A Direct One-Step Preparation of Triarylverdazylium Salts from the Corresponding Triarylformazans

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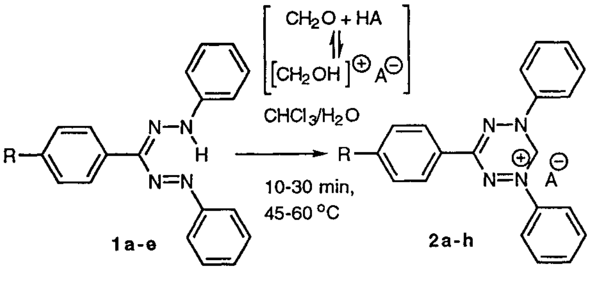
6-(4-Substituted-phenyl)-2,4-diphenylverdazylium salts **2** (8 examples, 55–93 %) were prepared by the reaction of 3-(4-substituted-phenyl)-1,5-diphenylformazans **1** with formaldehyde and different organic and inorganic acids in a two-phase chloroform/water medium by brief and gentle heating. Self-phase-transfer catalysis is apparently involved. Subsequent reductions of the salts **2** with excess ascorbic acid in the two-phase system give the corresponding verdazyl radicals, while in methanol the reduction proceeds to form leuco-verdazyls.

Verdazylium salts, together with the corresponding verdazyl radicals, are in continuous use for the study of single electron transfer (SET) reactions;[1–4] some of them are potential infrared absorbing dyes.[5] Previously described methods of verdazylium salt preparation involve the synthesis of the corresponding verdazyl radical, which is then oxidized to the verdazylium salt by various reagents. Thus, treatment of verdazyl radicals with strong electrophiles such as halogens in dry benzene gives verdazylium salts as a result of an SET reaction.[6,7] Verdazylium perchlorates were prepared by a two-step reaction of the corresponding verdazyl radicals first with tetranitromethane (forming a mixture of $C(NO_3)_3^-$ and NO_3^- verdazylium salts), followed by treatment with perchloric acid.[1] Different metal containing verdazylium double salts, i.e., chloro-platinates, -aurates, -palladates, and -ferrates, were synthesized by the reaction of verdazyl radicals with the corresponding metal chlorides in formic acid.[1,2] Triphenylverdazylium fluoroborate was obtained from triphenylverdazyl with $BF_3 \cdot OEt_2$ in dry CCl_4 or benzene.[8] A number of other oxidation reactions of verdazyl radicals leading to the formation of verdazylium salts (e.g., with peroxides, inorganic or organic acids, etc.) described in the literature are not of preparative significance (salts were not isolated or yields were moderate to low).[4]

We have now found that the reactions of triarylformazans **1a–e** with formaldehyde and acids in two-phase liquid–liquid (chloroform/water) medium occur rapidly at ambient temperatures to form verdazylium salts **2a–h** which are easy to isolate from the reaction media (Scheme 1).



2a-h	a	b	c	d	e	f	g	h
R	H	H	H	H	MeO	F	AcO	NO_2
A	BF_4	HSO_4	Picr.	ClO_4	ClO_4	ClO_4	ClO_4	CF_3SO_3

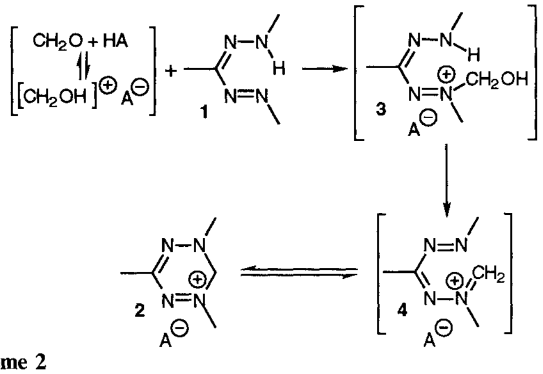
1a-e	a	b	c	d	e
R	H	MeO	F	AcO	NO_2

Scheme 1

Perchlorates **2d–g** are the most stable and were readily prepared. The success of the reaction evidently depends on the strength of the acid utilized: salts **2a,b** and especially picrate **2c** were obtained in lower yields and required longer reaction times and elevated temperatures. Salts **2a–c** are also more soluble than **2d** in diethyl ether or petroleum ether which were used for their isolation. Therefore their isolated yields were even lower where TLC of the final reaction mixture did not show any starting formazan.

Published preparations of verdazyl radicals sometimes include verdazylium salt formation as an intermediate stage, when the reaction of formazans with aliphatic aldehydes is carried out in the presence of acidic catalysts ($KHSO_4$, etc.).[6,9] However, these salts were formed in situ and their isolation, never previously reported, would pose serious problems under the reaction conditions described. As indicated above, all the verdazylium salts described in the literature were obtained by the oxidation of the corresponding verdazyls which were, in turn, synthesized from formazans.

Mechanisms for the formation of verdazylium salts are not well established.[4] In the present case, protonated formaldehyde may react with the formazan molecule **1** at the water/chloroform interface (Scheme 2) to form the *N*-(hydroxymethyl)tetraazapentadienylium cation **3**, which after dehydration gives cation **4** a ring-opened analog of verdazylium salt **2**. An equilibrium between **4** and **2** was suggested earlier[7] as an explanation of the

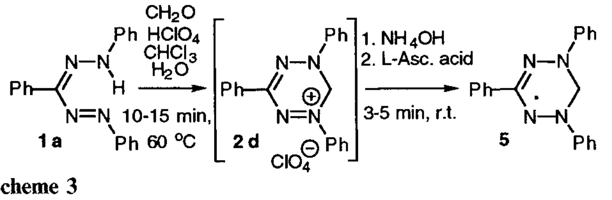


Scheme 2

high reactivity of verdazylium cations and the subsequent formation of ring-opened products.

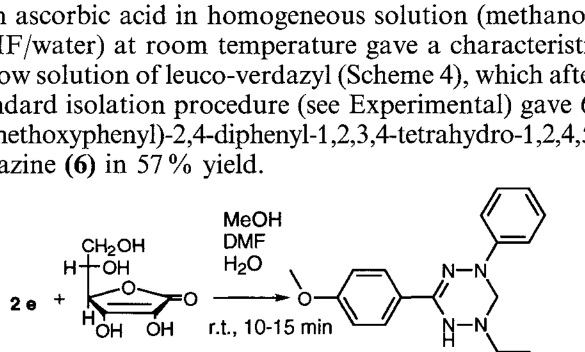
Formation of verdazylium salts **2** under these reaction conditions was also proved by their reduction into verdazyl radicals (Scheme 3) and leuco-verdazyls (Scheme 4).

When the TLC of reaction mixture of 1,3,5-triphenylformazan **1a** with formaldehyde and perchloric acid in the two-phase (chloroform/water) system at 45 °C showed the complete reaction of the formazan (15–20 min), ammonium hydroxide was added dropwise to raise the pH of the mixture to neutral, followed by the addition of ascorbic acid in methanol under vigorous stirring (Scheme 3). After a few minutes the color of the mixture became green indicating the complete reduction of the salt **2d** into 2,4,6-triphenylverdazyl **5**, which was isolated from the reaction mixture in 91 % yield. This procedure may also be used as a new one-pot preparation of verdazyls.



Scheme 3

The reduction of verdazylium salt **2e** (prepared as above) with ascorbic acid in homogeneous solution (methanol/DMF/water) at room temperature gave a characteristic yellow solution of leuco-verdazyl (Scheme 4), which after standard isolation procedure (see Experimental) gave 6-(4-methoxyphenyl)-2,4-diphenyl-1,2,3,4-tetrahydro-1,2,4,5-tetrazine (**6**) in 57 % yield.



Scheme 4

A comparison of the above reduction results indicates that when the reaction is carried out in two-phase liquid–liquid media the reduction stops at the radical stage, while in polar homogeneous phase it proceeded rapidly to give directly a leuco-compound.

Experimental data and physico-chemical characteristics of verdazylium salts are collected in the Table. The structures of the salts **2a–h** were confirmed by UV/VIS spectra and either HRMS (for both cations and anions) or elemental analysis data. Different anions in the unsubstituted triphenylverdazylium salts **2** do not strongly affect the position of long-wave absorption maximum (551–560 nm) in their UV/VIS spectra. Substitution in the *p*-position of the C_6 phenyl ring of perchlorates **2d–g** leads to either small hypso- (**2f, g**) or large bathochromic (**2e**) shifts of long-wave absorption maxima for electron-withdrawing or electron-donating substituents, respectively, compared to the maximum for the unsubstituted triphenylverdazylium perchlorate **2d**, which is in agreement with previously published data.[1,4,7] Picrate **1c** was found to be unstable in dioxane solution, while hydrogen sulfate **2b** was much less soluble than even perchlorates **2d–g**, and therefore its spectrum was recorded in methanol containing a small amount of sulfuric acid. The strongest hypsochromic shift in the series studied was observed for the salt **2h**, which is explained by the strong electron-withdrawing effect of the nitro group.

Melting points were measured with a Kofler Hot Stage apparatus and are uncorrected (Caution! Verdazylium perchlorates explode at the temperatures specified in the Table). The ^1H NMR spectrum of the leuco-verdazyl **6** was recorded on a Varian Gemini (300 MHz) spectrometer in $CDCl_3$ with TMS as internal standard. The UV/VIS spectra of verdazylium salts **2a–h** were recorded on an Olis Cary-14 spectrophotometer in dioxane (**2a, c–h**) or in methanol containing 0.5 % (v/v) of H_2SO_4 (**2b**) solutions (2.10^{-4} mol.L^{-1}). TLC was monitored using Kodak Chromatogram Sheets (silica gel) with $CHCl_3$ as an eluent. Starting compounds and solvents were commercially available (Aldrich, Fisher, Sigma) and were used as received. Formazans **1a–e** were prepared as previously described.[10]

Preparation of Verdazylium Salts 2a–h; General Procedure:

A mixture of the corresponding formazan **1a–e** (1 mmol), formaldehyde (0.45 mL of 37 % w/w water solution), $CHCl_3$ (25 mL), and

Table. Verdazylium Salts **2a–h**[a]

Salts 2	Yield (%) (Isolation Method)[b]	Reaction: Time (min) Temp (°C)	mp (°C)	Molecular Formula	UV/Vs, λ_{max} (nm) (log ε) (Dioxane)
a	81 (A)	30/60	173–175	$C_{20}H_{17}BF_4N_4$	551 (4.14)
b	55 (B)	10/60	125–127	$C_{20}H_{18}N_4O_4S$	554 (4.03)[c]
c	64 (C)	30/60	142–143	$C_{26}H_{19}N_7O_7$	558 (4.00)
d	84 (D)	15/45	178–179[d,e]	$C_{20}H_{17}ClN_4O_4$	560 (4.13)
e	91 (E)	30/45	206–207[d]	$C_{21}H_{19}ClN_4O_5$	583 (4.06)
f	88 (D)	10/45	176–177[d]	$C_{20}H_{16}ClFN_4O_4$	555 (4.07)
g	89 (D)	10/45	214[d]	$C_{22}H_{19}ClN_4O_6$	559 (3.98)
h	93 (D)	10/60	136–138	$C_{21}H_{16}F_3N_5O_5S$	546 (4.04)

[a] Satisfactory data of either HRMS (both for cation and for anion in **2a, b, d**) or elemental analyses (**2c, e–h**) were obtained for all the salts **2**.

[b] Method of isolation: trituration of the residue after evaporation of solvents with: A – Et_2O/ligroin; B – *i*-PrOH/Et_2O; C – petroleum ether (light); D – Et_2O; E – benzene/petroleum ether (light).

[c] In MeOH containing 0.5 % (v/v) H_2SO_4.

[d] Explodes.

[e] Lit.[1] mp 177 °C.

water (5 mL) was heated to 45 °C or 60 °C (Table) with vigorous stirring. The corresponding acid (5 mmol) was added in one portion and stirred continuously for 10–30 min (Table); at the end of the stirring, TLC of the reaction mixture showed the absence of starting formazan. Solvents were evaporated in vacuo, and the residue was triturated with solvents specified (Table) to give verdazylium salts **2a–h**, which were collected by filtration, washed with the same individual or mixed solvents (3 × 50 mL), and vacuum dried.

One-Pot Preparation of 2,4,6-Triphenylverdazylium Perchlorate (2d) and its Reduction into 2,4,6-Triphenylverdazyl 5:
Salt **2d** was prepared as described above from formazan **2a** (0.30 g, 1 mmol). After addition of perchloric acid the mixture was stirred for 15 min at 45 °C, cooled to r.t., and the acid was carefully neutralized by dropwise addition of conc. NH_4OH, followed by treatment with ascorbic acid (0.88 g, 5 mmol, in 30 mL of MeOH) with vigorous stirring. When the color of the reaction mixture became grass-green, it was diluted with $CHCl_3$ (100 mL) and water (100 mL), and extracted. The organic layer was separated, washed with water (3 × 50 mL), dried (Na_2SO_4), and the solvent was evaporated in vacuo. The residue was triturated with MeOH and filtered to give radical **5** (0.285 g, 91 %); mp 143–144 °C (Lit.[6] mp 142–143 °C).

Reaction of 6-(4-Methoxyphenyl)-2,4-diphenylverdazylium Perchlorate (2e) with Ascorbic Acid in Homogeneous Solution:
To a solution of perchlorate **2e** (0.22 g, 0.5 mmol) in a mixture of MeOH (40 mL) and DMF (10 mL) was added a solution of ascorbic acid (0.26 g, 1.5 mmol) in water (10 mL) at r.t. with stirring. After 10–15 min a yellow solution was obtained; it was diluted with water (100 mL) and extracted with $CHCl_3$ (100 mL). The organic layer was washed with water once (20 mL), separated and quickly dried (Na_2SO_4). $CHCl_3$ was evaporated at reduced pressure at 40 °C, and the residue was triturated with warm MeOH under N_2. Upon cooling the colorless plates were quickly filtered and dried in vacuo, yielding leuco-verdazyl **6** (0.098 g, 57 %); mp 126–128 °C (Lit.[11] mp 127–128 °C).

^1H NMR: $\delta = 7.84$ (d, 2 H, $J = 9.0$ Hz), 7.28–7.19 (m, 8 H), 6.96 (d, 2 H, $J = 9.0$ Hz), 6.92–6.85 (m, 2 H), 4.93 (s, 2 H), 3.86 (s, 3 H).

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