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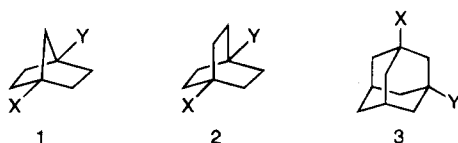
A Reinvestigation of the Trimethylstannylation of 1-Iodonorbornane: Competition between Polar and Radical Pathways

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In connection with the mechanistic definition of trimethylstannylation of 1,4-dihalobicyclo[2.2.1]heptanes, we reported several years ago that whereas the reaction of 1-bromonorbornane (1: X = Br, Y = H) with (trimethylstannyl)lithium (Me_3SnLi) in THF appears to proceed



exclusively via an $\text{S}_{\text{RN}}1$ free radical pathway, 1-iodonorbornane (1; X = I, Y = H) reacts by competing free radical and halogen-metal exchange (HME) pathways.¹ This proposal was based largely on product distribution results (substitution *versus* reduction) in the absence and presence of *tert*-butylamine (TBA) and, as well, the detailed results of trimethylstannylation of 1,4-dihalobicyclo[2.2.1]heptanes (1)¹ and 1,4-dihalobicyclo[2.2.2]octanes (2).² In particular, the chain nature of the free radical pathway was inferred from the results of the chloro bromo and chloro iodo derivatives of 1 (X = Cl, Y = Br and X = Cl, Y = I, respectively).¹

In contrast, on the basis of product analyses, the results of radical and radical anion experiments, deuterium labeling studies, and the nucleofugality effect, Ashby and co-workers³ have concluded recently that trimethylstannylation of 1-iodonorbornane (1; X = I, Y = H) with Me_3SnNa in THF proceeds by a single electron transfer (SET)-initiated $\text{S}_{\text{RN}}1$ free radical chain process. Although not explicitly stated by these workers, the paper leaves the distinct impression that the radical pathway is exclusive. Most pertinently, the iodo compound (1: X = I, Y = H) was specifically chosen by Ashby et al.³ as a model substrate to avoid competition between polar and SET mechanisms in their studies of various nucleophilic substitution reactions. In view of the discrepancy between the aforementioned reports, we decided to reexamine the trimethylstannylation of the iodo derivative of 1 (X = I, Y = H) with both Me_3SnLi and Me_3SnNa in the absence and presence of TBA (a carbanion trap)⁴ and dicyclohexylphosphine (DCPH; a radical trap)^{4,5} in each case. The results of these experiments are listed in Table 1. It can be seen that the product mixture

Table 1. Product Distribution Analysis of the Reaction between 1-Iodonorbornane (1; X = I, Y = H) and Trimethylstannyl Alkali (Me_3SnM , M = Li or Na) in THF^a

entry	alkali metal (M)	additive ^c	product distribution proportions, % ^b		extent of reaction
			1 (X = SnMe ₃ , Y = H)	1 (X = Y = H)	
1	Li	none	91	9	97
2	Li	TBA	79	21	91
3 ^d	Li	TBA	74	26	100
4	Li	DCPH	22	78	100
5	Na	none	96	4	96
6	Na	TBA	32	68	100
7	Na	DCPH	25	75	100

^a The Me_3SnM reagent (3 mol equiv) in THF (2 mL) was added to a THF solution (3 mL) of 1 (X = I, Y = H; 100 mg 0.45 mmol) in all cases. ^b Determined by VPC relative to decane as an internal standard on aliquots removed from the reaction mixture. ^c TBA = *tert*-butylamine (10 mol equiv); DCPH = dicyclohexylphosphine (10 molar equiv). ^d Duplicate experiment.

(substitution *versus* reduction) is markedly effected in the presence of both trapping agents. Thus, our previous report¹ is corroborated, namely, that both free radical and carbanion intermediates are strongly implicated as mediating species in the formation of the tin substitution product.⁶ Based on the product distribution results of trapping experiments with TBA of kinetically labile species such as 4-bromo- and 4-iodonorborn-1-yl carbanions,¹ the assumption of unit efficiency for this carbanion trap seems a reasonable first order approximation in the current context. Consequently, the yield of reduction product in the presence of TBA (Table 1) provides a means of semiquantitatively apportioning the competing mechanisms (Me_3SnLi : radical (79%), carbanion (21%); Me_3SnNa : radical (32%), carbanion (68%)). It is important to stress that no such deduction can be drawn from the DCPH data for several reasons. Firstly, although DCPH is well-known to be an efficient scavenger of alkyl radicals it is also known to be capable of trapping carbanions,^{4,5} albeit less efficiently than the former species. Secondly, there is some evidence that DCPH may perturb the mechanism of the reaction.⁷ In particular it may induce a radical chain reaction with iodoalkane substrates.³ However, there does not appear to be a general consensus on this point⁵ and it has been ruled out by some workers.⁸ Finally, there is evidence from our recent studies that DCPH does not function with unit efficiency in the trapping of 3-fluoro- and 3-chloroadamant-1-yl radicals⁹ as well as the 4-methyleneadamant-1-yl radical.¹⁰ This raises the question that the interpretation of the product distribution in such experiments may be complicated by rapid reactions occurring

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during mixing.¹¹ Of course this may also be a problem in the use of TBA as a trap but probably less so than DCPH because of the much lower viscosity of the former than the latter in mixtures with minimum amounts of THF.

In our previous study¹ we drew attention to the fact that partitioning between the radical and polar mechanisms in the reaction of **1** with Me_3Sn^- is delicately balanced, being dependent not only on the nature of the leaving group (Y = Br or I) but also on the substituent (X = H, F, Cl, Br, or I). The results reported herein suggest dependence also on the counterion (Li^+ or Na^+). The origin of this difference might lie in differences in degrees of aggregation in THF which is uncertain.⁵ Thus, in terms of the valence bond configurational description of the transition state (TS) previously proposed,¹ it can be envisaged that bonded interactions between I and Me_3Sn^- in the TS might be more important when the counterion is Na^+ than Li^+ . A similar explanation can be advanced based on the idea that the partitioning between radical and polar mechanisms may also be conceptualized in terms of competing inner- and outer-sphere electron transfer processes,¹² the carbanion component derives from the former (bond breaking (C–I) and bond formation (Sn–I) being concerted with the transfer of an electron)¹³ and the radical path from the latter (dissociative electron transfer).

Finally, we conclude that the results disclosed in this study indicate that the choice of 1-iodonorbornane as a model substrate to examine radical processes for nucleophilic substitution reactions in the absence of competing polar mechanisms³ is clearly inappropriate. Our previous work suggests that for this purpose the 1-halo(X)-adamantanes^{4,9} and 1-halo(X)bicyclo[2.2.2]octanes (**3** and **2**, X = Br or I, Y = H, respectively)^{2,14} are more

appropriate since bridgehead-substitution involving these compounds is not significantly mediated by carbanion intermediates. We favor the latter systems since they would be expected to be less susceptible to thermal and photolytically induced $\text{S}_{\text{N}}1$ processes¹⁵ than the former.

Experimental Section

Except for the analytical vapor-phase chromatographic (VPC) analyses, which were performed on a Perkin Elmer Auto system gas chromatograph with FID using a 25-m capillary column (Alltech RSL-150, 0.32 mm column), general methods, procedures, and trimethylstannylation reactions were the same as described in a recent paper.⁹

1-Iodonorbornane (1; X = I, Y = H). Following procedures recently described for the preparation of 1-chloro-3-iodoadamantane (**3**; X = Cl, Y = I) from 3-chloroadamantane-1-carboxylic acid,⁹ 4-carbomethoxybicyclo[2.2.1]heptane-1-carboxylic acid (**1**; X = COOH, Y = COOCH₃; 1.75 g, 8.84 mmol)¹ was converted into methyl 4-iodobicyclo[2.2.1]heptane-1-carboxylate (**1**; X = I, Y = COOCH₃).¹ Kugelrohr distillation (50–60 °C/0.1 mm) afforded the iodo ester as a colorless oil (2.17 g, 88%).

A mixture of the iodo ester (1.98 g, 7.07 mmol), tri-*n*-butyltin hydride (6.17 g, 21.2 mmol), and a small amount of AIBN in dry diethyl ether (50 mL) was irradiated (300 W lamp) for 4 h while the solution was maintained at 0 °C. The solvent was then removed in vacuo to afford a mixture to which was added aqueous ethanolic potassium hydroxide (1.19 g, 21.21 mmol of KOH in C₂H₅OH/H₂O (1:1, 13 mL)). After allowing the mixture to stand overnight, a standard workup gave bicyclo[2.2.1]heptane-1-carboxylic acid (810 mg, 74%) which was converted without purification into 1-iodonorbornane (**1**; X = I, Y = H) following the method indicated above for the iodo ester. The crude iodide was chromatographed (silica gel; pentane as eluent) to afford a colorless oil (720 mg, 56%): ¹H NMR (CDCl₃) δ 1.3 (2H, m), 1.7 (2H, m), 1.82–1.96 (5H, m), 2.05 (2H, m); ¹³C NMR (CDCl₃, relative to Me₄Si) δ 50.88, 43.13, 38.06, 34.66, 32.24. The compound had properties identical to the product we¹ previously prepared by another method.¹⁶

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(13) The predominant view in the literature is that single electron transfer (SET) is synonymous with radical processes.

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