

Keten. Part XII.¹ Addition Reactions of Ketens with Azo-compounds

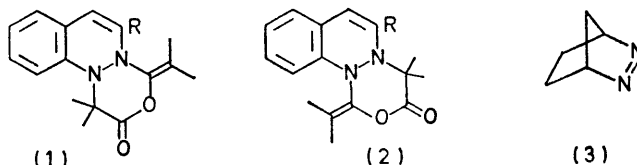
By Gerald Brooks, Munawer A. Shah, and Giles A. Taylor,* Department of Chemistry, University of Sheffield, Sheffield S3 7HF

Dimethylketen and diphenylketen form 2:1 cycloadducts with 2,3-diazabicyclo[2.2.1]hept-2-ene (3), the former adduct being isolated only as its hydrolysis product. The diphenylketen adduct is shown to have the structure (5b). Compound (3) failed to react with dimethylketen in methanolic solution but (*Z*)-azobenzene reacted in methanol with both dimethylketen and keten to give only diazetidinones.

FOLLOWING Staudinger's original report ^{2a} of a reaction between diphenylketen and (*E*)-³-azobenzene, other studies of the reaction of ketens with azo-compounds have been described.^{4,5} Usually diazetidinones are formed, and in some cases an ene reaction competes with cycloaddition^{5,6} where compounds of suitable stereochemistry are involved. Substituents on the azo-

group participate in cycloaddition only in the case of diacyl azo-compounds.⁶⁻⁸

The formation of 1:2 cycloadducts between azo-compounds and a keten was observed in reactions of



¹ Part XI, D. P. Stokes and G. A. Taylor, *J. Chem. Soc. (C)*, 1971, 2334.

² H. Staudinger, 'Die Ketene,' Ferdinand Enke, Stuttgart, 1912, (a) p. 91; (b) p. 83.

³ J. E. Blackwood, C. L. Gladys, K. L. Loening, A. E. Petrarca, and J. E. Rush, *J. Amer. Chem. Soc.*, 1968, **90**, 509.

⁴ C. K. Ingold and S. D. Weaver, *J. Chem. Soc.*, 1925, **127**, 378; A. H. Cook and D. G. Jones, *ibid.*, 1941, 184; L. Horner, E. Spietschka, and A. Gross, *Annalen*, 1951, **573**, 17; G. O. Schenck and N. Engelhard, *Angew. Chem.*, 1956, **68**, 71; M. Colonna and A. Risaliti, *Gazzetta*, 1960, **90**, 1165; C. W. Bird, *J. Chem. Soc.*, 1963, 674; 1964, 5284; W. Ried and R. Dietrich, *Annalen*, 1963, **666**, 113; W. Ried and K. Wagner, *ibid.*, 1965, **681**, 45; W. Fischer and E. Fahr, *Tetrahedron Letters*, 1966, 5245; J. Hall and R. Kellogg, *J. Org. Chem.*, 1966, **31**, 1079; W. Ried and E. Kahr, *Chem. Ber.*, 1970, **103**, 331.

cinnolines with dimethylketen,⁹ to give adducts of structure (1) and (2). At that time there was little information about the reaction of alkyl azo-compounds

⁵ R. C. Kerber and T. J. Ryan, *Tetrahedron Letters*, 1970, 703.

⁶ L. Horner and E. Spietschka, *Chem. Ber.*, 1956, **89**, 2765.

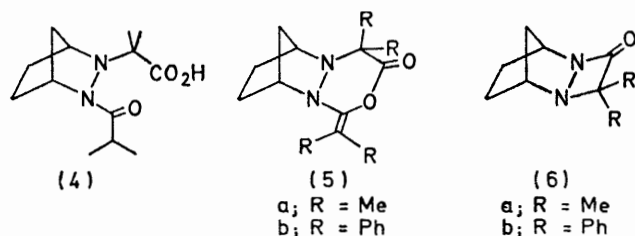
⁷ E. Fahr, K. H. Kiel, F. Scheckenbach, and A. Jung, *Angew. Chem. Internat. Edn.*, 1964, **3**, 646.

⁸ J. Markert and E. Fahr, *Tetrahedron Letters*, 1970, 769.

⁹ M. A. Shah and G. A. Taylor, *J. Chem. Soc. (C)*, 1970, 1642.

with ketens. We therefore examined the reaction of 2,3-diazabicyclo[2.2.1]hept-2-ene (3) with ketens, this azo-compound being chosen since (*Z*)-azo-compounds are known to be more active in the keten cycloaddition than their (*E*)-stereoisomers.⁴ Recently (*E*)-alkyl azo-compounds have been shown⁵ to undergo ene reactions with ketens.

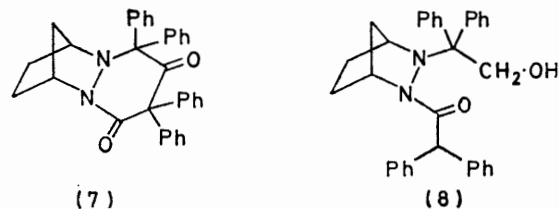
Reaction of dimethylketen with the diazabicycloheptene (3) in ether gave an oily product from which a crystalline solid, C₁₃H₂₂N₂O₃, was deposited after prolonged storage. This was assigned spectroscopically the structure (4), infrared absorptions at 1601 and 1736 cm⁻¹ and a broad absorption at 2598 cm⁻¹ indicat-



ing amide and carboxylic acid groups. The ¹H n.m.r. spectrum showed the signals for the isopropyl and *gem*-dimethyl groups as a broad absorption between τ 8 and 8.6, and two broadened, one-proton singlets at τ 5.44 and 6.08 corresponding to the diazabicycloheptane system. We believe that compound (4) arises by hydrolysis of an adduct of (3) with dimethylketen, and in view of the evident ease of hydrolysis we propose compound (5a) as the intermediate adduct. Attempts to isolate this or any other adduct were unsuccessful. However, the mother liquors from the reaction showed i.r. absorption at 1800 cm⁻¹, as did a further small amount of crude (4) deposited later. The ¹H n.m.r. spectrum of this crude material showed weak signals at τ 5.55 and 6.00 associated with the bridgehead signals of (4), which, in conjunction with the i.r. absorption could indicate the presence of (5a) or (6a).

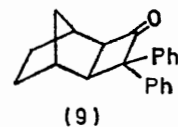
Much of the previous work on keten cycloadditions to azo-compounds has involved diphenylketen. The reaction of diphenylketen with (3) in benzene gave a 1:2 adduct, ν_{\max} 1752 and 1638 cm⁻¹. The ¹H n.m.r. spectrum was consistent with the preservation of the diazabicycloheptane skeleton, with bridgehead proton signals at τ 6.37 and 6.61 and five of the remaining aliphatic protons absorbing in an unresolved region from τ 8.0 to 8.9. One of the protons, presumably belonging to the bridging methylene group, showed as a high-field doublet at τ 9.01, evidently owing to screening by a phenyl group. On the basis of these data we considered two structures (5b) and (7). Assignment of structure (5b) was ultimately based on ozonolysis

of the adduct, which gave benzophenone, coupled with reduction of the adduct using lithium aluminium hydride to a compound identified spectroscopically as (8).



In this amido-alcohol, the magnetic shielding of the bridging methylene group is so great that its ¹H n.m.r. absorptions appear at τ 9.41 and 10.19. Treatment of the diphenylketen adduct with water, aniline, ammonia, and methanol gave intractable gummy products. The i.r. spectrum of the mother liquors from the preparation of the adduct (5b) showed no sign of formation of an adduct (6b). The diphenylketen- and biphenylene-keten adducts of heteroaromatic bases have been reported^{2b,10} to dissociate into the keten and heterocycle in solution. Dissociation was not detected for the adduct (5b), the i.r. spectrum of a carbon tetrachloride solution having no absorption at 2100 cm⁻¹.

Previous attempts by Kerber and Ryan to prepare 2:1 adducts of diphenylketen with a number of open-chain (*Z*)-azo-compounds were unsuccessful, the diazetidinones being the sole products. It appears that the formation of these adducts with (3) is a result of the strain in the diazetidinone (6), since (*Z*)-dibenzyl-di-imide readily forms a diazetidinone.⁶ Although an adduct (9) is reported¹¹ from diphenylketen and norbornene, these reagents combine extremely slowly and in this case an ionic reaction pathway seems



unlikely. We presume that the formation of (5) occurs by the polar mechanism shown to occur in the keten-imine reaction,¹² which we have previously assumed to be responsible for the addition reactions of dimethylketen with heteroaromatic systems.¹³ The failure of these heteroaromatic imines to form azetidiones may also be simply due to the strain involved in fusing the six- and four-membered rings.

Ketens have been shown¹⁴ to react with imines in methanol to form β -amino-esters. We treated (3) with dimethylketen in methanol but observed no reaction. (*Z*)-Azobenzene reacted in methanolic solution with both dimethylketen and keten to give the diazetidinones (10a and b) with no trace of α -hydrazino-ester formation. (*E*)-Azobenzene did not react with either

¹⁰ H. Staudinger, *Ber.*, 1906, **39**, 3062; *Annalen*, 1907, **356**, 51.

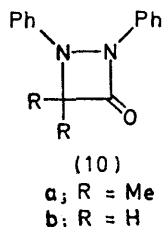
¹¹ R. Huisgen and L. A. Feiler, *Chem. Ber.*, 1969, **102**, 3391.

¹² R. Huisgen, B. A. Davis, and M. Morikawa, *Angew. Chem. Internat. Edn.*, 1968, **7**, 826.

¹³ R. N. Pratt, G. A. Taylor, and S. A. Procter, *J. Chem. Soc. (C)*, 1967, 1569.

¹⁴ S. A. Procter, P. D. English, and G. A. Taylor, *Chem. Comm.*, 1969, 936.

of the ketens in methanolic solution. The formation of the diazetidinone in these circumstances is good evidence for a concerted process⁵ in which the large



difference in reactivity between (*E*)- and (*Z*)-azobenzene is attributable to the steric interactions described by Isaacs.¹⁵

EXPERIMENTAL

N.m.r. spectra were measured with a Varian HA 100 spectrometer, i.r. spectra with a Unicam SP 100 or Perkin-Elmer PE 180 spectrometer, and u.v. spectra with a Cary 14 spectrometer.

Dimethylketen was prepared by pyrolysis of tetramethylcyclobutane-1,3-dione in a modified version of Johnson and Witzel's apparatus¹⁶ and used without further purification.

Diphenylketen.—Benzoylphenyldiazomethane¹⁷ was recrystallised from benzene-light petroleum keeping the temperature below 40°. A solution of the diazo-ketone (5 g) in benzene (25 ml) was boiled under reflux for 10–15 min. The cooled solution of diphenylketen was used for subsequent reactions. Addition of an excess of aniline followed by normal work-up gave crude diphenylacetanilide (6 g, 93%).

2-(3-Isobutyryl-2,3-diazabicyclo[2.2.1]heptan-2-yl)-2-methylpropionic Acid (4).—2,3-Diazabicyclo[2.2.1]hept-2-ene¹⁸ (2 g) dissolved in dry ether (120 ml) was treated with an excess of dimethylketen (from 10 g dimer) and the mixture was set aside overnight. Evaporation of the ether left an oil which was shaken with light petroleum (10 ml) and set aside for 10 weeks. The crystalline deposit of the *amido-acid* was then collected (1.5 g, 28%), m.p. 128° (from benzene-light petroleum) (Found: C, 61.4; H, 8.5; N, 10.9. C₁₃H₂₂N₂O₃ requires C, 61.4; H, 8.6; N, 11.0%), ν_{\max} (paste) 2722 and 2598, ν_{\max} (KBr) 1601 and 1736 cm⁻¹, τ (CDCl₃) 5.44br (1H), 6.08br (1H), 7.20 (1H, sept, *J* 7 Hz), 8.0–8.6 (6H, m), 8.50 (3H, s), 8.76 (3H, d, *J* 7 Hz), 8.81 (3H, s), and 8.83 (3H, d, *J* 7 Hz).

Attempted reaction of the azo-compound (3) with dimethylketen in methanol gave no new compound, starting material being recovered unchanged.

3-Diphenylmethylene-6,6-diphenyl-4-oxa-2,7-diazatricyclo-[6.2.1.0^{2,7}]undecan-5-one (5b).—The azo-compound (3) (2 g) in benzene (7 ml) was added to a solution of diphenylketen

(from 9.2 g diazo-ketone) in benzene (45 ml) and the mixture was set aside for 2 days. Evaporation of the benzene left a golden oil from which the *adduct* (5b) crystallised (28%), m.p. 184° (decomp.) (from benzene-light petroleum) (Found: C, 81.5; H, 6.0; N, 5.8. C₃₃H₂₈N₂O₂ requires C, 81.8; H, 5.8; N, 5.8%); ν_{\max} (paste) 1752 and 1638, ν_{\max} (CCl₄) 1768 and 1634 cm⁻¹, τ (CDCl₃) 2.4–2.6 (4H, m), 2.6–3.3 (16H, m), 6.37br (1H), 6.61br (1H), 8.0–8.9 (5, m), and 9.01 (1H, d, *J* 11 Hz).

In a repeated preparation, the reaction mixture was diluted with an equal volume of light petroleum (b.p. 40–60°) and seeded; compound (5b) crystallised out slowly (7.1 g, 70%), m.p. 180–182° (decomp.).

Ozonolysis of the Diphenylketen Adduct (5b).—A solution of the diphenylketen adduct (5b) (1 g) in carbon tetrachloride (100 ml) was cooled to –22° and an excess of ozone was bubbled in. Air was then bubbled through the mixture to remove residual ozone, and the solution was added to 2,4-dinitrophenylhydrazine (2 g) dissolved in methanol (200 ml) and sulphuric acid (4 ml). The mixture was boiled under reflux for 30 min, and then evaporated to dryness. Extraction of the residue with hot chloroform and evaporation of the solvent left a residue (1.6 g) which on recrystallisation from ethanol gave benzophenone 2,4-dinitrophenylhydrazone (0.2 g), identified by mixed m.p.

Reduction of the Diphenylketen Adduct (5b).—The adduct (5b) (0.5 g) was reduced by lithium aluminium hydride (0.5 g.) in boiling ether (50 ml). Work-up gave a clear gum (0.6 g) which partly crystallised on shaking with methanol to give *diphenylmethyl 3-(2-hydroxy-1,1-diphenylethyl)-2,3-diazabicyclo[2.2.1]heptan-2-yl ketone* (8) (0.3 g, 60%), m.p. 158–162° (decomp.) (from methanol) (Found: C, 80.9; H, 6.8; N, 5.6. C₃₃H₃₂N₂O₂ requires C, 81.2; H, 6.6; N, 5.7%); ν_{\max} (paste) 3345 and 1645 cm⁻¹, τ (CDCl₃) 2.4–3.3 (20H, m), 4.77 (1H, s), 4.77 (1H, dd, *J* 3 and 12 Hz, (OH), 5.63br (1H, s), 5.89 (1H, dd, *J* 3 and 12 Hz), 6.23br (1H, s), 6.76 (1H, t, *J* 12 Hz), 7.9–8.8 (4H, m), 9.41 (1H, d, *J* 10 Hz), and 10.19 (1H, dd, *J* 2 and 10 Hz).

4,4-Dimethyl-1,2-diphenyldiazetid-3-one (10a).—Treatment of (*Z*)-azobenzene in ether with an excess of dimethylketen gave the *diazetidone* (10a) as needles, m.p. 74° (from aqueous methanol) (Found: C, 75.6; H, 6.5; N, 11.2. C₁₆H₁₆N₂O requires C, 76.2; H, 6.4; N, 11.1%), λ_{\max} (EtOH) 245 and 263 nm (log ϵ 4.01 and 4.04), ν_{\max} (KBr) 1785 cm⁻¹, τ (CDCl₃) 2.6–3.2 (10H, m) and 8.65br (6H).

Reaction of (Z)-Azobenzene with Ketens in Methanol.—Solutions of (*Z*)-azobenzene in methanol were treated with keten or dimethylketen. Work-up gave only the azetidones (10a and b) (40 and 68%, respectively) identified by mixed m.p. Evaporation of the mother liquors and i.r. examination of the residues showed no absorption at 1720 cm⁻¹ due to α -hydrazino-ester.

[2/2888 Received, 28th December, 1972]

¹⁵ N. S. Isaacs and P. F. Stanbury, *Chem. Comm.*, 1970, 1061.

¹⁶ J. R. Johnson and J. M. Witzel, *Org. Reactions*, 1946, **3**, 136.

¹⁷ C. D. Nenitzescu and E. Solomonica, *Org. Synth.*, Coll. Vol. II, 1943, 496.

¹⁸ S. G. Cohen, R. Zand, and C. Steel, *J. Amer. Chem. Soc.*, 1961, **83**, 2895.