Reactive Intermediates. Part XXVI.[1] Flash Vacuum Pyrolysis of Phenyl-substituted 1,2,4-Triazoles; a new Synthesis of Isoindoles

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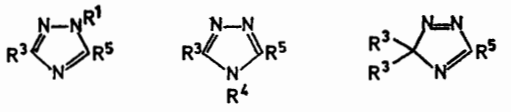
The nine mono-, di-, and tri-phenyl-1.2.4-triazoles have been subjected to flash vacuum pyrolysis at 650—800°, and the products have been isolated and identified. 1.3.5- and 3.4.5-Triphenyl-1.2.4-triazole both gave 1,3-diphenylisoindole in good yield. The formation of this product requires the extrusion of nitrogen from the triazoles, for which a mechanism is suggested involving a [1.5] phenyl shift and the generation of a non-aromatic 3*H*-1.2.4-triazole intermediate. The four diphenyl-1.2.4-triazoles reacted similarly to give 1-phenylisoindole, which was oxidised during work-up to 3.3'-diphenylbi-1*H*-isoindol-1-ylidene, and 1-phenyl-1.2.4-triazole gave isoindole, which was isolated as its Diels–Alder adduct with *N*-phenylmaleimide.

3-Phenyl-1.2.4-triazole underwent fragmentation in a different way, giving benzonitrile and cyanamide. From 4-phenyl-1.2.4-triazole a highly unstable product, thought to be *N*-cyano-*N*-phenylformamidine, was isolated at low temperatures. This product reacted with *N*-phenylmaleimide to give 2-(*N*-cyanoanilino)-*N*-phenylsuccinimide (7) for which a mechanism involving the transient formation of monophenylcarbodi-imide is suggested. An independent synthesis of the cyanamide (7) depended upon the formation of the lithium salt of phenylcyanamide from 1-phenyltetrazole and butyl-lithium.

4-(2.4.6-Trimethylphenyl)-1.2.4-triazole gave (2-amino-4.6-dimethylphenyl)acetonitrile (11) on pyrolysis, probably through 2-amino-5.7-dimethyl-3*H*-indole (10) as intermediate. This amino-indole readily isomerised on pyrolysis to give the phenylacetonitrile (11).

FIVE-MEMBERED aromatic compounds containing adjacent doubly bonded nitrogen atoms commonly undergo thermal or photochemical reactions involving the loss of molecular nitrogen. Such reactions have been observed with tetrazoles,[2] 1*H*-1,2,3-triazoles,[3] 1,2,3-thiadiazoles,[4] and 1,2,3-selenadiazoles.[5] In 1,2,4-triazoles there are two adjacent nitrogen atoms but in the aromatic 1*H*- and 4*H*-derivatives (1) and (2), these are not doubly bonded and there is no direct way in which molecular nitrogen can be extruded. Only in the unknown, non-aromatic 3*H*-derivatives (3) are the nitrogen atoms suitably bonded for extrusion.



(1) (2) (3)

(1) a; $R^1 = R^3 = R^5 = Ph$
b; $R^1 = R^3 = Ph$, $R^5 = H$
c; $R^1 = R^5 = Ph$, $R^3 = H$
d; $R^1 = H$, $R^3 = R^5 = Ph$
e; $R^1 = Ph$, $R^3 = R^5 = H$
f; $R^1 = R^5 = H$, $R^3 = Ph$

(2) a; $R^3 = R^4 = R^5 = Ph$
b; $R^3 = R^4 = Ph$, $R^5 = H$
c; $R^3 = R^5 = H$, $R^4 = Ph$
d; $R^3 = R^5 = H$, $R^4 = 2,4,6\text{-}Me_3C_6H_2$

In this paper the results of a systematic investigation of the thermal decomposition products of phenyl-substituted 1,2,4-triazoles are reported. The object was to discover whether 1,2,4-triazoles would undergo fragmentation directly (the loss of a nitrile fragment being the most closely analogous to the loss of molecular nitrogen in 1*H*-1,2,3-triazoles) or whether some more complex series of reactions leading to the loss of molecular nitrogen would occur.

There are three mono-, four di-, and two tri-phenyl-1,2,4-triazoles [(1a—f) and (2a—c)], and all have been reported previously. These were prepared by literature procedures (see Experimental section).

Preliminary experiments showed that, as anticipated, the 1,2,4-triazoles were more resistant to pyrolysis than the corresponding 1,2,3-triazoles.[3] With the flash vacuum pyrolysis apparatus described earlier,[6] it was found necessary to use oven temperatures in the range 650—800° in order to effect reasonable conversions. In addition, the heated quartz tube was packed with silicon carbide chips in several experiments in order to increase the contact time. Under these conditions, most of the pyrolyses went very cleanly, with little charring and good overall recovery of material.

1,3,5- (1a) and 2,4,5-triphenyl-1,2,4-triazole (2a) were each pyrolysed at 750—800° in a packed quartz tube. More than half the starting triazole passed through the hot zone unchanged, but in each case the same major product was obtained in good yield based on consumed triazole. The product was identified as 1,3-diphenylisoindole from its physical and spectral properties and from those of its Diels–Alder adduct with diethyl acetylenedicarboxylate.[7] Since the formation of 1,3-diphenylisoindole requires the loss of molecular nitrogen from the triazoles, the latter must rearrange before fragmentation takes place. A possible mechanism is shown in Scheme 1. This involves a [1,5] sigmatropic shift of the *N*-phenyl groups to give the same intermediate, 3,3,5-triphenyl-3*H*-1,2,4-triazole (3; $R^3 = R^5 = Ph$), from which molecular nitrogen is extruded. The resulting iminocarbene (or 1,3-diradical) would then readily cyclise to give 1,3-diphenylisoindole. The nitrogen extrusion and subsequent cyclisation have a close parallel in the photochemical conversion of 3,3-diphenylindazole into 9-phenylfluorene and nitrogen.[8]

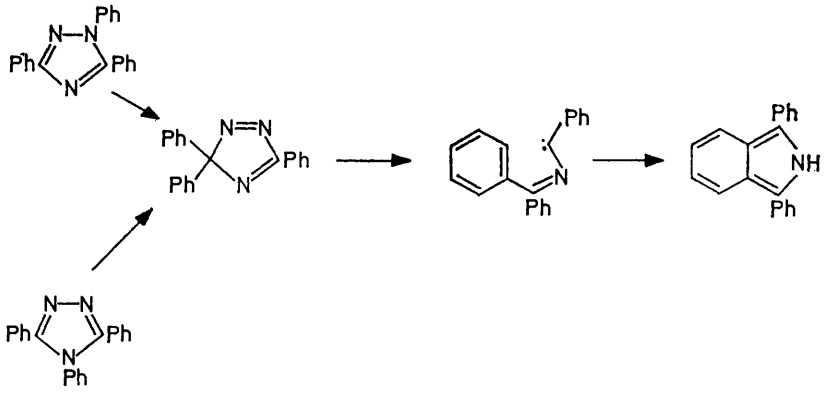
Similar high temperature conversions of pyrazoles[9]

[1] Part XXV, T. L. Gilchrist, C. W. Rees, and C. Thomas, preceding paper.
[2] F. R. Benson in 'Heterocyclic Compounds,' ed. R. C. Elderfield, Wiley, New York, 1967, vol. 8, p. 1.
[3] T. L. Gilchrist, G. E. Gymer, and C. W. Rees, *J.C.S. Perkin I*, 1973, 555, and references therein.
[4] T. L. Gilchrist, P. G. Mente, and C. W. Rees, *J.C.S. Perkin I*, 1972, 2165, and references therein.
[5] H. Meier and I. Menzel, *Tetrahedron Letters*, 1972, 445.
[6] D. J. Anderson, D. C. Horwell, E. Stanton, T. L. Gilchrist, and C. W. Rees, *J.C.S. Perkin I*, 1972, 1317.
[7] J. C. Emmett and W. Lwowski, *Tetrahedron*, 1966, **22**, 1011.
[8] A. A. Sale, Ph.D. Thesis, University of Leicester, 1969.
[9] C. Wentrup and W. D. Crow, *Tetrahedron*, 1971, **27**, 361.

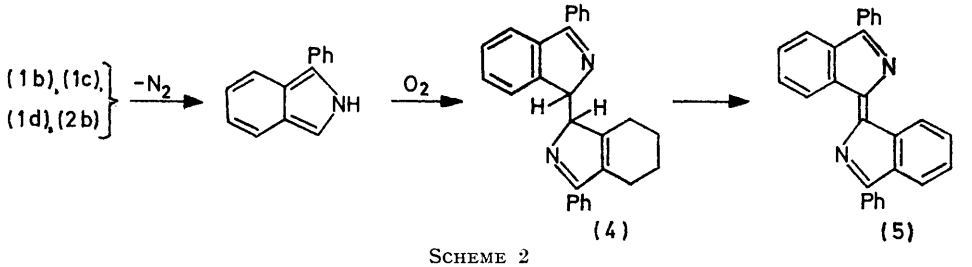
and indazoles [10] into non-aromatic isomers by migration of hydrogen,[10] cyano-,[9] and methyl [9] substituents have been proposed to explain the results of other fragmentations. A notable feature of the present reactions is the absence of other, competing pathways for the fragmentation.

The four diphenyl-1,2,4-triazoles (1b—d) and (2b) were pyrolysed at 750—800°. In all cases the product was a pale yellow gum which gave an intense blue colouration (Scheme 2). The oxidation of 1-phenylisoindole to the dimer (4) probably involves radical intermediates; the solutions containing the highly coloured intermediates showed an unresolved e.s.r. signal which markedly increased in intensity when the solutions were exposed to air.

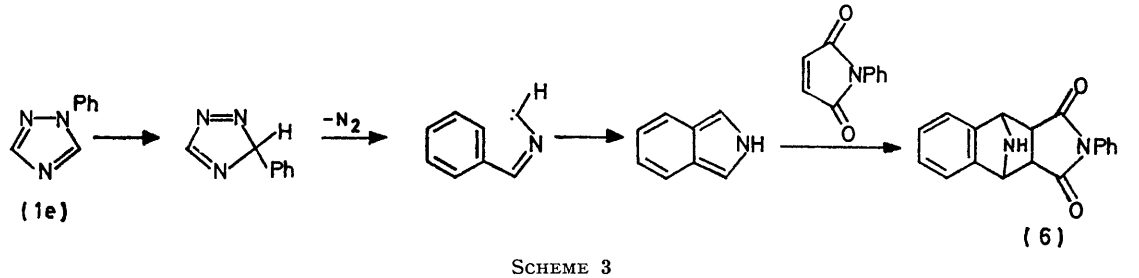
As with the triphenyl-1,2,4-triazoles, the predominant thermal reaction of diphenyl-1,2,4-triazoles involves phenyl migration followed by extrusion of nitrogen.



SCHEME 1



SCHEME 2



SCHEME 3

when treated with Ehrlich's reagent, and which was identified as 1-phenylisoindole from its u.v. spectrum (deoxygenated solvents) and by its interception with maleic anhydride.[11] When exposed to air and solvents, 1-phenylisoindole gave a complex highly coloured mixture, which, when kept in solution and in air for several days, gave a single orange substance which was isolated in yields of up to 87%. The substance was identified as 3,3′-diphenylbi-1*H*-isoindol-1-ylidene (5),[12,13] probably formed from 1-phenylisoindole through the partially oxidised dimer 3,3′-diphenylbi-1*H*-isoindol-1-yl (4) [13]

1-Phenyl-1,2,4-triazole (1e) was pyrolysed at 800°, in a packed quartz tube. Isoindole was the major detectable product; it was isolated (12%) as its Diels–Alder adduct (6) [14] with *N*-phenylmaleimide (Scheme 3). There was evidence of considerable charring and more complex decomposition which was not observed with the di- and tri-phenyltriazoles, although the major reaction appears to follow the same course.

3-Phenyl-1,2,4-triazole (1f) was noticeably less stable than the other triazoles. It was completely decomposed

[10] W. D. Crow and M. N. Paddon-Row, *Tetrahedron Letters*, 1972, 3207.

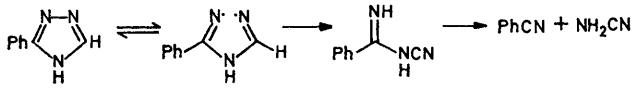
[11] D. F. Veber and W. Lwowski, *J. Amer. Chem. Soc.*, 1964, **86**, 4152.

[12] E. Maekawa, Y. Suzuki, and S. Sugiyama, *Chem. Ber.*, 1968, **101**, 847; B.P. 1,020,305 (*Chem. Abs.*, 1966, **64**, 17,758h).

[13] R. Kreher and J. Seubert, *Tetrahedron Letters*, 1966, 3015.

[14] R. Bonnett and R. F. C. Brown, *J.C.S. Chem. Comm.*, 1972, 393.

by pyrolysis in a packed quartz tube at 650°, the products being benzonitrile (85%) and cyanamide. The latter was detected by interception on a sodium chloride disc cooled to −196°, followed by determination of the i.r. spectrum.* A possible pathway for the formation of these products is shown in Scheme 4. The thermal reaction of 3-phenyl-1,2,4-triazole is clearly of a type different from that observed with the di- and tri-phenyltriazoles.



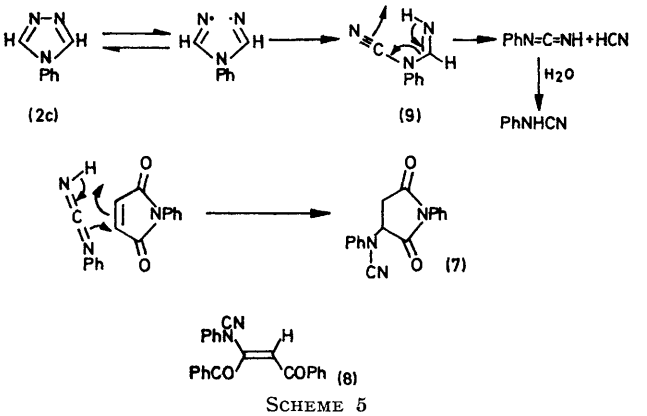
SCHEME 4

4-Phenyl-1,2,4-triazole (2c) also reacted in a different way from the di- and tri-phenyltriazoles. When pyrolysed at 775°, it gave a highly unstable amber gum, the i.r. spectrum of which, at −196°, showed a complex series of absorptions at 3200—2600 cm^{-1}, consistent with the presence of hydrogen-bonded NH, and a sharp strong absorption at 2220 cm^{-1} which indicated the presence of a cyanamide group. The product resinified when it was allowed to warm to −30°, and an additional strong i.r. absorption appeared at 2100 cm^{-1}, in the region of carbodi-imide absorptions.

When pre-cooled organic solvents were added to the pyrolysis product at low temperatures, phenylcyanamide was formed (26—52%). An attempt was made to intercept the primary product by adding a solution of *N*-phenylmaleimide, but again, phenylcyanamide and a resinous polymer were the only products. The reaction was then performed in a solvent-free system by pre-coating the surface of the condenser with a solid layer of *N*-phenylmaleimide. The pyrolysis of 4-phenyl-1,2,4-triazole was carried out using the coated condenser to intercept the pyrolysate, and the solid mixture was then allowed to warm to room temperature. From the mixture the adduct (7) was isolated (42%). The structure of the adduct was established from its spectroscopic properties ($\nu_{max.}$ 2215 cm^{-1}; ABX pattern in the n.m.r. spectrum) and by an independent synthesis (see later). Although this compound is formally an adduct of *N*-phenylmaleimide and phenylcyanamide, it was not formed in this way; *N*-phenylmaleimide did not react with phenylcyanamide even after heating in solution for several hours.

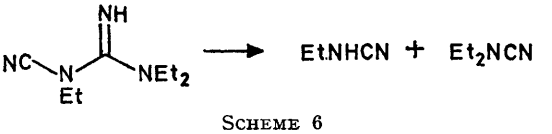
A similar adduct, tentatively assigned the structure (8), was isolated (12%) when the condenser was precoated with dibenzoylacetylene. No adducts were obtained with maleic anhydride, dibenzoylethylene, *trans*-stilbene, tetracyanoethylene, diethyl acetylenedicarboxylate, 4-phenyltriazoline-3,5-dione, or 1,3-diphenylisobenzofuran. Phenylcyanamide, when subjected to flash vacuum pyrolysis under the same conditions, was unchanged, the i.r. spectrum being clearly distinguishable from that of the pyrolysis product of 4-phenyl-1,2,4-triazole.

An interpretation of these observations is as follows. A reversible N–N bond cleavage, followed by hydrogen atom transfer, may occur, similar to that proposed in Scheme 4 to account for the products of pyrolysis of 3-phenyl-1,2,4-triazole. With 4-phenyl-1,2,4-triazole this leads to the formation of *N*-cyano-*N*-phenylformamidine (9) (Scheme 5), which is considered to be the unstable product detected on the condenser. In the condensed phase, hydrogen cyanide could be eliminated from the formamidine (9), possibly by cyclic hydrogen transfer, leaving phenylcarbodi-imide. This would polymerise on warming or, in the presence of proton-donating solvents, would isomerise to phenylcyanamide. Phenylcarbodiimide could also lead to the formation of the adducts (7) and (8) with *N*-phenylmaleimide and dibenzoylacetylene, through ' ene ' reactions as shown in Scheme 5.



SCHEME 5

The suggestion that *N*-cyano-*N*-phenylformamidine (9) is the unstable primary pyrolysis product is in accord with the low temperature i.r. spectrum of the product. Its instability in the condensed phase is greater than might have been expected for such a structure, although a similar compound, 1-cyano-1,3,3-triethylguanidine, undergoes an analogous fragmentation at room temperature (Scheme 6).[15]



SCHEME 6

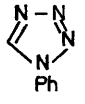
In order to attempt an alternative intramolecular trapping of the proposed diradical intermediate (Scheme 5), 4-(2,4,6-trimethylphenyl)-1,2,4-triazole (2d) was prepared and pyrolysed. This compound contains active hydrogen atoms in the two methyl groups adjacent to the triazole ring, well disposed to interact with the radical centres formed by N–N bond cleavage. The triazole (2d) was prepared by the acid-catalysed condensation of 2,4,6-trimethylaniline and *NN*-dimethylformamide azine.

* This involved the use of a modified pyrolysis apparatus in which the normal condenser was replaced by a copper block containing a sodium chloride plate held by stainless steel circle clips. The block was connected to a reservoir containing the coolant and it could be rotated through 90° after completion of the pyrolysis. This allowed the i.r. spectrum to be recorded through sodium chloride windows in the sides of the apparatus, the whole pyrolysis unit being inserted into the beam of an i.r. spectrometer with the target maintained *in vacuo* at −196°.

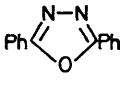
[15] P. H. Benders, *Tetrahedron Letters*, 1973, 3653.

The pyrolysis product was again an unstable gum, which gave a single crystalline solid after layer chromatography. This product was assigned structure (11) on the basis of its spectral properties. The n.m.r. spectrum showed signals for two different aromatic methyl groups and a benzylic methylene group, and the i.r. spectrum contained absorptions consistent with the presence of cyano- and amino-groups. The structure was established by an independent synthesis: 3,5-dimethylphenylacetonitrile was nitrated to give a mixture containing (3,5-dimethyl-2-nitrophenyl)acetonitrile as a major component. It proved possible to reduce the nitro-group without affecting the cyano-group by using sodium dithionite to give (2-amino-3,5-dimethylphenyl)acetonitrile (11).

A possible mechanism for the formation of compound (11), which is consistent with the intermediacy of a diradical as proposed in Scheme 5, is shown in Scheme 7. Hydrogen abstraction can now take place from an *ortho* methyl group, and the new diradical intermediate can collapse to give the indoline shown. Loss of hydrogen cyanide and opening of the heterocyclic ring could then give the aniline (11). The reverse of this ring opening (the conversation of 2-aminophenylacetonitrile into 2-amino-3*H*-indole) is known.[16] In order to test this postulated thermal conversion of the indole (10) into the aniline (11), 2-amino-5,7-dimethyl-3*H*-indole was prepared and pyrolysed under the same conditions as used for the triazole (2d). Although some of the indole (10)



(12)

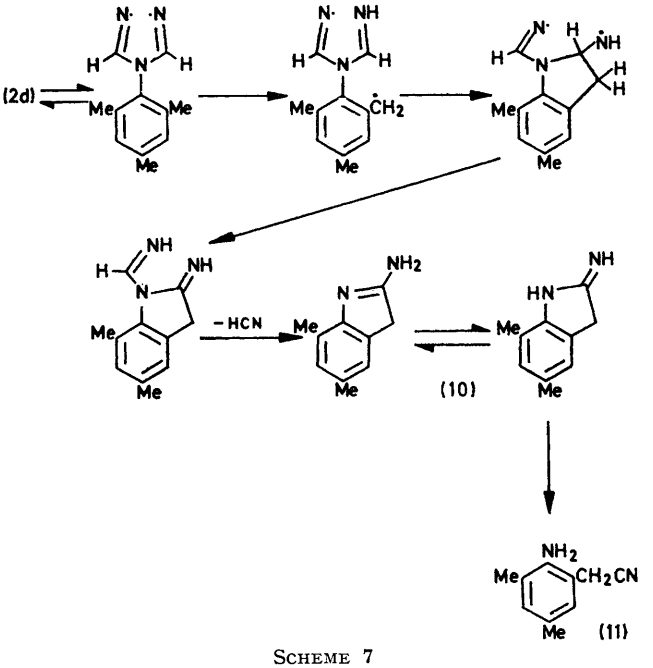


(13)

decomposed in the sublimation tube at 135° most of it vaporised and the pyrolysis product was identical with the aniline (11). In a control experiment, compound (10) was heated (135°) in the solid state under nitrogen, but none of the aniline (11) was formed. It therefore seems very reasonable that the 3*H*-indole (10) is the primary pyrolysis product from triazole (2d) and is partially converted into the aniline (11) under vapour phase pyrolysis conditions. This is further supported by the rapid development of a deep purple colour on exposure to air of a solution of the pyrolysate, exactly as was observed with the independently synthesised 3*H*-indole (10).

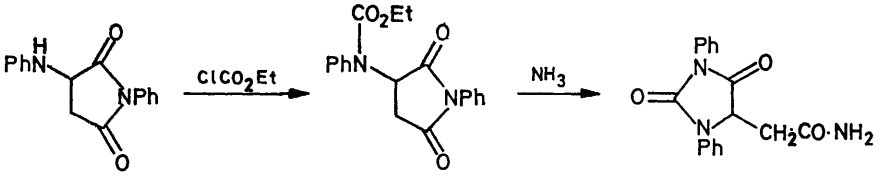
Flash vacuum pyrolyses of two other compounds structurally related to the phenyl-1,2,4-triazoles were performed. Pyrolysis of 1-phenyltetrazole (12) at 500° gave phenylcyanamide as the only detectable product; there was no evidence for any thermally unstable precursor of phenylcyanamide in the pyrolysate.

2,5-Diphenyl-1,3,4-oxadiazole (13) was pyrolysed in a packed quartz tube at 775° and gave a mixture containing benzonitrile and phenyl isocyanate as the major components.



SCHEME 7

Note on the Independent Synthesis of 2-(N-*Cyanoanilino*)-N-*phenylsuccinimide* (7).—Structure (7) proposed for the addition product of *N*-phenylmaleimide and the pyrolysate from 4-phenyl-1,2,4-triazole (2c) was confirmed by independent synthesis, initially with unexpected difficulty. *N*-Cyanation of 3-anilino-1-phenylsuccinimide (14), readily prepared from fumaric acid and aniline, was unsuccessful. Cyanation was attempted with cyanogen bromide and a variety of bases (triethylamine, butyllithium, and *N*-lithioethylenediamine) in various solvents (dichloromethane, dimethylformamide, and tetrahydrofuran) at various temperatures, but starting material only was recovered in varying amounts in all cases. *N*-Carbamoylation of 3-anilino-1-phenylsuccinimide (14) was equally unsuccessful, even with silicon tetraisocyanate (*cf.* ref. 17) in various solvents and at temperatures up to 130° in dimethylformamide. The anilino-compound (14) was readily ethoxycarbonylated, but

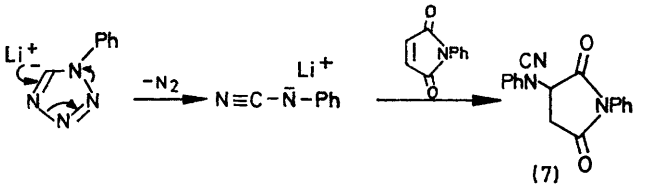


(14) (15)

[16] J. Kebrle and K. Hoffmann, *Helv. Chim. Acta*, 1956, **39**, 116.
[17] R. G. Neville and J. J. McGee, *Canad. J. Chem.*, 1963, **41**, 2123.

treatment of the product with ammonia gave not the required urea but rather the rearrangement product (15). This was presumably formed by opening of the succinimide ring by ammonia at the less hindered carbonyl group, followed by cyclisation with loss of ethanol. Assignment of the five-membered ring rather than the possible six-membered ring structure to (15) was based on the i.r. ring carbonyl absorptions for (15) and for the cyanide derived from it by dehydration with toluene-*p*-sulphonyl chloride and pyridine.

An alternative synthesis of compound (7) by Michael addition of phenylcyanamide to *N*-phenylmaleimide was then investigated. The lithium salt of phenylcyanamide could not be made cleanly by treatment with butyl-lithium; this caused extensive polymerisation of the cyanamide and gave an impure salt which did not react with *N*-phenylmaleimide to give (7). However the lithium salt of phenylcyanamide could be made, and isolated, by modifying Raap's method, which involves the ring opening of 1-phenyltetrazole with butyl-lithium.[18] When this was done at 0° in a small volume of tetrahydrofuran the stable lithium salt separated cleanly and quantitatively. Slow addition of this to *N*-phenylmaleimide in ethyl acetate at room temperature gave the required adduct (7).



(7)

Conclusions.—These experiments show that there are two major pathways for thermal fragmentation of phenyl-substituted 1,2,4-triazoles, one involving rearrangement and extrusion of molecular nitrogen and the other involving extrusion of a nitrile fragment, either directly or indirectly. There is some evidence that the second type of reaction, involving the extrusion of a nitrile, is a stepwise process with homolysis of the N–N bond as the first step. The two types of reaction must be very similar energetically. Apparently, increased phenyl substitution favours the [1,5] rearrangement process, so that this is the only reaction observed with di- and tri-phenyl-1,2,4-triazoles. When this type of reaction is precluded, however, as in 2,5-diphenyl-1,3,4-oxadiazole (13), the alternative type of cleavage takes place under identical conditions.

Pyrolysis of these 1,2,4-triazoles provides a new route to *N*-unsubstituted isoindoles. Pyrolysis of 4-phenyl-1,2,4-triazole also appears to provide an indirect source of monophenylcarbodi-imide, which may allow the chemistry of this compound to be investigated.

EXPERIMENTAL

I.r. spectra were recorded for Nujol mulls or KBr discs using a Pye Unicam SP 200 or a Perkin-Elmer 125 spectrometer. ^{1}H N.m.r. spectra were obtained using a Varian HA-100 spectrometer and mass spectra using A.E.I. MS12 and MS902 instruments. Kieselgel GF254 (Merck) was used for layer chromatography and silica gel M.F.C. for column chromatography of product mixtures. Petroleum refers to light petroleum, b.p. 60—80°.

Pyrolysis of Triazoles.—(a) 1,3,5-*Triphenyl*-1,2,4-*triazole* (1a).[19] (i) The triazole (202 mg) was vaporised at 230° and 0·01 mmHg and the vapour passed through a 20 cm packed quartz tube at 775°. The product mixure was separated by column chromatography (benzene) to give 1,3-diphenylisoindole (38·7 mg, 21%), m.p. 122—123° (crystallised from ethanol and sublimed at 120° and 0·01 mmHg without change in m.p.) [lit.,[7] 148—150° (decomp.)], $\lambda_{max.}$ (EtOH) 228 (log ε 4·26), 235 (4·26), 267 (4·19), 273 (4·23), 321 (4·07), 334 (4·09), and 389 nm (4·32) (in close agreement with that reported [7]). The remainder of the pyrolysate was unchanged triazole.

(ii) Pyrolysed in a 25 cm packed quartz tube at 760°, the triazole (1a) (100 mg) gave 1,3-diphenylisoindole (30 mg, 33%; 95% based on triazole consumed) as a pale yellow solid. The triazole (1a) (65 mg, 65%) was recovered. 1,3-Diphenylisoindole decomposed in various solvents (chloroform, ethyl acetate, and ether–benzene) at room temperature within 2—3 days.

(iii) The triazole (1a) (200 mg) was pyrolysed at 775° in a 20 cm packed quartz tube. Diethyl acetylenedicarboxylate (250 mg) in benzene was added to the product and the solution heated under reflux for 1 h under nitrogen. Petroleum was added to precipitate the product, which was purified by layer chromatography (petroleum–ether, 1 : 1) to give diethyl 1,4-dihydro-1,4-diphenyl-1,4-iminonaphthalene-2,3-dicarboxylate (20·5 mg, 14%), m.p. 171—173° (from acetone) (lit.,[7] 169—170°) (Found: C, 76·3; H, 5·8. Calc. for $C_{28}H_{25}NO_4$: C, 76·5; H, 5·7%); $\nu_{max.}$ 3260 (NH), 1720, and 1706 cm^{-1} (C=O); τ ($CDCl_3$) 8·80 (6H, t), 7·5 (1H, NH), 5·90 (4H, q), and 2·3—3·0 (14H, m).

(b) 3,4,5-*Triphenyl*-1,2,4-*triazole* (2a).[20] (i) The triazole (100 mg) was vaporised at 230° and 0·01 mmHg and the vapour passed through a 20 cm packed quartz tube at 775°. The product mixture was separated by layer chromatography (benzene) to give 1,3-diphenylisoindole (13 mg, 14%; 58% based on triazole consumed). The triazole (2a) (75 mg, 75%) was recovered.

(ii) The triazole (2a) (51 mg) was pyrolysed in the same way and the product mixture dissolved in benzene containing diethyl acetylenedicarboxylate (230 mg). The solution was heated under reflux for 1·5 h under nitrogen. The same adduct (11 mg, 14·5%) was isolated as in (a)(iii).

(c) 3,5-*Diphenyl*-1,2,4-*triazole* (1d).[21] (i) The triazole (221 mg) was vaporised at 190° and 0·02 mmHg and passed through an empty 20 cm quartz tube at 800°. The product, a yellow gum, was dissolved in ethyl acetate. (A portion of the solution gave an intense blue colouration with Ehrlich's reagent.) The solution was evaporated to give a green product (213 mg) which contained a blue component and several other coloured components (t.l.c.). Layer chromatography (benzene) gave a blue solid (12·5 mg), and an orange solid (144 mg) which was identified as 3,3′-diphenylbi-1*H*-isoindol-1-ylidene (5), m.p. 262—263° (from ethyl acetate) (lit.,[12] 263·5°) (Found: C, 87·5; H, 4·7; N, 7·1. Calc. for $C_{28}H_{18}N_2$: C, 88·0; H, 4·7; N, 7·3%), $\lambda_{max.}$ (C_6H_6) 342 (log ε 4·14) and 455 nm (4·55).

[16] R. Raap, *Canad. J. Chem.*, 1971, **49**, 2139.
[19] R. Engelhardt, *J. prakt. Chem.*, 1896, **54**, 143.
[20] E. Klingsberg, *J. Org. Chem.*, 1958, **23**, 1086.
[21] I. Y. Postovskii and N. N. Vereshchagina, *J. Gen. Chem.* (*U.S.S.R.*), 1959, **29**, 2105.

After isolation of these components the base-line material was extracted with ethyl acetate and kept in solution for 2 days. The dark blue colouration slowly faded, and the solution became orange. Evaporation gave more orange dimer (5) (52 mg). The blue solid obtained from the plate had $\lambda_{max.}$ (cyclohexane) 591 nm. When the blue solid was kept dissolved in ethyl acetate, it gave the orange dimer (5) (12 mg). The overall yield of dimer was 208 mg (87%).

(ii) The triazole (1d) (26 mg) was pyrolysed in the same way; the pyrolysate was immediately dissolved in deoxygenated ethanol and its u.v. spectrum recorded: $\lambda_{max.}$ (EtOH) 272 (log ε 3·90), 282 (3·93), 311sh (3·86), 324 (3·96), and 359 nm (4·09), consistent with that for 1-phenylisoindole.[11]

(iii) The triazole (1d) (111 mg) was pyrolysed in the same way and the pyrolysate dissolved in deoxygenated ether. A solution of maleic anhydride (57 mg) in ether was added and a grey solid precipitated; $\nu_{max.}$ 3300 (NH), 1860, 1835, and 1770 cm^{-1} (carboxylic anhydride), consistent with that reported for (3-phenylisoindol-1-yl)succinic anhydride.[11]

(d) 1,3-*Diphenyl*-1,2,4-*triazole* (1b).[22] The triazole (54 mg) was vaporised at 140—175° and 0·02 mmHg and passed through a packed quartz tube at 775°. The initial product distribution was very similar (t.l.c.) to that from 3,5-diphenyl-1,2,4-triazole (1d). After a solution of the pyrolysate in ethyl acetate had been set aside for 2 days, the orange dimer (5) (11 mg, 23%) was isolated by layer chromatography. The remainder of the pyrolysate was the starting triazole (t.l.c.).

(e) 1,5-*Diphenyl*-1,2,4-*triazole* (1c).[23] The triazole (51 mg) was vaporised at 120—150° and 0·02 mmHg and passed through a packed quartz tube at 775°. The orange dimer (5) (12 mg, 28%) was isolated as before. The remainder of the pyrolysate was the starting triazole (t.l.c.).

(f) 3,4-*Diphenyl*-1,2,4-*triazole* (2b).[24] The triazole (54 mg) was vaporised at 180—210° and 0·02 mmHg and passed through a packed quartz tube at 775°. After a solution of the pyrolysate in ethyl acetate had been kept in air for 2 days, the orange dimer (5) (15 mg, 31%) was isolated. The remainder of the pyrolysate was the starting triazole (t.l.c.).

(g) 1-*Phenyl*-1,2,4-*triazole* (1e).[25] The condenser was first coated with an even layer of *N*-phenylmaleimide (173 mg) by vaporisation through the apparatus. The apparatus was reassembled with the coated condenser and the triazole (1e) (153 mg) was vaporised at 110—120° and 0·025 mmHg and passed through a packed quartz tube at 800°. There was considerable charring in the hot zone. The product mixture was separated by layer chromatography ($CHCl_3$–EtOAc, 9 : 1) giving 1-phenyl-1,2,4-triazole (38 mg, 25% recovery), *N*-phenylmaleimide (84 mg), and the Diels–Alder adduct of *N*-phenylmaleimide and isoindole, *exo*-1,2,3,4-tetrahydro-*N*-phenyl-1,4-iminonaphthalene-2,3-dicarboximide (6) (27 mg, 9%), m.p. 205—206° (decomp.) (from ethyl acetate) [lit.,[14] 208—209° (decomp.)], τ ($CDCl_3$) 7·10 (2H), 5·12 (2H), and 2·6—2·9 (9H, m).

(h) 3-*Phenyl*-1,2,4-*triazole* (1f).[26] The triazole (104 mg) was vaporised at 145—170° and 0·015 mmHg and passed through a packed quartz tube at 650°. The product was mainly benzonitrile (62 mg, 85%) (i.r., t.l.c., g.l.c.). Cyanamide was also detected [$\nu_{max.}$ (−196°) 3260 (NH_2), 2250, and 2240 cm^{-1} (C≡N)].

(i) 4-*Phenyl*-1,2,4-*triazole* (2c).[27] (i) The triazole (102 mg) was vaporised at 176—196° and 0·015 mmHg and passed through a packed quartz tube at 775°. The pyrolysis product on the condenser was an amber-coloured film. The oven was removed and, with the condenser maintained at −78°, pre-cooled aqueous tetrahydrofuran was added. Layer chromatography ($CHCl_3$–EtOAc, 9 : 1) of the black solution gave phenylcyanamide (43 mg, 52%), identical with an authentic specimen prepared from *N*-phenylthiourea.[28] Similar experiments using ethanol and diethylamine in place of aqueous tetrahydrofuran also gave only phenylcyanamide (46 and 26%, respectively).

(ii) The triazole (2c) (145 mg) was pyrolysed under the same conditions but with the condenser pre-coated with *N*-phenylmaleimide (173 mg). The product mixture was separated by layer chromatography ($CHCl_3$: EtOAc, 9 : 1) to give crystals of 2-(*N*-*cyanoanilino*)-*N*-*phenylsuccinimide* (7) (122 mg, 42%), m.p. 132·5—133·5° (from benzene–cyclohexane) (Found: C, 69·9; H, 4·6; N, 14·3. $C_{17}H_{13}N_3O_2$ requires C, 70·1; H, 4·5; N, 14·4%), $\nu_{max.}$ (KBr) 2230 (C≡N), 1727 (C=O), 1600, and 1500 cm^{-1}, τ ($CDCl_3$) 6·44—6·97 (2H, sept, J_{AB} 18 Hz), 5·03—5·19 (1H, q, J_{AX} 8, J_{BX} 8 Hz), and 2·44—2·84 (10H, m, aryl H); τ (C_6H_6) 7·30—7·86 (2H, t, oct J_{AB} 18 Hz) and 6·23—6·38 (1H, q, J_{AX} 7·5, J_{BX} 7·5 Hz), *m/e* 291 (M^+), 173 (M^+ − PhNHCN), and 118 (PhNHCN).

(iii) The triazole (2c) (72 mg) was pyrolysed using a condenser pre-coated with dibenzoylacetylene (117 mg). The crude product mixture (166 mg) was subjected to layer chromatography (benzene). A purple band and superimposed yellow band were removed from the plate (48 mg) and the mixture separated on a second plate to give, as a purple solid, cis-(or trans-)N-(1,2-*dibenzoylvinyl*)-N-*phenylcarbamonitrile* (8) (22 mg, 12%), m.p. 174·5—176° (from cyclohexane) (Found: *m/e* 352·1212. $C_{23}H_{16}N_2O_2$ requires *m/e* 352·1212), $\nu_{max.}$ (KBr) 2225 (C≡N), 1670, and 1640 (C=O) cm^{-1}, $\lambda_{max.}$ (MeOH) 266 (log ε 4·01) and 544 nm (2·47), τ ($CDCl_3$) 3·02 (1H, olefinic CH) and 2·06—2·70 (15H, m), *m/e* 352 (M^+), 247 (M^+ − PhCO), and 105 ($PhCO^+$).

(iv) The triazole (2c) was pyrolysed on a small scale (5 mg) using the modified pyrolysis apparatus such that the pyrolysate was collected on a sodium chloride disc at the centre of the condenser, which was cooled with liquid nitrogen. The condenser was rotated through 90°, and the i.r. spectrum of the pyrolysate was recorded: $\nu_{max.}$ 3200—2600 (NH), 2220 (C≡N), 1600, 1530, 1500, and 760 cm^{-1}.

(j) 4-(2,4,6-*Trimethylphenyl*)-1,2,4-*triazole* (2d).[29] A mixture of *NN*-dimethylformamide azine (2·85 g), 2,4,6-trimethylaniline (27·1 g) and toluene-*p*-sulphonic acid (0·12 g) was refluxed for 3 days. The *triazole* (0·4 g, 11%), isolated by column chromatography (chloroform–ethyl acetate, 9 : 1) followed by washing well with ethyl acetate, had m.p. 232—233° (needles from water) (Found: C, 70·8; H, 7·1; N, 22·1. $C_{11}H_{13}N_3$ requires C, 70·6; H, 7·0; N, 22·4%), $\nu_{max.}$ (KBr) 3130, 3095, and 1600 cm^{-1}, τ ($CDCl_3$) 8·04 (6H), 7·67 (3H), 3·01 (2H, aryl H), and 1·87 (2H, triazole H), *m/e* 187 (M^+) and 159 (M^+ − 28).

The triazole (2d) (49·5 mg) was vaporised at 140—160° and 0·01 mmHg and passed through a packed quartz tube

[22] M. R. Atkinson and J. B. Polya, *J. Amer. Chem. Soc.*, 1953, **75**, 1471.
[23] Q. E. Thompson, *J. Amer. Chem. Soc.*, 1951, **73**, 5914.
[24] A. Spassov, E. Golovinsky, and G. Demirov, *Chem. Ber.*, 1966, **99**, 3734.
[25] O. Widman, *Ber.*, 1893, **26**, 2612.
[26] E. Hoggarth, *J. Chem. Soc.*, 1949, 1163.
[27] C. Ainsworth, N. R. Easton, M. Livezey, D. E. Morrison, and W. R. Gibson, *J. Medicin. Chem.*, 1962, **5**, 383.
[28] F. Berger, *Monatsh.*, 1884, **5**, 217; T. W. Evans and W. M. Dehn, *J. Amer. Chem. Soc.*, 1930, **52**, 3647.
[29] *Cf.* R. K. Bartlett and I. R. Humphrey, *J. Chem. Soc.* (*C*), 1967, 1664.

at 660°. The pyrolysate was a yellow gum (35·5 mg) which darkened on exposure to air and solvent. Layer chromatography (chloroform–ethyl acetate, 9 : 1) gave (2-amino-3,5-dimethylphenyl)acetonitrile (11) (9 mg, 21%), m.p. and mixed m.p. 160—162° (needles from petroleum–ethyl acetate), identical with the compound synthesised independently as described below.

(*2-Amino-3,5-dimethylphenyl*)*acetonitrile* (11).—(*a*) 3,5-Dimethylphenylacetonitrile [30] was synthesised (80%) from 1-bromomethyl-3,5-dimethylbenzene [31] by refluxing with aqueous ethanolic potassium cyanide for 1 h.

(*b*) To a solution of 3,5-dimethylphenylacetonitrile (4·9 g) in acetic anhydride (5·1 ml) and dichloromethane (17 ml) at 0°, a solution of fuming nitric acid (1·7 ml) in dichloromethane (33 ml) was added dropwise with stirring; stirring was continued at room temperature for 24 h. Column chromatography (silica; petrol–ether, 1 : 1) gave, as the first component, (*3,5-dimethyl-2-nitrophenyl*)*acetonitrile* (2·0 g), 31%), m.p. 49° (from petroleum) (Found: C, 63·3; H, 5·2; N, 14·8. $C_{10}H_{10}N_2O_2$ requires C, 63·2; H, 5·3; N, 14·7%); $\nu_{max.}$ (Nujol) 2250 (C≡N), 1520, and 1350 (−NO_2) cm^{-1}; τ (CCl_4) 7·72 (3H, s), 7·62 (3H, s), 6·36 (2H, s, CH_2CN), 2·95 (1H, s, aryl H), and 2·76 (1H, s, aryl H).

(c) A solution of the nitro-nitrile (0·62 g) in methanol (5 ml) and concentrated aqueous ammonia (2·5 ml) was treated slowly with sodium dithionite (3·75 g) in water (15 ml) with stirring. Crystals separated from the hot solution. After 24 h at room temperature, filtration gave the *amino-nitrile* (11) (0·2 g, 38%), m.p. 160·5—162° (needles from ethyl acetate–petroleum) (Found: C, 74·7; H, 7·7; N, 17·5. $C_{10}H_{12}N_2$ requires C, 75·0; H, 7·6; N, 17·5%), $\nu_{max.}$ 3390, 3340, 3250, 2250, and 1650 cm^{-1}, τ (CD_3CN) 3·17 (2H, s, aryl H), 6·18br (2H, NH_2), 6·44 (2H, s, CH_2·CN), 7·83 (3H, s), and 7·90 (3H, s), *m/e* 160 (M^+), 159 ($M^+ - 1$), and 145 ($M^+ - 15$).

2-*Amino-5,7-dimethyl*-3H-*indole* (10).—This was prepared as described by Kebrle and Hoffmann [16] for the parent aminoindole. (2-Amino-3,5-dimethylphenyl)acetonitrile (11) (0·38 g) was added to a solution of sodium ethoxide, prepared from sodium (0·25 g) and deoxygenated ethanol (10 ml), and refluxed for 2 h under nitrogen, after which no starting aniline (11) could be detected by t.l.c. (chloroform–ethyl acetate, 9 : 1). The solution was evaporated and the residue triturated with deoxygenated water (20 ml) under nitrogen. The crystalline residue was filtered under nitrogen and dried *in vacuo* to give 2-amino-5,7-dimethyl-3*H*-indole (10) (0·28 g, 74%), m.p. >130° (decomp. without melting), $\nu_{max.}$ (Nujol) 3450, 3300 (NH), 1650 (C=N), and 1560 cm^{-1}, τ (deoxygenated $CDCl_3$) 7·20 (3H, s), 7·14 (3H, s), 5·97 (2H, s), 4·00br (2H, NH), and 2·62 (2H, d, aryl H).

The indole (0·14 g) was dissolved in deoxygenated ether–methanol (20 : 1) and hydrogen chloride was bubbled through the solution to precipitate the indole hydrochloride (0·12 g), $\nu_{max.}$ (Nujol) 3350—3100 ($^+$NH), 1680 (C=N$^+$), and 1615 cm^{-1}.

The indole hydrochloride (0·12 g) was dissolved in warm water (3 ml); the solution was filtered (charcoal) and the filtrate treated dropwise with a slight excess of saturated aqueous picric acid solution to give a yellow precipitate of 2-*amino-5,7-dimethyl*-3H-*indole picrate* (0·13 g), m.p. >205° (decomp. without melting) (from ethanol) (Found: C, 49·2; H, 3·9; N, 18·2. $C_{16}H_{15}N_5O_7$ requires C, 49·4; H, 3·9; N, 18·0%), *m/e* 229 ($M^+ - 160$), 160 [$M^+ - C_6H_2(NO_2)_3OH$], 159, and 145.

2-(N-*Cyanoanilino*)-N-*phenylsuccinimide* (7).—(*a*) The lithium salt of phenylcyanamide was prepared by adding butyl-lithium (5 mmol) in hexane to a solution of 1-phenyltetrazole (12) [32] (730 mg, 5 mmol) in tetrahydrofuran (5 ml) at 0° and stirring for 1 h before filtering off the product (578 mg, 98%); $\nu_{max.}$ 2100 (C≡N), 1600, and 1500 cm^{-1}.

(*b*) This lithium salt (124 mg) was added in portions to a solution of *N*-phenylmaleimide (519 mg) in ethyl acetate (15 ml) at room temperature. After 20 h the product mixture was separated by layer chromatography (petroleum–ether, 7 : 3) to give the cyanamide (7) (59 mg, 20%), m.p. and mixed m.p. 133—135°.

3-(N-*Ethoxycarbonylanilino*)-N-*phenylsuccinimide*.— A mixture of 3-anilino-*N*-phenylsuccinimide [33] (2·66 g) and triethylamine (1·4 ml) in tetrahydrofuran (10 ml) was treated dropwise with ethyl chloroformate (1·0 ml) at 0°. Excess of ethyl chloroformate (20 ml) was then added and the solution was heated under reflux (2 h). Evaporation gave an oil which was dissolved in chloroform, washed with water, and dried ($MgSO_4$). Evaporation gave an oil which was dissolved in hot ethanol and cooled to give crystals of the *succinimide* (2·65 g, 79%), m.p. 160—161° (needles from ethanol) (Found: C, 67·4; H, 5·3; N, 8·1. $C_{19}H_{18}N_2O_4$ requires C, 67·4; H, 5·4; N, 8·3%), $\nu_{max.}$ (KBr) 1728, 1722. and 1710 cm^{-1}, τ ($CDCl_3$) 2·60—2·75 (10H, m, aryl H), 5·33—5·49 (1H, t), 5·78—6·00 (2H, q, O·CH_2·CH_3), 6·80—6·88 (2H, d), and 8·76—8·90 (3H, t, O·CH_2·CH_3), *m/e* 338 (M^+), 266, and 265 ($M^+ - CO_2Et$).

2,5-*Dioxo*-1,3-*diphenylimidazolidine*-4-*acetamide* (15).—The above succinimide (2·0 g) in refluxing ethanol (20 ml) was treated with concentrated aqueous ammonia (40 ml) at such a rate as to maintain a refluxing homogeneous solution, then refluxed for 48 h. Evaporation gave a solid residue which was extracted with hot ethanol, filtered, and allowed to cool to give crystals of the *amide* (0·5 g), m.p. 211—213° (prisms from ethanol) (Found: C, 65·6; H, 4·8; N, 13·8. $C_{17}H_{15}N_3O_3$ requires C, 66·0; H, 4·9; N, 13·6%), $\nu_{max.}$ (Nujol) 3395, 3180, 1750, 1700, 1680, and 1635 cm^{-1}, *m/e* 309 (M^+), 264 ($M^+ - 45$); *m** (309 ⟶ 264) 225·5. This amide was converted into the corresponding nitrile as follows. The amide (15) (20 mg) was dissolved in warm pyridine (0·5 ml) containing toluene-*p*-sulphonyl chloride (30 mg) and heated (steam) for 16 h. The major product (10 mg) was isolated by layer chromatography (chloroform–ethyl acetate, 9 : 1) as a viscous pale yellow oil which crystallised to give the nitrile, m.p. 144—148°, $\nu_{max.}$ ($CHCl_3$) 2250w, 1770, and 1710s cm^{-1}, τ ($CDCl_3$) 2·53—2·73 (10H, m, aryl H), 5·18—5·30 (1H, m), and 6·98—7·13 (2H, m), *m/e* 291 (M^+) and 251 ($M^+ - 40$); *m** (291 ⟶ 251) 216·5.

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[30] A. Schonne, E. Braye, and A. Bruylants, *Bull. Soc. chim. belges*, 1953, **62**, 155.
[31] R. G. Kadesch, *J. Amer. Chem. Soc.*, 1944, **66**, 1207.
[32] J. C. Kauer and W. A. Sheppard, *J. Org. Chem.*, 1967, **32**, 3580.
[33] W. H. Warren and M. R. Grose, *J. Amer. Chem. Soc.*, 1912, **34**, 1600.