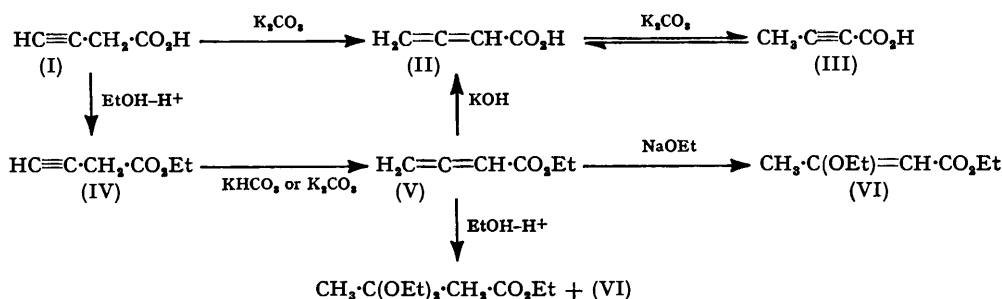*Researches on Acetylenic Compounds. Part XLV.* The Alkaline Isomerisation of But-3-ynoic Acid.*

By G. EGLINTON, E. R. H. JONES, G. H. MANSFIELD, and M. C. WHITING.

Under alkaline conditions but-3-ynoic acid is isomerised in good yields first to buta-2 : 3-dienoic (allenecarboxylic) acid, then under more vigorous conditions to but-2-ynoic (tetrolic) acid. The properties of buta-2 : 3-dienoic acid and its ester have been examined in some detail.

THIS communication describes the beginning of an attempt to extend the classical work of Kon and Linstead and their collaborators on the prototropy of ethylenic acids, esters, nitriles, and ketones (see, *inter al.*, Bennett and Baker, *Ann. Reports*, 1931, **28**, 105) to structurally similar substances possessing more than one unit of unsaturation. The obvious starting-point for such a study is the simplest βγ-acetylenic acid (I), which was first prepared by Sargent (Thesis, London, 1948; see Heilbron, Jones, and Sondheimer, *J.*, 1949, 606) by the oxidation of but-3-yn-1-ol with chromic acid. Since then this acid has been obtained by the interaction of propargylmagnesium bromide and carbon dioxide (Wotiz, Matthews, and Lieb, *J. Amer. Chem. Soc.*, 1951, **73**, 5503; cf. Prevost, Gaudemar, and Honigsberg, *Compt. rend.*, 1950, **230**, 1186). The American authors also found that the liquid acidic material obtained from the mother-liquors from (I) had an infra-red absorption spectrum suggesting that the allenic acid (II) was present. By analogy with Wotiz's earlier work on substituted propargyl bromides (*J. Amer. Chem. Soc.*, 1950, **72**, 1639) it was assumed that (II) was formed directly in the Grignard reaction. In view of the method of isolation reported we accept this assumption despite the ready isomerisation of (I) to (II) discussed below.

$$HC{\equiv}C{\cdot}CH_2{\cdot}CO_2H \xrightarrow{K_2CO_3} H_2C{=}C{=}CH{\cdot}CO_2H \underset{K_2CO_3}{\rightleftharpoons} CH_3{\cdot}C{\equiv}C{\cdot}CO_2H$$

(I)   (II)   (III)

$$\downarrow EtOH{-}H^+ \qquad\qquad \uparrow KOH$$

$$HC{\equiv}C{\cdot}CH_2{\cdot}CO_2Et \xrightarrow[KHCO_3 \text{ or } K_2CO_3]{} H_2C{=}C{=}CH{\cdot}CO_2Et \xrightarrow{NaOEt} CH_3{\cdot}C(OEt){=}CH{\cdot}CO_2Et$$

(IV)   (V)   (VI)

$$\downarrow EtOH{-}H^+$$

$$CH_3{\cdot}C(OEt)_2{\cdot}CH_2{\cdot}CO_2Et + (VI)$$

Preliminary investigations showed that under vigorous alkaline conditions (*e.g.*, 10% sodium hydroxide at 100°) the acid (I) was converted into acetone [presumably *via* (II), or perhaps (III), and acetoacetic acid]. Ethanolic alkali gave β-ethoxycrotonic acid. With milder reagents, however, buta-2 : 3-dienoic acid (II) was obtained. Its strong infra-red absorption band at 1980 cm.$^{-1}$ (ε = 140) made possible a systematic investigation of the effects of varying reaction conditions; optimally, treatment of (I) with 18% potassium carbonate solution at 40° for 3 hr. gave a 92% yield of (II).

Under more vigorous conditions (II) was further isomerised to tetrolic acid (III), a reaction which was studied similarly by using the 2250 cm.$^{-1}$ band (ε = 290) of the acetylenic acid. With 18% potassium carbonate at 90° a yield of 60% was obtained after 6 hours, which sets a limiting value of 1·5 for the equilibrium constant for the anions of (III) and (II). This was determined more accurately by prolonging the reaction period beyond the point of maximal yield of (III); the ratio of the extinction coefficients at the chosen frequencies then became constant, indicating a value for (III)/(II) of 2·22. When the equilibrium was approached from the other side, the value obtained was 2·15. It is

believed that this result is reliable to about ± 0.2 since absorption in this region of the spectrum with appreciable intensity is quite uncommon, and any by-products would presumably be almost transparent.

From the equilibrium constants it follows that the free-energy differences between the anions of (I) and of (II) at 40° is at least 1·5 kcals., and between those of (II) and (III), at 90°, 0·57 kcal. Unfortunately the kinetic distinction between the two isomerisations, and between the second of these and the hydration–decarboxylation reactions which ensue, are insufficient to permit much variation in the reaction conditions for quantitative experiments.

As might have been expected, the ester of (I) isomerised to the allene much more readily than the related anion. Even potassium hydrogen carbonate solution at 50° catalysed the reaction, which with 10% potassium carbonate proceeded almost to completion at 20° in 45 minutes in a heterogeneous system. Dilute ammonia solution effected the same change, though stronger solutions converted the product into β-aminocrotonic ester. Hydrolysis of either ethyl but-3-ynoate (IV) or ethyl buta-2 : 3-dienoate (V) with aqueous sodium hydroxide solution gave the butadienoic acid, together with some β-ethoxycrotonic ester (VI), which is comparatively resistant to hydrolysis. The ethoxy-ester was the main product when either ester was treated briefly with aqueous-ethanolic potassium hydroxide solution; on more prolonged treatment the corresponding acid was, of course, obtained. In contrast to these ready isomerisation reactions under alkaline conditions, (IV) was unaffected by dilute aqueous mineral acids at 20° or even, for brief periods, at 80°.

The allenic acid (II) is lower-melting and more volatile than either of its acetylenic isomers; it is stable in air at room temperature for several weeks. Its ester shows lachrymatory and skin-irritant properties, in contrast to but-3-ynoic and tetrolic esters. The acid can be esterified with diazomethane in low yield only, much polymeric material being formed simultaneously. Ethanolic sulphuric acid esterifies butadienoic acid, but the ester apparently adds ethanol at a comparable rate to give a mixture of β-ethoxy-crotonic and ββ-diethoxybutyric ester. When heated in an inert solvent the acid (II) gradually polymerised and a little dehydracetic acid was isolated, a fact which emphasises the close relationship of (II) to diketen, similarly an " anhydride " of acetoacetic acid.

The reactions of the ester (V) with nucleophilic reagents include the addition of ethanol in the presence of potassium carbonate, *i.e.*, a much milder catalyst than is necessary for similar addition reactions with αβ-acetylenic esters. Similarly piperidine and even aromatic amines (aniline and *p*-phenetidine) underwent exothermal addition reactions at room temperature; these latter amines react with, *e.g.*, tetrolic ester only on being warmed. The products were the β-substituted crotonic esters in every case. Thus it is probably safe to generalise that the allenic ester is more reactive than tetrolic ester toward nucleophilic reagents, and equivalent to it; since tetrolic ester is itself a more reactive equivalent of acetoacetic ester in many synthetic procedures (especially for heterocyclic compounds), this may be of some preparative significance.

Perhaps the most remarkable example of the exceptional reactivity to nucleophilic reagents at the β-carbon atom in these allenes was afforded by the action of lithium aluminium hydride on the acid and ester. The primary products were vinylacetic acid and ester, respectively; with an excess of the reagent these underwent some further reduction to but-3-en-1-ol, but buta-2 : 3-dien-1-ol could not be detected. Here this reagent, generally considered specific for the reduction of the $\diagup C{=}O$, as opposed to the $\diagup C{=}C\diagdown$, linkage, actually reduces the latter preferentially. In contrast, αβ-acetylenic esters are reduced first to acetylenic primary alcohols (Bates, Jones, and Whiting, *J.*, 1954, 1854). This behaviour of the simplest allenic ester and acid may be compared with the 1 : 4-addition of Grignard reagents to the 2-butyl derivative of (V) (Wotiz and Matthews, *J. Amer. Chem. Soc.*, 1952, **74**, 2559), though the ester of this substituted allenic acid behaved normally with lithium aluminium hydride.

As a complement to the chemical reduction described above, the partial catalytic hydrogenation of butadienoic acid in the presence of 1·5% palladium on calcium carbonate was examined. The product was essentially pure *cis*-crotonic acid, as judged by the almost complete absence of absorption at 690 cm.$^{-1}$, where the *trans*-isomer has an intense

band. A little vinylacetic acid may also have been present. *threo*-αβ-Dibromocrotonic acid was isolated in 70% yield on bromination, as expected. Preferential attack on the βγ-double bond is easily understood, but the complete stereospecificity of the hydrogenation is surprising; approach of an activated hydrogen molecule from the side unobstructed by the carboxyl group, giving the *cis*-isomer, is evidently far more probable.

The ultra-violet absorption spectra of the compounds discussed are :

Substance	(I)	(IV) *	(II)	(V) *	(III)	Methyl but-2-ynoate
$\lambda_{max.}$, Å	<2000	<2000	<2000	<2000	2055	2060
ε	(110) †	(630) †	(6400) †	(8300) †	6300	7200

* Purest specimen obtained. † At 2100 Å.

EXPERIMENTAL

In the work described below, infra-red absorption spectra were determined with a Perkin-Elmer Double-Beam Spectrometer, Model 21; ultra-violet spectra with a Unicam SP500 Spectrophotometer, in 95% ethanol; and melting-points with the Kofler block.

Buta-2 : 3-dienoic Acid (II).—But-3-ynoic acid (5·0 g.) was treated with potassium carbonate solution (18% ; 200 c.c.) at 40° for 3 hr. After acidification and isolation with ether the *acid* (4·6 g.) had m. p. 61—63°, raised to 65—66° by crystallisation from light petroleum (Found : C, 57·25; H, 4·7%; equiv., 84·2. $C_4H_4O_2$ requires C, 57·15; H, 4·8%; equiv., 84·1).

But-2-ynoic Acid (III).—Buta-2 : 3-dienoic acid (4·0 g.) was treated with potassium carbonate solution (18% ; 300 c.c.) at 90° for 8 hr. After acidification, extraction with ether, and recrystallisation from light petroleum (b. p. 60—80°) the product (2·4 g.) had m. p. 75—76°, undepressed on admixture with an authentic specimen of tetrolic acid.

Ethyl But-3-ynoate (IV).—A solution of but-3-ynoic acid (32 g.) in ethanol (270 c.c.) and sulphuric acid (10 c.c.) was set aside at 20° for 10 days. Isolation of the neutral fraction with especial care to minimise contact with alkaline solutions gave the *ester* (33 g.), b. p. 104—105°/190 mm., n_D^{19} 1·4291 (Found : C, 63·8; H, 7·2. $C_6H_8O_2$ requires C, 64·3; H, 7·2%).

Ethyl Buta-2 : 3-dienoate (V).—(*a*) A solution of but-3-ynoic acid (32 g.) in ethanol (200 c.c.) and sulphuric acid (12 c.c.) was set aside at 20° for 7 days. An excess of a saturated solution of potassium carbonate was added and the solution was filtered. After removal of most of the ethanol by distillation and addition of water (800 c.c.) the neutral fraction was isolated with ether and distilled, giving the *ester* (19 g., 44%), b. p. 44°/130 mm., n_D^{19} 1·4585 (Found : C, 64·65; H, 7·3. $C_6H_8O_2$ requires C, 64·25; H, 7·2%). The residue from the distillation was ethyl β-ethoxycrotonate (*ca.* 8 g.). Infra-red absorption data revealed the presence of a trace of the βγ-acetylenic ester (IV) in the allenic ester.

(*b*) Ethyl but-3-ynoate (1·1 g.) was shaken with 10% potassium carbonate solution (10 c.c.) for 10 min., and the suspension was set aside for 16 hr. Isolation with ether gave the allenic ester (0·9 g.), $n_D^{20·5}$ 1·4555 unchanged on repetition of this alkaline treatment. A somewhat greater quantity of the acetylenic ester than in the specimen described above (~10%) appeared to be present.

The ester reacted only slowly with bromine in carbon tetrachloride, iodine in ethanolic potassium iodide, or ozone at 20°; it did not polymerise when warmed to 100° with benzoyl peroxide or on treatment with boron trifluoride.

Ethyl β-Ethoxycrotonate (VI).—Ethyl but-3-ynoate (1·1 g.) was added dropwise to a solution of sodium ethoxide (from sodium, 0·23 g.) in ethanol. When the exothermal reaction ceased, the neutral fraction (1·45 g.) was isolated with ether; it solidified completely and had m. p. 30°, undepressed on admixture with an authentic specimen of ethyl β-ethoxycrotonate, m. p. 30°.

Ethyl β-Piperidinocrotonate.—Piperidine (0·85 g.), ethyl buta-2 : 3-dienoate (1·12 g.), and ether (10 c.c.) were warmed under reflux for 3 hr. Distillation then gave the ester (1·05 g.), b. p. 110° (bath temp.)/0·03 mm., n_D^{16} 1·5392 (Found : C, 66·9; H, 9·4; N, 7·1. Calc. for $C_{11}H_{19}O_2N$: C, 67·0; H, 9·7; N, 7·1%). (Feist, *Annalen*, 1906, **345**, 100, gives b. p. 169°/15 mm.) Light absorption : max., 2870 Å, ε = 24,700.

Ethyl β-Anilinocrotonate.—Aniline (0·93 g.) and ethyl buta-2 : 3-dienoate (1·12 g.) similarly gave the anilino-ester (1·15 g.), b. p. 106°/0·5 mm., n_D^{16} 1·5820 (Found : N, 7·0. Calc. for $C_{12}H_{15}O_2N$: N, 6·8%). (Coffey, Thompson, and Wilson, *J.*, 1936, 859, give b. p. 137—139°/6 mm.) Light absorption : max., 3010 Å, ε = 20,400.

Ethyl β-p-Ethoxyanilinocrotonate.—This was similarly prepared from *p*-phenetidine (0·68 g.) and the ester (V) (0·56 g.). After chromatographic purification and crystallisation from *iso*propyl

ether, the ester (0·95 g.) had m. p. and mixed m. p. 53—54°. Light absorption : max., 2960 Å, $\varepsilon = 22,800$.

A somewhat lower yield was obtained when the amine and ester were mixed at room temperature without a diluent; the temperature rose at once to 90°, necessitating external cooling.

Polymerisation of Buta-2 : 3-dienoic Acid.—A solution of the allenic acid (II) (500 mg.) in xylene (5 c.c.) was heated under reflux for 1 hr. Evaporation of the solid and sublimation at 0·1 mm. gave dehydracetic acid (60 mg.), m. p. and mixed m. p. 110° after recrystallisation from pentane. The infra-red spectrum was identical with that of an authentic specimen.

Hydrogenation of Buta-2 : 3-dienoic Acid.—A solution of the allenic acid (2·0 g.) in ethyl acetate (100 c.c.) was shaken in hydrogen with a palladium–calcium carbonate catalyst (1·5% Pd; 1 g.). After the compound had absorbed 1 mole (18 min.) of hydrogen the catalyst and solvent were removed; a portion of the residue (2·0 g.) was dissolved in carbon disulphide, and its infra-red spectrum was examined. Bands at 1940, 990, and 690 cm.$^{-1}$ were absent, which excludes the possibilities that buta-2 : 3-dienoic, vinylacetic, and *trans*-crotonic acid, respectively, were present in significant quantity. Bands at 820 cm.$^{-1}$ and 729 cm.$^{-1}$ were observed, the intensities approaching those of an authentic sample of *cis*-crotonic acid at these frequencies. Another portion (0·50 g.) was treated with bromine (0·93 g.) in carbon tetra-chloride (5 c.c.); evaporation of the solvent and recrystallisation from pentane gave *threo*-αβ-dibromobutyric acid (1·0 g.), m. p. 58—59° (Michael and Schulthess, *J. prakt. Chem.*, 1892, **46**, 241, give m. p. 59°).

Vinylacetic Acid and But-3-en-1-ol.—Buta-2 : 3-dienoic acid (II) (5·0 g., 0·059 mol.) in ether (50 c.c.) was added dropwise to an ethereal solution of lithium aluminium hydride (435 c.c.; containing 0·049 mol.) at −20° during 1·5 hr. Addition of water and sulphuric acid, and separation into acidic and neutral portions, gave but-3-en-1-ol (0·85 g.), b. p. 112°/767 mm., n_D^{21} 1·4180. Because of confusion in the literature on this compound, an authentic specimen was prepared by incomplete semihydrogenation of but-3-yn-1-ol; the acetylenic alcohol (but not butan-1-ol) can readily be separated from but-3-en-1-ol by fractional distillation. This had b. p. 115°/752 mm. (a more reliable figure than that of the small-scale distillation), n_D^{21} 1·4198. Both specimens gave an *α-naphthylurethane*, m. p. 76—77°, undepressed on admixture (Found : C, 74·75; H, 6·2; N, 5·5. $C_{15}H_{15}O_2N$ requires C, 74·65; H, 6·25; N, 5·8%), and their infra-red spectra were identical.

Distillation of the acid fraction gave vinylacetic acid (1·18 g.), b. p. 85° (bath temp.)/16 mm., n_D^{23} 1·4218 (Linstead, Noble, and Boorman, *J.*, 1933, 560, give b. p. 72°/14 mm., n_D^{20} 1·4220). Bromination gave βγ-dibromobutyric acid, m. p. 49—50° (Fichter and Sonneborn, *Ber.*, 1902, **35**, 938, give m. p. 49—50°).

A similar reduction of ethyl buta-2 : 3-dienoate gave ethyl vinylacetate, b. p. 75°/130 mm., n_D^{20} 1·4110 (Bruylants, *Bull. Soc. chim. Belg.*, 1929, **38**, 163, gives b. p. 124°/755 mm., n_D^{20} 1·4105) (Found : C, 62·6; H, 9·3. Calc. for $C_6H_{10}O_2$: C, 63·15; H, 8·85%). A small quantity of but-3-en-1-ol was also present.