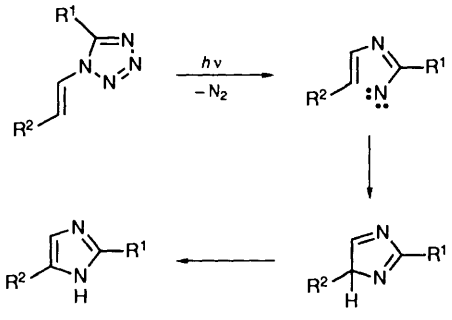
Synthesis of 3-Phenylpyrazoles from 2-Alkenyl-5-phenytetrazoles

Christopher J. Moody, Charles W. Rees and Richard G. Young
Department of Chemistry, Imperial College of Science, Technology and Medicine, London SW7 2AY, UK

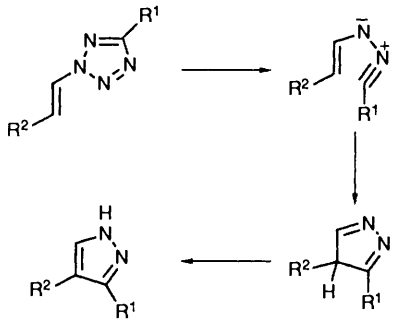
2-Alkenyl-5-phenyltetrazoles **7a–e** are readily converted by thermolysis or photolysis into 3-phenylpyrazoles **11a–e** in good to excellent yield (Table 2). The alkenyltetrazoles **7** are prepared by direct or indirect dehydration of the alcohols **5** formed by quenching α-lithioalkyltetrazoles with aldehydes.

In previous papers we have described a new synthesis of imidazoles in which the key step is the photochemical decomposition of 1-alkenyltetrazoles;[1,2] the reaction presumably involves the electrocyclisation of an intermediate *N*-vinylimidoylnitrene followed by a rapid aromatising hydrogen shift (Scheme 1). When this hydrogen is replaced by an alkyl group, non-aromatic 4*H*-imidazoles can be isolated.[3]



Scheme 1

In contrast, decomposition of 2,5-substituted tetrazoles is known to result in the formation of nitrilimines, which can be trapped in inter- or intra-molecular cycloadditions.[4,5] In particular, electrocyclisation of *C*,*N*-diphenylnitrilimine results in the formation of 3-phenylindazole.[6] Electrocyclisation of *N*-vinylnitrilimines, generated from 2-alkenyltetrazoles, would therefore be expected to give pyrazoles by way of their non-aromatic 4*H*-isomers (Scheme 2). Such a route to pyrazoles

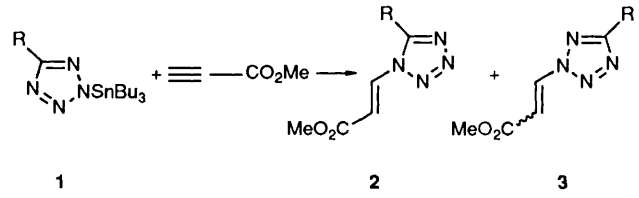


Scheme 2

would be of interest since there are few pyrazole syntheses culminating in the formation of a ring C–C bond.[7] We now find that pyrazoles can indeed be obtained from 2-alken-1-yltetrazoles, and report our results in this paper.

Results and Discussion

Preparation of 2-Alken-1-yltetrazoles.—We investigated three routes to 2-alken-1-yltetrazoles: conjugate addition of tetrazoles to electrophilic alkynes, direct vinylation of tetrazoles, and reaction of 2-lithioalkyltetrazoles with aldehydes. We have already described the reaction of 2-(tributylstannyl)tetrazoles **1** with electrophilic alkynes to give, after protonolysis, mixtures of 1- and 2- alkenyltetrazoles **2** and **3** (Scheme 3). The role of the



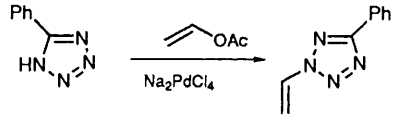
1 **2** **3**

Scheme 3

tributylstannyl group was to favour reaction at the tetrazole N-1 position, and indeed 1-alkenyltetrazoles were the major products.[2] Nevertheless, small quantities of the 2-alkenyltetrazoles (**3**, R = Ph, Me, CO_2Me) could be obtained by this route.[2]

Various attempts were made to effect conjugate addition of tetrazoles to activated alkynes, avoiding the tributyltin derivatives, in an effort to obtain higher yields of the desired 2-isomers, although largely without success. Thus, treatment of 5-methyltetrazoles with methyl propiolate in benzene in the presence of a catalytic amount of triethylamine gave three alkenyltetrazoles: the 2-isomers **3** (R = Me) (24% *E* plus 15% *Z*) and the 1-isomer **2** (R = Me) (31% *E* only). Thus the reaction gives more 2-isomer than that of the corresponding tributylstannyltetrazoles,[2] but it is hardly synthetically useful. Also attempted extension of the reaction to dimethyl acetylenedicarboxylate resulted in double incorporation of the alkyne, with the formation of a 2:1 adduct.[2]

The second route to 2-alkenyltetrazoles was based on the direct transition-metal catalysed *N*-vinylation of heterocycles with enol acetates.[8] Thus reaction of 5-phenyltetrazole with vinyl acetate in the presence of sodium tetrachloropalladate(II) gave 5-phenyl-2-vinyltetrazole **4** (Scheme 4). However, the yield



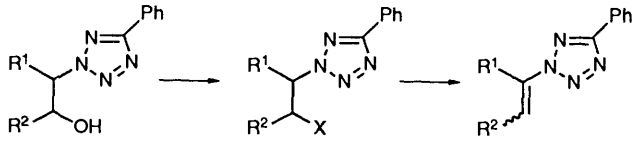
7a

Scheme 4

was low (17%), and the reaction mixture had a tendency to polymerise, and therefore this route was not investigated further.

The final route to the required 2-alken-1-yltetrazoles involved the lithiation of 2-alkyltetrazoles, which we have developed as a new synthesis of substituted tetrazoles.[9] Thus the 2-(2-hydroxyalkyl) tetrazoles **5a–c** were prepared by lithiation of 2-methyl-5-phenyltetrazole, followed by quenching with formal-

Table 1 Conversion of hydroxyalkyltetrazoles into alkenyltetrazoles.



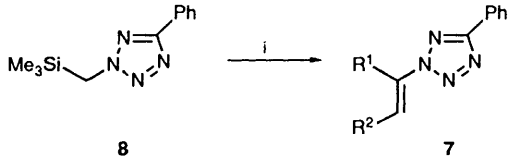
5 **6** **7**

	R^1	R^2	Method of dehydration	Yield **7** (%)	*E*/*Z* Ratio
a	H	H	**6** (X = Cl), DBU	77	—
b	H	Et	**6** (X = OMs), DBU	52	> 95.5
c	H	4-$MeOC_6H_4$	**5** PTSA	99	100:0
d	Me	Ph	**6**(X = OMs), DBU, Benzene	82[a]	86:14[b]
d	Me	Ph	**6** (X = OMs), DBU, THF	99	varies[b]

Notes: [a] At 46% conversion. [b] Undergoes *E*/*Z* isomerisation in daylight.

dehyde, propionaldehyde, and 4-anisaldehyde respectively, as previously described.[9] The tetrazole **5d** was prepared similarly, as a mixture of diastereoisomers, from 2-ethyl-5-phenyltetrazole and benzaldehyde. The alkenyltetrazoles **7** were prepared by dehydration of the alcohols **5**, which in the case of benzylic alcohol **5c** could be effected simply by refluxing in benzene in the presence of a catalytic amount of toluene-*p*-sulphonic acid (PTSA). In the other cases, the elimination was effected by way of the corresponding mesylate or chloride (Table 1).

The alkene **7b** was also prepared as an *E*/*Z*-mixture by Peterson reaction of 5-phenyl-2-trimethylsilylmethyltetrazole **8** with propionaldehyde (Scheme 5). The t-butyl derivative **7e** was



8 **7**

b; R^1 = H, R^2 = Et
e; R^1 = H, R^2 = Bu^t

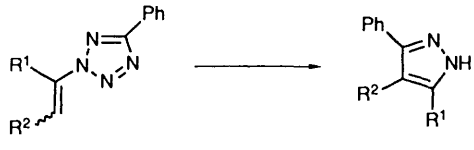
Scheme 5 *Reagents*: i Bu^tLi or LDA,-THF, −78 °C; R^2CHO

prepared similarly, and these reactions are described in the previous paper.[9]

Preparation of Pyrazoles.—In contrast to the formation of imidazole 4(5)-esters from the tetrazole-1-ylacrylates **2** which proceeded in good yield,[2] decomposition of the 2-alkenyl isomers **3** was not a useful route to pyrazoles. Although the 5-phenyltetrazole **3** (R = Ph) gave a 39% yield of methyl 3-phenylpyrazole-4-carboxylate when heated in xylene,[2] no pyrazoles could be obtained from the tetrazoles **3** (R = Me or CO_2Me), either on thermal or photochemical decomposition. The only identifiable product of any sort was obtained when the tetrazole **3** (R = Me) was irradiated in methanol or ethanol. In this case the intermediate nitrilimine was trapped by the alcohol to give the ene hydrazone **9** which undergoes reaction with more starting material followed by loss of 5-methyltetrazole to give the observed product **10** formed in 50 and 73% yield for reaction in methanol and ethanol respectively (Scheme 6). The structure of compound **10** (R = Me) was fully supported by its spectroscopic properties, and confirmed by NOE enhancement measurements (see Experimental section).

In contrast to the tetrazolylacrylates **3**, the 2-alkenyltetrazoles **7** could be readily converted into 3-phenylpyrazoles **11** in good

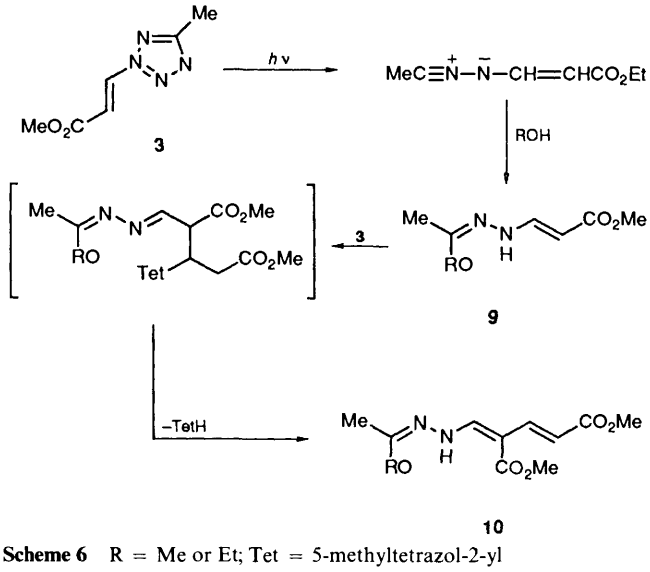
Table 2 Conversion of tetrazoles into pyrazoles



7 **11**

Tetrazole	R^1	R^2	Conditions	Yield **11** (%)
7a (=**4**)	H	H	Heat, DCB[a]	79
7a (=**4**)	H	H	*hν*, cyclohexane[b]	60
7b	H	Et	*hν*, light petroleum	65
7c	H	4-$MeOC_6H_4$	Heat, DCB	98
7c	H	4-$MeOC_6H_4$	*hν*, MeOH	100
7d	Me	Ph	*hν*, MeOH	73
7e	H	Bu^t	*hν*, MeOH	99

[a] 1,2,-Dichlorobenzene, b.p. 180 °C. [b] Or methanol (60%) yield)



3 **9** **10**

Scheme 6 R = Me or Et; Tet = 5-methyltetrazol-2-yl

to excellent yield by thermolysis or photolysis. The results, which are summarised in Table 2, establish that this is a general route to 3-phenylpyrazoles, proceeding in high yield under either thermal or photochemical conditions. The precursor tetrazoles are now readily available by the lithiation route, and

hence access to a greater range of pyrazoles than presently illustrated is possible.

Experimental

All solvents were distilled before use. Petroleum refers to light petroleum, b.p. 40–60 °C, and ether refers to diethyl ether. THF and ether were distilled from potassium–benzophenone and sodium–potassium–benzophenone respectively, immediately prior to use. Other solvents were purified and dried by standard procedures. Photolyses were carried out in a Rayonet photochemical reactor using lamps emitting at 254 or 360 nm as specified, in quartz vessels. Unless otherwise stated solutions were purged with nitrogen for 0.5 h prior to irradiation, which was carried out under nitrogen purge. No cooling was employed, so that the typical temperature for photolyses was 35 °C. The apparatus was flushed with nitrogen whilst cold and thermolyses were carried out in the solvent specified, magnetically stirred, under a nitrogen atmosphere. Flasks were heated with an oil-bath set at 10–20 °C above the relevant reflux temperature.

Thin layer chromatography (TLC) on commercial plates of silca gel 60 F_{254} on aluminium was used to monitor the progress of reactions. Column chromatography was carried out using silica gel 60H (E. Merck). IR spectra were recorded on a Perkin–Elmer 298 spectrophotometer in the range 600–4000 cm^{-1} and calibrated against polystyrene. The spectra of solids were recorded as Nujol mulls and of oils as thin films between sodium chloride plates.

UV spectra were recorded in the range 200–450 nm on a Pye Unicam SP800 spectrophotometer in quartz cells of 0.5 cm path length. Unless otherwise stated the solvent was methanol. ^1H NMR spectra were recorded on one of three instruments as follows: Varian Associates EM-360 (60 MHz), Perkin–Elmer R32 (90 MHz), and Bruker WM 250 (250 MHz) according to the frequency specified.

Tetramethylsilane (TMS) was used as an internal reference. Carbon-13 spectra were recorded on the Bruker instrument operating at 62.9 MHz. Mass spectra were recorded on a VG Micromass 7070B mass spectrometer. An ionising potential of 70 or 12eV was employed using a direct insertion probe or septum inlet.

Pd-*Catalysed Ethenylation of 5-Phenyltetrazole.*—Sodium tetrachloropalladate(II) (330 mg, 1.13 mmol) was added to a suspension of 5-phenyltetrazole (1.46 g, 10 mmol) in vinyl acetate (50 ml) and the whole was refluxed for 65 h. The mixture was filtered, the excess of vinyl acetate evaporated off, and the residue dissolved in ether (100 ml) and extracted with dilute aqueous sodium hydroxide to remove unchanged tetrazole. The solvent was evaporated off and the residue was chromatographed to give 5-phenyltetrazol-2-ylethene **4** (= **7a**) (287 mg, 17%); δ(250 MHz, $CDCl_3$): 5.40 (1 H, dd, *J*/Hz; 8.5 and 1.5), 6.28 (1 H, dd, *J*/Hz 15.5 and 1.5 Hz), 7.51 (3 H, m), 7.57 (1 H, dd, *J* 15.5 and 8.5 Hz), and 8.20 (2 H, m) identical (TLC, NMR) with an authentic sample.[1]

Derivatisation of 2-(2-*Hydroxyalkyl*)*tetrazoles*

Reaction of Tetrazole **5d** *with Methanesulphonyl Chloride.*—To a solution of tetrazole **5d** (238.7 mg, 0.852 mmol) in dry chloroform (20 ml) were added methanesulphonyl chloride (0.1 ml, 1.28 mmol, 1.5 equiv.) and triethylamine (0.59 ml, 4.26 mmol, 5.0 equiv.). The mixture was heated at reflux for 60 h and dichloromethane (50 ml) added. The solution was washed with dilute aqueous hydrochloric acid and water, dried $MgSO_4$), and the solvent evaporated off to give (R,S)-/(S,R)-1-*methylsulphonyloxy*-1-*phenyl*-2-(5-*phenyltetrazol*-2-*yl*)*propane* **6d** (X = OMs) (305 mg, 100%), m.p. 79–83 °C (Found: C, 57.1; H, 5.2; N, 15.3. $C_{17}H_{18}N_4O_3S$ requires C, 57.0; H, 5.1; N, 15.6%); ν_{max}/cm^{-1} 3030, 2940, 1530, 1465, 1450, 1370vs, 1180vs, 955, 845, 735 and 700; δ(250 MHz, $CDCl_3$) 1.50 (3 H, d, *J*/Hz: 7.6), 2.53 (3 H, s), 5.37–5.51 (1 H, br m), 5.98 (1 H, d, *J*/Hz: 9.3), 7.49 (8 H, m) and 8.20 (2 H, m); *m/z*(*20eV*): *358* (M^+), 330, 309, 259, 235, 222, 204, 188, 179, 164, 150, 136, 117, 104, 91, 86, 78, 57 and 43.

Reaction of Tetrazole **5a** *with Benzenesulphonyl Chloride.*—To a solution of tetrazole **5a** (212 mg, 1.11 mmol) and benzenesulphonyl chloride (0.156 ml, 1.23 mmol, 1.1 equiv.) in chloroform (10 ml) was added triethylamine (10 drops) and the mixture refluxed 17 h. Work-up and chromatography gave (i) 1-chloro-2-(5-phenyltetrazol-2-yl)ethane **6a** (X = Cl) (109 mg, 45%) as an oil (Found: M^+, 208.05150. $C_9H_9ClN_4$ requires 208.05157); ν_{max}/cm^{-1} 3080, 1525, 1420, 1355, 1190, 1040 and 730; δ(60 MHz, $CDCl_3$) 4.12 (2 H, t, *J*/Hz: 6), 5.01 (2 H, t, *J*/Hz: 6), 7.45–7.75 (3 H, m), and 8.15–8.45 (2 H, m); *m/z* 208/210 (M^+), 180/182, 141, 131, 104, 89, 77 and 63; and (ii) 1- phenylsulphonyloxy-2-(5-phenyltetrazol-2-yl)ethane **6a** (X = OSO_2-Ph) (92 mg, 25%), m.p. 79–81 °C (Found: $M^+ - 28$, 302.07250. $C_{15}H_{14}N_2O_3S$ requires 302.07251); δ(60 MHz, $CDCl_3$): 4.81 (4 H, br m), 7.35–7.68 (6 H, m), 7.72–7.95 (2 H, m) and 8.04–8.28 (2 H, m); *m/z*: 302 ($M^+ - 28$), 171, 141, 132, 104, 77, 71, 57 and 51.

2-*Alken*-1-*yltetrazoles by Elimination*

Work-up Procedure (*unless given*).—Ether (5 volumes) was added and the organic layer washed successively with dilute aqueous hydrochloric acid, aqueous sodium hydrogen carbonate and water and dried ($MgSO_4$). The solvent was removed by evaporation under reduced pressure and the residue chromatographed on silica gel with petroleum containing an increasing proportion of ether as eluant. Where necessary, ether containing an increasing proportion of methanol was subsequently employed.

(a) *Elimination in Base.—Tetrazole* **6a** (X = Cl).—To a solution of the tetrazole **6a** (X = Cl) (54 mg, 0.26 mmol) in THF (20 ml) was added DBU (10 drops) and the mixture was refluxed for 1 h. Work-up gave 5-phenyltetrazol-2-ylethene **7a** (34 mg, 77%) identical (TLC, NMR) with authentic material.[1]

Reaction of the tetrazole **5b** *with methanesulphonyl chloride.* To a solution of the tetrazole **5b** (393 mg, 1.80 mmol) in dioxane (15 ml) was added methanesulphonyl chloride (0.153 ml, 1.98 mmol, 1.1 equiv.) and 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU) (10 drops) and the mixture stirred at 100 °C for 0.25 h and 25 °C for 15 h. Work-up from dichloromethane gave an oil which was a mixture (NMR, TLC) of 2-methylsulphonyloxy-1-(5-phenyltetrazol-2-yl)butane **6b** (X = OMs), 2-chloro-1-(5-phenyltetrazol-2-yl)butane **6b** (X = Cl), and 1-(5-phenyltetrazol-2-yl) but-1-ene **7b**. The mixture was further treated with DBU (20 drops) in dry THF (20 ml) at 80 °C for 25 h. Work-up and chromatography gave (*E*/*Z*)-1-(5-phenyltetrazol-2-yl)but-1-ene *E*/*Z*-**7b** (> 95:5 by NMR) (189 mg, 52%) as an oil identical (NMR, TLC) to material isolated from the Peterson reaction.[9]

Tetrazole **6d** (X = OMs) *in benzene.* To a solution of the tetrazole **6d** (X = OMs) (280 mg, 0.78 mmol) in dry benzene (10 ml) was added DBU (0.129 ml, 0.86 mmol, 1.1 equiv.) and the mixture stirred at 50 °C for 16 h. Work-up and chromatography gave (i) a mixture of (E)-1-*phenyl*-2-(5-*phenyltetrazol*-2-*yl*)*prop*-1-*ene E*-**7d** (66. 7 mg, 33%) as an oil (Found: $M^+ - 28$ = 234.1159. $C_{16}H_{14}N_2$ requires 234.1157); ν_{max}/cm^{-1}: 3060, 1660w, 1530, 1465, 1450, 1210, 1020, 765, 730 and 695; δ(90 MHz, $CDCl_3$): 2.65 (3 H, s), 7.25–7.55 (8 H, m), 7.74 (1 H, s) and 8.15–8.30 (2 H, m); *m/z* 263 ($M^+ + 1$), 234, 206, 193, 165, 131, 116, 103, 90, 77, 63 and 51 and (*Z*)-1-phenyl-2-(5-phenyltetrazol-2-yl)prop-1-ene *Z*-**7d** (10.9 mg, 5%) which has δ(90 MHz,

$CDCl_3$) 2.50 (3 H, s), 6.75 (1 H, s), 6.82–6.97 (2 H, m), 7.12–7.31 (3 H, m), 7.37–7.57 (3 H, m) and 8.07–8.20 (2 H, m); and (ii) starting material (149.9 mg, 54%).

Tetrazole **6d** (X = OMs) *in THF.* To a solution of the tetrazole **6d** (X = OMs) 35.5 mg, 0.10 mmol) in THF (10 ml) was added DBU (0.5 ml) and the mixture stirred at 80 °C for 160 h. Work-up and removal of the solvent by evaporation gave the alkene **7d** (*E*/*Z*- mixture) (25.6 mg, 99%) as an oil identical with the product mixture from benzene (TLC), NMR). The alkene **7d** undergoes *E*/*Z*- photoequilibration in daylight.

(b) *Acid-catalysed Dehydration.—Tetrazole* **5c**. To a solution of the tetrazole **5c** (600 mg crude product) in dry benzene (20 ml) was added PTSA (*ca.* 100 mg) and the mixture heated at 80 °C for 36 h. Work-up and chromatography gave 1-(4-*methoxyphenyl*)-2-(5-*phenyltetrazol*-2-*yl*)*ethane* **7c** (367 mg, 76% from the methyltetrazole; estimated yield for this step: 99%), m.p. 105–107 °C (Found: C, 69.2; H, 5.1; N, 20.1. $C_{16}H_{14}N_4O$ requires C, 69.05; H, 5.1; N, 20.1%); ν_{max}/cm^{-1}: 3095, 3005, 1605, 1510, 1250, 1180, 1025, 940, 800, 730 and 700; δ(250 MHz, $CDCl_3$): 3.96 (3 H, s), 6.96 (2 H, d, *J*/Hz: 9), 7.45–7.58 (5 H, m), 7.66 (1 H, d, *J*/Hz: 14), 7.90 (1 H, d, *J*/Hz: 14 Hz) and 8.19–8.26 (2 H, m); *m*/*z* 278 (M^+), 250, 228, 222, 197, 147, 132 (base), 120, 103, 91, 77, 63, 57 and 51.

Photolysis of Methyl (E)-3-(5-*Methyltetrazol*-2-*yl*)*propenoate* **3** (R = Me).—A solution of the tetrazole **3** (R = Me) (182 mg) in methanol (180 ml) was irradiated for 2h. The solvent was evaporated off and the residue was chromatographed to give *methyl* N-(2,4-*dimethoxycarbonylbuta*-1,3-*dien*-1-*ylamino*)-*acetimidate* **10** (R = Me) (37.2 mg, 50%), m.p. 133–135 °C (Found: C, 51.6; H, 6.3; N, 10.9. $C_{11}H_{16}N_2O_6$ requires C, 51.6; H, 6.3; N, 10.9%); ν_{max}/cm^{-1}: 3040vw, 3010vw, 1700, 1690w, 1650, 1620, 1600vs, 1400, 1205 and 1160; ν_{max}/nm(MeOH) 293 (log ε 4.08) and 347 (4.40); δ(250 MHz, $CDCl_3$) 2.08 (3 H, s), 3.727 (3 H, s), 3.731 (3 H, s), 3.81 (3 H, s), 6.04 (1 H, d, *J*/Hz: 15.7), 7.46 (1 H, d, *J*/Hz: 15.7), 7.67 (1 H, d, *J*/Hz: 10.9) and 11.19 (1 H, br d, *J*/Hz: 10.9) (exch. D_2O) (in an NOED experiment irradiation of the signal at δ2.08 caused 0.3 and 17% enhancements of the signals at δ 3.81 and 11.19 respectively; irradiation of the signal at δ 3.73 caused 0.9, 1.3, 0.6 and 0.4% enhancements of the signals at δ 2.08, 6.04, 7.46 and 7.67 respectively; irradiation of the signal at δ 3.81 caused 0.3, 0.4 and 0.5% enhancements of the signals at δ 2.08, 6.04 and 7.46 respectively; irradiation of the signal at δ 6.04 caused 0.1, 0.2, 0.5, 1.2 and 14% enhancements of the signals at δ 2.08, 3.73, 3.81, 7.46 and 7.67 respectively; irradiation of the signal at δ 7.46 caused 0.1, 0.2, 2 and 16% enhancements of the signals at δ 3.73, 3.81, 6.04 and 7.67 respectively; irradiation of the signal at δ 7.67 caused 0.1, 10, 13 and 3% enhancements of the signals at δ 3.73, 6.04, 7.46 and 11.19 respectively; irradiation of the signal at δ 11.19 caused 5 and 2% enhancements of the signals at δ 2.08 and 7.67 respectively); *m*/*z* 256 (M^+), 224, 209, 193 (base), 183, 169, 141, 127, 109, 95, 69, 57 and 43.

A solution of the same tetrazole **3** (R = Me) (237 mg) in ethanol (180 ml) was irradiated for 2.2 h. The solvent was evaporated off and the residue was chromatographed to give the ethyl acetimidate **10** (R = Et) (86.5 mg, 73%); δ(60 MHz, $CDCl_3$): 1.31 (3 H, t, *J*/Hz: 7), 2.08 (3 H, s), 3.72 (3 H, s), 3.80 (3 H, s), 4.13 (2 H, q, *J*/Hz: 7), 6.05 (1 H, d, *J*/Hz: 15), 7.49 (1 H, d, *J*/Hz: 15), 7.68 (1 H, d, *J*/Hz: 11) and 11.27 (1 H, br d, *J*/Hz: 11); δ_C: 14.2, 14.6, 51.0, 51.1, 62.8, 93.4, 108.3, 142.5, 152.3, 159.2, 169.0 and 169.8

Pyrazoles by Loss of Nitrogen from 2-Alken-1-*yltetrazoles*

(a) *Thermolysis: General Procedure.*—The tetrazoles **7** in solvent (1 ml per mmol) were heated at reflux for the stated period. The product pyrazoles were isolated by evaporation of the solvent and chromatography or recrystallisation.

Tetrazole **7a**. A solution of the tetrazole **7a** (22.0 mg, 0.13 mmol) in ODCB (1.5 ml) was refluxed 2 h. The solvent was evaporated off and the residue was chromatographed to give 3-phenylpyrazole **11a** (14.6 mg, 79%), m.p. 59–60 °C (5% ether in petroleum, 0 °C), 59–60 °C (water, 0 °C), 60–62 °C (subl. at 10 Torr, 50 °C), identified as the picrate m.p. 171–172 °C (ethanol) (lit.,[10] 170–171 °C). The pyrazole **11a** has δ(60 MHz, $CDCl_3$) 6.62 (1 H, d, *J*/Hz: 2), 7.24–7.92 (6 H, m) and 11.23 (1 H, br s).

Tetrazole **7c**. A solution of the tetrazole **7c** (9.8 mg, 0.035 mmol) in ODCB (3 ml) was refluxed 1.5 h. The solvent was evaporated off and the residue was chromatographed to give 4-(4-*methoxyphenyl*)-3-*phenylpyrazole* **11c** (8.6 mg, 98%), m.p. 126–127 °C (Found: C, 76.8; H, 5.7; N, 11.1. $C_{16}H_{14}N_2O$ requires C, 76.8; H, 5.6; N, 11.2%); ν_{max}/cm^{-1}: 3160, 1615, 1535, 1495, 1250, 1030, 945, 830 and 700 cm^{-1}; δ(250 MHz, $CDCl_3$): 3.81 (3 H, s), 6.86 (2 H, ≃d, *J*/Hz: 9), 7.22 (2 H, ≃d, *J*/Hz: 9), 7.30–7.37 (3 H, m), 7.42–7.49 (2 H, m) and 7.62 (1 H, s); *m*/*z* 250 (M^+), 235, 205, 190, 178, 165, 152, 140, 128, 104, 85, 76 and 65.

(b) *Photolysis: General Procedure.*—A solution of the tetrazole **7** in the solvent specified was irradiated in a quartz vessel under a stream of nitrogen. The irradiation was continued until no tetrazole remained (TLC) and the products were isolated by chromatography.

Tetrazole **7a** in cyclohexane. A solution of the tetrazole **7a** (68.7 mg, 0.40 mmol) in cyclohexane (60 ml) was irradiated for 2.5 h. The solvent was evaporated off and the residue was chromatographed to give 3-phenylpyrazole **11a** (34.4 mg, 60%), m.p. 60–61 °C after sublimation.

Tetrazole **7a** *in methanol.* A solution of the tetrazole **7a** (20.0 mg, 0.12 mmol) in methanol (25 ml) was irradiated for 3 h. The solvent was evaporated off and the residue was chromatographed to give 3-phenylpyrazole **11a** and (10.0 mg, 60%), identified as the picrate, m.p. 171–172 °C.

Tetrazole **7b**. A solution of the tetrazole *E*/*Z*- **7b** (69 mg, 0.345 mmol) in petroleum (60 ml) was irradiated for 1.5 h. The solvent was evaporated off and the residue was chromatographed to give 4-ethyl-3-phenylpyrazole **11b** (38.3 mg, 65%);[11] δ(250 MHz, $CDCl_3$): 1.24 (3 H, t, *J*/Hz: 7.5 Hz), 2.67 (2 H, q, *J*/Hz: 7.5), 7.26 (1 H, s), 7.32–7.48 (3 H, m), 7.49 (1 H, s) and 7.52–7.60 (2 H, m); *m*/*z* 172 (M^+), 157 (base), 140, 130, 128, 103, 77, 65 and 51.

Tetrazole **7c**. A solution of the tetrazole **7c** (13.2 mg, 0.047 mmol) in methanol (20 ml) was irradiated for 3.0 h. The solvent was evaporated off to give 4-(4-methoxphyenyl)-3-phenylpyrazole **11c** (12.1 mg, 100%) identical (TLC, NMR) with material generated by thermolysis of **7c**.

Tetrazole **7d**. A solution of the tetrazole *E*/*Z*- **7d** (26.0 mg, 0.01 mmol) in methanol (30 ml) was irradiated for 3.0 h. The solvent was evaporated off and the residue was recrystallised from chloroform at 0 °C to give 5-*methyl*-3,4-*diphenylpyrazole* **11d** (17.0 mg, 73%), m.p. 176–179 °C; $\nu_{max}/cm^{-1}(CCl_4)$: 3470, 3190, 3070, 2930, 2860, 1605, 1445, 1070, 915 and 700 cm^{-1}; δ(250 MHz, $CDCl_3$): 2.18 (3 H, s), 7.15–7.43 (10 H, m) and 7.95–8.70 (1 H, br s); *m*/*z* 234 (M^+) (base), 219, 202, 190, 165, 117, 109, 103, 89 and 77.

Tetrazole **7e**. A solution of the tetrazole *E*-**7e** (44.3 mg, 0.194 mmol) in methanol (40 ml) was irradiated for 1.5 h. The solvent was evaporated off and the residue was chromatographed to give 3-phenyl-4-t-butylpyrazole **11e** (38.7 mg, 99%), m.p. 162–164 °C (Found: C, 77.8; H, 8.1; N, 14.0. $C_{13}H_{16}N_2$ requires C, 78.0; H, 8.05; N, 14.0%); ν_{max}/cm^{-1}: 3180–3100, 3040, 1500, 1360, 1120, 965, 770 and 710; δ(250 MHz, $CDCl_3$): 1.17 (9 H, s), 7.27 (1 H, s), 7.38 (5 H, s) and 9.2–10.0 (1 H, br s); *m*/*z* 200 (M^+), 185, 104, 93, 85, 82, 77 and 55.

Acknowledgements

We thank Mr. J. N. Bilton (mass spectrometry), Dr. M. Casey and Mr. R. N. Sheppard (NMR) for expert assistance and valuable discussions.

References

1 M. Casey, C. J. Moody and C. W. Rees, *J. Chem. Soc., Perkin Trans. 1*, 1984, 1933.
2 M. Casey, C. J. Moody, C. W. Rees and R. G. Young, *J. Chem. Soc., Perkin Trans. 1*, 1985, 741.
3 M. Casey, C. J. Moody and C. W. Rees, *J. Chem. Soc., Perkin Trans. 1*, 1987, 1389.
4 C. Wentrup, *Adv. Het. Chem.*, 1981, **28**, 231; R. N. Butler in *Comprehensive Heterocyclic Chemistry*, eds. A. R. Katritzky and C. W. Rees, Pergamon, Oxford, 1984, vol. 5, p. 791.
5 For a recent example of the intramolecular cycloaddition see L. Bruché and G. Zecchi, *Tetrahedron*, 1989, **45**, 7427.
6 C. Wentrup, A. Damerius and W. Reichen, *J. Org. Chem.*, 1978, **43**, 2037.
7 J. Elguero, in *Comprehensive Heterocyclic Chemistry*, eds. A. R. Katritzky and C. W. Rees, Pergamon, Oxford, 1984, vol. 5, p. 167.
8 E. Bayer and K. Geckeler, *Angew. Chem., Int. Ed. Engl.*, 1979, **18**, 533.
9 C. J. Moody, C. W. Rees and R. G. Young, *J. Chem. Soc., Perkin Trans. 1*, 1991, preceding paper.
10 L. Knorr, *Ber.*, 1895, **28**, 688 and 696.
11 M. W. Moon and G. Kornis, Can. Patent CA 1053231, 24 April 1979 (*Chem. Abstr.*, **91**: 140839).

Paper 0/03413D
Received 26*th July* 1990
Accepted 14*th August* 1990