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Synthesis of α-(Nitroaryl)benzylphosphonates via Oxidative Nucleophilic Substitution of Hydrogen in Nitroarenes†

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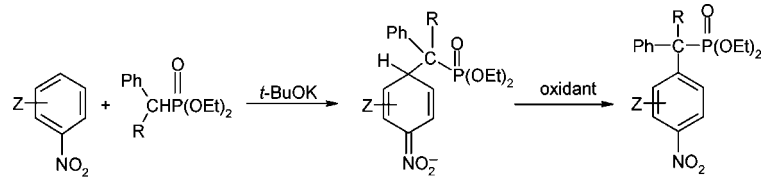

R = Me, H (+ *ortho* isomer)

Carbanions of diethyl benzylphosphonate and diethyl 1-phenylethylphosphonate add to nitroarenes to form relatively long-lived σ^H adducts that can be oxidized to products of oxidative nucleophilic substitution of hydrogen. By variation of the conditions, *o*- and *p*-nitroarylated derivatives of the starting phosphonates can be synthesized regioselectively. It has been proven that addition of carbanions of diethyl benzylphosphonate and diethyl 1-phenylethylphosphonate to nitroarenes is a fast process and the respective σ^H adducts are formed almost quantitatively.

Introduction

Esters of substituted phosphonic acids have found wide application in chemistry, medicine, and other fields. They are key intermediates in a variety of synthetically important reactions[1,2] and are widely used as agents in treatment of osteoporosis[3] or as chelating agents for many metals,[4] etc.[5]

Because of such wide applications there is continuous interest in efficient methods of synthesis of substituted phosphonates.[2] Methods of synthesis of these compounds can be divided into two major groups: synthesis of desired phosphonates from precursors that do not contain phosphorus via formation of new C−P bonds and modification of the carbon skeleton of the simpler phosphonates. There is a plethora of methods for introduction of phosphorus moiety into organic molecules that produce phosphonates such as Michaelis−Arbuzov[6] and Michaelis−Becker[7] reactions, among others.[8a,b] Also there are many methods that can be used for modification or extension of the carbon skeleton of phosphonates. Perhaps the most common and versatile of the latter approach are reactions of carbanions stabilized by phosphonate groups with a variety of electrophilic partners.[8b,9] Despite substantial interest in substituted phosphonates and a great variety of available methods of synthesis of these compounds, very little is known about phosphonates containing nitroaryl moieties. On the other hand, nitroaryl substituents offer interesting properties and possibilities of further transformations.

To our knowledge, α-nitrophenyl benzyl phosphonates have been obtained via Michaelis−Arbuzov reaction of *o*- and *p*-nitrobenzhydryl chlorides with trialkyl phosphites; however, because of steric hindrances yields of the phosphonates were low.[5] An alternative, general method of synthesis of such nitrobenzyl phosphonates was reported in our early paper via vicarious nucleophilic substitution of hydrogen (VNS) of dialkyl

† Dedicated to Professor O. N. Chupakhin on the occasion of his 75th birthday.

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α-chlorobenzyl phosphonates with nitroarenes.[10a,b] VNS with carbanions of chloromethyl-diphenylphosphinoxide was also used in synthesis of nitrobenzyl diphenyl phosphinoxides.[10c,d]

Here we present a new and general method of synthesis of α-(*o*- and *p*-nitroaryl) benzyl phosphonates via oxidative nucleophilic substitution of hydrogen, ONSH, in nitroarenes with the carbanion of diethyl benzylphosphonate. Oxidative nucleophilic substitution of hydrogen in nitroarenes proceeds via addition of nucleophilic agents to the electron-deficient aromatic rings in positions occupied by hydrogen followed by oxidation of the produced σ^H adducts with external oxidants.[11−15] The final outcome of this reaction is a replacement of the ring hydrogen with the nucleophile moiety. It should be stressed that addition of nucleophiles to electron-deficient aromatic rings proceeds faster in positions occupied by hydrogen than those similarly activated occupied by halogens, and thus ONSH should be a dominant process even in the reaction of halonitrobenzenes with nucleophiles. This protocol can be used for introduction of OH,[12] NH_2,[13] PAr_2,[14] and particularly carbon substituents into nitroaromatic rings.[15] For instance, addition of the alkyl Grignard reagents to the nitroaromatic ring followed by oxidation of the formed σ^H adducts with $KMnO_4$ or other oxidants is an efficient method of oxidative nucleophilic alkylation.[15f,i] A variety of carbanions enter similar reaction with nitroarenes provided they are sufficiently nucleophilic to form long-lived σ^H adducts.[15,16]

Oxidation of σ^H adducts of nucleophilic agents to substituted nitroarenes can be effected by a variety of oxidants such as DDQ,[15e−h,16] bromine,[16] $KMnO_4$,[15a,b] oxygen,[17] cerium ammonium nitrate,[19] etc. There are also many examples of anodic oxidation of σ^H adducts.[20] On the other hand, σ^H adducts of some carbanions to nitroarenes oxidized with dimethyl dioxirane produce substituted phenols. This oxidant directs its action on the negatively charged nitro group of the σ^H adducts.[21]

Results and Discussion

In one of our preceding papers we reported ONSH reaction in nitroarenes with carbanions of alkyl phenylacetates.[15e] Taking into account the similarity of these carbanions to that of diethyl benzylphosphonate **1**, we expected that ONSH with this carbanion should be a feasible process. Because the acidity of **1** (pK_a 27.5)[18a] is substantially lower than that of ethyl phenylacetate (pK_a 23),[18b] carbanion $\mathbf{1}^-$ should exhibit higher nucleophilicity and form relatively long-lived σ^H adducts to nitroarenes that could be oxidized with appropriate oxidants. Indeed in the first experiments in which the carbanion of **1** generated in THF/DMF by treatment of **1** with *t*-BuOK was reacted with nitrobenzene **2** at low temperature and the resulting mixture was treated with DDQ, we observed formation of a mixture of diethyl α-(*o*- and *p*-nitrophenyl)benzyl phosphonates **2a** and **2b** in moderate overall yield. Because we have encountered significant difficulties in chromatographic separation of the isomers, the mixture was not separated, and its composition was estimated on the basis of ^1H NMR spectra. Full analysis and identification of the individual *o*- and *p*-nitroisomers **2a** and **2b** were done using samples obtained under conditions that assured selective substitution in positions *ortho* and *para* to the nitro group. Spectra of products **2a** and **2b** possess a characteristic signal of a benzylic proton observed as a doublet with the largest coupling constant ($^1J_{HP} \approx 25-26$ Hz) at 5.41 and 4.53 ppm, respectively. The direct integration of both doublets allows determining the ratio of *ortho*/*para* isomers. Further identification of isomers was performed by analysis of spin system of ^1H NMR spectra or by ^{13}C NMR spectra, based in the case of *ortho* isomer on observation of coupling between the carbon bonded to the nitro group (the most deshielded) and phosphorus ($^3J_{CP} \approx 8-10$ Hz); in the case of the *para* isomer this coupling was not observed. This methodology was fully adopted to other products.

In a similar way **1** was reacted with a series of nitroarenes, usually giving the expected products of ONSH reactions as individual isomers or mixtures of *o*- and *p*-nitro isomers. Results are given in Table 1, conditions A. It should be stressed that 2-fluoronitrobenzene **3**, which is known to rapidly enter S_NAr of fluorine with a variety of nucleophiles,[11a] reacted exclusively along the ONSH pathway via fast formation of σ^H adducts predominantly in position 4, giving a mixture of 2-nitro-3-fluoro- and 4-nitro-3-fluoro-phenyl derivatives **3a** and **3b**. ONSH in nitroarenes with the carbanion of **1** and DDQ oxidant, although generally giving good yields of the desired products, suffers some drawbacks. The oxidant, DDQ, is a relatively expensive compound of rather high molecular weight, and often we experienced difficulties in purification of the products from the reduced form of DDQ. Thus, the conditions presented in Table 1, column A are not attractive in practical use, and moreover they do not provide possibilities for the control of the orientation of the substitution. We have already shown that the most convenient conditions for ONSH in nitroarenes with carbanions of arylacetonitriles and esters of arylacetic acids is liquid ammonia with $KMnO_4$ oxidant.[15a,b,e] Here we have found that these conditions are also very convenient for ONSH reaction of **1** with nitroarenes. Thus, the reaction of **1** with a variety of nitroarenes carried out in liquid ammonia in the presence of

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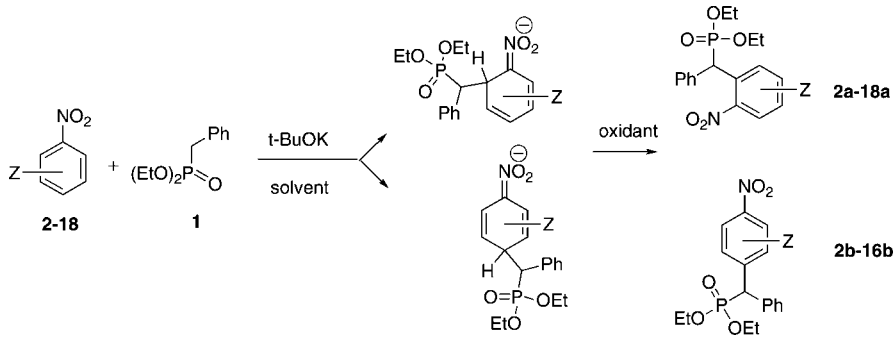
SCHEME 1. Oxidative Nucleophilic Substitution of Hydrogen in Nitroarenes 2−18 with Carbanion of 1 under Various Conditions[a]



[a] Conditions: (A) THF/DMF, −78 °C, addition of DDQ; (B) liquid ammonia, −78 °C, addition of $KMnO_4$; (C) THF, −78 °C, addition of $KMnO_4$ and liquid ammonia; (D) DMSO, rt, dry air.

TABLE 1. Results of ONSH in Nitroarenes with Carbanion of 1 under Various Conditions (Scheme 1)

				conditions						
	nitroarenes			A		B		C		D
entry	Z	no.	products	yield %	ratio[a]	yield %	ratio[a]	yield %	ratio[a]	yield %
1	H	**2**	**2a**	37	2	70	1	68		
			2b		1		1			30
2	2-F	**3**	**3a**	66	1	58	1	0		
			3b		9		9			46
3	3-F	**4**	**4a**					0		
			4b	29		63				78
4	4-F	**5**	**5a**			77				
5	2-Cl	**6**	**6a**	39	1			37		
			6b		1	39				47
6	3-Cl	**7**	**7a**					31	1[b]	
			7b	66		66			1.2	74
7	4-Cl	**8**	**8a**	60		80				
8	3-MeO	**9**	**9a**					0		
			9b			72				
9	4-MeO	**10**	**10a**			73				
10	3-Me	**11**	**11b**			55				
11	3-CN	**12**	**12a**	80	3[b]			55	2[b]	48
			12b		2				1	
12	3-CF_3	**13**	**13a**			34	1[b]	43		
			13b				3.5			
13	4-CF_3	**14**	**14a**			32		57		
14	3-NO_2	**15**	**15a**	56						
15	2,3-Cl_2	**16**	**16b**	69						
16	3-NO_2-4-Cl	**17**	**17a**	56						
17	1-NN[c]	**18**	**18a**	95						

[a] Ratio of isomeric products established on the basis of ^1H NMR or/and ^{31}P NMR spectra. [b] Substitution in position 6- of 3-*Z*-nitrobenzene. [c] 1-NN: 1-nitronaphthalene.

t-BuOK, for generation of the carbanion, and subsequent oxidation of the σ^H adducts with $KMnO_4$ gave better yields of the nitroarylated products compared with that presented in Table 1, column A. Results of the reaction carried out in liquid ammonia with $KMnO_4$ as an oxidant are presented in Table 1, column B. Additionally in some cases better selectively in sense of formation of *p*-nitro isomers was observed. As we have reported in early papers oxidation of the anionic σ^H adducts is sensitive to steric hindrance by substituents located in the vicinity of the addition site. For instance, in the case of tertiary (methinic) carbanion of 2-phenylpropionitrile only σ^H adducts in the position *para* to the nitro groups were oxidized with $KMnO_4$. Oxidation of these *para* σ^H adducts is decelerated or totally inhibited by additional substituents located in the vicinity of the addition site. Thus ONSH with 2-phenylpropionitrile carbanion in 3-iodonitrobenzene proceeds in low yield and not at all in 3,5-dichloronitrobenzene. By independent experiments it was shown that this carbanion forms quantitatively σ^H adducts with these nitroarenes in *para* positions as well as with 4-chloronitrobenzene in *ortho* position, but they are not oxidized with $KMnO_4$.[15a] Addition of the secondary (methylenic) carbanion of **1** to nitroarenes and oxidation of the formed σ^H adducts is less sensitive to steric hindrances; thus the reaction with nitrobenzene carried out in liquid ammonia and $KMnO_4$ oxidant produces a mixture of *o*- and *p*-nitrophenyl isomers **2a** and **2b** in equal amounts. One should particularly stress that the reaction of **1** with 4-chloro- and even 4-fluoronitrobenzenes **8** and **5** proceeded exclusively as ONSH in the position *ortho* to the nitro group without even traces of the conventional nucleophilic substitution of halogen (S_NAr). This is a very clear-cut proof that the addition in positions occupied by hydrogen proceeds much faster and that at low temperature dissociation of the initially formed σ^H adducts is a slow process, so no equilibration of the addition takes place.

Despite bulkiness of the diethoxyphosphoryl group, tendency for *para* substitution in the ONSH with the carbanion of **1** in

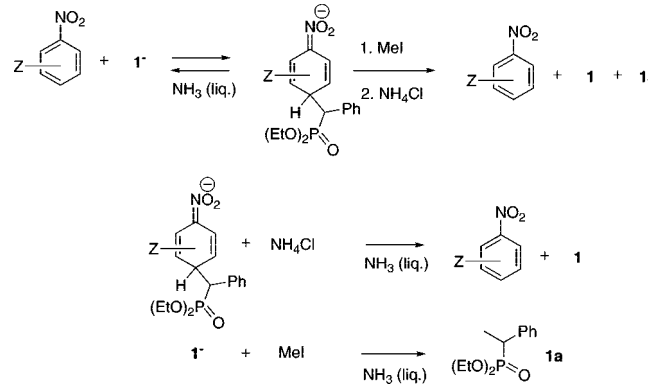
nitroarenes that can form σ^H adducts in *ortho* and *para* positions is not strongly pronounced (Table 1, entries 1, 2, and 12) Although is some cases we could obtain selectively one of the isomeric products containing an *o*- or *p*-nitroaryl ring, the problem of selectivity of the substitution was not solved.

In one of our early papers we reported that the VNS reaction in nitroarenes with secondary carbanion of chloromethyl phenyl sulfone proceeds selectively *ortho* to the nitro group when carried out under action of potassium butoxide in neat THF. The selective addition of the carbanion in vicinity of NO_2 group was due to interaction of the potassium cation of the tight ion pair carbanion-potassium cation that exists in THF with the oxygen atoms of the nitro group.[22] We thus expected that the ONSH reaction carried out via addition of the carbanion of **1** to nitroarenes in neat THF followed by oxidation of the produced σ^H adducts with a solution of $KMnO_4$ in liquid ammonia or tetraalkylammonium permanganate that is soluble in THF should proceed selectively or preferentially *ortho* to the nitro group. Indeed under these conditions we observed preferential or selective ONSH *ortho* to the nitro group, although yields of the products were rather moderate (Table 1, column C).

We have already shown that orientation of the VNS reaction that also proceeds via formation of the σ^H adduct depends on the conditions. Under conditions assuring equilibration of the σ^H adducts formation, substitution proceeds mostly in the *para* position (thermodynamic control).[23] Thus, in order to afford selectively or dominantly substitution in the *para* position it is necessary to create conditions that ensure equilibration of the σ^H adducts formation. Upon some experimentation we have found that treatment of mixtures of nitroarenes, **1**, and *t*-BuOK in DMSO at room temperature with air or oxygen resulted in exclusive formation of *p*-nitroarylated derivatives of **1** usually in good yields (Table 1, column D). Thus, we have elaborated a method of synthesis of α-(*o*- and *p*-nitroaryl)benzylphosphonates by a simple one-pot process that consists of generation of carbanion of **1**, its addition to nitroarenes followed by oxidation of the produced σ^H adducts.

In the case when the substitution can produce isomeric products containing *o*- or *p*-nitroaryl moieties, we can control orientation of the substitution by proper selection of the conditions, thus in majority of cases individual *ortho*- and *para*-nitroarylated products can be obtained. The results presented in Table 1 indicate that in the majority of cases yields of the desired products are good, particularly taking into account that they are overall yields of three consecutive reactions. Nevertheless in some instances the ONSH products were obtained in moderate or low yields or no desired products were obtained at all. Taking into account that the reactions were carried out under standard conditions A, B, C or D, we could suppose that elaboration of optimal procedures for a given case should increase yields and possibly selectivity. We should nevertheless clarify which step of the overall process is responsible for the failure of the ONSH: addition resulting in formation of the σ^H adducts or oxidation of the σ^H adducts. For this purpose we should determine (estimate) degree of conversion of $\mathbf{1}^-$ and $ArNO_2$ in the σ^H adducts. Since direct measurements of amount (conc.) of the σ^H adducts in the reaction mixtures are infeasible, we have applied the method that was already used in our

SCHEME 2. Estimation of Degree of Conversion of $\mathbf{1}^-$ into σ^H Adducts



previous paper for a clarification of similar question, alkylation of the carbanion with methyl iodide. Addition of the carbanion of **1** to nitroarenes is a reversible process, and thus when the anionic σ^H adducts formed in liquid ammonia are neutralized with NH_4Cl (equivalent of HCl in liquid ammonia) they are quantitatively converted into starting nitroarenes and **1**. On the other hand, treatment of $\mathbf{1}^-$ under identical conditions in the absence of nitroarene with methyl iodide results in quantitative methylation. Thus when equimolar amounts of the carbanion of **1** and a nitroarene were mixed and after a few minutes the mixture was exposed to an excess of methyl iodide and the whole subsequently treated with NH_4Cl, full recovery of **1** and absence of the product of its methylation, diethyl 1-phenylethylphosphonate **1a**, indicates that no free carbanion was present in the system. Thus, all carbanions were engaged in reversible formation of the σ^H adducts, which when acidified with the weak acid NH_4Cl dissociate to nitroarenes and **1**. To confirm this supposition we have made experiments in which 1 mol of a nitroarene in liquid ammonia was treated with 2 mol of the carbanion of diethyl benzylphosphinate **1** and after a few minutes an excess of methyl iodide was added. In this case, after quenching of the mixture with NH_4Cl, GLC analysis of the product indicated the presence of **1** and its methylation product in a ratio of ca. 1:1. On the basis of these experiments we can believe that this simple method gives reliable information concerning the degree of conversion of the carbanion of **1** into σ^H adducts. This method of estimation of degree of conversion is shown in Scheme 2.

It should be noted that in all cases when yields of the ONSH products were low or the reaction did not proceed, the σ^H adducts of $\mathbf{1}^-$ to nitroarenes were formed quantitatively. No free carbanions $\mathbf{1}^-$ were detected in the reaction mixtures by the methylation method. Thus, the failure of the ONSH reaction was due to problems with the oxidation and not with the addition step. It is not clear why in some cases oxidation of the σ^H adducts was inefficient or did not proceed at all. Raising the temperature of the oxidation step did not improve the results. Quantitative formation of the σ^H adducts indicates that selection of a more efficient oxidant could overcome the failure observed for the ONSH in some cases.

Replacement of hydrogen atom in the methylenic group of **1** with *o*- or *p*-nitroaryl substituents results in substantial increase of CH acidity of the produced ONSH products **2a**−**17b** and **18a**. This effect, however, does not result in complication of the reaction course. During the reaction we have not observed deprotonation of the products and formation of the nitrobenzyl-

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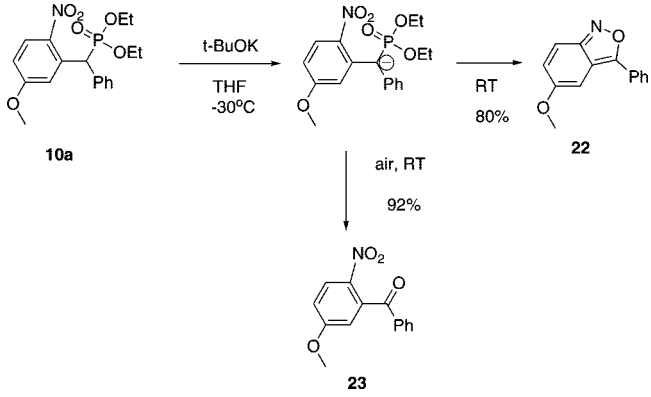
SCHEME 3. Conversion of Carbanion of 10a into Nitrobenzophenone and 2,1-Benzisoxazole Derivatives



type carbanion that could react further. On the other hand, isolated ONSH products, when treated with moderately strong base, undergo rapid deprotonation giving deep-colored nitrobenzylic carbanions. This behavior can be used in TLC analysis of the products that can be detected as strongly colored spots by treatment with solution of a base (e.g., ethanolic solution of NaOH).

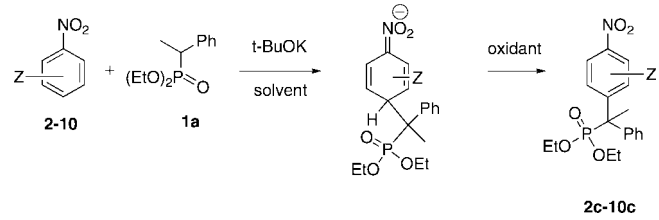
The nitrobenzylic carbanions of **10a** are readily oxidized with air oxygen to give respective substituted nitrobenzophenone. The reaction apparently proceeds via hydroxylation followed by dissociation of the C−P bond. Thus, when a solution of **10a** in THF was treated with *t*-BuOK and dry air, 2-nitro-5-methoxybenzophenone was formed in nearly quantitative yield. On the other hand, when carbanions of α-(*o*-nitroaryl)benzylphoshonates are kept protected from air, spontaneous conversion into substituted 3-phenyl-2,1-benzisoxazoles (anthranils) takes place (Scheme 3). This interesting transformation is a subject of a separate publication.[24]

Continuing our work, we have studied ONSH reaction in nitroarenes with carbanion diethyl 1-phenylethylphosphonate **1a**. Due to the tertiary (methinic) character of this carbanion, its reaction with nitroarenes will be much more sensitive to steric effects of the nitro group and other substituents in the ring. On the other hand, one should expect that higher nucleophilicity of the carbanion of **1a** will increase the rate of the nucleophilic addition and stability of σ^H adducts. Indeed, addition of the carbanion of **1a** to nitroarenes proceeds exclusively in position *para* to the nitro group giving σ^H adducts that can be oxidized to expected products of ONSH, diethyl 1-(*p*-nitroaryl)-1-phenylethylphosphonate. For this reaction two conditions were tested, generation of the carbanion by action of *t*-BuOK on **1a** and nitroarene in THF/DMF mixture at low temperature followed by oxidation with DDQ (conditions A) and treatment of a mixture of **1a** and nitroarene in liquid ammonia at −78 °C with *t*-BuOK followed by oxidation of the produced σ^H adducts with potassium permanganate (conditions B, Scheme 4). Results are given in Table 2.

Yields of the ONSH products are usually high or excellent. Conditions B are not only simpler and more convenient, they also ensure much higher yields. The reaction with 4-chloronitrobenzene **8** gave negative results, and the starting materials were fully recovered. It seems that the addition of the bulky carbanion **1a** in the position *ortho* to the nitro group does not proceed, whereas under these mild conditions (low temp)

(24) Sulikowski, D.; Mąkosza, M. *Acta. Chim. Slov.* **2009**, in press.

SCHEME 4. Oxidative Nucleophilic Substitution of Hydrogen in Nitroarenes with Carbanion of 1a[a]



[a] Conditions: (A) THF/DMF, −78 °C, addition of DDQ; (B) liquid ammonia, −78 °C, addition of $KMnO_4$.

TABLE 2. Results of ONSH in Nitroarenes with Carbanion of 1a

nitroarene			yields (%)	
Z	no.	products	condition A	condition B
H	**2**	**2c**	70	99
2-F	**3**	**3c**		97
3-F	**4**	**4c**		95
2-Cl	**6**	**6c**	38	94
3-Cl	**7**	**7c**	82	
3-CN	**8**	**8c**	78	

addition in the *para* position occupied by halogen is very slow, so conventional S_NAr does not proceed either. We can say that chlorine in the *para* position of **8** protects this position against nucleophilic addition. Also, no ONSH product was obtained in the reaction of **1a** with 3-(trifluoromethyl)nitrobenzene **13**. It appears that in this case the σ^H adduct was formed but because of the steric hindrance the oxidation was inhibited.

Conclusion

We have found that carbanions of diethyl benzylphosphonate **1** and diethyl 1-phenylethylphosphonate **1a** add to nitroarenes at low temperature to form relatively long-lived σ^H adducts that can be oxidized to respective α-nitroarylbenzylphosphonates. These interesting compounds were synthesized in generally good yields. We have also shown that in the cases of low yields or total failure of ONSH reaction the σ^H adducts were formed but not oxidized with the used oxidants. This observation suggests that σ^H adducts can be used as intermediates in other reactions.

Experimental Section

Procedures for the reaction under conditions A, B, C, and D:

Conditions A. To a stirred solution of carbanion precursor **1** or **1a** (1 mmol) and nitroarene **2**−**18** (2 mmol) in THF/DMF (10 mL/2 mL) cooled to −78 °C was added dropwise a solution of *t*-BuOK in THF (1.05 mmol, 1.05 mL, 1.00 M) during 5 min. After 30 min of stirring at the same temperature the reaction mixture was treated with DDQ (272 mg, 1.2 mmol) in THF (1 mL). The resulted dark thick solution was stirred for a further 5 min, and the reaction was quenched by adding 5% aq solution of NH_4Cl (5 mL). After reaching rt, the mixture was extracted with ethyl acetate (2 × 50 mL). The organic phase was washed twice with water (100 mL) and then with brine (100 mL). After drying with anhydrous sodium sulfate and evaporation, crude product was purified by column chromatography on silica gel using ethyl acetate/hexane as eluent (1:4 to 1:1).

Conditions B. To liquid ammonia (15 mL) kept at −78 °C was added a solution of proper nitroarene **2**−**14** (2 mmol) and carbanion precursor **1** or **1a** (1 mmol) in THF (2 mL) followed by dropwise addition of solution of *t*-BuOK in THF (1.05 mmol, 1.05 mL, 1.00 M). After stirring for 30 min, solid potassium permanganate (174 mg, 1.1 mmol) was added. The dark solution was stirred for further

5 min and treated with excess of solid NH_4Cl. After evaporation of ammonia, the residue was partitioned between water and ethyl acetate and filtered trough a small pad of cellite, and the organic phase was separated. The purification was performed in the same way as in procedure **A**.

Conditions C. To a solution of carbanion precursor **1** (1.0 mmol) and nitroarene **2**−**14** (2.0 mmol) in THF (10 mL) cooled to −78 °C was added dropwise a solution of *t*-BuOK in THF (1.05 mmol, 1.05 mL, 1.00 M) during 5 min. Then, the reaction mixture was stirred 30 min at this temperature. After this time, solid potassium permanganate (174 mg, 1.1 mmol) was added in one portion, followed by addition of liquid ammonia (10 mL). After 5 min, the reaction was quenched by addition of solid NH_4Cl. Further workup was performed as described in procedure **B.**

Conditions D. To a solution of carbanion precursor **1** (1.0 mmol) and nitroarene **2**−**12** (2.0 mmol) in DMSO (10 mL) at room temperature was added dropwise a solution of *t*-BuOK in THF (1.5 mmol, 1.5 mL, 1.00 M) during 1 min, and dry air was passed through this dark-colored mixture for 15 min. Then, a 5% aq solution of NH_4Cl was added and after standard aqueous workup, as in procedure **A**, products were isolated by column chromatography on silica gel using ethyl acetate/hexane (1:1 to 1:4).

Analytical and Spectral Data for Representative Compounds. Diethyl α-(2-Nitrophenyl)-benzylphosphonate (2a). Oil; IR (film, CH_2Cl_2) ν_{max} 2982, 1528, 1355, 1252, 1051, 1025 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 8.14−8.05 (m, 1H), 7.80 (d, J = 8.1 Hz, 1H), 7.64−7.52 (m, 3H), 7.41−7.22 (m, 4H), 5.41 (d, J = 25.6 Hz, 1H), 4.14−3.66 (m, 4H), 1.11 (t, J = 7.2 Hz, 3H), 1.10 (t, J = 7.2 Hz, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 149.7 (d, J = 9.8 Hz), 135.0 (d, J = 5.1 Hz), 132.6 (d, J = 2.0 Hz), 131.8 (d, J = 5.6 Hz), 131.0 (d, J = 3.8 Hz), 129.8 (d, J = 8.2 Hz), 128.6, 127.9 (d, J = 2.0 Hz), 127.6 (d, J = 1.8 Hz), 124.6, 62.9 (d, J = 85.1 Hz), 62.8 (d, J = 75.2 Hz), 43.6 (d, J = 137.3 Hz), 16.1 (d, J = 10.5), 16.0 (d, J = 5.7 Hz); ^{31}P NMR (202 MHz, $CDCl_3$) δ 25.0 (s); LRMS-EI *m/z* (%) 349 (M, 4), 212 (100), 195 (54), 167 (65). Anal. Calcd for $C_{17}H_{20}NO_5P$: C, 58.45; H, 5.77; N, 4.01. Found: C, 58.29; H, 5.98; N, 3.81.

Diethyl α-(4-Nitrophenyl)-benzylphosphonate (2b). Oil; IR (film, CH_2Cl_2) ν_{max} 2983, 1595, 1520, 1348, 1250, 1049, 1025 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 8.17 (d, J = 8.7 Hz, 2H), 7.71 (dd, J = 8.8 Hz, 1.8 Hz, 2H), 7.51 (dd, J = 5.3 Hz, 3.6 Hz, 2H), 7.38−7.27 (m, 3H), 4.53 (d, J = 25.1 Hz, 1H), 4.07−3.88 (m, 3H), 3.83 (m, 1H), 1.16 (t, J = 7.1 Hz, 3H), 1.11 (t, J = 7.1 Hz, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 147.0, 144.6 (d, J = 5.1 Hz), 135.4 (d, J = 5.7 Hz), 130.3 (d, J = 7.8 Hz), 129.5 (d, J = 7.9 Hz), 128.9, 127.8, 123.7, 63.1 (d, J = 70.1 Hz), 63.0 (d, J = 70.3 Hz), 51.1 (d, J = 139.0 Hz), 16.3 (d, J = 6.2 Hz), 16.2 (d, J = 6.2 Hz); ^{31}P NMR (202 MHz, $CDCl_3$) δ 24.8 (s); LRMS-EI *m/z* (%): 349 (M, 31), 319 (17), 303 (20), 212 (94), 196 (63), 165 (100), 109 (32). Anal. Calcd for $C_{17}H_{20}NO_5P$: C, 58.45; H, 5.71 N, 4.01. Found: C, 58.59; H, 6.03; N, 4.31.

Diethyl α-(4-Nitrophenyl)-α-methylbenzylphosphonate (2c). Oil; IR (film, CH_2Cl_2) ν_{max} 2983, 1519, 1349, 1253, 1049, 1024 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 8.13 (d, J = 8.5 Hz, 2H), 7.75−7.55 (m, 2H), 7.48−7.38 (m, 2H), 7.38−7.21 (m, 3H), 4.19−3.88 (m, 3H), 3.79 (m, 1H), 2.00 (d, J = 15.8 Hz, 3H), 1.23 (t, J = 7.1 Hz, 3H), 1.17 (t, J = 7.1 Hz, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 151.2 (d, J = 3.9 Hz), 146.4, 141.4 (d, J = 4.9 Hz), 129.9 (d, J = 6.9 Hz), 128.9 (d, J = 6.6 Hz), 128.2 (d, J = 1.0 Hz), 127.2 (d, J = 1.8 Hz), 122.9, 62.9 (d, J = 35.5 Hz), 62.8 (d, J = 35.5 Hz), 50.4 (d, J = 139.1 Hz), 25.0 (d, J = 5.3 Hz), 16.2 (d, J = 5.4 Hz), 16.1 (d, J = 5.4 Hz); ^{31}P NMR (202 MHz, $CDCl_3$) δ 28.1 (s); LRMS-EI *m/z* (%): 363 (M, 15), 317 (5), 226 (100), 209 (73), 178 (28), 165 (35). Anal. Calcd for $C_{18}H_{22}NO_5P$: C, 59.50; H, 6.10; N, 3.85. Found: C, 59.32; H, 5.37; N, 3.87.

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Supporting Information Available: Analytical and spectral characterization data and ^1H and ^{13}C NMR spectra. This material is available free of charge via the Internet at http://pubs.acs.org.

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