

125. *Investigations of the Olefinic Acids. Part XII. β -Phenylhexenoic and β -Methylpentenoic Acids.*

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THE experiments to be described were undertaken primarily in order to study the relationship between configurational and tautomeric changes in simple olefinic acids. Some dibasic acids have already been examined by Linstead and Mann (J., 1931, 726), who suggested that configurational changes in the stereoisomeric $\alpha\beta$ -acids probably proceed by way of a tautomeric change, through the intermediate production of the Δ^β -acid.

Stereoisomeric β -alkylcinnamic acids have been prepared by Stoermer, Grimm, and Laage (*Ber.*, 1917, **50**, 966), and the two forms of β -methyl- β -propylacrylic acid by Kon, Leton, Linstead, and Parsons (J., 1931, 1411); no Δ^β -unsaturated acid has yet been obtained in two forms. The tautomerism of the β -alkylcinnamic acids was first examined by Johnson and Kon (J., 1926, 2750), but owing to the inadequate technique then available, their results require correction in a number of respects. The errors are principally due to the method of separation of Δ^α - and Δ^β -acids by means of their basic copper salts (Stoermer, Grimm, and Laage, *loc. cit.*), which is now found to be inadequate.

Pure β -phenyl- Δ^β -hexenoic acid has now been prepared by the method of partial esterification, in addition to the two pure Δ^α -acids already known. Mixtures of these acids can be analysed by a bromometric method which estimates the Δ^β -acid present, and an approximate separation of the two Δ^α -acids can be effected through their basic copper salts.

The acids were very slowly isomerised by boiling alkali and the mobility could be determined only approximately [$(k_1 + k_2) \times 10 = 0.05-0.1$]; the equilibrium point is 32% of Δ^α -acid. This corresponds closely to the values already determined for β -methyl-

and β -propyl-hexenoic acids, namely, 33 and 34% respectively (Kon, Leton, Linstead, and Parsons, *loc. cit.*; Kon and May, J., 1927, 1549); the phenyl group in the β -position thus has the same effect as an alkyl group on the position of equilibrium. The equilibrium mixtures obtained starting with any one acid (*cis*- Δ^{α} -, *trans*- Δ^{α} -, and Δ^{β} -) appear to contain all three acids, but the *cis-trans* interconversion is far from complete and is evidently an extremely slow process; for this reason it was impossible to determine the nature of the equilibrium, if any, attained between the stereoisomeric Δ^{α} -acids.

The β -methylpentenoic acids are relatively mobile, but their stereochemistry is more complicated. The products of dehydration of β -hydroxy- β -methylvaleric acid and of its ester have now been found to consist of four different unsaturated acids. Two of these are stereoisomeric forms of β -methyl- Δ^{α} -pentenoic acid (β -methyl- β -ethylacrylic acid), the well-known solid acid of m. p. 48—49° (lit. 45°) (*trans*) and a new *cis-isomeride*, m. p. 12°. The other two are the stereoisomeric Δ^{β} -acids melting at 1° and 35°. The existence of a second Δ^{α} -acid has long been suspected (compare Kandiah and Linstead, J., 1929, 2139); it has now been isolated from the liquid by-product which accompanies the acid, m. p. 45°, when it is obtained by the dehydration of β -hydroxy- β -methylvaleric acid with acetic anhydride. It has the same general properties as the known Δ^{α} -acid and yields the same derivatives (compare Newbery, J., 1925, 127, 295; Kandiah and Linstead, *loc. cit.*), but its melting point is depressed by admixture of the latter.

The Δ^{β} -acid of m. p. 1°, provisionally called the *cis*, was obtained by the equilibration of either of the Δ^{α} -acids with alkali. The Δ^{β} -acid obtained by the dehydration of ethyl β -hydroxy- β -methylvalerate by the customary methods (compare Kon and Nargund, J., 1932, 2461) was, however, a mixture containing the second Δ^{β} -acid, m. p. 35°. When this mixture was boiled with alkali, a product was obtained which had a higher iodine addition than that formed from either of the Δ^{α} -acids or the Δ^{β} -acid, m. p. 1°. The acid, m. p. 35°, itself has a high affinity for iodine and this combination of facts suggested that it might be the Δ^{γ} -isomeride. Oxidation with ozone yielded products which definitely establish the $\beta\gamma$ -position of the double bond and it is not clear why the acid does not appear to participate in the tautomeric interchange in presence of alkali.

Both Δ^{α} -acids give on equilibration a mixture containing 62.5% of the Δ^{β} -acid, m. p. 1°; the mobility is 0.69. Interconversion of the stereoisomeric acids takes place at the same time and even more rapidly than the tautomeric change, and must therefore be supposed to occur, to some extent at least, independently of the latter. The proportion of the two Δ^{α} -acids in these mixtures can be estimated with some accuracy (p. 603) and it appears that approximately equal amounts are present at equilibrium.

It has been suggested that the movement of the double bond in β -alkylolefinic acids under the influence of sulphuric acid is more rapid than their conversion into lactones. The β -methylpentenoic acids provide definite evidence in support of this statement. Both the stereoisomeric Δ^{α} -acids and the Δ^{β} -acid are converted into β -methyl- γ -valerolactone (Fichter and Gisiger, *Ber.*, 1909, 42, 4707) at the same rate in cold sulphuric acid. Moreover, the Δ^{α} -acid can be isolated from the product of the incomplete lactonisation of the Δ^{β} -acid, showing that tautomeric change between the acids does occur before it is finally masked by the irreversible conversion into lactone. All the four possible types of unsaturated acid-lactone systems (Linstead, J., 1932, 115) have thus been experimentally realised.

Some β -hydroxy- β -methylvaleric acid was formed as a by-product in these experiments. It could not have been an effective intermediate in the change, because, although it is partly converted into β -methyl- γ -valerolactone and the unsaturated acids under the same experimental conditions, the formation of the lactone from it is much slower than from the unsaturated acids. The hydroxy-acid could, however, be formed by the hydrolysis of an intermediate of the type postulated by Linstead and Noble (this vol., p. 611).

EXPERIMENTAL.

cis- and trans- β -Phenyl- Δ^{α} -hexenoic Acids.—These were obtained as described by Stoermer, Grimm, and Laage (*loc. cit.*) and by Johnson and Kon (*loc. cit.*). The separation by the basic

copper salt method required several repetitions before pure products could be obtained and only gives approximate results; the *cis*-acid is more readily purified than the *trans*-, but no separation of the *cis*- from the Δ^β -acid is possible by this method.

β -Phenyl- Δ^β -hexenoic Acid.—The crude ester, prepared as described by Johnson and Kon (*loc. cit.*), was hydrolysed by keeping it with a slight excess of 10% aqueous potassium hydroxide and enough alcohol to give a homogeneous solution, for 4 days at room temperature. The acid was isolated, and partly esterified for 5 hours under the conditions of Kon and Thakur (J., 1930, 2220). The ester obtained (46% yield) had b. p. 146—150°/15 mm.; the unesterified acid gave a 14% yield of *trans*- Δ^α -acid on freezing. The mother-liquor from this was again partly esterified for 4 hours, more crude Δ^β -ester being obtained; the recovered acid gave a fresh crop of Δ^α -acid on freezing. The liquid acid was again esterified for 24 hours to remove the last trace of the Δ^β -acid, the solid recovered being a mixture of the *cis*- and *trans*- Δ^α -acids.

The ester obtained above was hydrolysed in the cold, and the acid (*M*, 196.9) freed from non-acidic impurities by repeated extraction of its solution in 10% aqueous sodium bicarbonate with ether and reprecipitation. The purified acid (*M*, 191.1; calc., 190.1) was partly esterified for 2 hours; the small amount of ester formed was re-hydrolysed as above to an acid which had practically the same bromine addition (see below) as the unesterified portion. The latter was therefore partly esterified for 24 hours, giving a 55% yield of the pure Δ^β -ester, b. p. 153—155°/22 mm., d_4^{20} 1.0047, n_D 1.5157, $[R_L]_D$ 65.55. The acid obtained from it on hydrolysis had, after purification through sodium bicarbonate, b. p. 154—156°/3 mm., d_4^{20} 1.0598, n_D 1.5436, $[R_L]_D$ 56.57, and *J* 87.7% (Found: *M*, 190.1); it did not solidify at -60° . The unesterified portion had *J* 85.3%.

Analysis of Mixtures.—The Δ^β -acid reacts very slowly with iodine in potassium iodide (Linstead and May, J., 1927, 2565); with bromine in potassium bromide solution, both it and the two Δ^α -acids react to a considerable extent. The use of bromine in chloroform solution (*N*/20) gave suitable differences in reaction velocity with *M*/60-solutions of the acids in the same solvent. The largest differences were observed with a reaction period of 5 minutes; all the experiments were conducted as nearly as possible at 20° with fresh solutions of the halogen. The *trans*- Δ^α -acid had a higher addition than the *cis*- (28 and 20% respectively); only the former was employed in the construction of the reference curve from the following values:

Mixture, % Δ^α	0	10	20	40	60	80	90	100
<i>J</i> , %	88.1	88.6 ?	80.6	68.0	52.3	39.1	34.0	26.0

Numerous experiments were made to devise an analytical method for the estimation of all three acids in mixtures. Bougault's method (*Compt. rend.*, 1904, 139, 864; compare Linstead and May, *loc. cit.*) could not be successfully applied. Partial esterification removed the Δ^β -acid, the amount of which could be determined bromometrically as above, only if the treatment was repeated, and neither of the Δ^α -acids was appreciably esterified in 16 hours. Two alternative methods were then tried on two mixtures containing known amounts of the three acids: partial esterification for two periods of 16 hours, followed by a separation of the remaining Δ^α -acids by the copper salt method, and the reverse procedure, whereby a mixture of *cis*- Δ^α - and Δ^β -acid was obtained and subjected to partial esterification. Neither method gave more than an approximate separation.

Equilibrations.—The three acids were equilibrated under Linstead's standard conditions (J., 1927, 2579) for 1, 2, and 6 hours, but no measurable change was observed. A sample of the Δ^β -acid equilibrated for 48 hours at the b. p. (copper flask) showed 10% change. This was confirmed by isolating the Δ^α -acid formed by the copper salt method (Found: 11.5%). The equilibrium point was determined by equilibrating mixtures of Δ^β - and *trans*- Δ^α -acid:

No.	Mixture.	Time (hours).	<i>J</i> .	% Δ^α -Acid.	<i>M</i> (by titration).
1	50% Δ^α -Acid	48 at b. p.	66.2	42.5	192.5
2	Product of 1.....	"	70.4	37.0	193.5
3	Product of 2.....	"	74.3	32.0	—
4	75% Δ^α -Acid	398 at b. p.	76.5	29.0	192.5
5	25% Δ^α -Acid	48 at b. p.	74.3	32.0	194.0

Configurational Change.—(i) 10 G. of the Δ^β -acid were equilibrated for 217 hours with 25% potassium hydroxide solution at 100°, giving 7.7 g. of acid containing 10% of Δ^α -acid. After two partial esterifications (24 and 16 hours) 1.5 g. of acid remained unesterified; this partly solidified in ice and, after being washed with petroleum and pressed on a tile, the solid had m. p. 91—95°, thus consisting of almost pure *trans*- Δ^α -acid. (ii) The *trans*- Δ^α -acid was equi-

brated for 72 hours at the b. p., and the recovered solid acid pressed on a tile and subjected to separation by the copper salt method. Practically pure *trans*- Δ^{α} -acid was recovered from the soluble portion of the salt; a small amount of insoluble fraction gave an acid also consisting mainly of the *trans*-acid, but evidently containing a little *cis*-acid. (iii) An experiment with the *cis*- Δ^{α} -acid showed that the Δ^{β} -acid was produced from it at a rate comparable with the equilibration of the *trans*-isomeride; the formation of the *trans*-acid from it was not directly established owing to the slowness of the reaction.

cis- and trans- β -Methyl- Δ^{α} -pentenoic Acids.—The Δ^{α} -acid was prepared as described by Kon and Linstead (J., 1925, 127, 616). The liquid portion of the product (83 g. from 140 g. of hydroxy-acid) was freed from Δ^{β} -acid and acetic acid by partial esterification for 12 hours; crystals of the *trans*-acid which separated when the unesterified portion (56 g.) was kept were filtered off; a further crop was obtained by cooling the mother-liquor to 0° (total yield, 21.5 g.), m. p. 48—49° after crystallisation from petroleum (b. p. 40—60°), *M*, 114.2 (calc., 114.1), and *J* 1.6 in 1 hour by the standard method of Linstead and May (*loc. cit.*). The acid chloride had b. p. 85—86°/20 mm., and the amide, m. p. 94—94.5° (compare Kon and Linstead, *loc. cit.*).

The mother-liquor from the *trans*-acid was freed from neutral impurities by solution in 10% aqueous sodium bicarbonate and repeated extraction with ether. The recovered acid was distilled to remove a high fraction (probably hydroxy-acid); the fraction (23 g.), b. p. 88—92°/3 mm., solidified completely in a freezing mixture. It was allowed to liquefy to some extent and submitted to filtration, but only a little solid was collected. The liquid had f. p. 4.25° and *J* 2.0 and therefore did not contain any Δ^{β} -acid; the f. p. was first depressed and then elevated by progressive additions of the *trans*- Δ^{α} -acid. The liquid was dried in ethereal solution and redistilled; a specimen, f. p. 5.6°, was then obtained which was shown to be approximately homogeneous by filtering the partly solidified specimen and determining the f. p. of the solid and the liquid portion (5.55° and 5.4° respectively). A second preparation gave a specimen, which is regarded as the pure *cis*-acid, b. p. 96°/5 mm., f. p. 11.6°, m. p. 12°, d_4^{20} 0.9830, n_D 1.4650, $[R_L]_D$ 32.08 (calc., 31.10), *J* 2.6 (Found: C, 62.9; H, 8.9; *M*, by titration, 114.4. $C_6H_{10}O_2$ requires C, 63.1; H, 8.9%; *M*, 114.1).

cis- and trans- β -Methyl- Δ^{β} -pentenoic Acids.—The crude Δ^{β} -ester (Kon and Nargund, J., 1932, 2461) was hydrolysed as described on p. 601, and the product subjected to partial esterification for 5 hours. The ester obtained in 42% yield had d_4^{20} 0.9060, n_D 1.4273, $[R_L]_D$ 40.32 (calc., 40.33), *J* 81.4 in 1 hour. The acid obtained on hydrolysis was freed from neutral impurities by means of sodium bicarbonate and had *J* 45.5 in 10 minutes. It was again esterified for 3 hours; the ester obtained together with a good deal of unesterified acid was similar to the above, *J* 82.2, and gave an acid with *J* 47.5. The remainder of the acid was esterified for 8 hours; the acid obtained from this ester had d_4^{20} 0.9733, n_D 1.4439, $[R_L]_D$ 31.14 (calc., 31.10), *M* 114.0, and *J* 47.3; another sample of very similar properties was also obtained, m. p. 9—11°, *J* 76.8 in 1 hour. The acid chloride had b. p. 55°/20 mm., and the *p*-toluidide, m. p. 85°.

Separation of cis- and trans-Acids.—Certain equilibrations (see below) of the Δ^{β} -acid obtained as above gave equilibrium mixtures with higher iodine additions than those derived from the Δ^{α} -acid; this suggested the presence of an impurity of high iodine addition, which was at first thought to be the Δ^{γ} -acid (compare Goldberg and Linstead, J., 1928, 2343). For this reason a pure specimen of the Δ^{β} -acid was prepared by the partial esterification of a mixture derived from the equilibration of 40 g. of *trans*- Δ^{α} -acid for 3 days. The ester on hydrolysis gave an acid, b. p. 90—94°/7 mm., m. p. 1°, d_4^{20} 0.9762, n_D 1.4430, $[R_L]_D$ 30.98, *M* 115.1, and *J* 76.2 in 1 hour; this is assumed to be the pure *cis*-form of the Δ^{β} -acid.

The stereoisomeric acid was isolated by a similar process from the Δ^{β} -acid obtained as described above. This was first equilibrated on the assumption that the Δ^{β} -acid in it would be partly converted into the Δ^{α} -; on partial esterification a product rich in the supposed Δ^{γ} -acid would result. After several equilibrations, followed by partial esterification, an acid with the high iodine addition of 85.4 was isolated; it had b. p. 95°/11 mm., d_4^{20} 0.9755, n_D 1.4438, and melted at about 25°; after two crystallisations from petroleum (b. p. 40—60°) it attained the constant m. p. 35°, *J* 87.7 (Found: C, 63.2; H, 8.8; *M*, 114.4. $C_6H_{10}O_2$ requires C, 63.2; H, 8.9%; *M*, 114.1). The *trans* (?) - Δ^{β} -acid appears to be more rapidly esterified than its stereoisomeride and accumulates in the first portions of the ester formed in partial esterification. The ester obtained from it, b. p. 63°/13 mm., was ozonised in chloroform solution, and the ozonide freed from solvent and decomposed with water. The solution contained much acetaldehyde, which was identified by means of dimethyldihydroresorcinol, together with an oil giving an intense colour with ferric chloride, from which no crystalline derivatives could be obtained.

Analysis of Mixtures.—The percentage of Δ^β -acid contained in mixtures was determined by the iodometric method of Linstead and May (*loc. cit.*), with the aid of a reference curve constructed from the following values :

Mixture, % Δ^α	0	10	20	40	60	80	90	100
<i>J</i> , % in 1 hour	78.0	73.1	67.6	55.5	40.6	23.0	13.1	3.3

The Δ^β -acid used for the above curve was a mixture of *cis*- and *trans*-forms. Owing to the lower addition of the pure *cis*-acid (76.0), which appears to be the only form produced on equilibration of the Δ^α -acid, a slight correction has to be applied to the above figures.

Mixtures of the two Δ^α -acids could be analysed with the aid of a freezing-point curve constructed from the following values :

Mixture, % <i>cis</i>	0	19.2	32.5	43.9	50.6	50.4	63.1	67.2	72.1	87.4	91.4	95.5	100
F. p. (average of several)	45.0°	38.4°	33.9°	29.3°	26.4°	26.0°	20.6°	16.9°	13.8°	7.4°	7.0°	8.2°	11.4°

Two synthetic mixtures, A and B, of the three acids were completely analysed. The % of Δ^β -acid was first determined iodometrically; they were then partly esterified for 12 hours. The combined esters (yield, 20%; calc., 32%) had *J* 50.2. This shows that some Δ^α -acid had been esterified, but as both the *cis*- and the *trans*- Δ^α -acid are esterified at comparable rates, this is immaterial. The unesterified portion had the following properties :

Mixture.	Yield.	<i>J</i> .	% Δ^α .	<i>M</i> .	F. p. observed.	% <i>cis</i> .
A	34	10.2	93.0	115.1	24.2°, 23.6°	55.5
					24.2°, 24.3°	
B	53	5.1	98.0	114.8	19.3°, 20.0°	64.0
					20.05°, 19.9°	

Hence for the original mixtures :

	A.	Found.	Actual.	B.	Found.	Actual.
Δ^β		50.0	50.4		18.5	18.2
<i>cis</i> - Δ^α		27.7	25.0		52.7	55.1
<i>trans</i> - Δ^α		22.3	24.6		29.8	26.7

Evidently for mixtures containing over 20% of Δ^β -acid two successive partial esterifications are necessary; this procedure was adopted as standard.

Equilibrations.—Linstead's standard method (*loc. cit.*) was used. Several methods of working up the products were tried, the purity of the acid being checked by titration; it was not found necessary to distil the equilibrated acid in steam (compare Goldberg and Linstead, *loc. cit.*), but it was freed from neutral impurities by means of sodium bicarbonate and distilled under reduced pressure. Of the numerous experiments performed, the following may be recorded :

Initial material.	Time (hours).	<i>J</i> .	% Δ^α -Acid.	Initial material.	Time (hours).	<i>J</i> .	% Δ^α -Acid.	Initial material.	Time (hours).	<i>J</i> .	% Δ^α -Acid.
<i>trans</i> - Δ^α -	5	38.4	63.0	<i>trans</i> - Δ^α -	24	51.4	46.0	<i>cis</i> - Δ^α -	5	37.1	64.0
"	10	43.4	56.5	"	"	54.5	41.5	"	10	41.3	59.0
"	"	48.0	49.5	"	"	55.9	39.5	"	24	55.2	40.5
"	"	45.9	53.5	"	36	52.4	44.4	"	"	57.0	38.0
"	24	47.5	51.5	"	48	53.5	43.2	<i>cis</i> - Δ^β -	48	60.4	32.0
				"	96	58.0	36.5				

Numerous experiments were also carried out with the Δ^β -acid before it was realised that it was a mixture; final values varying from 20.5 to 35.5% Δ^α -acid were obtained. The final equilibrium was ascertained at the b. p. of the solution and checked by equilibrating mixtures of Δ^α - and Δ^β -acids; from these experiments an average value of 37.5% Δ^α -acid was deduced.

Configurational Change.—The equilibrium mixtures derived from each of the three acids were twice subjected to partial esterification, and the recovered Δ^α -acids analysed as described above.

Initial material.	Time (hours).	<i>J</i> .	% Δ^α .	F. p. (average).	% <i>cis</i> .
<i>trans</i> - Δ^α -	10	4.0	99	27.1°	49
"	24	4.9	98	27.7	48
<i>cis</i> - Δ^α -	10	2.9	100	21.0	62
"	24	4.6	99	21.75	61
Δ^β -	24	6.6	96	24.5	55
"	48	5.3	98	22.5	62

Owing to the scarcity of material the existence of an equilibrium between the two forms of the Δ^β -acid could not be ascertained.

Lactonisation.—The acids used were the pure *trans*- Δ^α -acid and two samples of the *cis*- Δ^α -acid, m. p. 9—9.5° and 4—7° respectively. The Δ^β -acid in Expt. 3 was the pure *cis*-form prepared from the Δ^α -acid by equilibration.

4 G. samples of the acids were treated with 60 c.c. of cold 60% sulphuric acid, the mixture being worked up and analysed as described by Linstead (J., 1932, 115).

No.	Initial material.	Time (hours).	% Acid.	% Lactone.	No.	Initial material.	Time (hours).	% Acid.	% Lactone.
1	Δ^β -Acid	24	29.6	71.6	4	<i>trans</i> - Δ^α -Acid	24	29.3	74.2
2	"	48	12.4	91.5	5	"	48	12.7	92.3
3	"	96	16.6	83.4	6	<i>cis</i> - Δ^α -Acid	24	54.8	44.3
					7	"	48	32.0	68.5

Another specimen of the *trans*- Δ^α -acid gave values in close agreement with those for the *cis*- Δ^α -acid. The acids recovered from the above experiments were almost pure Δ^α -acids (92—95.5%). The same lactone was obtained in every case, b. p. 75°/3 mm., d_4^{20} 1.0163, n_D 1.4352, $[R_L]_D$ 29.31. There was also a higher-boiling fraction; it was carefully freed from traces of lactone and redistilled, b. p. 138°/14 mm.; it evidently consisted of β -hydroxy- β -methylvaleric acid (Found: M , 133.3. Calc.: M , 132.1).

Lactonisation of β -Hydroxy- β -methylvaleric Acid.—The pure hydroxy-acid was obtained by the hydrolysis of the ester formed from ethyl bromoacetate, methyl ethyl ketone, and zinc; after two distillations it had b. p. 137—138°/13 mm., d_4^{19} 1.0793, n_D 1.4475, $[R_L]_D$ 32.74. It was treated with 60% sulphuric acid as above:

Time (hours).	% Unsaturated acid.	% Hydroxy-acid.	% Lactone.
24	32.5	49.9	25.6
48	24.9	30.4	44.7

It is therefore clear that the hydroxy-acid is converted into the lactone much more slowly than the unsaturated acids.

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