Photocyclisation and Photoisomerisation of 1,3,4- and 1,4,5-Triphenylpyrazole

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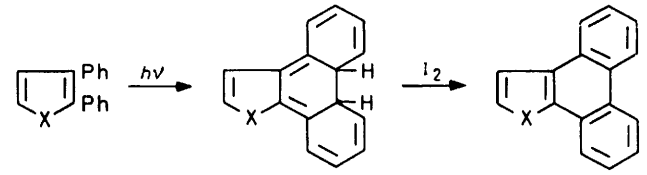
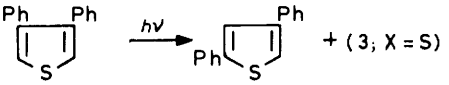
Irradiation of 1,4,5-triphenylpyrazole in the presence of iodine gives 1-phenyl-1*H*-phenanthro[9,10-*c*]pyrazole, identical with a specimen prepared by an independent route. 1,3,4-Triphenylpyrazole does not react under these conditions: this is thought to be because the intermediate non-aromatic polyene would be dipolar. Irradiation of 1,4,5-triphenylpyrazole in the presence of benzophenone gives 3-anilino-2,3-diphenylacrylonitrile, which is itself inert towards irradiation. 3-Aminoacrylonitriles are postulated as intermediates in some rearrangements of pyrazoles to imidazoles.

IRRADIATION of 2,3-diphenylheterocycles of the type (1; X = O, S, or NH) in the presence of oxygen or iodine leads to the corresponding phenanthro-heterocycle (3; X = O, S, or NH) *via* intermediates of the type (2) which are dehydrogenated by the inorganic reagent.[1,2] The reaction has also been carried out with five-membered ring heterocyclic compounds containing two heteroatoms and with analogous of (1; X = S) possessing pyridyl substituents in place of phenyl.[3] A review of this reaction and the related conversion of stilbenes into phenanthrenes is available.[4] The failure of 3,4-diphenylthiophen (4) to undergo a related cyclisation has been noted.[5] Also, 1,2,4,5-tetraphenylimidazole and 1,2,3-triphenylindole undergo a corresponding reaction only between the phenyl groups attached to positions 4 and 5 for the first example and 2 and 3 for the second.[2]

It was therefore of interest to examine the photochemical behaviour of 1,3,4- and 1,4,5-triphenylpyrazoles for any differences of reactivity in this cyclisation process. The photochemical rearrangement of five-membered ring heteroaromatic compounds has been widely studied,[6] so it was also of interest to see if the





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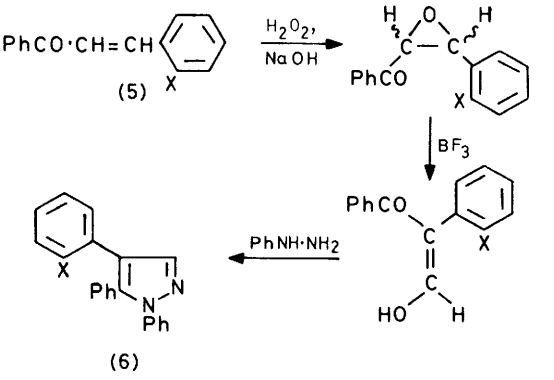
two independent processes of cyclisation and rearrangement could be achieved with these triphenylpyrazoles. Relevant to this objective are the isomerisations of indazoles to benzimidazoles,[7,8] and of alkylpyrazoles to imidazoles [7] promoted by benzophenone as sensitiser in an inert atmosphere.

Irradiation of 1,4,5-triphenylpyrazole under nitrogen in the presence of iodine afforded a crystalline compound, m.p. 160—162°, $C_{21}H_{14}N_2$, M^+ 294. In the absence of



iodine only starting material was recovered. The new compound was identical with 1-phenylphenanthro-[9,10-*c*]pyrazole (7) obtained from an independent synthesis.

The chlorophenylpyrazole (6; X = Cl) was prepared by the route used for 1,4,5-triphenylpyrazole (6; X = H).[9] 2-Chlorobenzylideneacetophenone was oxidised to a mixture of *cis*- and *trans*-oxirans; these rearranged under the action of boron trifluoride to a 1,3-dicarbonyl compound from which the pyrazole was obtained by treatment with phenylhydrazine. A useful method for ring closure of the halogeno-derivative (6; X = Cl) to the phenanthro-heterocycle (7) is electrochemical reduction.[10] Electrochemical reduction of aryl halides in an

[1] A. Padwa and R. Hartman, *J. Amer. Chem. Soc.*, 1966, **88**, 3759.

[2] J. L. Cooper and H. H. Wasserman, *Chem. Comm.*, 1969, 200; C. A. Mudry and A. R. Frasca, *Tetrahedron*, 1974, **30**, 2983.

[3] (*a*) A. Mitschker, U. Brandl, and T. Kauffmann, *Tetrahedron Letters*, 1974, 2343; (*b*) J. Hennessy and A. C. Testa, *J. Phys. Chem.*, 1972, **76**, 3362; (*c*) M. Maeda and M. Kojima, *J.C.S. Perkin I*, 1977, 239.

[4] E. V. Blackburn and C. J. Timmons, *Quart. Rev.*, 1969, **23**, 482.

[5] H. Wynberg, H. van Driel, R. M. Kellog, and J. Butler, *J. Amer. Chem. Soc.*, 1967, **89**, 3487.

[6] Thiophen: R. M. Kellog, *Tetrahedron Letters*, 1972, 1429; R. M. Kellogg, J. K. Dik, H. van Driel, and H. Wynberg, *J. Org. Chem.*, 1970, **35**, 2737; ref. 5; H. Wynberg and H. van Driel, *J. Amer. Chem. Soc.*, 1965, **87**, 3998. Furan: E. E. van Tamelen and T. H. Whitesides, *J. Amer. Chem. Soc.*, 1971, **93**, 6129. Thiazole and isothiazole: C. Riou, J. C. Poite, G. Vernin, and J. Metzger, *Tetrahedron*, 1974, **30**, 879; M. Maeda and M. Kojima, *Tetrahedron Letters*, 1973, 3523; C. Riou, G. Vernin, H. J. M. Dou, and J. Metzger, *Bull. Soc. chim. France*, 1972, 2673; A. Lablache-Combier and A. Pollet, *Tetrahedron*, 1972, **28**, 3141. Oxazole and isoxazole: ref. 3*c*; J. P. Ferris, F. R. Antonucci, and R. N. Trimmer, *J. Amer. Chem. Soc.*, 1973, **95**, 919; E. F. Ullman and B. Singh, *ibid.*, 1967, **89**, 6911; H. Goth, A. R. Gagneux, C. H. Engster, and H. Schmidt, *Helv. Chim. Acta*, 1967, **50**, 137.

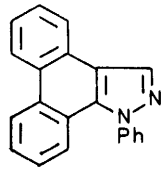
[7] H. Tiefenhaler, W. Dorscheln, H. Goth, and H. Schmidt, *Helv. Chim. Acta*, 1967, **50**, 2244.

[8] J. P. Ferris, K. V. Pravhu, and R. L. Strong, *J. Amer. Chem. Soc.*, 1975, **97**, 2835.

[9] H. O. House, *J. Amer. Chem. Soc.*, 1956, **78**, 2298.

[10] W. J. Begley, J. Grimshaw, and J. Trocha-Grimshaw, *J.C.S. Perkin I*, 1974, 2633.

aprotic solvent leads to addition of one electron then cleavage of the carbon–halogen bond to give halide ion and an aryl σ-radical. When the structure of the molecule is appropriate the latter radical will cyclise onto an adjacent phenyl group to generate a new six-membered ring. Application of this reaction to the pyrazole



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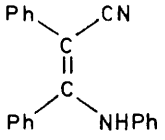

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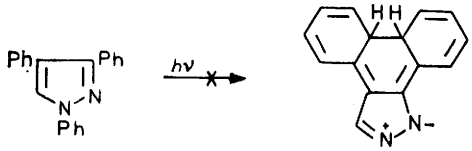
(6; X = Cl) led to the same product (7) as was obtained photochemically from 1,4,5-triphenylpyrazole.

1,3,4-Triphenylpyrazole (9) was obtained by decomposition of *N*-phenylsydnone in the presence of diphenylacetylene.[11] An alternative procedure was the oxidation by lead(IV) acetate of 1,3,4-triphenyl-Δ^2-pyrazoline, obtained by dehydration and cyclisation of the phenylhydrazone from 2-hydroxy-1,2-diphenylpropan-1-one. Preparation of this Δ^2-pyrazoline from phenylhydrazine and the Mannich base from deoxybenzoin, formaldehyde, and an amine led to a mixture of the Δ^2-pyrazoline and 1,4,5-triphenylpyrazole;[12] in one publication[13] this latter compound was mistakenly identified as 1,3,4-triphenyl-Δ^2-pyrazoline.

1,3,4-Triphenylpyrazole was recovered unchanged from irradiation in the presence of iodine. It is already known that the third isomer, 1,3,5-triphenylpyrazole, also undergoes no reaction under the same conditions.[10] The failure of these compounds to react can be understood by considering the structures of the non-aromatic polyene intermediates formed photochemically and then dehydrogenated. 1,3,4-Triphenylpyrazole, if it reacted, would give the intermediate (10), which can only be written in a dipolar form and only one canonical representation is given. A dipolar intermediate must also be formed from 1,3,5-triphenylpyrazole if it is to undergo photocyclisation. In contrast the intermediate from 1,4,5-triphenylpyrazole is not dipolar and has a structure



(9) (10)

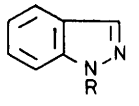
like type (2). Only 1,4,5-triphenylpyrazole undergoes this photocyclisation so one may infer that the cyclisation will occur only if it leads to a polyene intermediate without charge separation. When a dipolar intermediate is formed, the photoequilibrium between starting material and this intermediate will be unfavourable because of the large free energy charge so that the cyclisation product is not detected.

The above explanation also accounts for the failure of 3,4-diphenylthiophen (4) to undergo cyclisation without a prior rearrangement of the thiophen ring.[5] It also explains the preferred reaction between the 4- and 5-phenyl substituents of 1,4,5-triphenylpyrazole to give (7), rather than an isomer, and the preferred reactions of tetraphenylimidazole and 1,2,3-triphenylindole.[2]

Photoreaction of 1,4,5-triphenylpyrazole with benzophenone as sensitiser led to a different type of process. The products were separated by preparative t.l.c. Starting material was recovered together with a yellow substance, m.p. 200—201°, M^+ 296, $\nu_{max.}$ 2 200 cm^{-1} (C≡N). This was identified as 3-anilino-2,3-diphenylacrylonitrile (8) by comparison with an authentic sample.[14] Previous studies[7] of the benzophenone-sensitised reactions of other pyrazoles led to the expectation of finding 1,4,5-triphenylimidazole[15] among the products. However comparative analytical t.l.c. with an authentic sample of this imidazole did not reveal its presence.

1,3,4-Triphenylpyrazole was unchanged on irradiation in the presence of benzophenone. Authentic 1,2,4-triphenylimidazole was prepared. This imidazole was not found after irradiation of the pyrazole although studies with alkylpyrazoles[7] led us to expect it.

The formation of the amino-nitrile (8) from 1,4,5-triphenylpyrazole resembles the photoreactions of 1-alkyl- and 1-aryl-indazoles, for example the conversion of (11) into (12).[7] This conversion does not occur in the



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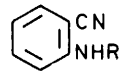

(12) R = Me, CH_2Ph, or Ph

indazole series when a 3-alkyl or 3-aryl substituent is present, and this again resembles our observations in that 1,3,4-triphenylpyrazole is inert.

It has been suggested, by analogy with the oxazole–isoxazole rearrangement,[6] that the photorearrangement of pyrazoles to imidazoles involves an azirine intermediate.[7] In support of this, the azirine (13) is known to afford 1,2-diphenylimidazole on irradiation *via* a nitrile ylide.[16] The discovery of compound (8) as a product from irradiation of 1,4,5-triphenylpyrazole allows speculation on the existence of a second route for pyrazole–imidazole rearrangements. Aminoacrylonitriles (14) are known to give imidazoles on irradiation,

[11] R. Huisgen, H. Gotthardt, and R. Grashey, U.S.P. 3,254,093/1966 (*Chem. Abs.*, 1966, **65**, 7183).

[12] (*a*) J. Matti and M. Perrier, *Bull. Soc. chim. France*, 1955, 525; (*b*) J. F. K. Wilshire, *Austral. J. Chem.*, 1974, **27**, 2041.

[13] J. D. Kendall and G. F. Duffin, U.S.P. 2,740,793/1956, (*Chem. Abs.*, 1956, **50**, 13465).

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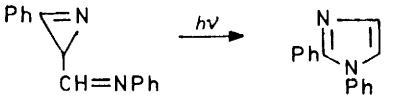
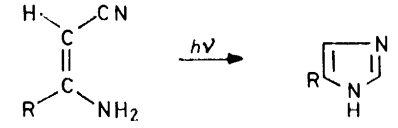
[15] A. E. Everest and H. McCombie, *J. Chem. Soc.*, 1911, **99**, 1751.

[16] A. Padwa, J. Smolanoff, and A. Tremper, *J. Amer. Chem. Soc.*, 1975, **97**, 4682.

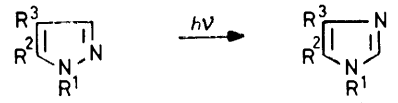
probably *via* four-membered ring intermediates.[17] Thus pyrazoles with only hydrogen in the 3-position may rearrange by the sequence pyrazole ⟶ aminoacrylonitrile ⟶ imidazole.

Schmidt [7] has found a number of rearrangements of pyrazoles (15) to imidazoles which could occur *via* an aminoacrylonitrile and in the cases of pyrazole and 3-methylpyrazole, Ferris [17] has shown that the appropriate aminoacrylonitrile does undergo photoconversion





(14) R = H, Me, or Ph



(15) R^1 = H, Me, CH_2Ph, or Ph, R^2 = R^3 = H
R^2 = Me, R^1 = R^3 = H
R^3 = Me, R^1 = R^2 = H
R^1 = R^3 = Me, R^2 = H

into the imidazole. Photorearrangement of 3-methylpyrazole gives 2-methylimidazole as well as 4-methylimidazole, which may arise *via* the aminocrotononitrile (14; R = Me). Compound (8) was found to be photostable under both sensitised and unsensitised conditions; a possible explanation is that the compound exists largely in the form with *trans*-arrangement of nitrile and amino-groups. Molecular models indicate considerable strain in the *cis*-form.

EXPERIMENTAL

Analytical t.l.c. was carried out on Merck fluorescent silica gel plates eluted with dichloromethane. U.v. spectra were measured for solutions in methanol.

4-(2-Chlorophenyl)-1,5-diphenylpyrazole.— Alkaline hydrogen peroxide reagent was prepared by dissolving sodium peroxide (100 g) in iced water (800 ml) and adding concentrated hydrochloric acid (180 ml) with stirring and cooling in ice–salt to keep the temperature below 5 °C; finally ethanol (70 ml) was added. This reagent was added rapidly over 2 min to a stirred solution of 2-chlorobenzylideneacetophenone [18] (5; X = Cl) (130 g) in ethanol (2 500 ml) warmed to 35 °C. When the mixture had become almost colourless, it was cooled to 0 °C and the resulting crystalline epoxide (106 g, 77%), m.p. 71—73°, was collected. The crude dry epoxide (100 g) was suspended in benzene (850 ml) and boron trifluoride–ether (150 ml) was slowly added with stirring. The mixture was set aside for 20 min, and the resulting solution washed with water. The benzene layer was diluted with ethanol (1 000 ml) and a solution of phenylhydrazine hydrochloride (85 g) and anhydrous sodium acetate (134 g) in water (800 ml) was added, followed by sufficient ethanol to make a homogeneous solution. After 24 h at room temperature, evaporation under reduced pressured allowed precipitation of the crude product (21 g, 16%). *4-(2-Chlorophenyl)-1,5-diphenylpyrazole* (6; X = Cl) crystallised from aqueous ethanol as needles, m.p. 115—117° (Found: C, 76.2; H, 4.8; Cl, 10.7; N, 8.4. $C_{21}H_{15}ClN_2$ requires C, 76.3; H, 4.6; Cl, 10.7; N, 8.5%); M^+ 332/330, $\lambda_{max.}$ 212 (ε 37 000) and 251 nm (20 000). The substance showed two polarographic waves in dimethylformamide (0.1M-tetrapropylammonium perchlorate), $E_{\frac{1}{2}}$ −2.1 (with pronounced maximum) and −2.45 V *vs.* s.c.e.

1-Phenyl-1H-phenanthro[9,10-c]pyrazole (7).—A small H-type electrochemical cell with a mercury cathode and a platinum anode was used with tetrapropylammonium perchlorate (0.1M) in anhydrous dimethylformamide as supporting electrolyte and solvent. A solution of 4-(2-chlorophenyl)-1,5-diphenylpyrazole (2 g) in the solvent (15 ml) was reduced at a cathode potential of −2.3 V (*vs.* s.c.e.) until the current fell to a low value. Dilution of the mixture with water precipitated the product (1.35 g, 68%) which was collected and chromatographed on a column of silica gel (dichloromethane as eluant). This separated three components: (*a*) t.l.c. R_F 0.45 (1.5 mg), m.p. 170—200°, *m/e* 365 (highest mass), (*b*) R_F 0.24, major component, and (*c*) R_F 0.04 (24 mg), m.p. 280—285°, *m/e* 298 (highest mass). The major component was dissolved in the minimum of hot ethanol and treated with a solution of 1,3,5-trinitrobenzene in ethanol to give a precipitate of *1-phenyl-1H-phenanthro[9,10-c]pyrazole 1,3,5-trinitrobenzene adduct*, which crystallised from ethanol as yellow needles, m.p. 168—169° (Found: C, 63.7; H, 3.6; N, 14.0. $C_{27}H_{17}N_5O_6$ requires C, 63.9; H, 3.4; N, 13.8%). A solution of the adduct in dichloromethane was washed several times with 5M-sodium hydroxide, then water, and dried ($MgSO_4$). Evaporation left *1-phenyl-1H-phenanthro[9,10-c]pyrazole* (7), which crystallised as colourless needles from ethanol, m.p. 160—162° (0.30 g, 15%) (Found: C, 85.5; H, 4.6; N, 9.4. $C_{21}H_{14}N_2$ requires C, 85.7; H, 4.8; N, 9.5%).

1,3,4-Triphenylpyrazole.—(*a*) A mixture of *N*-phenylsydnone (3.24 g) and diphenylacetylene (10.6 g) sealed in a Carius tube was heated at 160—170 °C for 14 days. The product was purified by t.l.c. on silica gel (elution with dichloromethane) to yield 1,3,4-triphenylpyrazole, m.p. 93—96° [from light petroleum (b.p. 40—60 °C)] (lit.,[11] 96—97°), $\lambda_{max.}$ 225 (ε 16 000) and 285 nm (15 000).

(*b*) 1,2-Diphenyl-2-hydroxypropan-1-one phenylhydrazone [12a] [m.p. 95°; τ 2.6—3.5 (16 H, m) 5.4 (1 H, s, OH), and 8.25 (3 H, s, CH_3); 3.0 g] was refluxed for 2 h in benzene (50 ml) containing boron trifluoride–ether complex (1 ml). The solution was then washed with water, dried (Na_2SO_4), and evaporated to yield 1,3,4-triphenyl-Δ^2-pyrazoline, as needles, m.p. 134—135° (lit.,[12] 132—134°) (2.6 g, 87%). The pyrazoline (2.2 g) was dissolved in dichloromethane (12 ml) and a solution of lead(IV) acetate in dichloromethane (10 ml) added. After 24 h at room temperature aqueous acetic acid (50 ml; 10%) was added, followed by sufficient

[17] T. H. Koch and R. M. Rodehorst, *J. Amer. Chem. Soc.*, 1974, **96**, 6707; J. P. Ferris and R. W. Trimmer, *J. Org. Chem.*, 1976, **41**, 19; J. P. Ferris and J. E. Kuder, *J. Amer. Chem. Soc.*, 1970, **92**, 2527; J. P. Ferris, R. A. Sanchez, and L. E. Orgel, *J. Mol. Biol.*, 1968, **33**, 693; J. P. Ferris and L. E. Orgel, *J. Amer. Chem. Soc.*, 1966, **88**, 1074.

[18] C. L. Bickel, *J. Amer. Chem. Soc.*, 1946, **68**, 865.

aqueous hydrazine solution to destroy the brown precipitate of lead dioxide. The dichloromethane layer was separated, washed with water, dried (K_2CO_3), and evaporated to leave 1,3,4-triphenylpyrazole, needles (2.0 g), m.p. 93—95° [from light petroleum (b.p. 40—60 °C)].

Photochemistry of 1,4,5-*Triphenylpyrazole*.—A Hanau 150 W medium-pressure mercury lamp surrounded by a quartz water jacket was immersed in a solution of the pyrazole (0.30 g) [$\lambda_{max.}$ 213 (ε 20 000) and 262 nm (13 000)] and any other reagent (see Table) in dioxan (120 ml). After irradiation the solution was evaporated under reduced pressure, the residue diluted with water, and the product extracted with dichloromethane. The extract was washed with sodium disulphite solution (for reaction mixtures containing iodine) and water, dried ($MgSO_4$), and evaporated. The product from reactions 1—3 could be crystallised. The products from reaction 4 were separated by preparative t.l.c. on silica gel (elution with dichloromethane). All the named products (see Table) were identified by mixed m.p. with authentic samples. Reaction 4 generated six other products, all in negligible quantities (2—4 mg); none of these was identical with 1,4,5-triphenylimidazole, m.p. 172°, which showed R_F 0.04 on t.l.c. 3-Anilino-2,3-diphenylacrylonitrile,[14] m.p. 205—206°, had R_F 0.69 on t.l.c., $\lambda_{max.}$ (MeOH) 212 (ε 16 600) and 256 nm (17 000). This compound (0.3 g) was irradiated in dioxan (100 ml) as above in the presence of benzophenone (0.01 g) and separately without benzophenone. In neither case did a reaction occur (t.l.c.).

Photochemistry of 1,3,4-*Triphenylpyrazole*.—Irradiation under the same conditions as used for experiments 1—4 (Table) led only to recovery of starting material.

Products from irradiation of 1,4,5-triphenylpyrazole

No.	Irradiation time (h)	Additional reagents	Product	Yield
1	26	None	Starting pyrazole	0.29 g (96%)
2	115	None	Starting pyrazole	0.20 g (67%)
3	140	I_2 (0.1 g)	Phenanthropyrazole (7)	0.20 g (67%)
4	5	Ph_2CO (0.01 g)	Starting pyrazole	0.09 g (48%)
			Nitrile (8)	0.01 g (6%)

1,2,4-*Triphenylimidazole*.— *N*-(2-Phenyl-2-oxoethyl)-benzanilide [19] (1.0 g) and concentrated aqueous ammonia (1.0 g; s.g. 0.880) were heated in a sealed tube at 120 °C for 16 h (several trials were made to determine these optimum conditions). The gummy product was dissolved in dichloromethane and the solution washed with water, dried (Na_2SO_4), and evaporated. The residual gum was chromatographed in benzene on a column of alumina to give 1,2,4-*triphenylimidazole*, which crystallised from light petroleum (b.p. 40—60 °C) as needles, m.p. 84—85° (0.10 g, 10%) (Found: C, 85.2; H, 5.4; N, 9.3. $C_{21}H_{16}N_2$ requires C, 85.1; H, 5.4; N, 9.5%), M^+ 296, $\lambda_{max.}$ (MeOH) 210 (ε 26 000), 220 (24 000), and 270 nm (27 000).

[7/490 *Received*, 21*st March*, 1977]

[19] R. Möhlau, *Ber.*, 1881, **15**, 2471.