Intramolecularity of the Thermal Rearrangement of Allyloxytetrazoles to *N*-Allyltetrazolones†

J. Chem. Research (S), 1997, 164–165†

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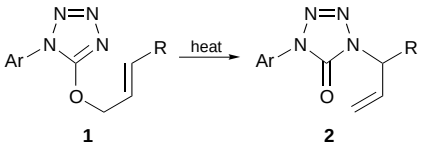
The intramolecularity of the thermal rearrangement of 1-aryl-5-allyloxy-1*H*-tetrazoles **1** to 1-aryl-4-allyl-1,4-dihydrotetrazol-5-ones **2** has been investigated through cross-over studies: the results support the hypothesis for a concerted sigmatropic rearrangement occurring through a highly polar transition state, in which a partially positively charged allyl group migrates from oxygen to nitrogen, without leaving the solvent cage.

1-Aryl-5-allyloxytetrazoles **1** (Scheme 1) rearrange thermally to give 1-aryl-4-allyltetrazolones **2** in high yield.[1,2] As with the analogous Claisen rearrangement,[3] this reaction has potential for producing unusual bonding patterns from readily

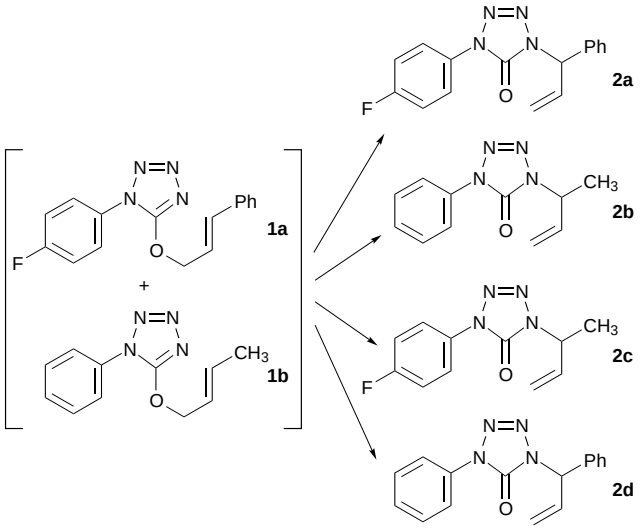


Scheme 1

available starting materials. Rate measurements on a series of 1-aryl-5-allyloxytetrazoles in polar and non-polar solvents have been reported.[2] These studies showed that the rearrangement was unimolecular and afforded measurements of enthalpies and entropies of activation. Based on enthalpies and entropies of activation, relative rates of migration for variously substituted aryl and allyl groups in polar and non-polar solvents and a lack of electron paramagnetic resonance effects, the results suggested a rearrangement mechanism involving a cyclic polar transition state, in which a partially positively charged allyl group migrates from oxygen to nitrogen with inversion, similar to the [3,3] Claisen rearrangement of allyl aryl ethers to allylphenols[4] or of allyl vinyl ethers to alkenyl carbonyl compounds.[5] However, the rate studies did not show whether the rearrangement of the tetrazoles was intra- or inter-molecular, *viz*. whether it took place entirely within a solvent cage. By simultaneously rearranging two different allyloxytetrazoles, which are known to undergo migration at similar rates in high yield, any intermolecularity in the reaction would be expected to show up by the presence of 'cross-over' products. This cross-over criterion has been used successfully for other rearrangements as, for example, with the Claisen transformation of allyl aryl ethers.[6] In the present experiments, a mixture of 1-(4-fluorophenyl)-5-[(*E*)-3-phenylprop-2-en-1-yloxy]-1*H*-tetrazole **1a** (R = Ph, Ar = 4-fluorophenyl) and 4-[(*E*)-but-2-en-1-yloxy]-1-phenyl-1*H*-tetrazole **1b** (R = Me, Ar = Ph), for which the rates of rearrangement at 100 °C are similar,[2] was examined for evidence of the formation of crossed products (Scheme 2).

Results and Discussion

Thermal rearrangement of a mixture of tetrazoles **1a**,**b** (Scheme 2) would be expected to yield products **2a**,**b** if the migration were intramolecular but products **2a**,**b**,**c**,**d** if the reaction were wholly or partly intermolecular. Because of the mass differences of the products **2a–d**, mass spectrometry is a convenient method for analysis of the products of mixed rearrangement. Molecular ions of the products of reaction at *m*/*z* 296 and 216 would imply no cross-over, but ions at *m*/*z*

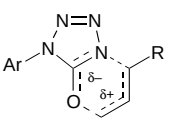


Scheme 2

296, 278, 234 and 216 would indicate that the reaction was not totally intramolecular.

An equimolar mixture of compounds **1a**,**b** in 1,1,2,2-tetrachloroethane was heated to 100 °C for 4 h, a time known to be more than sufficient for complete reaction.[2] After evaporation of the solvent, the residue (X) represented an almost 100% yield of rearranged material; a ^{1}H NMR spectrum of this residue (X) was indistinguishable from that of a material (Y) obtained by separately mixing equimolar quantities of the authentic rearrangement products **2a**,**b**. By mass spectrometry of the crude product mixture (X) only ions at *m*/*z* 296 and 216 were observed and there were no ions at *m*/*z* 234 or 278 that exceeded the normal noise level of the mass spectrum. From the sensitivity setting of the mass spectrometer and the detectable peak heights, the maximum cross-over that could have occurred was less than about 0.3% of the total reaction product. Mass spectra from the mixed rearrangement process (X) and from the authentic mixture of products (Y) were identical. Since the experiment revealed no detectable cross-over, it is reasonable to conclude that the two allyl groups were never completely free of the solvent cage for each tetrazole.

The earlier hypothesis of a concerted [3,3] sigmatropic rearrangement proceeding through a charged transition state similar to that shown in structure **3**,[2] based on the structures of the rearranged products, on the order of reaction, on the analysis of thermal activation energies and on the negative results of EPR experiments, is further supported by these cross-over results.



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†This is a **Short Paper** as defined in the Instructions for Authors, Section 5.0 [see *J. Chem. Research (S)*, 1997, Issue 1]; there is therefore no corresponding material in *J. Chem. Research (M)*.

Experimental

Melting points were recorded on a Reichert microscopic apparatus and are uncorrected. Mass spectra were obtained on a VG 7070E mass spectrometer by electron ionization (EI), at 70 eV. IR spectra were recorded on a Perkin Elmer 1720X FT-IR spectrometer, liquids as films and solids as KBr disks. NMR spectra were recorded either on a Bruker WM 250 MHz FT or on a Bruker AC 200 FT spectrometer, using tetramethylsilane as internal standard. Solvents, diethyl ether and tetrahydrofuran, were freshly dried by refluxing them over sodium diphenylketyl prior to use. Other chemicals were used as purchased.

Preparation of Tetrazoles **1a**,**b**—(*i*) A slow stream of chlorine was bubbled through a solution of 4-fluorophenyl isothiocyanate (2 g, 14.8 mmol) in CH_2Cl_2 (40 mL) for 24 h. The solution was then purged of excess of chlorine by nitrogen gas, filtered and the filtrate concentrated to give *N*-(4-fluorophenyl)-1,1-dichloroazomethine as a colourless liquid (2.25 g, 79%); δ_H ($CDCl_3$) 7.0–7.2 (m); ν_{max}/cm^{-1} 1651, 1502, 1232, 897 and 833. This product was used without further purification. Activated sodium azide (0.12 g, 1.9 mmol) was added to the *N*-(4-fluorophenyl)-1,1-dichloroazomethine (0.31 g, 1.61 mmol) in 1,2-dimethoxyethane (5 mL) and the mixture was stirred at room temperature for 36 h. The resulting sodium chloride was filtered off and the filtrate was evaporated to afford a colourless solid, which was recrystallized from benzene–ethanol (1:1) to give colourless crystals of the required 5-chloro-1-(4-fluorophenyl)-1*H*-tetrazole (0.25 g, 78%), mp 85–86 °C (lit.,[7] 88 °C) (Found: C, 42.5; H, 2.0; N, 28.1. Calc. for $C_7H_4ClFN_2$: C, 42.3; H, 2.0; N, 28.2%); δ_H ($CDCl_3$) 7.2–7.4 (m, 2 H), 7.5–7.7 (m, 2 H); *m*/*z* 198, 200 (M^+, 3:1, Cl isotopes). A mixture of (*E*)-3-phenylprop-2-en-1-ol (cinnamyl alcohol; 0.15 g, 1 mmol) and sodium hydride (0.048 g, 1.6 mmol) in THF (10 mL) was stirred at room temperature until effervescence had ceased, at which stage a solution of 5-chloro-1-(4-fluorophenyl)-1*H*-tetrazole (0.2 g, 1 mol) in THF (5 mL) was added. After the mixture had been stirred for a further 2 h, the reaction was worked up by addition of ice–water (30 mL) and extraction with diethyl ether. After drying (Na_2SO_4), evaporation of solvent and 'flash' chromatography on silica gel with CH_2Cl_2 as eluent, colourless crystals of 1-(4-*fluorophenyl*)-5-[(E)-3-*phenylprop*-2-*en*-1-*yloxy*)-1H-*tetrazole* **1a** were isolated (0.11 g, 37%), mp 83–85 °C (Found: C, 65.2; H, 4.5; N, 18.7. $C_{16}H_{13}FN_4O$ requires C, 64.9; H, 4.4; N, 18.9%): δ_H ($CDCl_3$) 5.25 (d, 2 H, *J* 6 Hz), 6.4-6.6 (m, 1 H), 6.9 (d, 1 H, *J* 14.8 Hz), 7.2–7.6 (m, 7 H), 7.6–7.8 (m, 2 H); ν_{max}/cm^{-1} 1563, 1514, 1367 and 1232; *m*/*z* 296 (M^+).

(*ii*) (*E*)-But-2-en-1-ol (crotyl alcohol; 1.0 g, 13.9 mmol) in dry THF (20 mL) was added to a slurry of sodium hydride (0.6 g, 14.6 mmol) in dry THF (20 ml) and the mixture was stirred at room temperature under nitrogen until effervescence had ceased (30 min). To the resulting mixture was added 5-chloro-1-phenyl-1*H*-tetrazole (2.5 g, 13.9 mmol) in dry THF (10 mL). After the mixture had been stirred at room temperature for 2 h, the reaction products were worked up as for the tetrazole **1a** above to afford a light yellow oil, which was recrystallized from light petroleum (bp 40–60 °C) to give 5-[(*E*)-but-2-en-1-yloxy]-1-phenyl-1*H*-tetrazole **1b** as pale yellow crystals (1.8 g, 61%), mp 36–37 °C (lit.,[8] 32–33 °C) (Found: C, 61.1; H, 5.6; N, 26.0. Calc. for $C_{11}H_{12}N_4O$. C, 61.1; H, 5.6; N, 25.9%); δ_H ($CDCl_3$) 1.75 (d, 3 H, *J* 8.7 Hz), 5.05 (d, 2 H, *J* 7.9 Hz), 5.7–5.9 (m, 1 H), 5.9–6.1 (m, 1 H), 7.4–7.6 (m, 3 H), 7.75 (d, 2 H, *J* 8.3 Hz); IR, ν_{max}/cm^{-1} 1597, 1560, 1505, 1448 and 761; *m*/*z* 216 (M^+).

N-*Allyltetrazolones* **2a**,**b**.—(*i*) The tetrazole **1a** (0.3 g, 1 mmol) was heated in 1,1,2,2-tetrachloroethane at 100 °C for 3 h. After evaporation of the solvent, 1-(4-fluorophenyl)-4-(1-phenylprop-2-en-1-yl)-1,4-*dihydrotetrazol*-5-*one* **2a** was isolated as a colourless oil (0.29 g, 98%) (Found: C, 64.8; H, 4.4; N, 18.8. $C_{16}H_{13}FN_4O$ requires C, 64.9; H, 4.4; N, 18.9%); δ_H ($CDCl_3$) 5.26–5.52 (m, 2 H), 6.0 (d, 1 H, *J* 5.7 Hz), 6.39–6.55 (m, 1 H), 7.12–7.50 (m, 7 H), 7.90–8.0 (m, 2 H); ν_{max}/cm^{-1} 1729, 1605, 1511, 1386, 1233 and 723; *m*/*z* 296 (M^+).

(*ii*) Similarly, 1-*phenyl*-4-(*but*-3-*en*-2-*yl*)-1,4-*dihydrotetrazol*-5-*one* **2b** was prepared from the tetrazole **1b** and was isolated as a colourless oil (98% yield) (Found: C, 61.0; H, 5.6; N, 26.1. $C_{11}H_{12}N_4O$ requires C, 61.1; H, 5.6; N, 25.9%); δ_H ($CDCl_3$) 1.65 (d, 3 H, *J* 5.7 Hz), 4.9–5.1 (m, 1 H), 5.22–5.4 (m, 2 H), 6.0–6.2 (m, 1 H), 7.3–7.55 (m, 3 H), 7.95 (d, *J* 8.6 Hz); ν_{max}/cm^{-1} 1729, 1599, 1504, 1382 and 757; *m*/*z* 216 (M^+).

Cross-over Experiment.—A mixture of **1b** (0.044 g, 0.2 mmol) and **1a** (0.060 g, 0.2 mmol) in 1,1,2,2-tetrachloroethane (4 ml) was heated at 100 °C for 4 h. The product was isolated by evaporation of the solvent to give an oily residue which was subjected to mass spectrometry (EI). Molecular ion peaks in the mass spectrum at *m*/*z* 296 and 216 were observed, corresponding to the molecular ions of the two tetrazolones **2a**,**b** resulting from rearrangement of the tetrazoles, but no peaks were observed at *m*/*z* 234 or 278 that would correspond to cross-over. The appearance of the mass spectrum resulting from heating the mixture of tetrazoles **1a**,**b** was identical with that produced by an authentic mixture of the *N*-allyltetrazoles **2a**,**b**.

We gratefully acknowledge the financial assistance to M. L. S. C. of JNICT (Portugal) and of the Eschenmoser Trust.

Received, 11th December 1996; Accepted, 21st January 1997
Paper E/6/08333A

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