54. *Researches on Acetylenic Compounds. Part XXII. The Reaction Between Nickel Carbonyl and Monosubstituted Acetylenic Compounds.*

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The reaction between monosubstituted acetylenes ($RC{\equiv}CH$), nickel carbonyl, and water in the presence of acids leads to the formation of α-substituted acrylic acids [$RC(CO_2H){=}CH_2$]. The application of this reaction to various types of acetylenic alcohol has been studied; the expected substituted acrylic acids are obtained, but with αβ-acetylenic carbinols [*e.g.* $CHPr(OH)\cdot C{\equiv}CH$], it is preferable to employ the acetates rather than the free alcohols, and the products from βγ-acetylenic carbinols [*e.g.*, $CH_2(OH)\cdot CH_2\cdot C{\equiv}CH$] cyclise spontaneously to lactones. In this way the synthesis of the naturally occurring antibiotic, α-methylenebutyrolactone, has been achieved. The behaviour of certain other monosubstituted acetylenes has been examined, and some conclusions relating to the part played by water in the reaction are drawn.

Certain reports on wartime work by W. Reppe and his co-workers (B.I.O.S. Final Reports Nos. 266, 355, and 358; see also *Experientia*, 1949, **5**, 93) contain brief descriptions of a novel reaction in which acetylenic compounds are treated either with nickel carbonyl and an acid at about 40° ("stoicheiometric process") or with carbon monoxide under pressure at 100—180° in the presence of a nickel halide ("catalytic process"). In each case a compound possessing an active hydrogen atom, *e.g.*, water or an alcohol, is also present. The overall equations are given as:

Stoicheiometric

$$4RC{\equiv}CH + Ni(CO)_4 + 4EtOH + 2HCl = 4RC(CO_2Et){=}CH_2 + NiCl_2 + H_2$$

Catalytic

$$RC{\equiv}CH + CO + EtOH \xrightarrow[\text{halide}]{Ni} RC(CO_2Et){=}CH_2$$

It is implied that when carbon monoxide and a nickel halide are used nickel carbonyl is formed *in situ* and is the effective catalyst, and that the two methods are essentially similar. Acrylic acid or its derivatives are formed from acetylene itself, and it is stated that mono- and di-substituted acetylenes give, respectively, α-substituted and αβ-disubstituted acrylic acids, unsymmetrical disubstituted acetylenes giving a mixture of the two possible products. It is claimed that alcohols, water, amines, and thiols can be used as the active-hydrogen-containing component, and that a wide variety of acetylenes may be employed; however, except in the case of acetylene itself, no experimental details are given.

The reaction between some monosubstituted acetylenes (mostly alcohols of various types), nickel carbonyl, and water in the presence of acids ("stoicheiometric process") has been examined, partly in order to prepare some otherwise inaccessible αβ-unsaturated lactones and hydroxy-acids of possible biological interest (cf. Haynes, *Quarterly Reviews*, 1948, **2**, 46) and partly in an attempt to obtain information concerning the mechanism of this reaction. Work directed towards the second end is still in progress, and the present contribution is concerned only with the preparative aspect of the reaction and with the part played in it by water. Once a moderately satisfactory technique for effecting the reaction had been evolved it was applied to a variety of compounds with little variation; the conditions employed are therefore to some extent arbitrary.

Because of the lack of information on the German work, reactions with the hydrocarbons, hex-1-yne and phenylacetylene, were first carried out. When either of these was dissolved in a mixture of ethanol and concentrated hydrochloric acid and treated with an alcoholic solution of nickel carbonyl at about 55° an exothermic reaction took place after a short induction period. The proportions of the reactants were in accordance with the equation already given except that ethanol was used in large excess as the solvent and, because of the difficulty of weighing accurately small quantities of nickel carbonyl, a moderate (10—25%) excess was always employed. Isolation of the neutral fraction at the end of the reaction gave ethyl α-butylacrylate and ethyl atropate, each in about 50% yield; in the case of phenylacetylene it was also possible to isolate a small quantity (5% yield) of atropic acid, presumably in equilibrium with the ester. None of the starting material was recoverable in either case.

When this method was applied to representative αβ-acetylenic carbinols (propylethynylcarbinol and 1-ethynyl*cyclo*hexanol) however, no exothermic reactions were observed, no appreciable yields of the expected hydroxy-esters were obtained, and in both cases considerable

amounts of the starting materials were recovered. In an endeavour to find satisfactory methods for these compounds numerous procedures were examined, including the addition of quinol or alternatively of benzoyl peroxide to the reaction mixture, and the use of the acetate in place of the carbinol itself, both under the normal conditions and (in the expectation of obtaining a mixed anhydride; cf. the German work) with the ethanol replaced by glacial acetic acid. In all these cases no exothermic reaction was observed; but when propylethynylcarbinol in *n*-propanol and acetic acid was treated with nickel carbonyl at 95° a violent reaction took place, and distillation of the neutral fraction gave some heterogeneous high-boiling material. Finally it was found that the acetate of propylethynylcarbinol (I) underwent a smooth exothermic reaction in ethanol containing acetic acid, although the induction period was rather lengthy unless a temperature of about 70° was used. Surprisingly, distillation of the neutral fraction of the reaction product gave very little volatile material, which moreover was heterogeneous. The acidic fraction on the other hand was appreciable in quantity and crystallised readily, giving the *acetoxy-acid* (II), m. p. 69°, in 40% yield.

$$\text{(I.)}\quad CHPr(OAc)\cdot C{\equiv}CH \longrightarrow CHPr(OAc)\cdot C(CO_2H){=}CH_2 \quad \text{(II.)}$$

It was concluded that in this reaction, since the free acid and not the ester was formed, water must be involved. When the requisite amount of water was added to the alcohol used the yield was improved to 48%.

This technique, *i.e.*, the use of ethanol as solvent, glacial acetic acid in slight excess, and 0·5—2 molecular equivalents of water (within these limits the amount used appeared to be immaterial) with a reaction temperature of about 70°, was now applied to a number of acetylenes. It gave satisfactory yields of the free acids (35% and 48%) with the hydrocarbons, hex-1-yne and phenylacetylene, and also with the acetates of phenylethynylcarbinol (50%) and propargyl alcohol (40%). The tertiary carbinyl acetates derived from dimethylethynylcarbinol and 1-ethynyl*cyclo*hexanol, however, still failed to react exothermally, although in the latter case isolation of the acidic fraction of the reaction mixture gave a very small yield of the expected *acetoxy-acid* (III; $R_1R_2 = [CH_2]_5$, R_3 = Ac), m. p. 98·5°. Rather unexpectedly propargyl alcohol reacted exothermally under these conditions, but the isolation of the product, presumably

$$R_1R_2C(OR_3)\cdot C(CO_2H){=}CH_2 \quad \text{(III.)}$$

the somewhat unstable and very water-soluble hydroxy-acid (III; $R_1 = R_2 = R_3 = H$), was not possible. Phenylethynylcarbinol itself failed to react exothermally, but isolation of the acidic fraction of the reaction product gave a 10% yield of the expected *hydroxy-acid* (III; R_1 = Ph; $R_2 = R_3 = H$), accompanied by much syrupy, acidic material.

It therefore appears that with αβ-acetylenic carbinols and their acetates the reaction can proceed either exothermally and in good yield, or slowly without visible evolution of heat and in poor yield. The first type of reaction is observed with propargyl acetate and probably propargyl alcohol, and with secondary carbinyl acetates; the second with free secondary carbinols, tertiary carbinols, and tertiary carbinyl acetates.

The products thus obtained from the α-carbinols and their acetates showed the expected properties (hydrolysis and alcoholysis of the acetyl groups, esterification, etc.). Perhaps the most interesting was the compound (III; $R_1 = R_2 = H$; R_3 = Ac), m. p. 53°, prepared from propargyl acetate. This was hydrolysed with barium hydroxide solution to the corresponding *hydroxy-acid* which showed a strong tendency to polymerise, *e.g.*, during an attempted isolation by continuous extraction of an aqueous solution with ether. The polymer proved to be insoluble in methanol and acetone but readily soluble in water. Its *methyl* ester, prepared by treating the acetoxy-acid with methanolic sulphuric acid, is closely related to methyl methacrylate. Like the hydroxy- and acetoxy-acids it was found to be much less stable than analogues derived from secondary acetylenic carbinols.

When the method first used, *i.e.*, ethanol–hydrochloric acid at 55°, was applied to the βγ-acetylenic carbinols, but-3-yn-1-ol and pent-4-yn-2-ol (IV; R = H and Me), an exothermic reaction took place in both cases, and distillation of the neutral fractions of the reaction mixtures

$$\text{(IV.)}\quad RCH(OH)\cdot CH_2\cdot C{\equiv}CH \longrightarrow RCH\cdot CH_2\cdot C{=}CH_2 \quad \text{(V.)}$$
$$\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\quad O\text{———}CO$$

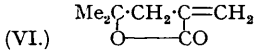
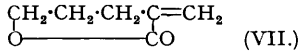
gave the two α-methylene-γ-lactones (V; R = H and Me, respectively) as liquids which polymerised on storage to clear glasses.* Some polymerisation seemed to take place during the reaction, and it was suspected that the products were somewhat impure. When the aqueous–ethanolic acetic acid technique was employed in these two cases no polymer was formed, and

the two lactones obtained (yields 23% and 30%, respectively) proved to be homogeneous; the refractive indices differed slightly from those of specimens obtained by the hydrochloric acid method. They could be kept at room temperature for several weeks, or indefinitely when quinol was added. It is noteworthy that (V; R = H; " α-methylenebutyrolactone ") was obtained by Cavallito and Haskell (*J. Amer. Chem. Soc.*, 1946, **68**, 2332) by the hydrolysis of a presumably glycosidic precursor occurring in *Erythronium americanum*, and was found by them to exhibit weak antibacterial properties. More complex substances containing the α-methylenebutyrolactone grouping have been isolated from natural sources [Asahina and Asano, *J. Pharm. Soc. Japan*, 1927, **539**, 1 (*Chem. Abstracts*, 1928, **22**, 4470); Asano and Kanematsu, *Ber.*, 1932, **65**, 1174; Cavallito and Kirchner, *J. Amer. Chem. Soc.*, 1947, **69**, 3030], but no previous synthesis of this type of compound has been reported. The physical properties of the synthetic material agreed well with those recorded by Cavallito and Haskell (*loc. cit.*), but the synthetic lactone did not show the skin-irritant properties of the natural product. It is possible that the latter contained a trace of some other substance which was responsible for these, or that individual susceptibility varies widely.

On being heated to 100° in the presence of a little benzoyl peroxide the two lactones polymerised to clear, hard resins, softening at 160—190°.*

Attempts were made to improve the yield of α-methylenebutyrolactone by carrying out the nickel carbonyl reaction with the *acetate* of but-3-yn-1-ol, whereby the *acid* $AcO{\cdot}CH_2{\cdot}CH_2{\cdot}C(CO_2H){=}CH_2$ (p-*bromophenacyl* ester, m. p. 76°) was readily obtained in 47% yield. Attempts to hydrolyse this with alkali or to effect cyclisation to (V; R = H) by treatment with 1% methanolic sulphuric acid proved relatively unsuccessful since only moderate (30—60%) yields of rather impure lactone were obtained, apparently because of the instability of the latter towards mineral acids. This factor was probably responsible for the poor quality of the material obtained from but-3-yn-1-ol and nickel carbonyl when hydrochloric acid was used. As a further variant the hydroxyl group of but-3-yn-1-ol was protected by reaction with 2 : 3-dihydropyran (cf. Woods and Kramer, *J. Amer. Chem. Soc.*, 1947, **69**, 2246); the expected *ether* was readily obtained, but its reaction with nickel carbonyl gave only a 20% yield of the corresponding *acid*, the conversion of which into the methylenelactone (V) was therefore not studied.

In view of the differences between the primary, secondary, and tertiary types of αβ-acetylenic carbinols it was of interest to examine the behaviour of the tertiary βγ-acetylenic carbinol, 2-methylpent-4-yn-2-ol (Henbest, Jones, and Walls, *J.*, 1949, 2696). No exothermic reaction was observed, but after careful fractionation a 10% yield of the expected *lactone* (VI) was obtained. Its behaviour is thus similar to that of the secondary αβ-carbinol, phenylethynylcarbinol. The reaction with nickel carbonyl of the only γδ-acetylenic carbinol so far reported, pent-4-yn-1-ol (Lespieau, *Compt. rend.*, 1932, **194**, 287; Eglinton, Jones, and Whiting, forthcoming publication) was also examined. With this compound an exothermic reaction was observed, and the δ-lactone (VII) was obtained in 20% yield.

(VI.)  (VII.) 

Concurrently with the work on acetylenic carbinols the application of the nickel carbonyl reaction to monosubstituted acetylenes of some other types was attempted. With the vinylacetylenic compounds, 2-methylpent-1-en-3-yne, 1-ethynyl*cyclo*hexene, pent-2-en-4-yn-1-ol, and pent-2-en-4-yn-1-yl acetate no exothermic reactions were observed either in ethanolic hydrochloric acid or in aqueous–ethanolic acetic acid. In the case of 1-ethynyl*cyclo*hexene under the latter conditions, isolation of the acidic fraction gave only a 1·5% yield of a high-melting solid clearly not the expected acid. No exothermic reaction was observed with phenyl ethynyl ketone (acetic acid technique); as was the case with the reactions involving vinylacetylenes, much dark polymeric material was formed.

In this communication the results of investigations, as yet incomplete, with various disubstituted acetylenes, and on the mechanism of the reaction, will not be discussed. However, even at this stage it can be pointed out that it is almost certainly the free acids, and not the esters, which are formed initially in this reaction, and the presence of water (either added to the reaction mixture or formed *in situ* in side reactions) is necessary. This is convincingly demonstrated by the fact that even when carefully dried ethanol is employed as solvent in experiments employing acetic acid, the free acid and not the ester is the principal product. In

* Patents applied for (B.P. Applications, 7091 and 7092/48).

most reactions a little ester is also formed (its isolation is usually difficult and was not generally attempted) but this is in all probability the result of subsequent esterification, which of course takes place to equilibrium when a mineral-acid catalyst is present. When dried alcohol was used as solvent the yields of crystalline acids in the cases of phenylacetylene and phenylethynylcarbinyl acetate were reduced to 30% and 24%, respectively (normally 48% and 50%). If it is assumed that the hydrogen formed in the reaction according to the equation given by Reppe is converted into water a 25% yield of the acid would be possible.*

The light-absorption properties of the acids and lactones obtained are shown below.

Compound.	λ, A.	ε.	Compound.	λ, A.	ε.
$CH_2(OH)\cdot C(CO_2H)=CH_2$	2140	3000	$CH_2\cdot CH_2\cdot C(O\text{———}CO)=CH_2$ (in water)	2200 [1]	7500
	2300	300		2250	5000
				2350	900
$CHPr(OH)\cdot C(CO_2H)=CH_2$	2150	6500		2400	400
	2450	1300		2450	250
$CHPh(OH)\cdot C(CO_2H)=CH_2$	2170	7000	$CH_2\cdot CH_2\cdot C(O\text{———}CO)=CH_2$ (in water) [2]	2300	2400
	2380	1800		2350	900
				2400	500
$[CH_2]_5{>}C(OH)\cdot C(CO_2H)=CH_2$	2190	4000			
	2250	1200	$CH_2\cdot CH_2\cdot CH_2\cdot C(O\text{———}CO)=CH_2$ (in water)	2200 [1]	5700
				2250	4450
$[CH_2]_5{>}C(OAc)\cdot C(CO_2H)=CH_2$	2170	4000		2300	3100
	2320	900		2350	1750
				2400	1000
$CH_2\cdot CH_2\cdot C(O\text{———}CO)=CH_2$	2200	5000		2450	470
	2250	500			

None of the above compounds exhibited any maximal absorption in the range examined.

Except where otherwise stated alcoholic solutions were employed and a Hilger Medium Spectrograph was used.

[1] Beckman spectrograph used. [2] Cavallito and Haskell, *loc. cit.*

Experimental.

General Method —The apparatus consisted of a flask of 250 c.c. capacity equipped with a thermometer whose bulb dipped into the liquid in the flask, a mercury-seal stirrer, a reflux condenser, a gas inlet, and a dropping funnel. The acetylenic compound, the solvent, the acid used, and in some cases water were stirred under nitrogen while the flask was heated with a free flame until the liquid reached the desired temperature (55—80°). About 2 c.c. of the solution of nickel carbonyl were added and, after an induction period of variable length, the reaction began, as shown by a marked rise in temperature and in some cases a transient deep-brown coloration. The remainder of the carbonyl solution was then added dropwise at such a rate that the temperature remained constant until the reaction was complete, when the temperature began to fall. As soon as the reaction mixture was sufficiently cool, ether (5—10 times the volume of nickel carbonyl used) was added, the apparatus was adapted for distillation, and the flask was warmed on the steam-bath until everything volatile under these conditions had distilled. The distillate was poured away carefully.

Up to this stage all operations were carried out in a well-ventilated fume-cupboard, but when the excess of nickel carbonyl had been removed the reaction mixture could be handled in the open laboratory. The solution was poured into dilute sulphuric acid and extracted with ether or chloroform; the extract was washed thoroughly with sodium hydrogen carbonate solution, and the neutral and acidic fractions were isolated, the procedure varying from case to case.

Ethyl Atropate.—The reaction was carried out by the general method, using phenylacetylene (20·6 g.), ethanol (60 c.c.), and concentrated hydrochloric acid (8 c.c.), to which a solution of nickel carbonyl (6·6 c.c.) in ethanol (20 c.c.) was added. The temperature was kept at 55° by occasional external cooling. The acid fraction gave, after crystallisation from water, atropic acid (1·5 g.), m. p. 105—106°; the neutral portion was distilled giving the ester (16·7 g.), b. p. 57—63°/10^{-2} mm., n_D^{22} 1·5229 (Auwers and Eisenlohr, *J. pr. Chem.*, 1911, **84**, 89, give b. p. 120·2—120·4°/14 mm., n_D^{16} 1·5260).

Ethyl α-Butylacrylate.—Hex-1-yne (16·4 g.), ethanol (60 c.c.), and concentrated hydrochloric acid (9 c.c.) reacted at 50—70° with a solution of nickel carbonyl (8 c.c.) in ethanol (20 c.c.). Isolation with pentane gave ethyl α-butylacrylate (16·0 g.), b. p. 66°/10 mm., n_D^{20} 1·4290 (Blaise and Luttringer, *Bull. Soc. chim.*, 1905, **33**, 778, give b. p. 177°).

Atropic Acid.—(*a*) The reaction was carried out by the general method at 70° using phenylacetylene (15·3 g.), acetic acid (6 c.c.), ethanol (30 c.c.), water (2 c.c.), and a solution of nickel carbonyl (6 c.c.) in ethanol (15 c.c.). Isolation of the acidic fraction followed by crystallisation from light petroleum (b. p. 60—80°) gave atropic acid (10·65 g., 48%) as prismatic needles, m. p. 106—107° (Fittig and Wurster, *Annalen*, 1879, **195**, 147, give m. p. 106—107°). From the mother-liquors a solid (380 mg.), m. p. 89—90°,

* Since writing the above account it has been found that an exothermic reaction takes place on adding nickel carbonyl to a solution of phenylacetylene and glacial acetic acid in dry anisole at 60°, atropic acid being obtained in 20% yield. In this case the water required must clearly be formed in side-reactions involving nickel carbonyl and the acetylene, since none could be formed from the solvent mixture alone.

was obtained by crystallisation. Recrystallisation of this from light petroleum (b. p. 60—80°) gave irregular rhombic plates, m. p. 86—87° undepressed on admixture with atropic acid (mixed m. p. 90—94°) (Found: C, 73·65, 71·75; H, 5·45, 5·4%). Light absorption: Maxima at 2600 and 2800 A., $E_{1\,cm.}^{1\%}$ = 430 and 330, respectively (cf. atropic acid, which has a maximum at 2500 A., $E_{1\,cm.}^{1\%}$ = 350, and end absorption). The constitution of this solid was not investigated further.

(*b*) Repetition of this experiment using ethanol dried over magnesium ethoxide, and omitting the water gave crude atropic acid, m. p. 101—103° (6·65 g.). Crystallisation of this material gave the pure acid, m. p. 106—107° (5·6 g., 30%).

α-Butylacrylic Acid.—Hex-1-yne (41 g.), ethanol (100 c.c.), glacial acetic acid (15 c.c.), and water (7 c.c.), reacted with a solution of nickel carbonyl (17 c.c.) in ethanol (50 c.c.) at *ca.* 67° by the general method in a 1-l. flask. Isolation of the acidic fraction followed by distillation gave α-butylacrylic acid (21·75 g.), b. p. 69—70°/0·2 mm., $n_D^{19\cdot5}$ 1·4453 (Blaise and Luttringer, *loc. cit.*, give b. p. 109—110°/10 mm.).

3-Acetoxyhex-1-ene-2-carboxylic Acid (II).—Propylethynylcarbinyl acetate (Bowden, Heilbron, Jones, and Weedon, *J.*, 1946, 45) (9·3 g.), ethanol (20 c.c.), glacial acetic acid (5 c.c.), and water (1 c.c.) reacted at 74—78° by the general method with nickel carbonyl (3 c.c.) in ethanol (10 c.c.). Isolation of the acidic fraction with chloroform, followed by evaporation of the solvent, gave a residue which solidified when scratched and, on crystallisation from light petroleum (b. p. 40—60°), gave a product (5·9 g., 48%), m. p. 67°. Recrystallisation from the same solvent gave the *acetoxy-acid* as long needles, m. p. 68·5° (Found: C, 58·2; H, 7·6. $C_9H_{14}O_4$ requires C, 58·05; H, 7·6%).

3-Hydroxyhex-1-ene-2-carboxylic Acid (III; $R_1 = R_3 = H$, $R_2 = Pr$).—The acetoxy-acid (3 g.) was dissolved in a solution of potassium hydroxide (3 g.) in water (6 c.c.) with cooling. After 18 hours at 20° the solution was acidified; isolation with ether followed by distillation at 80° (bath temp.)/10^{-4} mm. gave the *hydroxy-acid* (1·65 g.) as a syrup, n_D^{22} 1·4685 (Found: C, 58·35; H, 8·75. $C_7H_{12}O_3$ requires C, 58·3; H, 8·4%). The *ethyl* ester was prepared by heating the hydroxy-acid (2·5 g.), ethanol (12 c.c.), and concentrated sulphuric acid (0·6 c.c.) under reflux for three hours. Isolation of the product with ether and distillation gave the ester (2·3 g.), b. p. 95°/5·5 mm., n_D^{18} 1·4521 (Found: C, 62·75; H, 9·6. $C_9H_{16}O_3$ requires C, 62·75; H, 9·35%). The ethyl ester *α-naphthylurethane*, prepared at room temperature, formed felted needles, m. p. 88°, from light petroleum (b. p. 60—80°) (Found: N, 4·1. $C_{20}H_{25}O_4N$ requires N, 3·95%).

3-Acetoxy-3-phenylprop-1-ene-2-carboxylic Acid (III; $R_1 = H$, $R_2 = Ph$, $R_3 = Ac$).—Phenylethynylcarbinyl acetate (Jones and McCombie, *J.*, 1942, 733) (11·6 g.), ethanol (20 c.c.), glacial acetic acid (3 c.c.), and water (2 c.c.) reacted at 70° by the general method with nickel carbonyl (3 c.c.) in ethanol (10 c.c.). Isolation of the acidic fraction with ether gave an oil which soon solidified; crystallisation from light petroleum (b. p. 60—80°) gave the *acetoxy-acid* (7·4 g., 50%) as stout needles, m. p. 110·5° unchanged on recrystallisation from the same solvent (Found: C, 65·45; H, 5·5. $C_{12}H_{12}O_4$ requires C, 65·25; H, 5·55%).

3-Hydroxy-3-phenylprop-1-ene-2-carboxylic Acid (III; $R_1 = R_3 = H$, $R_2 = Ph$).—(*a*) The acetoxy-acid (3 g.) was dissolved in a solution of sodium hydroxide (2 g.) in water (20 c.c.). After storage at 20° for 48 hours, acidification and isolation with ether gave a syrup which was induced to crystallise by keeping it for several hours at 35°. Recrystallisation from benzene gave a product (2·0 g.), m. p. 79—80°; after further recrystallisation from the same solvent the *hydroxy-acid* formed fine needles, m. p. 81° (Found: C, 67·15; H, 5·55. $C_{10}H_{10}O_3$ requires C, 67·4; H, 5·65%).

(*b*) Phenylethynylcarbinol (18·3 g.), ethanol (30 c.c.), glacial acetic acid (6 c.c.), and water (2 c.c.) were heated to 80° and maintained at about this temperature while a solution of nickel carbonyl (6 c.c.) in ethanol (15 c.c.) was added in small portions during 20 minutes. No exothermic reaction took place; isolation of the acidic fraction with ether gave a syrup (7·0 g.) whose benzene solution, on addition of light petroleum (b. p. 60—80°) and seeding with material obtained by method (*a*), gave the crude hydroxy-acid (3·1 g.), m. p. 72—75°. After recrystallisation from benzene this had m. p. 81°, undepressed on admixture with a specimen prepared by method (*a*).

3-Acetoxyprop-1-ene-2-carboxylic Acid (III; $R_1 = R_2 = H$, $R_3 = Ac$).—Propargyl acetate (6·5 g.), ethanol (20 c.c.), glacial acetic acid (3 c.c.), and water (1 c.c.) were heated to 70°, and a solution of nickel carbonyl (3 c.c.) in ethanol (10 c.c.) was added, the temperature being maintained at about 75°. After removal of the excess of nickel carbonyl, ether (100 c.c.) was added, and the solution was shaken with a solution of concentrated sulphuric acid (1 c.c.) in water (10 c.c.), which was then extracted with ether (2 × 20 c.c.). The combined ethereal extracts were shaken with a slight excess of a saturated solution of potassium hydrogen carbonate, which was acidified with concentrated hydrochloric acid. After being decanted from the precipitate of potassium chloride, which was washed well with ether, the aqueous solution was extracted with ether (5 × 150 c.c.). Evaporation of most of the solvent from the dried extract through an 8-inch Lapworth column and the removal of the remainder under reduced pressure below 20° gave an oil which readily solidified; crystallisation from light petroleum (b. p. 40—60°) containing a little benzene gave a product (3·1 g.), m. p. 49—50°; a further 0·6 g. of less pure material, m. p. 44°, was obtained from the filtrate. After recrystallisation from light petroleum (b. p. 40—60°) the *acetoxy-acid* formed nacreous leaflets, m. p. 53° (Found: C, 50·2; H, 5·8. $C_6H_8O_4$ requires C, 50·0; H, 5·6%).

3-Hydroxyprop-1-ene-2-carboxylic Acid (III; $R_1 = R_2 = R_3 = H$).—The acetoxy-acid (2·05 g.) was dissolved in a solution of barium hydroxide (4 g.) in water (40 c.c.). After 24 hours the solution was brought to pH *ca.* 2·5 by adding sulphuric acid; after filtration it was found to give no precipitate with barium chloride solution and only a very faint turbidity with sulphuric acid. Evaporation under reduced pressure and distillation at 60—75° (bath temp.)/10^{-4} mm. gave the *hydroxy-acid* (530 mg.), n_D^{19} 1·4760 (Found: C, 46·4; H, 6·4. $C_4H_6O_3$ requires C, 47·05; H, 5·95%).

Methyl 3-Hydroxyprop-1-ene-2-carboxylate.—The acetoxy-acid (2·5 g.), methanol (15 c.c.), and concentrated sulphuric acid (0·5 c.c.) were heated under reflux for five hours. Ether (25 c.c.) was added and the solution was washed with a solution of potassium carbonate (1·5 g.) in water (2 c.c.), the aqueous

layer being extracted with ether (2 × 5 c.c.). The combined extracts were partly dried (Na_2SO_4), and the ether and methanol were evaporated off through an 8-inch Lapworth column. The residue contained a large quantity of water; chloroform and sodium sulphate were added, and, after some time, the latter was separated and the chloroform was distilled off through a column. Distillation of the residue gave the *methyl* ester, b. p. 81°/9 mm., n_D^{16} 1·4548 (Found: C, 51·6; H, 6·85. $C_5H_8O_3$ requires C, 52·2; H, 6·8%).

α-1-*Acetoxy*cyclo*hexylacrylic Acid* [III; $R_1R_2 = (CH_2)_5$, R_3 = Ac].—1-Ethynyl*cyclo*hexyl acetate (Rupe, Messner, and Kambli, *Helv. Chim. Acta*, 1928, **11**, 453) (11·1 g.), dry ethanol (20 c.c.), and glacial acetic acid (3 c.c.) were heated to 75° and maintained at about that temperature for 15 minutes while a solution of nickel carbonyl (3 c.c.) in ethanol (10 c.c.) was added in small portions. Isolation of the acidic portion of the resulting mixture with ether gave a syrup which was dissolved in light petroleum and cooled to 0°. On storage, a rather gummy solid (700 mg.) was obtained, which by crystallisation from light petroleum (b. p. 60—80°) gave the *acetoxy-acid* as stout prismatic needles (500 mg.), m. p. 98·5° unchanged on recrystallisation from the same solvent (Found: C, 62·3; H, 7·6. $C_{11}H_{16}O_4$ requires C, 62·25; H, 7·6%).

α-1-*Hydroxy*cyclo*hexylacrylic Acid* [III; $R_1R_2 = (CH_2)_5$, R_3 = H].—α-1-Acetoxy*cyclo*hexylacrylic acid (200 mg.) was dissolved in a solution of potassium hydroxide (300 mg.) in water (1 c.c.). After 18 hours, isolation of the acidic fraction with ether gave an oil which crystallised after about two weeks at 20°. Recrystallisation from light petroleum (b. p. 60—80°), in which it was rather soluble, gave the *hydroxy-acid* (85 mg.) as acicular prisms, m. p. 78—81°. Further recrystallisation from the same solvent or from aqueous methanol did not alter the melting point; and more drastic conditions of hydrolysis did not improve the yield (Found: C, 63·85; H, 8·05. $C_9H_{14}O_3$ requires C, 63·5; H, 8·2%).

But-3-yn-1-yl Acetate.—Acetylation of but-3-yn-1-ol (IV; R = H) (46 g.) with acetic anhydride (69 c.c.) and pyridine (55 c.c.) with cooling, then for 20 hours at room temperature, gave the *acetate* (54·5 g., 75%), b. p. 65°/40 mm., n_D^{25} 1·4230 (Found: C, 64·0; H, 7·2. $C_6H_8O_2$ requires C, 64·25; H, 7·2%).

4-*Acetoxybut*-1-*ene*-2-*carboxylic Acid.*—But-3-yn-1-yl acetate (7·5 g.), ethanol (20 c.c.), water (0·6 c.c.), and glacial acetic acid (3 c.c.) reacted by the general method with a solution of nickel carbonyl (3 c.c.) in ethanol (20 c.c.). Isolation of the acidic fraction with ether gave a pale yellow oil (4·1 g.), n_D^{22} 1·4520, which was distilled to give the *acid acetate* (3·4 g.), b. p. 100°/0·05 mm., n_D^{24} 1·4515 (Found: C, 53·1; H, 6·65. $C_7H_{10}O_4$ requires C, 53·1; H, 6·35%). The p-*bromophenacyl* ester separated from aqueous methanol in flat needles, m. p. 76° (Found: C, 50·75; H, 4·4. $C_{15}H_{15}O_5Br$ requires C, 50·7; H, 4·25%).

4-(2-*Tetrahydropyranyloxy*)*but*-1-*yne.*—To a mixture of but-3-yn-1-ol (IV; R = H) (15·0 g.) and 2 : 3-dihydropyran (18·5 g.), concentrated hydrochloric acid (0·2 g.) was added. An exothermic reaction took place which was moderated by ice-cooling. After the solution had been kept for 18 hours at 20° potassium hydroxide (0·3 g.) was added, and the precipitated potassium chloride was filtered off; distillation then gave the *ether* (26 g.), b. p. 92—95°/18 mm., n_D^{18} 1·4589 (Found: C, 70·3; H, 9·65. $C_9H_{14}O_2$ requires C, 70·1; H, 9·15%).

4-(2-*Tetrahydropyranyloxy*)*but*-1-*ene*-2-*carboxylic Acid and its Ethyl Ester.*—The above ether (11·4 g.) in ethanol (25 c.c.), glacial acetic acid (4 c.c.), and water (1·5 c.c.) reacted with a solution of nickel carbonyl (4 c.c.) in ethanol (10 c.c.) at 75°. The standard procedure was employed, an exothermic reaction taking place. Isolation of the acidic fraction then gave an oil (3·5 g.) of which a portion (2·2 g.) was distilled at 75° (bath temp.)/10^{-4} mm. to give the *acid* (1·8 g.), n_D^{15} 1·4773 (Found: C, 60·1; H, 8·05. $C_{10}H_{16}O_4$ requires C, 60·0; H, 8·05%). The neutral fraction was distilled to give the corresponding *ethyl* ester (1·5 g.), b. p. 82·5°/0·2 mm., n_D^{18} 1·4612 (Found: C, 63·2; H, 8·85. $C_{12}H_{20}O_4$ requires C, 63·15; H, 8·85%). Attempts to characterise the acid by preparation of crystalline *p*-nitrobenzyl and *p*-bromophenacyl esters proved unsuccessful.

4-*Hydroxybut*-1-*ene*-2-*carboxylic Acid Lactone* ("*α-Methylenebutyrolactone*") (V; R = H).—(*a*) But-3-yn-1-ol (IV; R = H) (10·5 g.), ethanol (30 c.c.), glacial acetic acid (6 c.c.), and water (2 c.c.) reacted at 80° with a solution of nickel carbonyl (6 c.c.) in ethanol (10 c.c.). The reaction began only after a lengthy induction period. After the excess of nickel carbonyl had been removed water was added, the solution was thoroughly extracted with ether, and the extract was washed with the minimum quantities of dilute sulphuric acid and sodium hydrogen carbonate solution. A little quinol was added at this stage. Evaporation of the solvent through an 8-inch Dufton column and distillation gave the lactone (3·4 g., 23%), b. p. 38°/0·2 mm., n_D^{23} 1·4707. Careful re-fractionation gave five fractions whose refractive indices were constant to within 0·0004 (Found: C, 60·9; H, 6·55. Calc. for $C_5H_6O_2$: C, 61·2; H, 6·15%) (Cavallito and Haskell, *loc. cit.*, give b. p. 57—60°/2 mm., n_D^{20} 1·470).

(*b*) A solution of nickel carbonyl (7 c.c.) in methanol (15 c.c.) was added to but-3-yn-1-ol (10·5 g.) in methanol (40 c.c.) and concentrated hydrochloric acid (6 c.c.) at 60°. An exothermic reaction took place; isolation of the neutral fraction (care being taken to remove powdery polymer by decantation) followed by distillation gave the lactone (3 g.), b. p. 92—95°/13 mm., n_D^{21} 1·4662. After a few days an elastic polymer was formed.

4-*Hydroxypent*-1-*ene*-2-*carboxylic Acid Lactone* (V; R = Me).—(*a*) Pent-4-yn-2-ol (IV; R = Me) (12·6 g.) reacted at 80° exactly as in the previous preparation [method (*a*)]. Distillation of the crude product gave the *lactone* (5·05 g.), b. p. 33°/0·02 mm., n_D^{18} 1·4596. Careful re-fractionation gave five fractions whose refractive indices were constant to within 0·0010 (Found: C, 64·5; H, 7·5. $C_6H_8O_2$ requires C, 64·25; H, 7·2%).

(*b*) The reaction was carried out by the general method at 50—55° using pent-4-yn-2-ol (12·6 g.) in methanol (45 c.c.) and concentrated hydrochloric acid (6 c.c.) and adding a solution of nickel carbonyl (5 c.c.) in methanol (15 c.c.). The reaction was strongly exothermic; isolation of the neutral fraction followed by distillation gave the lactone (7·1 g.), b. p. 87—90°/9 mm., which polymerised on storage.

4-*Hydroxy*-4-*methylpent*-1-*ene*-2-*carboxylic Acid Lactone* (VI).—2-Methylpent-4-yn-2-ol (Henbest, Jones, and Walls, *J.*, 1949, 2696) (15·8 g.) was dissolved in ethanol (30 c.c.), glacial acetic acid (7 c.c.), and water (3 c.c.), and the mixture was heated to 75—80° for 20 minutes during the addition of a solution of nickel carbonyl (8 c.c.) in ethanol (10 c.c.). No exothermic reaction was observed; isolation of the neutral fraction and distillation gave a product (3 g.), b. p. 40—64°/1·0 mm., n_D^{19} 1·4375—1·4541, which

after careful refractionation gave the *lactone* (1·5 g.), b. p. 45°/1 mm., n_D^{17} 1·4561 (Found: C, 66·5; H, 8·0. $C_7H_{10}O_2$ requires C, 66·6; H, 8·0%).

5-Hydroxypent-1-ene-2-carboxylic Acid Lactone (VII). Pent-4-yn-1-ol (Eglinton, Jones, and Whiting, forthcoming publication) (12·6 g.) was dissolved in ethanol (20 c.c.), glacial acetic acid (6 c.c.), and water (2 c.c.), and the mixture was heated to 80°. A solution of nickel carbonyl (6 c.c.) in ethanol (10 c.c.) was added; an exothermic reaction began only after a long induction period. Isolation of the neutral fraction and careful fractional distillation gave the *lactone* (3·5 g.), b. p. 56·5°/0·07 mm., n_D^{18} 1·4810. This appeared to be homogeneous, but despite purification by repeated fractional distillation analytical results were inaccurate (Found: C, 63·25, 63·2; H, 7·55, 7·5. $C_6H_8O_2$ requires C, 64·25; H, 7·2%). Its light-absorption properties (see table) were normal.

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