

The Influence of Catalysts on the Rearrangement of Acyldiazoethanes

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Contrary to previous findings, decomposition of α -diazo-*p*-nitropropiophenone by silver oxide is slow at room temperature, and, rather than providing *p*-nitrophenyl vinyl ketone, yields 3-methyl-3,5-bis-*p*-nitrobenzoyl- Δ^2 -pyrazoline (VI). At higher temperatures, silver oxide-assisted Wolff rearrangement sets in. In contrast, decomposition by silver nitrate is much more rapid and leads to *p*-nitrophenyl vinyl ketone together with smaller amounts of the pyrazoline (VI) and 1-methyl-1,2-bis-*p*-nitrobenzoylcyclopropane (VII). When molar rather than catalytic quantities of silver nitrate are used, decomposition is virtually instantaneous and the unsaturated ketone is obtained in high yield. Other α -diazopropiophenones behave similarly. The fact that similar decompositions may be effected with silver trifluoroacetate, many metallic nitrates, and aniline hydrochloride, but not by silver benzoate or trimethylamine hydrochloride, suggests that the reaction is one of acid catalysis rather than specific silver catalysis. The results obtained by decompositions effected by nitric, perchloric, and formic acids support this view.

SILVER oxide and silver nitrate¹ appear to be equally effective as catalysts for the rearrangement of acyldiazo-methanes (I; R' = H). In contrast, the rearrangement of acyldiazoethanes (I; R' = Me) is usually brought about by pyrolytic procedures^{2,3} since the silver oxide method leads to complex mixtures containing little rearrangement product. In these laboratories it was shown⁴ that decomposition by silver nitrate in ethanol containing aniline, rather than providing Wolff rearrangement products, gave β -anilino-ketones (V). $\alpha\beta$ -Unsaturated ketones (IV), which were assumed to

be intermediates, were, however, not isolated. It was therefore unexpected when Franzen⁵ reported that acyldiazoethanes (I; R' = Me) when shaken with silver oxide in aqueous dioxan at room temperature gave $\alpha\beta$ -unsaturated ketones (IV) in high yield. We now report that all our attempts to reproduce his results have been unsuccessful. In particular, the decomposition of α -diazo-*p*-nitropropiophenone (I; R = *p*-NO₂C₆H₄, R' = Me) which, according to Franzen, readily provides *p*-nitrophenyl vinyl ketone (IV; R =

³ A. L. Wilds and A. L. Meader, *J. Org. Chem.*, 1948, **13**, 763.

⁴ G. Baddeley, G. Holt, and J. Kenner, *Nature*, 1949, **163**, 766.

⁵ V. Franzen, *Annalen*, 1957, **602**, 199.

¹ See 'Org. Reactions,' vol. I, Wiley, New York, 1942, p. 38, for compilation of references.

² B. Eistert, *Angew. Chem.*, 1941, **54**, 124.

(CC), and 1000 cm^{-1} , τ (CDCl_3) 1.75 (8H, m, aromatic), 7.97 and 8.30 (double AB quartets, two non-identical protons, J 4.5 Hz, CH_2 each coupled [J 7.5 and 6.0 Hz] with one proton [quartet at τ 6.43] on an adjacent asymmetric centre, CH), and 8.56 (3H, s, Me). When the cyclopropane derivative had been removed, elution with toluene-chloroform (1:1) provided the pyrazoline (VI) (0.62 g, 66.5%), identical (mixed m.p., i.r., and n.m.r. spectra) with that already described.

Wolff Rearrangement of Diazoethyl Ketones.— α -Diazo-*p*-nitropropiofenone (5 g), aniline (3 g), and silver oxide (0.2 g) were stirred at 70° in ethanol (60 ml) until nitrogen evolution was complete (6.5 h). The hot solution was filtered and the solvent removed to leave a sticky solid which was shaken with chloroform and dilute hydrochloric acid. The aniline-free organic layer was washed with water, dried, and concentrated; the crude product crystallised from benzene to provide 2-(*p*-nitrophenyl)propionanilide (4 g, 62%), m.p. $158\text{--}159^\circ$ (lit.,³ 159°). A similar result was obtained when the silver oxide was omitted but the reaction time was then 8.5 h. When dioxan was used as solvent the corresponding reaction times were 14 and 20 h. Subsequent experiments were carried out at three-fold dilution, under which conditions 2-diazoheptan-3-one gave 2-methylvalerianilide (64%), m.p. 96° [from light petroleum (b.p. $60\text{--}80^\circ$)] (lit.,⁸ $94.5\text{--}95.0^\circ$). *p*-Chloro- α -diazopropiofenone similarly yielded 2-(*p*-chlorophenyl)propionanilide (35%), m.p. $152\text{--}153^\circ$ (lit.,³ $154.5\text{--}155.0^\circ$).

β -Anilino-ketones.—(a) To α -diazo-*p*-nitropropiofenone (5 g) and aniline (3 g) in ethanol (60 ml) at 70° was added 10% aqueous silver nitrate (5 ml). When nitrogen evolution was complete (15 min) the solution was filtered hot and the filtrate on cooling deposited orange needles of β -anilino-*p*-nitropropiofenone (3.7 g, 55%) (Found: C, 67.0; H, 5.3; N, 10.2. Calc. for $\text{C}_{15}\text{H}_{14}\text{N}_2\text{O}_3$: C, 66.7; H, 5.2; N, 10.4%), m.p. $131\text{--}132^\circ$ (from methanol) (lit.,⁹ $131\text{--}132^\circ$).

When the experiment was repeated except that the aniline was not added until the evolution of nitrogen was complete (5 min) a similar yield of the β -anilino-ketone was obtained. When the aniline present in experiment (a) was increased to 25 g the yield of β -anilino-ketone was 54% but it was necessary to add a second portion of silver nitrate solution to effect complete decomposition of the diazo-ketone (1.5 h). In a dilution experiment the diazo-ketone (5 g) in ethanol (400 ml) containing aniline (15 g) was decomposed by addition of aqueous 10% silver nitrate (20 ml). The reaction took ca. 45 min and β -anilino-*p*-nitropropiofenone (5.2 g, 80%) was isolated.

(b) **General procedure.** On the basis of the experience gained in (a) the following general procedure was developed. To a stirred solution of the diazo-ketone (10 mmol) and aniline (20 mmol) in ethanol (75 ml) at 70° , aqueous 10% silver nitrate (1.5 ml, 1.0 mmol) was added. When nitrogen evolution was complete (10–30 min) the hot solution was filtered and the β -anilino-ketone which precipitated on cooling was separated. By this procedure the following β -anilino-ketones were prepared (yields in the Table). R in $\text{RCO}\cdot\text{CH}_2\cdot\text{CH}_2\cdot\text{NHP}$: Ph, m.p. and mixed m.p.¹⁰ 116° (from petroleum); *p*- $\text{MeO}\cdot\text{C}_6\text{H}_4$, m.p. and mixed m.p.¹⁰ 129° (from ethanol); *m*- $\text{NO}_2\cdot\text{C}_6\text{H}_4$, m.p. $124\text{--}125^\circ$ (from petroleum) (lit.,⁹ $122\text{--}123^\circ$); *p*- ClC_6H_4 , m.p.

$123\text{--}124^\circ$ (from ethanol) (lit.,¹¹ $122\text{--}123^\circ$); *p*- $\text{PhSO}_2\cdot\text{C}_6\text{H}_4$ (β -anilino-*p*-phenylsulphonylpropiofenone) (Found: C, 69.0; H, 5.2; N, 4.0. $\text{C}_{21}\text{H}_{19}\text{NO}_3\text{S}$ requires C, 69.0; H, 5.2; N, 3.8%), m.p. $181\text{--}182^\circ$ (from benzene).

Catalysed Decomposition of α -Diazo-*p*-nitropropiofenone in the Absence of Aniline.—(a) To α -diazo-*p*-nitropropiofenone (5 g) in ethanol (60 ml) at 70° was added aqueous 10% silver nitrate (5 ml). When nitrogen evolution was complete (5 min) the solution was filtered hot and the filtrate on cooling deposited crude *p*-nitrophenyl vinyl ketone (1.34 g), m.p. $72\text{--}80^\circ$ [$85\text{--}87^\circ$ from light petroleum (b.p. $60\text{--}80^\circ$)]. The filtrate from which this material had separated was concentrated to provide a sticky solid (3.46 g), which was chromatographed on silica gel (200 g; 47×2.7 cm). Elution with toluene provided crude *p*-nitrophenyl vinyl ketone (0.79 g), m.p. $73\text{--}81^\circ$, followed by the cyclopropane derivative (VII) (0.54 g, 12.4%), m.p. $143\text{--}146^\circ$. Subsequent elution with toluene-chloroform (1:1) gave two fractions, neither of which was crystalline, but t.l.c., i.r. and n.m.r. spectroscopy indicated that the major component of the more mobile one (0.09 g, 1.8%) was α -diazo-*p*-nitropropiofenone, and that of the less mobile one (0.09 g, 1.9%) was the pyrazoline (VI). The total yield (2.13 g) of the vinyl ketone was 49%.

(b) To the diazo-ketone (2.05 g) in dioxan (20 ml) at $21\text{--}22^\circ$ was added silver nitrate (0.16 g) in water (4 ml). The mixture was stirred until nitrogen evolution (179 ml) was complete (6 h). After filtration to remove silver, water (40 ml) was added and the oily mixture on cooling overnight at $0\text{--}5^\circ$ deposited a yellow solid (1.76 g), m.p. $68\text{--}130^\circ$ (decomp.). The dried solid was extracted (Soxhlet) with light petroleum (b.p. $40\text{--}60^\circ$) to remove the *p*-nitrophenyl vinyl ketone (0.61 g, 35%), m.p. $73\text{--}83^\circ$. The petroleum-insoluble residue (1.10 g, 58%), m.p. $132\text{--}140^\circ$ (decomp.) on crystallisation from acetonitrile (Norit) provided the pyrazoline (VI), m.p. and mixed m.p. $164\text{--}165^\circ$ (decomp.).

Vinyl Ketones.—General procedure. To a stirred solution of the diazo-ketone (0.1 mol) in ethanol (250 ml) at 70° was added silver nitrate (21.3 g, 0.125 mol) in water (35 ml) as rapidly as the vigorous evolution of nitrogen permitted (2–5 min). The hot solution was filtered, cooled rapidly, and diluted with water (700 ml) and the unsaturated ketone was separated. In those instances where no solid separated, the solution was extracted with chloroform (3×100 ml) and the $\alpha\beta$ -unsaturated ketone was isolated by distillation of the residue obtained by concentrating the dried chloroform extract. (With *p*-methoxyphenyl vinyl ketone there was considerable resinification during the distillation.) The identity of the liquid $\alpha\beta$ -unsaturated ketones was confirmed by their i.r. spectra and by the m.p.s of the derivatives formed with aniline and with phenylhydrazine. By these procedures the following vinyl ketones (IV) were obtained: (1) phenyl, b.p. $64\text{--}72^\circ$ at 0.5 mmHg [β -anilino-ketone, m.p. 116° (from ethanol) (lit.,¹⁰ 116°); pyrazoline, m.p. $152\text{--}153^\circ$ (from ethanol) (lit.,¹² $153.5\text{--}154.0^\circ$)]; (2) 4-methoxyphenyl, b.p. $93\text{--}98^\circ$ at 0.5 mmHg [β -anilino-ketone, m.p. $130\text{--}132^\circ$ (from ethanol) (lit.,¹⁰ 130°); pyrazoline, m.p. $140\text{--}142^\circ$ (from ethanol) (lit.,¹² $139.5\text{--}141^\circ$)]; (3) 4-nitrophenyl, m.p. $88\text{--}90^\circ$ [from light petroleum (b.p. $60\text{--}80^\circ$)] (lit.,⁵ 91°); (4) 3-nitrophenyl,

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⁹ F. Nerdel and G. Kresze, *Chem. Ber.*, 1952, **85**, 168.

¹⁰ J. Kenner and F. S. Statham, *J. Chem. Soc.*, 1935, 299.

¹¹ D. Hodson, G. Holt, and D. K. Wall, *J. Chem. Soc. (C)*, 1970, 971.

¹² A. V. Dombrovskii and M. I. Shevchuk, *Zhur. obshchei Khim.*, 1964, **34**, 192 (*Chem. Abs.*, 1964, **60**, 10581g).

m.p. 106—107° [from light petroleum (b.p. 60—80°)] (lit.,¹³ 102—103°); (5) 4-phenylsulphonylphenyl vinyl ketone, m.p. 110—112° [from light petroleum (b.p. 60—80°)] (Found: C, 66.0; H, 4.6. C₁₅H₁₂O₃S requires C, 66.1; H, 4.4%), ν_{\max} 3100m, 1605s, 1325s, and 1160s cm⁻¹.

When, under the conditions described, the silver nitrate was replaced by copper nitrate, α -diazo-*p*-nitropropio-phenone (1.03 g) lost its diazo nitrogen almost instantly. Chromatography of the crude product on silica gel (80 g; 2 × 33 cm) (toluene as eluant) provided *p*-nitrophenyl vinyl ketone (36%), m.p. and mixed m.p. 81—84°. Nickel(II), zinc(II), lead(II), iron(III), and mercury(I) nitrates all brought about rapid decomposition of the diazo-ketone. The organic products of the reaction were not investigated in detail but t.l.c. showed that they all contained both $\alpha\beta$ -unsaturated ketone and pyrazoline. The use of an equivalent quantity of aniline hydrochloride in place of these metallic salts provided a complex mixture from which was isolated β -anilino-*p*-nitropropio-phenone (17%), m.p. and mixed m.p. 132—133°.

*Acid-catalysed Decompositions of α -Diazo-*p*-nitropropio-phenone.*—(a) *With nitric acid.* To the diazo-ketone (2.05 g) in pure dioxan (20 ml) and water (3 ml) at 21° was added 0.5M-nitric acid (2 ml). There was an initially brisk evolution of nitrogen which subsided after about 30 min. It was necessary to add two similar portions of nitric acid before the i.r. spectrum of the mixture indicated that decomposition was complete (2.25 h). Water (50 ml) was then added and the solution was neutralised with sodium hydrogen carbonate, then extracted with chloroform (3 × 50 ml). The water-washed chloroform extracts were dried (MgSO₄) and evaporated to provide a yellow oil which was chromatographed on silica gel (100 g; 37 × 2 cm). Elution with toluene gave a yellow oil (0.6 g, 25%), which t.l.c. showed to be a single substance, apparently α -methyl-*p*-nitrophenacyl nitrate, ν_{\max} 1708s (C=O), 1640s (O·NO₂, asym.), 1605m (aromatic C=C), 1525s (NO₂, asym.), and 1345s cm⁻¹ (NO₂, sym.), τ 1.6 (4H, ABq, aromatic), 3.7 (1H, q, CO·CHMe·ONO₂), and 8.3 (3H, d, Me). Subsequent elution with toluene-chloroform (1:1) provided a fraction (1.49 g, 78%), m.p. 143—148° (decomp.), which on crystallisation from acetonitrile proved to be identical [mixed m.p. 160—162° (decomp.), i.r. and n.m.r. spectra] with the pyrazoline (VI).

(b) *With perchloric acid.* To the diazo-ketone (2.05 g,

10 mmol) in dioxan (30 ml) and water (20 ml) at 21° was added 0.464M-perchloric acid (2.5 ml, 1.2 mmol). There was a steady evolution of nitrogen which was complete in 3 h, after which diazo-ketone was no longer present. The solution was neutralised with sodium hydrogen carbonate, diluted with water (50 ml), and extracted with chloroform (3 × 50 ml). The water-washed chloroform extracts were dried (MgSO₄) and evaporated to provide a yellow oil, which was chromatographed on silica gel (80 g; 2 × 48 cm). Elution with 1:1 toluene-light petroleum (b.p. 60—80°) gave a yellow solid (0.38 g, 21%), m.p. 75—81°, which after recrystallisation from light petroleum (b.p. 60—80°) proved to be identical (mixed m.p. and i.r. spectrum) with *p*-nitrophenyl vinyl ketone. Subsequent elution with toluene-chloroform (1:1) gave an orange-coloured solid (1.62 g, 84%), m.p. 136—148° (decomp.), which after recrystallisation from acetonitrile (Norit) proved to be identical (mixed m.p. and i.r. spectrum) with the pyrazoline (VI).

(c) *With aqueous formic acid.* When the diazo-ketone (2.05 g) was added to aqueous 70% formic acid (50 ml) at 21—22°, nitrogen evolution was complete in 2 min. Dilution of the mixture with water (180 ml) and cooling to 5° produced a solid (1.33 g), m.p. 69—82°. A further crop (0.83 g) of this material was obtained from the aqueous solution by extraction with chloroform. The combined material was chromatographed on silica gel (80 g; 2 × 33 cm). Elution with toluene-light petroleum (b.p. 60—80°) gave a yellow solid (1.1 g, 62%), m.p. 79—85°, which, after crystallisation from light petroleum (b.p. 60—80°), proved to be identical (mixed m.p., i.r. and n.m.r. spectra) with *p*-nitrophenyl vinyl ketone. Subsequent elution with toluene-chloroform (1:1) gave a pale yellow solid (0.91 g, 40%), m.p. 94—99°. Recrystallisation from ethanol provided α -methyl-*p*-nitrophenacyl formate, m.p. 99—102° (Found: C, 54.0; H, 4.3; N, 6.2. C₁₀H₉NO₃ requires C, 53.8; H, 4.05; N, 6.25%), ν_{\max} 1729s, 1715s, 1699s, 1600m (aromatic C=C), 1524s (NO₂, asym.), and 1352s cm⁻¹ (NO₂, sym.), τ (CDCl₃) 1.72 (4H, m, aromatic), 1.83 (1H, s, HCO·O), 3.91 (1H, q, CH), and 8.41 (3H, d, Me).

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¹³ I. Sheng Kao *et al.*, *Sci. Sinica*, 1957, **6**, 1031 (*Chem. Abs.*, 1960, **54**, 4457g).