Thermal Decomposition of Silver Salts of Aryldinitromethanes in the Presence of Unsaturated Systems. Possible Formation of Arylnitrocarbenes[1]

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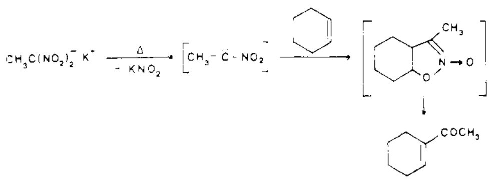
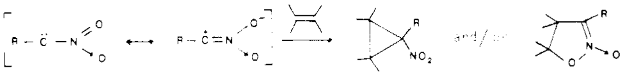
Received March 12, 1980

Decomposition of several silver salts of aryldinitromethanes at 100 °C in the presence of 1,1-diarylethylenes leads to the formation of Δ^2-isoxazoline *N*-oxides in moderate yields and to Δ^2-isoxazolines as byproducts. The spectral data of the new compounds and the reaction mechanisms are discussed. The formation of the *N*-oxides is proposed to occur via arylnitrocarbene intermediates.

In contrast to other carbenes, there is very little information about nitrocarbenes and several attempts at generation and isolation of these species have been unsuccessful. Schöllkopf and co-workers[3,4] tried to generate nitrocarbenes by thermal or photochemical decomposition of nitrodiazo compounds, but without success. It was reported by Chyng-yann Shiue[5] that thermal decomposition of the potassium salt of 1,1-dinitroethane in the presence of cyclohexene gave 1-acetylcyclohexene. The formation of this ketone was considered evidence for methylnitrocarbene, which could react as a 1,3-dipole, giving as an intermediate the Δ^2-isoxazoline *N*-oxide precursor to the ketone.



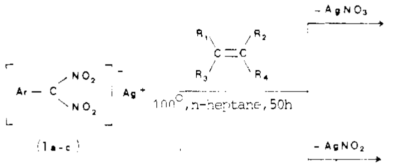
Nitrocarbenes must be strongly electrophilic and must react selectively with electron-rich alkenes.[6,7] In the presence of alkenes, they must be expected to yield cyclopropanes or Δ^2-isoxazoline *N*-oxides, considering the nitrocarbenes as 1,3-dipoles like the ketocarbenes which give dihydrofurans.[8]



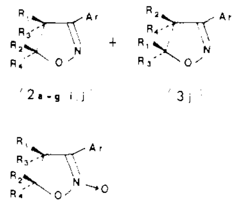
In our previous work[9] attempts were made to generate and trap arylnitrocarbenes by means of thermal decomposition of sodium salts of arylbromonitromethanes in the presence of alkenes. We found that the reaction products with several alkenes were neither cyclopropane derivatives nor Δ^2-isoxazoline *N*-oxides but were Δ^2-isoxazolines, identical with those obtained by 1,3-dipolar cycloaddition of the corresponding nitrile oxides and alkenes.

Rahman and Clapp[10] also recently reported the thermal decomposition of potassium salts of dinitroalkanes in the presence of various alkenes gave Δ^2-isoxazolines and not the expected Δ^2-isoxazoline *N*-oxides, indicating that the corresponding nitrocarbenes had been formed.

We report now that the silver salts of aryldinitromethanes (1) decompose in the expected way. Thus, thermal decomposition of the silver salts of aryldinitromethanes at 100 °C in *n*-heptane in the presence of several 1,1-diarylethylenes (electron-rich alkenes) gave mainly the corresponding Δ^2-isoxazoline *N*-oxides (4) and in low yields Δ^2-isoxazolines (2). Mixtures of Δ^2-isoxazoline *N*-oxides and Δ^2-isoxazolines were also obtained by the thermal decomposition of the silver salt of phenyldinitromethane (**1a**) in the presence of cyclohexene and *trans*-stilbene, whereas in the presence of dimethyl fumarate and methyl cinnamate (electron-poor alkenes) only Δ^2-isoxazolines were obtained.



a, Ar = C_6H_5
b, Ar = $C_6H_4CH_3$-*p*
c, Ar = C_6H_4Cl-*p*



(2a-g, i, j) (3j) (4a-h)

a, $R_1 = R_2 = H$; $R_3, R_4 = -(CH_2)_4-$; Ar = C_6H_5
b, $R_1 = R_4 = H$; $R_2 = R_3 = C_6H_5$; Ar = C_6H_5
c, $R_1 = R_3 = H$; $R_2 = R_4 = C_6H_5$; Ar = C_6H_5
d, $R_1 = R_3 = H$; $R_2 = R_4 = C_6H_5$; Ar = $C_6H_4CH_3$-*p*
e, $R_1 = R_3 = H$; $R_2 = R_4 = C_6H_5$; Ar = C_6H_4Cl-*p*
f, $R_1 = R_3 = H$; $R_2 = C_6H_5$; $R_3 = C_6H_4CH_3$-*p*; Ar = C_6H_5
g, $R_1 = R_3 = H$; $R_2 = C_6H_5$; $R_3 = C_6H_4Br$-*p*; Ar = C_6H_5
h, $R_1 = R_3 = H$; $R_2 = R_4 = C_6H_4CH_3$-*p*; Ar = C_6H_5
i, $R_1 = R_4 = H$; $R_2 = R_3 = COOCH_3$; Ar = C_6H_5
j, $R_1 = R_4 = H$; $R_2 = C_6H_5$; $R_3 = COOCH_3$; Ar = C_6H_5

Yields of the various products based on the amount of the starting salt, and not on that which actually reacted, are given in Table I.

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[1] Preliminary communication, N. E. Alexandrou and E. Coutouli-Argyropoulou, 1st European Symposium on Organic Chemistry, Abstracts of Papers, Cologne, Federal Republic of Germany, 1979, p 90.

[2] Taken in part from the Ph.D. Thesis of E.C.-A., University of Thessaloniki, 1980.

[3] U. Schöllkopf and P. Tonne, *Justus Liebigs Ann. Chem.*, **753**, 135 (1971).

[4] U. Schöllkopf and P. Markusch, *Justus Liebigs Ann. Chem.*, **753**, 143 (1971).

[5] Chyng-yann Shiue, *Diss. Abstr. B*, 31, Part 1, 7198 (1971).

[6] R. Hoffman, G. D. Zeiss, and G. W. VanDine, *J. Am. Chem. Soc.*, **90**, 1485 (1968).

[7] R. A. Moss, M. Fedorynski, and Wen-Chung Shieh, *J. Am. Chem. Soc.*, **101**, 4736 (1979).

[8] R. A. Moss and M. Jones, "Carbenes", Wiley, New York, Vol. 1, 1973, p 112.

[9] N. Alexandrou, E. Coutouli, and A. Varvoglis, *Tetrahedron Lett.*, 2131 (1975).

[10] A. Rahman and L. B. Clapp, *J. Org. Chem.* 41, 122 (1976).

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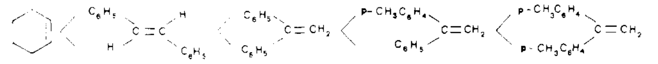
Table I. Yields[a] of Δ^2-Isoxazolines and Δ^2-Isoxazoline *N*-Oxides Formed by Thermal Decomposition of Silver Salts of Aryldinitromethanes with Various Alkenes

starting compd		reaction products			
silver salt	alkene	Δ^2-isoxazoline	yield, %	Δ^2-isoxazoline *N*-oxide	yield, %
1a	cyclohexene	2a[b]	1	4a	5
1a	*trans*-stilbene	2b[c]	14	4b[h]	19
1a	1,1-diphenylethylene	2c[d]	3	4c	34
1b	1,1-diphenylethylene	2d	7	4d	9
1c	1,1-diphenylethylene	2e	4	4e	37
1a	1-phenyl-1-(*p*-tolyl)ethylene	2f[e]	2	4f	42
1a	1-(*p*-bromophenyl)-1-phenylethylene	2g[e]	1	4g	36
1a	1,1-di-(*p*-tolyl)-ethylene			4h	49
1a	dimethyl fumarate	2i[f]	8		
1a	methyl cinnamate	2j[g] 3i[g]	10 5		

[a] The yields are the average value of two experiments. [b] G. Zinner and H. Günther, *Chem. Ber.*, **98**, 1353 (1965). [c] G. S. D'Alcontres and P. Grünanger, *Gazz. Chim. Ital.*, **80**, 831 (1950); *Chem. Abstr.*, **46**, 4527*h* (1952). [d] K. Kotera, Y. Takano, A. Matsuura, and K. Kitahonoki, *Tetrahedron*, **26**, 539 (1970). [e] P. Grünanger, *Gazz. Chem. Ital.*, **84**, 359 (1954); *Chem. Abstr.*, **49**, 5436*f* (1955). [f] Reference 10. [g] R. Sustmann, R. Huisgen, and H. Huber, *Chem. Ber.*, **100**, 1802 (1967). [h] A. T. Nielsen and T. G. Archibald, *J. Org. Chem.*, **34**, 984 (1969).

The reactivity of various alkenes based on the yield of *N*-oxides from the decomposition of the silver salt of phenyldinitromethane is in general the following:

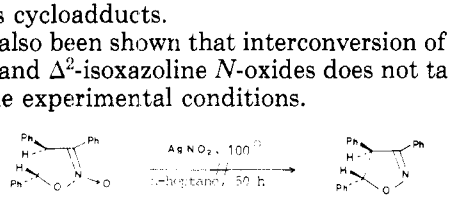


The regioselectivity of the reaction with respect to the formation of Δ^2-isoxazolines is the same as that observed in the reactions of nitrile oxides with alkenes. Thus, in the reactions with 1,1-diarylethylenes only regioisomers of the type **2** were obtained, whereas in the reaction with methyl cinnamate the two regioisomers **2j** and **3j** were obtained in a ratio of 2:1, which is similar to the ratio observed in the reaction of benzonitrile oxide with the same alkene.[11]

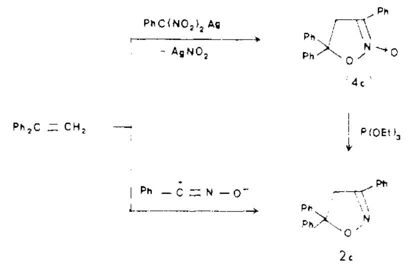
The regioselectivity of the reaction leading to Δ^2-isoxazoline *N*-oxides is also the same as that leading to Δ^2-isoxazolines, as shown in Scheme I.

It is of interest to note that trans alkenes gave in all cases the trans cycloadducts.

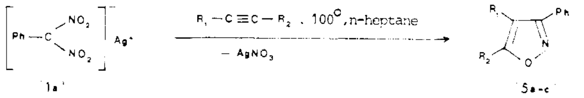
It has also been shown that interconversion of Δ^2-isoxazolines and Δ^2-isoxazoline *N*-oxides does not take place under the experimental conditions.



Scheme I

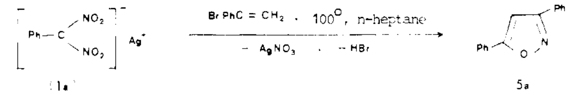


Decomposition of the silver salt of phenyldinitromethane in the presence of several alkynes led to the formation of the corresponding isoxazoles (**5a**,[12] **5b**,[13] and **5c**) in yields of 5–15%, without any formation of the expected isoxazole *N*-oxides.



a, $R_1 = H$, $R_2 = Ph$
b, $R_1 = R_2 = CO_2CH_3$
c, $R_1 = CH_3$; $R_2 = N(CH_2CH_3)_2$

On the other hand the reaction of α-bromostyrene with the silver salt of phenyldinitromethane (**1a**) gave, upon elimination of hydrogen bromide, the corresponding isoxazole (**5a**) instead of the expected *N*-oxide.



It is of interest to note that thermal decomposition of the sodium salt of phenyldinitromethane in the presence of cyclohexene gave only the Δ^2-isoxazoline (**2a**), in agreement with our previous work[9] and the results of Clapp.[10] However, in the presence of 1,1-diphenylethylene both Δ^2-isoxazoline (**2c**) and Δ^2-isoxazoline *N*-oxide (**4c**) were isolated in low yields (3% and 6%, respectively). The decomposition of the sodium salt of phenylbromonitromethane in the presence of 1,1-diphenylethylene gave similar results.

The new compounds were fully characterized by their IR, NMR, and mass spectra, whereas the compounds **2b–e**, **5a**, and **5c** were identical with authentic samples prepared from the corresponding unsaturated systems and nitrile oxides. The only known *N*-oxide (**4b**) was also identical with an authentic sample prepared from α-nitrostilbene.[14]

IR spectra of the *N*-oxides (**4**) showed absorptions in the range 1585–1615 (C=N) and 1215–1235 cm^{-1} (N→O). In the mass spectra they gave, besides the molecular ion, peaks at ($M^+ - 16$) in a relative abundance of less than 10%. A possible fragmentation pattern for the 3,5,5-triphenyl-Δ^2-isoxazoline *N*-oxide (**4c**) is given in Scheme II.

The Δ^2-isoxazoline *N*-oxides show in the NMR spectra a lower field shift (0.17–0.27 ppm) for the isoxazoline ring protons (4-H, 5-H) and the ortho protons of the 3-aryl group than do the corresponding Δ^2-isoxazolines. The chemical shifts (δ values) of the protons of *N*-oxide **4a** and

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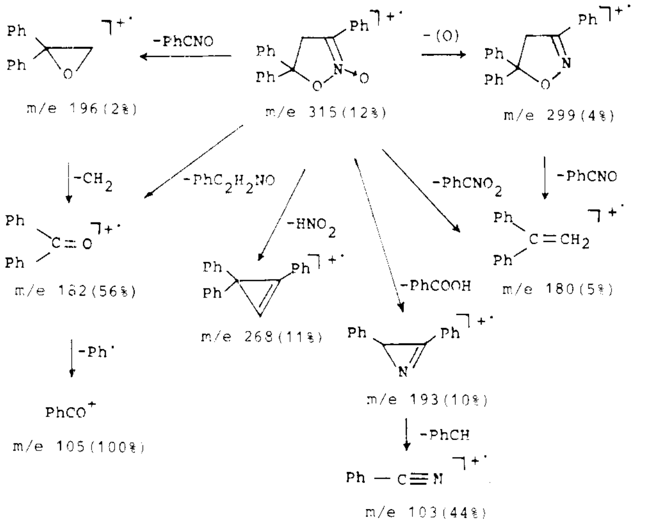
(11) M. Christl and R. Huisgen, *Tetrahedron Lett.*, 5209 (1968).

(12) A. Quilico and G. Speroni, *Gazz. Chim. Ital.*, **76**, 148 (1946); *Chem. Abstr.*, **41**, 961*g* (1947).

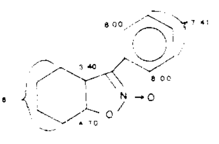
(13) L. Erichomovitch and L. F. Chubb, *Can. J. Chem.*, **44**, 2095 (1966).

(14) A. Dornow and F. Boberg. *Justus Liebigs Ann. Chem.*, **578**, 94 (1952).

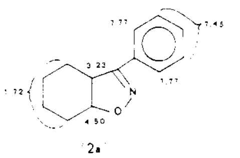
Scheme II. Fragmentation Pattern of 3,5,5-Triphenyl-Δ^2-isoxazoline *N*-Oxide (4c)



the corresponding isoxazoline **2a** are given below (the given values are the center of the multiplets). This low field



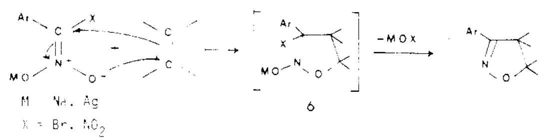
4a



2a

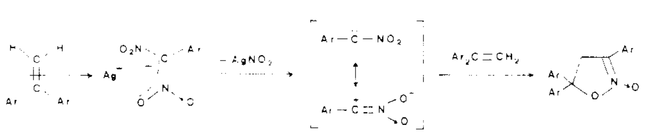
shift in the *N*-oxides might be attributed to a magnetic anisotropy effect of the N→O group.

Concerning the reaction mechanism leading to the Δ^2-isoxazolines, it is proposed in agreement with our previous work[9] that the addition of the alkene takes place on the nitronate form of the salt, and upon elimination of MOX from the intermediate **6**, the isoxazoline derivative is formed.



The formation of nitrile oxides as intermediates is improbable since furoxans were not isolated as products. Thermal decomposition of the silver salt of phenyldinitromethane in *n*-heptane in the absence of unsaturated systems gave benzoic acid as the main product, in agreement with previous results.[10]

Concerning the formation of Δ^2-isoxazoline *N*-oxides, it is noted that these products are mainly obtained from the decomposition of silver salts in the presence of electron-rich alkenes. According to the principle of hard and soft acids and bases,[15] the soft silver ion in the ambient anions would rather be attached to the soft carbon atom than to the oxygen. In this case α-elimination of silver nitrite takes place. This process is also facilitated by the presence of electron-rich alkenes, probably by formation of a π complex between the alkene and Ag^+.



Assuming that **6** is a common intermediate for the formation of both Δ^2-isoxazolines and Δ^2-isoxazoline *N*-oxides, the influence of substituents in the alkene and the preferred elimination of silver nitrite instead of silver nitrate, which is a common process with the sodium and potassium salts, could not be explained.

In conclusion, the present experimental results are most compatible with an arylnitrocarbene intermediate. On the other hand, with respect to the proposed mechanism the aspect of a two-step reaction cannot be ruled out completely and this problem is under further consideration.

Experimental Section

All melting points are uncorrected. They were obtained with a Kofler hot-stage apparatus. IR spectra were obtained with a Perkin-Elmer Model 257 spectrophotometer. NMR spectra, reported in δ units, were obtained with a Varian A-60A spectrometer with Me_4Si as internal reference. The mass spectra were measured with a Hitachi Perkin-Elmer Model RMU-6L spectrometer, with an ionization energy of 70 eV. Elemental analyses were performed with a Perkin-Elmer analyser Model 240.

Preparation of Starting Materials. Silver salts of aryldinitromethanes[16] were prepared from the corresponding sodium salts with silver nitrate in aqueous solution. Sodium salts[17] were prepared from the corresponding aryldinitromethanes with sodium ethoxide in ethanolic solution, whereas aryldinitromethanes were prepared from the corresponding benzaldoximes by a known procedure.[18] The silver salts, before their use, were dried in vacuo over phosphorus pentoxide. The new salts **1b** and **1c** gave satisfactory analytical values for C, H, N. The several diarylethylenes and α-bromostyrene were also prepared by known methods,[19,20] whereas the other alkenes and alkynes were commercially available.

General Procedure for Thermal Decomposition of Silver Salts of Aryldinitromethanes in the Presence of Alkenes and Alkynes. A suspension of the silver salt (5 mmol) in *n*-heptane (40 mL, freshly distilled from sodium) and alkene or alkyne (5 mmol) was stirred under dry nitrogen for 50 h under reflux (~100 °C). The insoluble residue was removed by filtration and washed with chloroform (100 mL). The IR spectrum of the solid residue showed the presence of the starting silver salt. The solid residue also gave the brown ring test for nitrates,[21] whereas this test for the starting salt was negative. The filtrate and washings were evaporated and the oily residue was chromatographed on silica gel and eluted with a mixture of hexane–ethyl acetate (10:1). The *N*-oxides were eluted after the corresponding Δ^2-isoxazolines. In the case of the thermal decomposition of the silver salt of phenyldinitromethane in the presence of cyclohexene, the latter was used in excess as solvent. Analytical data are summarized in Table II.

Preparation of Δ^2-Isoxazolines and Isoxazoles from Nitrile Oxides. An ether solution of the unsaturated compound (1 mmol) was added to an ether solution of the nitrile oxide (1 mmol), prepared by a known method,[22] and the solution remained at room temperature for 24 h. After evaporation of the solvent, the reaction product was crystallized from the residue by adding ethanol. In the case of the isoxazole (**5c**), it was separated from the reaction mixture by chromatography (silica gel with a mixture of hexane–ethyl acetate as eluant).

Deoxygenation of *N*-Oxide 4c to Δ^2-Isoxazoline 2c. A mixture of *N*-oxide **4c** (0.07 g) and triethyl phosphite (2 mL) was heated under reflux. After 1 h, benzene (10 mL) was added to the reaction mixture and the benzene layer was extracted with

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(15) R. G. Pearson and J. Songstad, *J. Am. Chem. Soc.*, **89**, 1827 (1967).

(16) *Beilstein, 4th ed.*, **5**, 343 (1950).

(17) A. Hantzsch, *Chem. Ber.*, **40**, 1533 (1907).

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(20) K. Yates and J. J. Perie, *J. Org. Chem.*, **39**, 1902 (1974).

(21) F. Feigl, "Spot Tests in Inorganic Analysis", Elsevier, New York, 1958, p 326.

(22) P. Rajagopalan, B. G. Advani, and C. N. Talaty, *Org. Synth.*, **49**, 71 (1969).

Table II. Analytical Data for Compounds 2d,e, 4a,c-h, and 5c

compd	mp, °C	formula	mol wt	anal.						IR (Nujol), cm^{-1}		NMR (CDCl$_3$), δ	mass spectrum, *m/e* (%)
				calcd			found						
				C	H	N	C	H	N	C=N	N→O		
2d	127-128[a]	$C_{22}H_{19}NO$	313.38	84.31	6.11	4.47	84.45	6.28	4.55	1600		2.35 (s, 3 H), 3.95 (s, 2 H), 7.42 (m, 14 H)	313 (100 M$^+$), 312 (67), 296 (27), 180 (89), 179 (30), 178 (17), 165 (35), 105 (37), 77 (19)
2e	143-146[a]	$C_{21}H_{16}ClNO$	333.84	75.55	4.83	4.20	74.99	4.78	4.29	1600		3.93 (s, 2 H), 7.45 (m, 14 H)	333 (90 M$^+$), 332 (60), 316 (29), 180 (100), 179 (39), 178 (23), 165 (46), 105 (42), 77 (21)
4a	108-110[b]	$C_{13}H_{15}NO_2$	217.26	71.86	6.96	6.45	71.88	6.93	6.45	1585	1220	1.76 (m, 8 H), 3.40 (m, 1 H), 4.70 (m, 1 H), 7.41 (m, 3 H), 8.00 (m, 2 H)	217 (100 M$^+$), 201 (7), 200 (28), 188 (22), 172 (48), 130 (58), 104 (29), 98 (30), 77 (44)
4c	183-185[a]	$C_{21}H_{17}NO_2$	315.35	80.00	5.40	4.44	80.14	5.52	4.42	1615	1220 1235	4.12 (s, 2 H), 7.40 (m, 13 H), 7.95 (m, 2 H)	315 (12 M$^+$), 299 (4), 268 (11), 196 (2), 193 (10), 182 (56), 180 (5), 105 (100), 103 (44), 77 (74)
4d	193-195[c]	$C_{22}H_{19}NO_2$	329.38	80.22	5.81	4.25	80.48	6.10	4.25	1615	1215 1235	2.37 (s, 3 H), 4.13 (s, 2 H), 7.43 (m, 12 H), 7.87 (d, 2 H)	329 (27 M$^+$), 313 (8), 282 (19), 207 (11), 196 (3), 182 (90), 180 (12), 117 (75), 105 (100), 77 (75)
4e	184-186[a]	$C_{21}H_{16}ClNO_2$	349.84	72.10	4.61	4.00	71.98	4.44	4.09	1610	1230	4.12 (s, 2 H), 7.39 (m, 12 H), 7.89 (d, 2 H)	349 (10 M$^+$), 333 (5), 302 (6), 227 (6), 196 (n),[e] 82 (100), 180 (7), 137 (50), 105 (90), 77 (31)
4f	132-133[a]	$C_{22}H_{19}NO_2$	329.38	80.22	5.81	4.25	79.99	5.80	4.09	1615	1235	2.32 (s, 3 H), 4.12 (s, 2 H), 7.35 (m, 12 H), 7.95 (m, 2 H)	329 (12 M$^+$), 313 (2), 282 (11), 210 (3), 207 (8), 196 (51), 194 (5), 193 (8), 119 (100), 105 (38), 103 (49), 91 (38), 77 (54)
4g	195-197[c]	$C_{21}H_{16}BrNO_2$	394.27	63.96	4.09	3.55	63.76	4.09	3.48	1615	1235 1225	4.13 (s, 2 H), 7.44 (m, 12 H), 7.95 (m, 2 H)	393 (8 M$^+$), 377 (2), 346 (5), 274 (3), 271 (6), 258 (2), 193 (16), 183 (52), 105 (100), 103 (74), 77 (83)
4h	164-166[a]	$C_{23}H_{21}NO_2$	343.41	80.44	6.16	4.08	80.52	6.18	4.11	1615	1230 1215	2.33 (s, 6 H), 4.12 (s, 2 H), 7.33 (m, 11 H), 7.97 (m, 2 H)	343 (11 M$^+$), 327 (4), 296 (13), 224 (3), 210 (85), 208 (12), 207 (13), 119 (100), 103 (70), 91 (70), 77 (36)
5c	*d*	$C_{14}H_{18}N_2O$	230.30	73.01	7.88	12.17	73.27	7.94	12.02	1615		1.17 (t, J = 8 Hz, 6 H), 1.97 (s, 3 H), 3.30 (q, J = 8 Hz, 4 H), 7.45 (m, 5 H)	230 (100 M$^+$), 215 (14), 158 (60), 132 (55), 130 (61), 105 (80), 104 (46), 77 (25), 72 (22)

[a] Recrystallized from ethanol. [b] Recrystallized from hexane-chloroform. [c] Recrystallized from hexane-dichloromethane. [d] Liquid, IR (neat), NMR (CCl$_4$). [e] n = negligible intensity.

two 20-mL portions of H_2SO_4 (2 N) and four times with water. After the solution was dried over sodium sulfate and the solvent was evaporated, the Δ^2-isoxazoline (**2c**) was obtained quantitatively, identical with that previously prepared.

Attempted Interconversions of Δ^2-Isoxazolines and Δ^2-Isoxazoline *N*-Oxides. A. Equimolecular amounts of *N*-oxide **4b** (0.024 g) and silver nitrite (0.012 g) in *n*-heptane (5 mL) were heated under reflux for 50 h with stirring. After removal of the insoluble solids and the solvent, the residue was chromatographed (preparative TLC, silica gel, hexane–ethyl acetate (10:1)) to yield 0.021 g of unreacted **4b**.

B. Equimolecular amounts of Δ^2-isoxazoline **2c** (0.06 g) and silver nitrate (0.03 g) in *n*-heptane (5 mL) were heated under reflux for 50 h with stirring. After removal of the insoluble solids and the solvent, the unreacted Δ^2-isoxazoline **2c** was obtained quantitatively.

Registry No. **1a**, 74609-84-0; **1b**, 74609-85-1; **1c**, 74609-86-2; **2a**, 50899-27-9; **2b**, 4894-25-1; **2c**, 5050-64-6; **2d**, 74609-87-3; **2e**, 74609-88-4; **2f**, 74609-89-5; **2g**, 74609-90-8; **2i**, 17669-31-7; **2j**, 17669-33-9; **3j**, 17669-32-8; **4a**, 74609-91-9; **4b**, 19018-61-2; **4c**, 74609-92-0; **4d**, 74609-93-1; **4e**, 74609-94-2; **4f**, 74609-95-3; **4g**, 74609-96-4; **4h**, 74609-97-5; **5c**, 74609-98-6; cyclohexene, 110-83-8; *trans*-stilbene, 103-30-0; 1,1-diphenylethylene, 530-48-3; 1-phenyl-1-(*p*-tolyl)ethylene, 948-55-0; 1-(*p*-bromophenyl)-1-phenylethylene, 4333-76-0; 1,1-di-(p-tolyl)ethylene, 2919-20-2; dimethyl fumarate, 624-49-7; methyl cinnamate, 103-26-4.

Acylphosphonates: P–C Bond Cleavage of Dialkyl Acylphosphonates by Means of Amines. Substituent and Solvent Effects for Acylation of Amines

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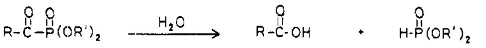
Received February 5, 1980

Studies on the benzoylation of amines of dialkyl benzoylphosphonates (**1A–F**) were described in detail. Stoichiometric reactions of diethyl benzoylphosphonate (**1B**) with a variety of amines (**2a–i**) gave amides as the main products along with diethyl phosphonate (**4B**) and α-(phosphoryloxy)benzyl phosphonate (**5B**). The yields of amides increased with the ratio of **1B**/**2a–i**. The use of hindered dialkyl benzoylphosphonates resulted in high yields of amides while the reaction rates decreased markedly. The benzoylations of *n*-propylamine (**2d**) with **1B** in various solvents having dielectric constants of 1.9–36.7 were conducted. The yields of *N*-*n*-propylbenzamide (**3d**) and **5B** were surprisingly almost constant. However, the reaction rates varied as follows. In nonpolar solvents such as *n*-hexane and cyclohexane benzoylation was remarkably rapid while the benzoylation in methylene chloride was much slower than that in other solvents used. Compound **1B** underwent smooth reaction with aliphatic amines but did not react with aromatic amines under the same conditions. Selective N-benzoylation of the bifunctional amine, ethanolamine, was achieved by means of diisopropyl benzoylphosphonate (**1C**) in tetrahydrofuran. The use of the hindered dialkyl benzoylphosphonate **1C** resulted in poorer yields of amides in the case of the reaction with a hindered amine such as diethylamine, but higher yields of amides in the case of primary amines. Addition of triethylamine and 4-(dimethylamino)pyridine (DMAP) slightly accelerated the benzoylation, but yields of amides were similar to those in the absence of the catalysts. Optimum conditions for high yields of amides were proposed for the practical use of dialkyl benzoylphosphonates as the acylating agents in the present reaction.

Acylation of functional groups such as hydroxyl and amino groups is one of the important and fundamental reactions in organic synthesis. Various kinds of acylating agents have been developed and employed, such as acyl halides, anhydrides, mixed anhydrides, active esters, azolides, and ketones.[1] On the other hand, it is generally recognized that phosphorus–carbon (P–C) bonds of organophosphorus compounds are quite stable and are not cleaved easily under the usual conditions.[2] Hence, studies of the cleavage reaction of the P–C bond are lacking and very little data are available for the utilization of organophosphorus compounds as synthetic agents. However, the following character of dialkyl acylphosphonates might provide some information in this direction. Dialkyl acylphosphonates possessing C(O)–P bonds are known to be labile, even toward moisture in air, and decompose into carboxylic acids and dialkyl phosphonates.[3-8]



$$\mathrm{R{-}\overset{O}{\overset{\|}{C}}{-}\overset{O}{\overset{\|}{P}}(OR')_2 \xrightarrow{H_2O} R{-}\overset{O}{\overset{\|}{C}}{-}OH + H{-}\overset{O}{\overset{\|}{P}}(OR')_2}$$

A few studies on nucleophilic displacement reactions of acylphosphonates have also been reported for reactions with alcohols,[9-11] thiols,[12,13] amines,[11,14] and carbanions.[15-18] In spite of the above features of acylphosphonates, no systematic study on acylphosphonates as acylating agents has appeared.

In this paper, a systematic study on the benzoylation of various amines by use of dialkyl benzoylphosphonates is described in detail.

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