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Synthesis and Characterization of New Triazenide Salts†

Andrej Virag, Anton Meden, Marijan Kočevar, and Slovenko Polanc*

Faculty of Chemistry and Chemical Technology, University of Ljubljana, Aškerčeva 5, SI-1000 Ljubljana, Slovenia

slovenko.polanc@fkkt.uni-lj.si

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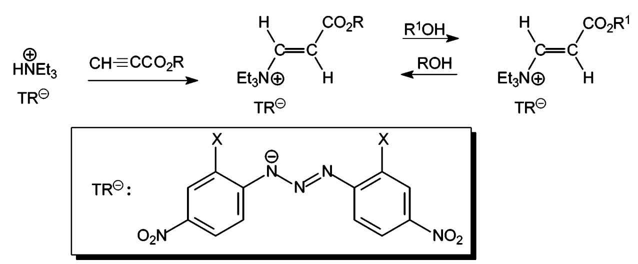
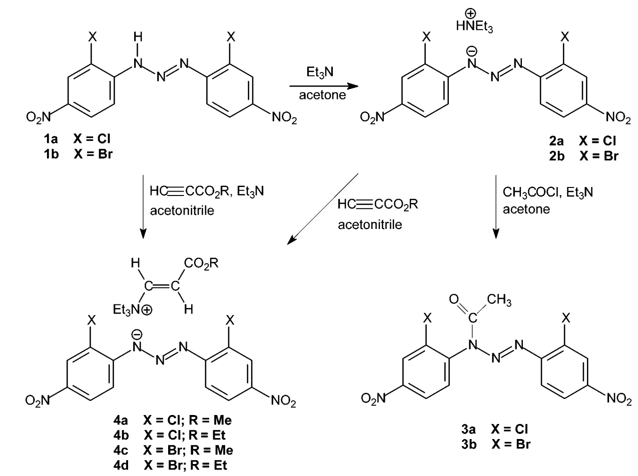


Stable triethylammonium triazenide salts were obtained on treatment of the appropriate triazenes with triethylamine. Those salts are described and fully characterized for the first time and are used for the preparation of alkoxycarbonylvinyltriethylammonium triazenides, which are prone to transesterification.

Triazenes are known as a versatile tool in organic synthesis.[1] Although they have been studied for their anorectic activity[2] and potency against specific tumor cell lines,[3] applied as protecting groups in natural product synthesis,[4] or used to form heterocycles,[5] most reports describe their application as multifunctional linkers.[1,6]

In recent years, we have focused on various aspects of hydrazides[7] and other N−N bond-containing compounds.[8] In the course of this work, we also developed an efficient procedure for obtaining 1,3-diaryltriazenes,[9] which served as precursors of 3-acyl-1,3-diaryltriazenes, a new, neutral, and selective acylating agent. The latter were easily obtained from reactions of 1,3-diaryltriazenes with acid chlorides in the presence of a base.[10] The use of triethylamine as a base in these transformations was always associated with the appearance of a deep violet color of the reaction mixture. A careful examination of the process showed that the corresponding triethylammonium triazenide was formed first. Until now, only one triethylammonium triazenide was mentioned in the literature, that is, obtained as a side product during the coupling of α-amino carboxylic esters with 2,4-dinitrobenzenediazonium tetrafluoroborate in the presence of triethylamine.[11] Unfortunately, no details were given about its structure. Here, we report on an access to the new triazenide salts (Scheme 1). In a typical procedure, a solution of 1,3-bis(2-chloro-4-nitrophenyl)triazene **1a** or its bromo analogue **1b** in boiling acetone was treated with triethylamine (2 equiv), and the reaction mixture was then kept at −19 °C for 24 h to give **2a** or **2b** as stable triazenide salts in 73 and 74% isolated yield, respectively.

SCHEME 1. Synthesis of Triazenide Derivatives



The X-ray structure analysis of **2a** revealed that the triazenide moiety is nearly planar, exposing a negatively charged part toward the cationic moiety (Figure 1). A weak hydrogen bond of 3.012(2) Å between N(6) and N(3) causes slight asymmetry in the triazenide part of the anionic moiety. This, along with other crystal packing requirements, results in the two 2-chloro-4-nitrophenyl groups of **2a** being crystallographically unequivalent in the solid state. However, the ^{1}H and ^{13}C NMR spectra of its solution in DMSO-d_6 indicate that the aryl groups are

† Dedicated to Professor Miha Tišler on the occasion of his 80th birthday.

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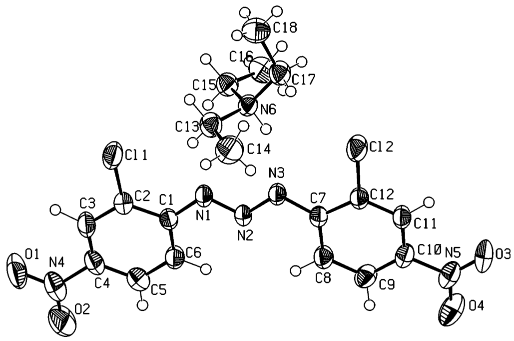
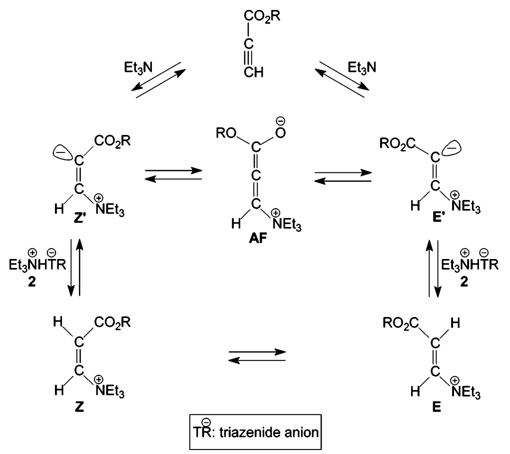


FIGURE 1. ORTEP view of compound **2a** with labeling of the nonhydrogen atoms (ellipsoids are drawn at 50% probability level). Selected bond lengths (Å): C(1)−N(1), 1.398(2); N(1)−N(2), 1.289(2); N(2)−N(3), 1.313(2); N(3)−C(7), 1.388(2).

SCHEME 2. Addition to Alkyl Propiolate



equivalent. Similar behavior is documented for triazenide complexes.[12]

The treatment of the triazenide salts **2a** or **2b** with acid chlorides indeed led to the formation of 3-acyl-1,3-diaryltriazenes, as shown by the synthesis of **3a**[10] or **3b**. We also noticed that **2a** and **2b** smoothly reacted at room temperature with either methyl or ethyl propiolate to give the alkoxycarbonylvinyltriethylammonium triazenides **4a**−**d** in 85−92% isolated yields. The same products were isolated if triethylamine was added to a mixture of alkyl propiolate and a selected triazene in acetonitrile. The compounds **4** were exclusively of the *E* configuration, which was evident from ^{1}H NMR spectra of the crude reaction mixtures; the coupling constants of the vinylic protons were always 14.4 Hz. The reaction of the salt **2** with alkyl propiolate to produce the ester **4** probably proceeds as described by Jung and Buszek for the addition of trialkylammonium salts to activated acetylenes.[13] On the basis of their explanation, a small amount of free triethylamine, present in the salt **2**, should be added to the alkyl propiolate to give **Z′** rather than **E′** as the major isomer (Scheme 2). If the equilibrium between **Z′** and **E′**, which proceeds via the allenic form **AF**, is slow versus protonation, one would expect the **Z** product to predominate over the **E** isomer. When the equilibration is fast, one should obtain the thermodynamically more stable compound

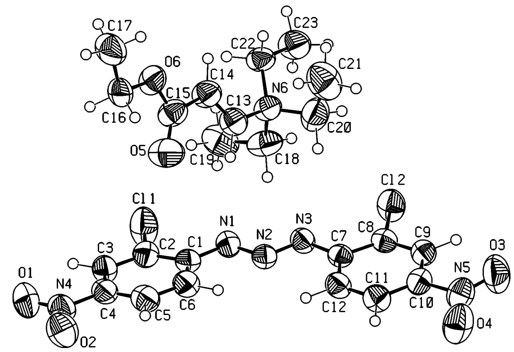


FIGURE 2. ORTEP view of compound **4b** with labeling of the nonhydrogen atoms (ellipsoids are drawn at 50% probability level). Selected bond lengths (Å): C(1)−N(1), 1.401(4); N(1)−N(2), 1.303(3); N(2)−N(3), 1.309(3); N(3)−C(7), 1.393(3).

E as the major or the only product. The above process was also followed by ^{1}H NMR spectroscopy to consider the possibility of equilibration between the products **Z** and **E**. Examination of the reaction of **2a** with methyl propiolate in acetonitrile revealed that two products, that is, the **Z** and the **E** isomers, were obtained in the reaction mixture after 30 min; the ratio **Z**/**E** was about 1:9. The **Z** isomer was assigned by a typical coupling constant (J = 10.8 Hz) for two doublets that appeared at 6.29 and 6.59 ppm. However, the **Z** form isomerized into the **E** isomer (i.e., the product **4a**) during the course of the reaction. As already mentioned, there was no evidence for the **Z** product in the crude reaction mixture when the reagents were consumed (after 8 h). The reaction of **2a** with methyl propiolate was also carried out in methanol as a solvent and gave the ester **4a** as an exclusive product within 15 min.

The structure of **4b** was supported by X-ray structure analysis (Figure 2). Here, both 2-chloro-4-nitrophenyl groups are still crystallographically unequivalent as the whole triazenide moiety is in the asymmetric unit and no symmetry element relates one-half of it to the other half. The asymmetry, however, is much smaller than in the case of **2a**, because there is no hydrogen bond from the cationic part, as is the case in **2a**. In solution, the crystal-packing restrictions are completely eliminated and both 2-chloro-4-nitrophenyl groups become equivalent (^{1}H and ^{13}C NMR evidence).

The alkoxycarbonylvinyltriethylammonium triazenides **4a**−**d** are prone to transesterification. Thus, **4a**−**d** could easily be transformed to the appropriate esters when dissolved in the selected alcohol with the solution being kept at room temperature for the time indicated in Table 1. For example, **4a** reacted with allyl alcohol to give **4f** within 8 h. Transesterification is a reversible process, as indicated by the conversion of **4a** into **4b**, **4c** into **4d** or **4j**, and vice versa.

It should be noted that the reactivity of **4a**−**d** with alcohols was compared with that of an analogous alkoxycarbonylvinyltriethylammonium chloride, obtained as described earlier.[14] We found that the latter compound remained unchanged under reaction conditions required for the formation of **4e**−**j**. In addition, transesterification was not observed on alkoxycarbonylvinyltrimethylammonium tetrafluoroborates when they were prepared from trimethylammonium tetrafluoroborate and alkyl propiolates in methanol under reflux,[13] that is, the ester

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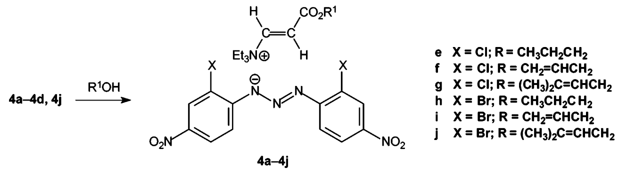
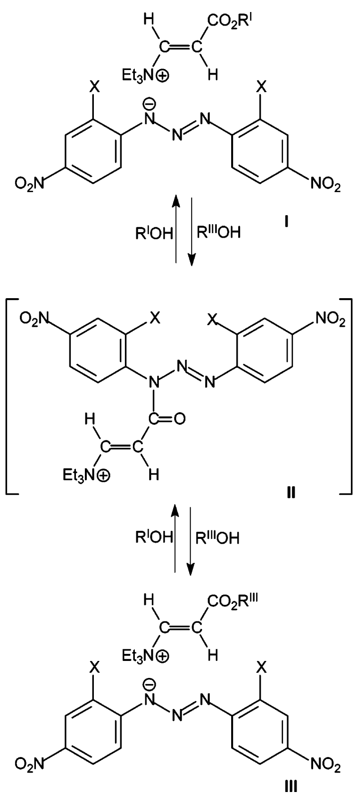
TABLE 1. Transesterification of Triazenides 4



triazenide	R^1OH	time[a] (h)	product	yield[b]
4a	EtOH	173	**4b**	86
4a	PrOH	288	**4e**	85
4a	$CH_2{=}CHCH_2OH$	8	**4f**	63
4a	$Me_2C{=}CHCH_2OH$	48	**4g**	79
4b	MeOH	4.5	**4a**	81
4b	$CH_2{=}CHCH_2OH$	96	**4f**	85
4b	$Me_2C{=}CHCH_2OH$	96	**4g**	79
4c	EtOH	173	**4d**	71
4c	PrOH	374	**4h**	73
4c	$CH_2{=}CHCH_2OH$	10	**4i**	63
4c	$Me_2C{=}CHCH_2OH$	24	**4j**	70
4d	MeOH	4.5	**4c**	85
4d	$CH_2{=}CHCH_2OH$	72	**4i**	60
4d	$Me_2C{=}CHCH_2OH$	72	**4j**	77
4j	MeOH	2	**4c**	82

[a] Reactions were carried out at rt. Conversion was always over 95%, as evident from ^{1}H NMR spectra of the crude reaction mixtures. [b] Isolated yields are given.

SCHEME 3. Reversible Transesterification



functionality of the product was always intact. The counteranion obviously plays an important role in the above-mentioned transesterification process, and the influence of the triazenide anion is undoubtedly different from that of the chloride or tetrafluoroborate anions. A plausible reaction pathway that would explain the transesterification of esters is proposed in Scheme 3. In the case of the ester **I**, we assume the attack of the triazenide counterion on the ester functionality and the formation of an unstable *N*-acyltriazene **II**, which would then react with a solvent ($R^{III}OH$) to give the ester **III**. Similarly, **III** could lead to **I** via the same triazene (**II**) when being treated with the alcohol R^IOH.[15] Chloride and tetrafluoroborate counteranions are not nucleophilic enough to form the corresponding reactive species that would enable a smooth transesterification.

In conclusion, the first fully characterized triethylammonium triazenides are described. These salts are stable compounds that can be used for the preparation of the corresponding alkoxycarbonylvinyltriethylammonium triazenides. The latter compounds are smoothly transformed to other esters, thus opening a simple entry to a larger pool of similar vinyltriethylammonium salts. We expect that the above results will stimulate further investigations toward the synthesis of other trialkylammonium triazenides, as well as to a variety of applications of the described triazenides.

Experimental Section

Procedure for the Synthesis of Triazenide Salts 2. A suspension of a selected triazene (**1a** or **1b**, 1 mmol) was heated in acetone (25 mL) under reflux for 5 min. Then triethylamine was added (2 mmol, 202 mg), and the reaction mixture was kept at −19 °C for 24 h. The solid material was filtered off and washed with cold acetone (5 mL) to give **2a** (73% yield) or **2b** (74% yield).

***N,N*-Diethylethanaminium 1,3-Bis(2-chloro-4-nitrophenyl)triazenide (2a).** Mp 203−204 °C (from acetone); IR 1574, 1499, 1334, 1323, 1262, 1213, 1183, 1166, 1117, 887 cm^{-1}; ^{1}H NMR (300 MHz, DMSO-d_6) δ 1.16 (9H, t, $J = 7.2$), 3.06 (6H, q, $J = 7.2$), 7.77 (2H, d, $J = 9.2$), 8.03 (2H, dd, $J_1 = 2.6$, $J_2 = 9.2$), 8.18 (2H, d, $J = 2.6$); ^{13}C NMR (75 MHz, DMSO-d_6) δ 8.8, 45.7, 116.1, 123.0, 125.5, 125.9, 140.7, 156.1; MS (FAB$^-$ for $C_{12}H_6Cl_2N_5O_4$) *m/z* 354 (40%, M − Et_3NH), 184 (81), 156 (83), 86 (100). Anal. Calcd for $C_{18}H_{22}Cl_2N_6O_4$ (457.31): C, 47.28; H, 4.85; N, 18.38. Found: C, 47.35; H, 4.96; N, 18.03.

***N,N*-Diethylethanaminium 1,3-Bis(2-bromo-4-nitrophenyl)triazenide (2b).** Mp 209−211 °C (from acetone); IR 1568, 1501, 1321, 1255, 1155, 1087, 878 cm^{-1}; ^{1}H NMR (300 MHz, DMSO-d_6) δ 1.16 (9H, t, $J = 7.3$), 3.06 (6H, q, $J = 7.3$), 7.71 (2H, d, $J = 9.2$), 8.05 (2H, dd, $J_1 = 2.6$, $J_2 = 9.2$), 8.33 (2H, d, $J = 2.6$); ^{13}C NMR (75 MHz, DMSO-d_6) δ 8.8, 45.8, 116.1, 116.5, 123.5, 128.5, 141.0, 157.2; MS (FAB$^-$ for $C_{12}H_6Br_2N_5O_4$) *m/z* 442 (3%, M − Et_3NH), 306 (46), 168 (32), 153 (100). Anal. Calcd for $C_{18}H_{22}Br_2N_6O_4$ (544.01): C, 39.71; H, 4.08; N, 15.44. Found: C, 39.57; H, 4.11; N, 15.29.

General Procedure for the Synthesis of Triazenides 4a−d. (1*E*)-*N,N,N*-Triethyl-3-methoxy-3-oxo-1-propen-1-aminium 1,3-Bis(2-chloro-4-nitrophenyl)triazenide (4a). To a stirred suspension of the triazene **1a** (712 mg, 2 mmol) in acetonitrile (20 mL) was added triethylamine (202 mg, 2 mmol) and methyl propiolate (185 mg, 2.2 mmol) at room temperature. The reaction mixture was stirred at room temperature for 3 h, evaporated to dryness under reduced pressure, and treated with diethyl ether (20 mL), and the crude product was filtered off to give **4a** (976 mg, 90% yield): mp 126−128 °C (from methanol); IR 1736, 1573, 1499, 1324, 1261, 1161, 1094, 887 cm^{-1}; ^{1}H NMR (300 MHz, DMSO-d_6) δ 1.16 (9H, t, $J = 7.2$ Hz), 3.57 (6H, q, $J = 7.2$ Hz), 3.78 (3H, s), 6.65 (1H, d, $J = 14.4$ Hz), 7.17 (1H, d, $J = 14.4$ Hz), 7.74 (2H, d, $J = 9.2$ Hz), 8.00 (2H, dd, $J_1 = 2.6$ Hz, $J_2 = 9.2$ Hz), 8.16 (2H, d, $J = 2.6$ Hz); ^{13}C NMR (75 MHz, DMSO-d_6) δ 7.8, 52. 5, 54.1, 115.8,

(15) These esters are promoters for some other transesterifications. Namely, several alkyl 4-nitrobenzoates can be successfully transformed into methyl 4-nitrobenzoate at room temperature in a methanolic solution in the presence of 10 mol % of the ester **4c**. The reactions are supposed to proceed via *N*-acyltriazene, which is similar to **II** (acyl = 4-nitrobenzoyl, X = Br). Unpublished results from our laboratory.

122.5, 123.0, 125.5, 126.0, 140.4, 145.6, 157.0, 163.7; MS (FAB^+ for $C_{10}H_{20}NO_2$) *m/z* 186 (100), 154 (92), 55 (89); MS (FAB^- for $C_{12}H_6Cl_2N_5O_4$) *m/z* 354 (23), 153 (100). Anal. Calcd for $C_{22}H_{26}Cl_2N_6O_6$ (541.38): C, 48.81; H, 4.84; N, 15.52. Found: C, 48.71; H, 4.90; N, 15.28.

General Procedure for Transesterification of Triazenides 4. (1*E*)-3-Allyloxy-*N,N,N*-triethyl-3-oxo-1-propen-1-aminium 1,3-Bis(2-chloro-4-nitrophenyl)triazenide (4f). A suspension of the triazenide **4a** (278 mg, 0.5 mmol) in allyl alcohol (5 mL) was stirred at room temperature for 8 h. The reaction mixture was evaporated to dryness, and allyl alcohol (0.5 mL) and diethyl ether (10 mL) were added. The solid material was filtered off to give the product **4f** (161 mg, 63% yield): mp 126−128 °C (from ethyl acetate/diisopropyl ether); IR 1740, 1572, 1499, 1322, 1262, 1159, 1088 cm^{-1}; ^1H NMR (300 MHz, DMSO-d_6) δ 1.16 (9H, t, $J = 7.2$ Hz), 3.58 (6H, q, $J = 7.2$ Hz), 4.73 (2H, dt, $J_1 = 1.4$ Hz, $J_2 = 5.6$ Hz), 5.29 (1H, tdd, $J_1 = 1.4$ Hz, $J_2 = 2.8$ Hz, $J_3 = 10.5$ Hz), 5.39 (1H, tdd, $J_1 = 1.4$ Hz, $J_2 = 2.8$ Hz, $J_3 = 17.2$ Hz), 5.98 (1H, m), 6.69 (1H, d, $J = 14.4$ Hz), 7.19 (1H, d, $J = 14.4$ Hz), 7.74 (2H, d, $J = 9.2$ Hz), 8.00 (2H, dd, $J_1 = 2.6$ Hz, $J_2 = 9.2$ Hz), 8.16 (2H, d, $J = 2.6$ Hz); ^{13}C NMR (75 MHz, DMSO-d_6) δ 7.5, 54.1, 65.7, 115.8, 118.6, 122.5, 123.0, 125.5, 126.0, 131.9, 140.3, 145.8, 156.9, 162.9; MS (FAB^+ for $C_{12}H_{22}NO_2$) *m/z* 212 (100), 185 (31), 93 (38); MS (FAB^- for $C_{12}H_6Cl_2N_5O_4$) *m/z* 354 (51), 305 (40), 168 (35), 153 (100). Anal. Calcd for $C_{24}H_{28}Cl_2N_6O_6$ (567.42): C, 50.80; H, 4.97; N, 14.81. Found: C, 50.94; H, 5.09; N, 14.78.

X-ray Crystallography. Single-crystal X-ray diffraction data were collected at room temperature on a Kappa CCD diffractometer (MoKα radiation) using the Nonius Collect Software.[16] Denzo and Scalepack[17] were used for indexing and scaling of the data. The structures were solved by means of SIR97.[18] The refinement was done using the Xtal3.4[19] program package, and the crystallographic plots were prepared by ORTEP III.[20] The crystal structures were refined on *F* values using the full-matrix least-squares procedure. The nonhydrogen atoms were refined anisotropically. The positions of the hydrogen atoms were geometrically calculated, and their positional and isotropic atomic displacement parameters were not refined. An absorption correction was not necessary. The Regina[21] weighting scheme was used. Crystallographic data have been deposited with the Cambridge Crystallographic Data Centre as CCDC 293609 (**2a**) and CCDC 293610 (**4b**).

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Supporting Information Available: Procedure for the preparation of compound **3b**; characterization data for compounds **3b**, **4b**−**e**, and **4g**−**j**; and the data (CIF files) for the X-ray crystallographic analyses for **2a** and **4b**. This material is available free of charge via the Internet at http://pubs.acs.org.

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