ions. The nucleophile (0.8 mmol) was prepared in liquid ammonia as in the previous reaction. Both substrates (1 mmol each) were dissolved in 1 mL of anhydrous diethyl ether, and after 1 h of irradiation, the reaction was quenched with an excess of ammonium nitrate and the ammonia was allowed to evaporate. The reaction mixture was extracted with diethyl ether and water. The reaction was quantified by GLC using the internal standard method.

Relative Reactivity of 1-ClAd and 9 toward Ph_2P^- Ions. The procedure was similar to that for the previous reaction. The Ph_2P^- ions were prepared in liquid ammonia from Ph_3P (0.5 mmol) and Na metal (1.1 mmol) as was described previously.[28]

Relative Reactivity of Me_3Sn^- and Ph_3Sn^- Ions toward 1-BrAd. Both nucleophiles were prepared in liquid ammonia from Ph_3SnCl (6 mmol), Me_3SnCl (0.5 mmol), and Na metal (13 mmol). The substrate was dissolved in 1 mL of anhydrous diethyl ether, and after 1 h of irradiation the reaction was quenched with an excess of ammonium nitrate and the ammonia was allowed to evaporate. The reaction mixture was extracted with diethyl ether and water. Substitution products were quantified by GLC using the internal standard method.

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[28] Rossi, R. A.; Palacios, S. M.; Santiago, A. N. *J. Org. Chem.* **1982**, *47*, 4654−4657.