

209. The Hydration of Undeca-1,7-diyne.

By I. D. CAMPBELL, N. A. DOBSON, and G. EGLINTON.

Mercuric salt-catalysed hydration of undeca-1,7-diyne by four different techniques leads *via* undec-7-yn-2-one to a mixture of the two diketones undecane-2,7-dione and undecane-2,8-dione in which the former predominates to an unexpected degree (approximately 2 : 1).

A preliminary investigation¹ of the hydration of undeca-1,7-diyne seemed to produce the startling result that the mode of hydration could be substantially directed towards the exclusive production of either of the two expected diketones undecane-2,7-dione or undecane-2,8-dione by a suitable choice of hydration techniques. The unexpected nature of these observations seemed to warrant closer examination by precise gas-liquid chromatography (g.l.c.), and the results of this investigation now follow.

To study the g.l.c. behaviour of mixtures of these two hitherto unknown diketones unequivocal syntheses for these compounds were devised. Oxidation of 1-n-butylcyclohexan-1-ol with chromium trioxide² gave 6-oxodecanoic acid which was converted into the glycol ester of 6,6-ethylenedioxydecanoic acid by treatment with ethylene glycol. Base hydrolysis gave the free acid which, by reaction with methyl-lithium gave 7,7-ethylenedioxyundecan-2-one; acid hydrolysis of this ketal furnished the required undecane-2,7-dione. For the second diketone, 2-n-butyrylcyclohexan-1-one was subjected to base-catalysed fission to yield 7-oxodecanoic acid. By procedures cognate to those above this acid was converted into undecane-2,8-dione. A mixture of these two diketones liquefied.

Satisfactory g.l.c. separation of synthetic mixtures of these two closely-related diketones proved predictably difficult. Both nonpolar (Apiezon "L" and S.E.30) and polar [poly(ethylene glycol adipate), Q.F.1, and Carbowax] phases produced no trace of separation. Attempted separation of the two corresponding di(ethyleneketals) on Apiezon "L" was more successful but still inadequate for quantitative purposes. Success in separating the diketones was achieved by means of the high resolution available from a poly(propylene glycol)-coated capillary column (50 m.). Under these conditions there was a difference of one minute in retention time, which proved adequate for quantitative measurements involving peak triangulation. The results of this process applied to weighed mixtures of the two diketones gave a satisfactory linear relation for peak area-composition. This technique was then applied to the products of hydration of undeca-1,7-diyne.

Hydration by mercuric oxide-boron trifluoride³ gave the easily separable mono-hydration product undec-7-yn-2-one (confirmed by hydrogenation to the known undecan-2-one) and a higher-boiling diketone mixture which solidified. The proportion of monoketone could be substantially reduced by prolonging the reaction time. Similar results were obtained by carrying out the hydration with mercuric chloride-aniline.⁴ With mercuric sulphate-sulphuric acid⁵ no monoketone was isolable; long reaction times appeared to cause acid-catalysed aldol cyclisation of the diketones to a low-boiling mixture of unsaturated monoketones which was not further investigated. Mercury-impregnated resin⁶ also gave a diketone mixture together with impurities derived from the resin.

Analysis by g.l.c. of the mixtures derived from these four hydration techniques showed that within the limits of experimental error the proportions of 2,8- to 2,7-diketone were the same in all the products. This was certainly the expected result and gainsaid the

¹ Dobson, Ph.D. Thesis, Queen's University, Belfast, 1957, pp. 74 *et seq.*

² Fieser and Szmuszkowicz, *J. Amer. Chem. Soc.*, 1948, **70**, 3352.

³ Islam and Raphael, *J.*, 1952, 4086.

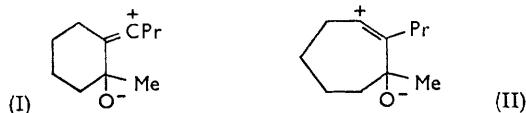
⁴ Stavelly, *J. Amer. Chem. Soc.*, 1941, **63**, 3127.

⁵ Heilbron, Jones, Smith, and Weedon, *J.*, 1946, 54; Fraser and Raphael, *J.*, 1952, 226; Thomas, Campbell, and Hennion, *J. Amer. Chem. Soc.*, 1938, **60**, 718.

⁶ Newman, *J. Amer. Chem. Soc.*, 1953, **75**, 4740.

indications of the earlier work. Less expected, however, was the finding that the proportions of the two diketones were not 50 : 50 but consistently 70 : 30 in favour of the 2,7-diketone. It is hardly likely that the hydration of the central triple bond of the initially-produced undec-7-yn-2-one would be influenced by an inductive effect of the carbonyl group transmitted through four methylene groups; in any case such an effect would favour the formation of the 2,8-dione (it is relevant that hydration of stearolic acid produces the expected equimolecular mixture of the two keto-acids⁷).

More plausible is the operation of some proximity effect, which in the case of undec-7-yn-2-one could lead to charge-transfer intermediates of the type (I) or (II).



Nucleophilic attack on these structures would lead to the 2,8- and 2,7-dione, respectively. It is difficult, however, to rationalise any favouring of the latter intermediate which would give rise to the observed preferred direction of hydration. More detailed speculation would seem to be unfruitful at this stage in view of the present unsatisfactory state of knowledge of the mechanism of these mercuric-catalysed hydrations.

EXPERIMENTAL

Light petroleum was of b. p. 40—60°, except where otherwise stated. M. p.s were determined on a Kofler hot stage and are uncorrected. High-resolution infrared spectra were recorded with a Unicam S.P. 100 spectrophotometer equipped with an S.P. 130 prism-grating double monochromator operated under vacuum. Gas-liquid chromatographic measurements were obtained on a Pye Argon chromatograph with 46 in. \times $\frac{1}{8}$ in. columns, unless stated to the contrary.

Undeca-1,7-diyne.—This was prepared according to the literature,⁸ and the purity of the product was carefully checked by g.l.c. [10% Apiezon "L" on Celite (80—100 mesh) at 100°, flow rate \sim 45 ml./min., retention time 12 min.], and by titration of the ethynyl content⁹ (1.04 active hydrogen per mole).

1-n-Butylcyclohexan-1-ol.—This was prepared in 65% yield according to the general procedure¹⁰ and was an oil, b. p. 98—102°/14 mm., n_D^{24} 1.4627 (Signaigo *et al.*¹⁰ give b. p. 88—91°/7 mm., n_D^{20} 1.4648).

6-Oxodecanoic Acid.—A vigorously stirred solution of 1-n-butylcyclohexan-1-ol (18 g.) in glacial acetic acid (750 ml.) was treated with chromic acid (56 g.) in small portions. Stirring was continued for 24 hr., whereupon the reaction mixture was concentrated *in vacuo* (to 250 ml.) and then diluted with water (500 ml.). The acid fraction was isolated with ether and distilled to give the oxo-acid (6.7 g.), b. p. 135—140°/0.1 mm., a solid of rancid odour which separated from light petroleum as needles, m. p. 41—42° (Found: C, 64.4; H, 9.7. Calc. for C₁₀H₁₈O₃: C, 64.5; H, 9.7%). Its semicarbazone had m. p. 159°, after crystallisation from methanol. (Found: C, 54.1; H, 8.3; N, 16.7. Calc. for C₁₁H₂₁N₃O₃: C, 54.3; H, 8.7; N, 17.3%). (Yoshioka¹¹ gives 42 and 159° as the m. p.s of the oxo-acid and semicarbazone, respectively.)

7,7-Ethylenedioxyundecan-2-one.—A solution of 6-oxodecanoic acid (3.75 g.), ethylene glycol (12.5 g.), and toluene-*p*-sulphonic acid (60 mg.) in benzene (90 ml.) was stirred under reflux for 6 hr., water being collected continuously from the returning solvent. The benzene solution was then shaken with anhydrous potassium carbonate, washed with a solution of sodium acetate and water, and finally dried (MgSO₄). Removal of the benzene gave 2-hydroxyethyl 6,6-ethylenedioxydecanoate as an oil (5.12 g.) which was used without further

⁷ Smith and Thickbroom, *Chem. and Ind.*, 1962, 695.

⁸ Raphael and Sondheimer, *J.*, 1950, 115.

⁹ Raphael, "Acetylenic Compounds in Organic Syntheses," Butterworth's Scientific Publications, London, 1955, p. 207.

¹⁰ Signaigo and Cramer, *J. Amer. Chem. Soc.*, 1933, **55**, 3326.

¹¹ Yoshioka, *J. Pharm. Soc. Japan*, 1955, **75**, 606.

purification or characterisation. The infrared spectrum (see below) showed no ketonic or carboxylic acid absorption. This ester (2.74 g.) was hydrolysed by heating it under reflux for 2 hr. with aqueous sodium hydroxide solution (0.3N; 50 ml.). The aqueous solution, after being washed with ether, was carefully acidified at 0° to pH 6, and the acidic fraction isolated with ether to yield 6,6-ethylenedioxydecanoic acid as an oil (2.04 g.). The infrared spectrum now showed the presence of a carboxylic function but no ketonic or ester carbonyl.

To a solution of this acid (420 mg.) in anhydrous ether (5 ml.) was added ethereal methyl-lithium (0.37M; 5 ml.) and the reaction mixture heated under reflux for 1 hr. and cooled, and water added. Isolation with ether furnished 7,7-ethylenedioxyundecan-2-one (390 mg.), as a pleasant-smelling oil, b. p. 99—101°/10⁻⁴ mm., n_D^{25} 1.4550 (Found: C, 68.1; H, 10.5. C₁₃H₂₄O₃ requires C, 68.4; H, 10.6%), with ketonic absorption at 1721 cm.⁻¹ (in CCl₄).

Undecane-2,7-dione.—A solution of 7,7-ethylenedioxyundecan-2-one (390 mg.) in aqueous methanol (65%; 10 ml.) containing one drop of concentrated hydrochloric acid, was heated on a steam-bath for 30 min. Isolation with ether gave the solid diketone (280 mg.), which separated from light petroleum as plates, m. p. 39.5—40° (Found: C, 71.6; H, 10.7. C₁₁H₂₀O₂ requires C, 71.7; H, 10.9%), ν (CO) 1721 cm.⁻¹ in carbon tetrachloride. The *bis-semicarbazone* crystallised from ethanol as prisms, m. p. 177° (Found: N, 28.6. C₁₃H₂₄O₂N₆ requires N, 28.6%).

2-n-Butyrylcyclohexanone.—This compound was prepared¹² from cyclohexanone and n-butyric anhydride in the presence of boron trifluoride-acetic acid complex (1:1) and was obtained as an oil, b. p. 128—130°/15 mm. (Adams and Hauser¹² give b. p. 133—134°/20 mm.)

7-Oxodecanoic Acid.—2-n-Butyrylcyclohexanone (22.3 g.) was heated under reflux for 2 hr. in aqueous sodium hydroxide (1.3N; 125 ml.). Isolation of the acid fraction in the usual way followed by distillation, gave the oxo-acid (18.5 g.), b. p. 144—149°/0.9 mm., as flakes, m. p. 42—43°, from light petroleum (Found: C, 64.5; H, 9.8. Calc. for C₁₀H₁₈O₃: C, 64.5; H, 9.7%). (Manyik *et al.*¹³ give m. p. 42—43°.)

Hydroxyl and carbonyl stretching absorptions.

Solvent	Heptyl propyl ketone ν (CO)	2-Hydroxyethyl stearate		Stearic acid			6-Oxodecanoic acid		
		ν (OH)	ν (CO)	monomer ν (OH)	dimer ν (CO)	monomer ν (OH)	dimer ν (CO)	ketone ν (CO)	
CCl ₄	1716	3624	1743	3535	1759	1711	3534	1759	1712
	(320)	(50) 3520 †	(425)	(50)	(175)	(605)	(45)	(155)	(790)
Et ₂ O-CCl ₄	1716	3624	1742	~3150m *	1737	—	~3140m *	1736	—
(1:4 by volume)	(310)	(15) 3470 *	(485)	~3500vw	(480)	—	~3500vw	(465)	(~300)
		(100)							

ϵ_a Values are given in parentheses and these have been approximated to the nearest 5 units.

† Hydroxyl intrahydrogen bonded to ester function. * Hydroxyl interhydrogen-bonded to diethyl ether molecules.

m medium, vw very weak.

8,8-Ethylenedioxyundecan-2-one.—Treatment of 7-oxodecanoic acid in a manner analogous to that described above for 6-oxodecanoic acid gave in similar yield 8,8-ethylenedioxyundecan-2-one as a liquid, b. p. 110—112°/10⁻² mm., n_D^{25} 1.4552 (Found: C, 68.2; H, 10.5. C₁₃H₂₄O₃ requires C, 68.4; H, 10.6%), ν (CO) 1721 cm.⁻¹ in carbon tetrachloride.

Undecane-2,8-dione.—The foregoing monoketal was hydrolysed exactly as in the cognate experiment to give a comparable yield of *undecane-2,8-dione* which crystallised from light petroleum as plates, m. p. 36—38° (Found: C, 71.6; H, 10.8. C₁₁H₂₀O₂ requires C, 71.7; H, 10.9%), ν (CO) 1722 cm.⁻¹ in carbon tetrachloride.

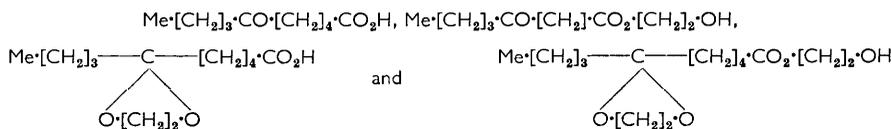
The *bis-semicarbazone* formed microprisms, m. p. 165—167°, from methanol (Found: N, 28.7. C₁₃H₂₄N₆O₂ requires N, 28.6%).

¹² Adams and Hauser, *J. Amer. Chem. Soc.*, 1945, **67**, 284.

¹³ Manyik, Frostick, Sanderson, and Hauser, *J. Amer. Chem. Soc.*, 1953, **75**, 5030.

A mixture of undecane-2,7-dione and undecane-2,8-dione could not be separated by thin-layer chromatography (t.l.c.) [alumina G with petrol-benzene (1 : 1) as eluent and silica G with chloroform as eluent; 2,4-dinitrophenylhydrazine sulphate reagent as spray].

Protection of the Keto-group in the Decanoic Acids.—It was found that the product resulting from the attempted ketalisation of 6-oxodecanoic acid with only a small excess of ethylene glycol in the presence of toluene-*p*-sulphonic acid, was a mixture of the four possible compounds.



This was revealed (iodine spray; 4 spots) by t.l.c. on kieselguhr G and elution with chloroform, and was confirmed by infrared spectral examination (see Table) of this mixture, the oxo-acid alone, and reference compounds in carbon tetrachloride and ether-carbon tetrachloride (1 : 4 by volume).

The carbon tetrachloride measurements indicated that some ester had been formed [ν_{max} . 1742 cm^{-1} (315), $\nu(\text{CO})$; 3623 cm^{-1} (25), $\nu(\text{OH})$ free; and 3536 cm^{-1} (50), $\nu(\text{OH})$ intrahydrogen-bonded for $\text{RCO}_2\text{CH}_2 \cdot \text{CH}_2 \cdot \text{OH}$] but that there were also unchanged carboxylic acid and ketonic groups [ν_{max} . 1759sh cm^{-1} , $\nu(\text{CO})$ for $\text{R} \cdot \text{CO}_2\text{H}$ monomer; 1714 cm^{-1} (410), $\nu(\text{CO})$ for $\text{R} \cdot \text{CO}_2\text{H}$ dimer and RCOR' ; and 3536 cm^{-1} (50), $\nu(\text{OH})$ for RCO_2H monomer (and for intrahydrogen-bonded $\text{RCO}_2 \cdot \text{CH}_2 \cdot \text{CH}_2 \cdot \text{OH}$, as above)]. Confirmation was obtained by the ether-carbon tetrachloride measurements, only two bands in the carbonyl region being observed [ν_{max} . 1739 cm^{-1} (485), $\nu(\text{CO})$ for $\text{RCO}_2\text{H} \cdot \cdot \cdot \text{OEt}_2$ and $\text{RCO}_2\text{R}'$; and 1719 cm^{-1} (315), $\nu(\text{CO})$ for RCOR'].

Hydration of Undeca-1,7-diyne.—(a) *Mercuric oxide-boron trifluoride method.*³ On a preparative scale, the hydrocarbon (88.8 g.) in methanol (20 ml.) was added with shaking to a warm mixture of mercuric oxide (1.0 g.), boron trifluoride-ether complex (0.5 ml.), trichloroacetic acid (10 mg.), and methanol (2 ml.). Shaking was continued and, after a variable induction period, the solution rapidly darkened and warmed. After 24 hr. the mixture was poured into dilute sulphuric acid and shaken well. The product was then extracted with ether, and the ethereal extract washed with sodium hydrogen carbonate solution and with water before being dried (MgSO_4) and the solvent removed by evaporation. The product from two such experiments was distilled to give two fractions.

The lower-boiling component, b. p. 114—116°/12 mm., n_D^{24} 1.4481, proved to be undec-7-yne-2-one (7.9 g.) (Found: C, 79.2; H, 10.8. $\text{C}_{11}\text{H}_{18}\text{O}$ requires C, 79.5; H, 10.9%). The *semicarbazone* crystallised from methylated spirits as prisms, m. p. 95—96° (Found: C, 63.7; H, 9.6; N, 18.3. $\text{C}_{12}\text{H}_{21}\text{N}_3\text{O}$ requires C, 64.5; H, 9.5; N, 18.8%). The 2,4-dinitrophenylhydrazone formed pale orange needles, m. p. 77—77.5°, from light petroleum (Found: C, 59.2; H, 6.4; N, 16.0. $\text{C}_{17}\text{H}_{22}\text{N}_4\text{O}_4$ requires C, 58.9; H, 6.4; N, 16.2%). The monoketone (1 g.) was hydrogenated with 10% palladium on charcoal in methanol (25 ml.). Absorption of hydrogen ceased with the uptake of 2.0 molecular equivalents of hydrogen. The product had the reported properties of methyl nonyl ketone and the semicarbazone of this hydrogenated material did not depress the melting point of an authentic specimen of methyl nonyl ketone semicarbazone, m. p. 122—123°.

The high-boiling fraction (b. p. 80—100°/0.1 mm.), which eventually solidified, was a mixture (8.8 g.) of undecane-2,7- and -2,8-diones.

In another experiment, isolation directly after the initial exothermic reaction gave predominantly the monoketone. For g.l.c. estimation the total undistilled product after a 24 hr. reaction time was used.

(b) *Mercuric chloride-aniline method.*⁴ A solution of undeca-1,7-diyne (5.92 g.) in benzene (650 ml.) was added to a mixture of mercuric chloride (45.75 g.) in water (46 ml.) and aniline (8.16 g.) in benzene (900 ml.). The mixture was stirred at 60° for 18 hr. and after this time hydrochloric acid (36%; 12 ml.) was added. The reaction mixture was then saturated with hydrogen sulphide and filtered. The precipitate was washed with benzene (3 × 100 ml.), and the filtrate and washings shaken with sodium hydrogen carbonate solution and with water before being dried (MgSO_4) and the solvent evaporated. Distillation as in (a) gave undec-7-yne-2-one (1.15 g.) and the diketone mixture (2.7 g.). Again, for g.l.c. examination the undistilled total product was used.

(c) *Mercuric sulphate-sulphuric acid.*⁵ Undeca-1,7-diyne (137 mg.), mercuric sulphate (10 mg.), and concentrated sulphuric acid (10 mg.) were refluxed for 6 hr. in 75% aqueous ethanol (3 ml.), and then cooled. Sodium hydrogen carbonate solution was added and the reaction mixture extracted with ether. The ethereal extract was washed with water and dried (MgSO₄). Evaporation of the ether gave a solid mixture of the diketones (137 mg.) melting just above room temperature. This total product was used for g.l.c. examination.

(d) *Mercury-impregnated resin.*⁶ Undeca-1,7-diyne (110 mg.) and mercury-impregnated Amberlite resin [I.R.-120 (H); 130 mg.] were refluxed in 10% aqueous acetic acid (10 ml.) for 4 hr., during which time the brown resin became black. After being cooled and filtered, concentrated sodium hydroxide solution was added to neutralise the acetic acid, and the reaction mixture was extracted with ether. The ethereal extract was washed thoroughly with water and dried (MgSO₄). Removal of the ether gave a brown oil (94 mg.) which was used for g.l.c. examination. The g.l.c. recordings revealed several other peaks which were subsequently shown to have come from the resin itself, but the results were generally less satisfactory than those for the other methods.

Gas-Liquid Chromatographic Methods.—The g.l.c. separation of the two isomeric diketones was unsuccessful on a Pye Argon chromatograph using columns packed with either 10% of Apiezon "L" grease on Celite (80–100 mesh), 1% of poly(ethylene glycol adipate) on Embacel, 10% of poly(ethylene glycol adipate) on Embacel, 1% of S.E. 30 on Embacel, 1% of Q.F.1 on Embacel, 5% of Carbowax 400 on Embacel, 5% of Carbowax 600 on Embacel, or 25% of Carbowax on Embacel.

The bis(ethylene glycol ketals) separated partially on a column of 0.5% of Apiezon "L" grease on Celite (80–100 mesh), but the separation was inadequate for a quantitative study.

Separation of the isomeric diketones was achieved on a Perkin-Elmer 451 fractometer, a 50-metre Golay capillary column being used, coated with poly(propylene glycol) at 150° (flow rate 55 ml./min. of helium: sample size — ~10 μl. of 0.5% chloroform solution, splitting ratio 2:1: column: vent). The retention times of the 2,7- and 2,8-diketones were 35.5 and 37 min., respectively. This is equivalent to a column resolution¹⁴ of 1.57 and column efficiency¹⁵ of 577. Equimolar mixtures of the two diketones separated sufficiently for quantitative area measurements, but the flame ionisation detector was about 2.5 times more sensitive to the 2,7-isomer than to the 2,8-isomer. This unexpected result was checked repeatedly. Known mixtures of the two synthetically prepared ketones were dissolved in chloroform (AnalaR), subjected to g.l.c. examination on the capillary column, and the areas of the peaks measured by both triangulation and square counting. The plot of area ratio to weight ratio was a straight line passing through the origin. The hydration products were then examined in a similar fashion (10 μl. samples of 0.5% solutions), their areas measured, and by using the above plot, the ratio by weight obtained. In all cases the ratio of 2,7- to 2,8-isomer was close to 2:1.

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CHEMISTRY DEPARTMENT, THE UNIVERSITY, GLASGOW W.2.

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¹⁴ "Gas Chromatography," ed. Scott, Butterworth's Scientific Publications, London, 1960, p. 429.

¹⁵ McWilliams, *Rev. Pure Appl. Chem.*, 1961, **11**, 33.