

REACTIONS OF 1,3-DIHALOADAMANTANES WITH DIPHENYLPHOSPHIDE IONS BY THE $S_{RN}1$ MECHANISM. COMPETITION BETWEEN INTERMOLECULAR AND INTRAMOLECULAR ELECTRON TRANSFER REACTIONS

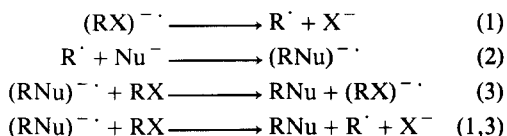
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The reactivity of 1,3-dihaloadamantanes with diphenylphosphide ions (Ph_2P^-) in liquid ammonia was studied. 1,3-Dichloroadamantane (1a), 1-bromo-3-chloroadamantane (1b) and 1,3-dibromoadamantane (1c) reacted with Ph_2P^- ions under photostimulation by the $S_{RN}1$ mechanism. Irradiation of 1c without Ph_2P^- ions gave no reaction (<5%). Three products were found: 1,3-bis(diphenylphosphinyl)adamantane (2), (3-X-1-adamantyl)diphenylphosphine (X = Cl, 3a; X = Br, 3b) and 1-adamantyldiphenylphosphine (4). Compounds 2 and 4 were formed by intramolecular electron transfer (ET) of the radical anion $3a^{\cdot-}$ ($3b^{\cdot-}$); whereas 3a (3b) were formed by intermolecular ET of this radical anion to the substrates. It was observed that the product distribution depends on the substrate and reaction conditions.

INTRODUCTION

Nucleophilic substitution by the $S_{RN}1$ mechanism is a well known process.^{1,2} The main reaction steps proposed involve the fragmentation of the radical anion of the substrate to give a radical intermediate and the nucleofugal group [equation (1)]; the reaction of the radical with the nucleophile to give the radical anion of the substitution product [equation (2)] which by an electron transfer (ET) to the substrate completes the chain propagation cycle of the proposed mechanism [equation (3)] (Scheme 1).



Scheme 1

In aliphatic systems without a low-lying π^* MO such as bridgehead, cyclopropyl, cyclohexyl and neopentyl halides, the radical anion $(\text{RX})^{\cdot-}$ probably is not an intermediate and equations (1) and (3) occur simultaneously [equation (1,3)].^{2b,d} This mechanism needs

an initiation step. One of the proposed initiation reactions involves the ET from a suitable electron donor such as the nucleophile present in the reaction media, by a thermal (or spontaneous) or by photostimulated reactions.^{1,2}

We have reported the photostimulated reaction of 1-haloadamantanes with organometallic nucleophiles in liquid ammonia,³ and that of 1-iodoadamantane reacted with carbanionic nucleophiles in dimethyl sulphoxide under photostimulation⁴ by the $S_{RN}1$ mechanism. Taking this into account, we undertook an investigation of the photostimulated reactions of 1,3-dihaloadamantanes with diphenylphosphide (Ph_2P^-) ions in liquid ammonia due to the mechanistic and synthetic relevance of the disubstitution products in an adamantane system.

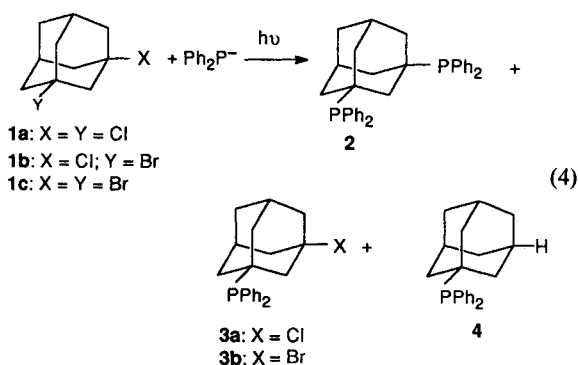
RESULTS AND DISCUSSION

The photostimulated reaction during 135 min of 1,3-dichloroadamantane (1a) with Ph_2P^- ions in liquid ammonia gave mainly the disubstitution product 2, the monosubstitution product with retention of chlorine, 3-chloro-1-adamantyldiphenylphosphine (3a), and the monosubstitution product 1-adamantyldiphenylphosphine (4) (Expt 1, Table 1) [equation (4)]. This

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Table 1. Reactions of 1,3-dihaloadamantanes with diphenylphosphide ions in liquid ammonia

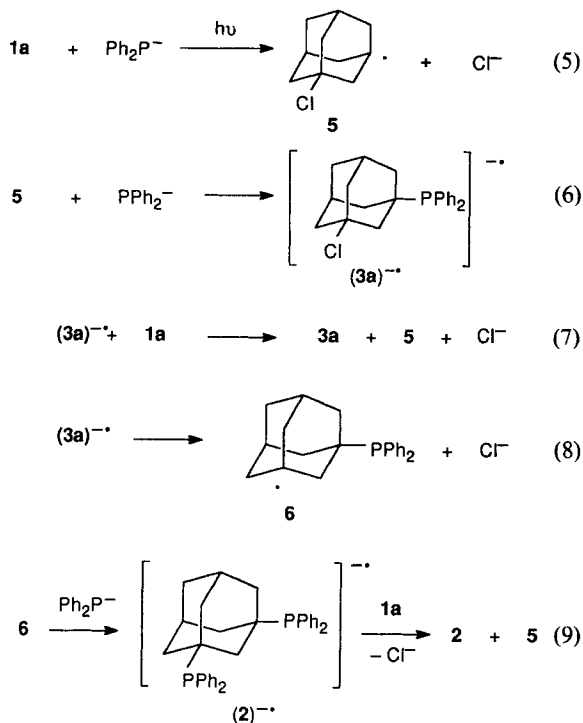
Expt	[I] (10 ³ M)	[Ph ₂ P ⁻] (10 ³ M)	Conditions, (time, min)	Yield (%) ^a			
				X ⁻ ^a	2 ^b	3 ^b	4 ^b
1	1a 2.53	5.87	hν, 135	Cl 176 ^c	74	3a 3.0	14
2	1a 2.53	5.33	Dark, 150	Cl <2	—	—	—
3 ^c	1a 2.60	5.33	hν, 135	Cl 76	19	3a 1.4	2.4
4	1a 2.67	5.34	hν, 60	Cl 69	21	3a <1	4.7
5	1b 2.67	5.93	hν, 45	Br 100	76	3a 7.3	4.2
				Cl 85			
6	1b 2.67	5.34	Dark, 45	Br 13	3	3a 14	—
				Cl 4			
7 ^c	1b 2.67	5.87	Dark, 45	Br 2	—	3a <2	—
				Cl —			
8 ^c	1b 2.67	5.34	hν, 45	Br 83	50	3a 29	—
				Cl 61			
9	1b 2.67	5.87	hν, 10	Br 84	71	3a 3.0	3
				Cl 79			
10 ^c	1b 2.67	5.87	hν, 10	Br 67	33	3a 38	<1
				Cl 33			
11	1b 0.15	0.33	hν, 45	Br 100	80	3a 3.0	12
				Cl 97			
12	1b 0.91	2.2	hν, 45	Br 100	77	3a 4.0	6
				Cl 92			
13	1b 6.67	16.96	hν, 45	— ^d	65	3a 15	8
14	1b 2.68	2.76	hν, 5	Br 53 ^c	35	3a 10	3
				Cl 37			
15	1c 2.67	5.87	hν, 45	Br 184	88	3b <2	8
16	1c 2.53	5.87	hν, 10	Br 188	83	3b <1	7
17	1c 2.67	5.87	Dark, 45	Br 28	12	3b <1	<1
18 ^c	1c 2.67	5.87	hν, 10	Br 120	53	3b —	3
19	1c 2.50	0	hν, 10	Br <5	—	3b —	—

^a Halide ions were determined potentiometrically.^b Organic products, after oxidation with 30% H₂O₂ were determined by HPLC with internal standard (diphenyl disulphide).^c *p*-Dinitrobenzene (20 mol%) was added.^d Not quantified.^e 40% of substrate was recovered.

reaction did not occur in the dark, and the photostimulated reaction is inhibited by *p*-dinitrobenzene (*p*-DNB), a well known inhibitor in *S_{RN}1* reactions (Expts 2–3, Table 1).

These results can be explained according to the *S_{RN}1* mechanism. By a photostimulated ET from the nucleophile to the substrate, which gives the radical intermediate **5** and chloride ion [equation (5)]. This radical couples with Ph₂P⁻ ions to give the radical anion intermediate (**3a**)^{-•} [equation (6)]. This radical anion has two competing reactions, intermolecular ET to the substrate to give **3a** and **5** [equation (7)], or intramolecular ET to the σ* MO of the C—Cl bond, which by fragmentation gives the radical intermediate **6** [equation (8)], which by coupling with Ph₂P⁻ ions leads to the radical anion (**2**)^{-•} finally giving the disubstitution product **2** by ET to **1a** (Scheme 2). The distribution of products suggests that the intramolecular ET of (**3a**)^{-•} is much faster than the intermolecular ET to the substrate.

Although the photostimulated reaction of 1-chloroadamantane with Ph₂P⁻ ions in liquid ammonia is rather sluggish,⁵ it is possible that **2** could be formed



Scheme 2

by the photostimulated reaction of the intermediate **3a** with Ph_2P^- ions. If this were the case, the inhibited reaction, or the photostimulated reaction at shorter time would give an increased yield of **3a**. The photostimulated reaction in the presence of *p*-DNB and the photostimulated reaction (60 min) gave less than 1% yield of **3a** suggesting that **3a** is not an intermediate for the formation of **2** (Expts 3–4, Table 1), although some contribution to the formation of **2** could be due to the reaction of **3a** with any radical anion in the system to give radical **6** [equation (10)], that finally yields **2** following equation (9).⁶



The photostimulated reaction of 1-bromo-3-chloroadamantane (**1b**), with Ph_2P^- ions in 45 min gave mainly the disubstitution product **2** (76% yield), together with **3a** and **4** (Expt 5, Table 1), and **3b** was not found as a product, which agrees with the fact that bromine is a better leaving group than chlorine in $\text{S}_{\text{RN}}1$ reactions. In dark conditions there is some debromination, **3a** being formed in 14%, but the dark reaction is completely inhibited by *p*-DNB (Expts 6–7, Table 1).

The intermolecular ET depends on the acceptor used so much so that the better is the acceptor, the more pro-

ducts are formed through an intermolecular ET. Thus, in Expts 5 and 6 there are higher yields of **3a** than in the reactions with **1a** as substrate. With **1b**, a substrate that is a better electron acceptor than **1a**, the rate of the intermolecular ET from the same radical anion intermediate $(\text{3a})^{\cdot-}$ of both reactions to give **3a** as product is faster than with **1a**.

In the presence of *p*-DNB, the photostimulated reaction gave a higher yield of **3a** (Expt 8, Table 1). Clearly, *p*-DNB does not inhibit the reaction of **1b** as effectively as the intermolecular reaction of **3a** with **1b**, giving a higher yield of **3a**.

Likewise, the photostimulated reaction of **1b** in only 10 min gave 71% yield of **2**, and the inhibition with *p*-DNB gave only 33% of **2**, and as high as 38% yield of **3a** under the same conditions (Expts 9–10, Table 1). These high yields of **3a** in the reaction with *p*-DNB agree with the fact that *p*-DNB is a better electron acceptor than the substrate and that under these experimental conditions, the intermolecular ET to the substrate and to *p*-DNB is faster than the intramolecular ET to the C–Cl σ^* MO.

The intermolecular ET of $(\text{3a})^{\cdot-}$ with the substrate depends on the concentration of $(\text{3a})^{\cdot-}$ and **1b**. In the photostimulated reaction of **1b** at different concentrations, the yields of products **2** and **4** increase as **3a** decreases in more diluted conditions, in agreement with the decrease in the intermolecular reaction at lower **1b** concentration (Expts 5, 11–13, Table 1).

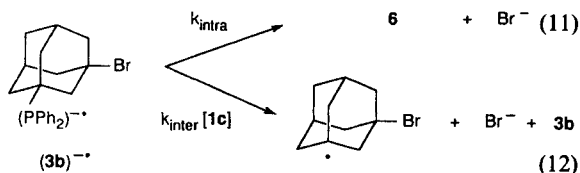
The photostimulated reaction of **1b** with Ph_2P^- ions in ca 1:1 ratio gave 35% of **2** in 5 min with only 10% of **3a**, whereas **1b** was recovered in 40% yield, indicating that **3a** is not an intermediate of these reactions (Expt 14, Table 1).

The photostimulated reaction of **1c** with Ph_2P^- ions in 45 min and also in 10 min gave high yields of the disubstitution product **2**. Only very small amounts of **3b** were found, which indicates a fast intramolecular ET. Even though the dark reaction gave only 12% of **2**, but less than 1% of **3b**, and the photostimulated reaction in presence of *p*-DNB gave only **2** and a small amount of **4** (Expts 15–18, Table 1), **3b** is not an intermediate of these reactions.

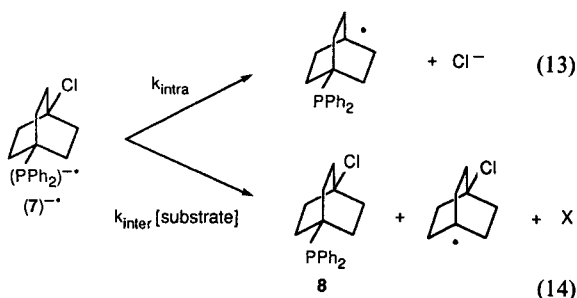
There is no reaction during irradiation of **1c** without Ph_2P^- ions (Expt 19, Table 1), indicating that no photolysis of **1c** occurs under our experimental conditions.

Although **1c** is the best electron acceptor of all the substrates studied, the intermolecular ET from the intermediate 1-bromo-3-diphenylphosphinyladamantane radical anion $(\text{3b})^{\cdot-}$ to **1c** [equation (12)] does not compete with the intramolecular ET to the σ^* MO of the C–Br bond [equation (11)].

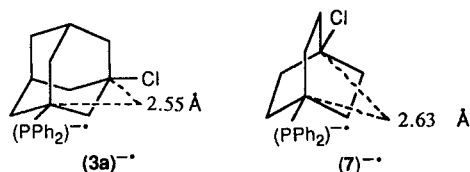
In the photostimulated reaction of 1-X-4-chlorobicyclo[2.2.2]octane (X = bromo, iodo) with Ph_2P^- ions in liquid ammonia, only the monosubstitution product **8** with retention of chlorine was



obtained [equation (14)], which suggests that the rate of the ET reaction of the intermediate radical anion (7)^{••} of these reactions to the substrate is faster than the intramolecular ET to the σ MO of the C—Cl bond [equation (13)].⁷



If we compare the radical anions intermediates (3a)^{••} and (7)^{••}, we have the same radical anion donor (PPh₂)^{••} and the same type of acceptor, the MO σ^* of the C—Cl bond. The distance of both reactive centres is similar (distances calculated by the MMX method on the neutral species), but in (3a)^{••} the rate of intramolecular ET is faster than the intermolecular ET to the substrates, opposite to the behaviour (7)^{••}. The main differences in both radical anion intermediates are the number of sigma bonds [two in (3a)^{••} and three in (7)^{••}], and the greater tension energy for (7)^{••} [the greater the tension energy, the higher is the reduction potential (higher LUMO) of the substrate⁸]. These differences are probably responsible for the reactivity observed.



EXPERIMENTAL

General methods. NMR spectra were recorded on a Bruker FT-200 nuclear magnetic resonance spectrometer. Mass spectral measurements were obtained with a Finnigan Model 3300 mass spectrometer. Gas chromatographic analyses were performed on a Shimadzu GC-8A or Konik 3000 HRGC instrument with

a flame-ionization detector and a Shimadzu CR-3A data system, using a column packed with 5% OV-17 on Chromosorb P (1.5 m $\times$ 3 mm i.d.). High-performance liquid chromatography (HPLC) was performed on an LKB Model 2249 instrument with a LKB Model 2122 UV-visible detector, Spherisorb ODS-2 column (5 μ m, 250 $\times$ 4 mm i.d.) (methanol-water, 80:20) and a Spectra Physics SP-2400 data system. 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 on halide ions was performed with a pH meter (Seybold), using an Ag/Ag⁺ electrode and AgNO₃ as standard. Melting points were obtained with a Büchi 510 apparatus and are not corrected.

Oxidation of 1-haloadamantane and halogenation of 3-haloadamantanol. The procedures were similar regardless of the starting material used.⁹ To a stirred solution of pulverized 1-chloroadamantane (1.7 g, 10 mmol) (or 1-bromoadamantane) in acetic acid and acetic anhydride (1:1) was added chromic acid (3 g, 30 mmol) over 60 min and stirring was continued at room temperature for 24 h. The residue was dissolved with 50 ml of cold water, and then extracted three times with diethyl ether (25 ml each) and three times with methylene chloride (25 ml each). The combined organic extract was washed with saturated NaHCO₃ aqueous solution and dried with NaSO₄. All products were isolated as white solid after chromatography on silica gel and eluted with different solvents. 3-Chloroadamantanol eluted with light petroleum ether–diethyl ether (80:20), was then halogenated with thionyl chloride. 1,3-Dichloroadamantane was eluted with light petroleum ether and sublimed: m.p. 131–132 °C (lit.¹⁰ m.p. 133 °C). 3-Bromoadamantanol was halogenated with thionyl chloride and 1-bromo-3-chloroadamantane was eluted with light petroleum ether and sublimed: m.p. 100–101 °C (lit.¹¹ m.p. 101.5–103 °C). 3-Bromoadamantanol was obtained by oxidation of 1-bromoadamantane and then halogenated with hydrobromic acid. 1,3-Dibromoadamantane was eluted with light petroleum ether and sublimed: m.p. 111–112 °C (lit.¹⁰ m.p. 112–113 °C).

Photostimulated reaction of 1,3-dihaloadamantane with Ph₂P^{••} ions in liquid ammonia. The following procedure is representative of all the reactions. Into a three-necked, 500-ml, round-bottomed flask equipped with a cold-finger condenser charged with dry ice–ethanol, a nitrogen inlet and a magnetic stirrer were condensed 300 ml of ammonia previously dried with Na metal under nitrogen. Triphenylphosphine (1.6 mmol) and Na metal (3.2 mmol) were added to form diphenylphosphide ions, and *t*-BuOH (1.6 mmol) was

added to neutralize the amide ions formed. To this solution substrate **1a** (0.8 mmol) was added and then irradiated for 135 min. The reaction was quenched by adding ammonium nitrate in excess, and the ammonia was allowed to evaporate. The residue was dissolved with water, then twice extracted with diethyl ether (50 ml each) and twice with methylene chloride (50 ml each). The products were oxidized with H_2O_2 and then quantified by HPLC with the internal standard method.

In another experiment the products were oxidized with H_2O_2 and **2** was isolated as a white solid after chromatography on silica gel, eluted with diethyl ether–ethanol (80:20) and recrystallized from light petroleum ether–methylene chloride: m.p. 290–291 °C. ^1H NMR (CDCl_3), δ 1.9 (14 H, m), 7.5 (12 H, m), 7.9 (8 H, m). ^{13}C NMR (DCCl_3 relative to TMS), δ 36.61 ($^1J_{\text{C,P}} = 72.53$ Hz, $^3J_{\text{C,P}} = 9.54$ Hz, C_1 and C_3), 35.18 (C_2), 34.30 (C_4 , C_8 , C_9 and C_{10}), 27.84 ($^3J_{\text{C,P}} = 10$ Hz, C_5 and C_7), 33.94 (C_6), 129.81 ($^1J_{\text{C,P}} = 91.47$ Hz, C_1), 132.11 ($^2J_{\text{C,P}} = 7.96$ Hz, C_o), 132.04 ($^2J_{\text{C,P}} = 7.41$, C_o), 128.37 ($^2J_{\text{C,P}} = 7.37$, C_o), 131.62 (C_p), 128.35 ($^2J_{\text{C,P}} = 11.03$, C_m). Mass spectrum, m/z (relative intensity, %): 537 (26), 536 (52), 535 (10), 336 (50), 335 (100), 334 (10), 202 (31), 194 (6), 191 (6), 185 (23), 135 (19), 134 (31), 133 (29), 104 (28), 93 (25), 92 (23), 91 (64), 83 (29), 81 (64).

Synthesis of (3-Chloro-1-adamantyl)diphenylphosphine oxide in liquid ammonia. The procedure was similar to that for the previous reaction, except that 1-bromoadamantane was used as substrate, yielding 1-adamantyldiphenylphosphine oxide.³ ^{13}C NMR (DCCl_3), δ 36.95 ($^1J_{\text{C,P}} = 72.24$ Hz, C_1), 37.87 ($^2J_{\text{C,P}} = 1.15$ Hz, C_2 , C_8 , C_9), 27.45 ($^3J_{\text{C,P}} = 10.31$ Hz, C_3 , C_5 , C_7), 35.28 ($^4J_{\text{C,P}} = 1.42$ Hz, C_4 , C_6 , C_{10}), 130.42 ($^1J_{\text{C,P}} = 91.5$ Hz, C_1), 132.22 ($^2J_{\text{C,P}} = 7.95$ Hz, C_o), 128.17 ($^3J_{\text{C,P}} = 10.7$ Hz, C_m), 131.45 ($^4J_{\text{C,P}} = 2.53$ Hz, C_p). This product was oxidized⁹ with CrO_3 and halogenated with thionyl chloride, and **3a** was isolated as a white solid chromatography on silica gel, eluted with diethyl ether–ethanol (80:20) and recrystallized from light petroleum ether–methylene chloride. ^1H NMR (DCCl_3), δ 1.6–2.3 (14 H, m), 7.5 (4 H, m), 8.0 (6 H, m). ^{13}C NMR (DCCl_3), δ 40.90 ($^1J_{\text{C,P}} = 72.73$ Hz, C_1), 45.10 (C_2), 67.47 ($^3J_{\text{C,P}} = 14$ Hz, C_3), 46.59 (C_4 , C_{10}), 30.90 ($^3J_{\text{C,P}} = 11$ Hz, C_5 , C_7), 34.40 (C_6), 33.69 ($^2J_{\text{C,P}} = 1$ Hz, C_8 , C_9), 130.99 ($^1J_{\text{C,P}} = 91.5$ Hz, C_1), 132.17 ($^2J_{\text{C,P}} = 8$ Hz, C_o), 128.47 ($^3J_{\text{C,P}} = 11$ Hz, C_m), 131.79 ($^4J_{\text{C,P}} = 2.7$ Hz, C_p).

Photostimulated reaction of 1,3-dihaloadamantane with Ph_2P^- ions and *p*-DNB. The procedure was similar to that for the previous reaction, except that 20 mol% of *p*-DNB were added before the substrate.

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