

1143. Isomerisation during Allylic Bromination of Unsaturated Esters with *N*-Bromosuccinimide.

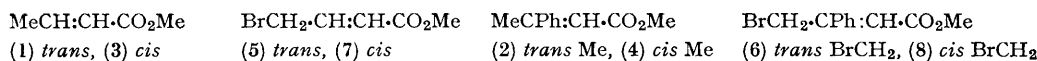
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The allylic bromination, by means of *N*-bromosuccinimide, of a pure *cis* or a pure *trans* unsaturated ester is preceded by a rapid isomerisation about the double bond to form an equilibrium *cis,trans* mixture of esters. This isomerisation has been studied for two *cis,trans* pairs of methyl but-2-enoates.

THE *cis-trans* isomerisation of unsaturated compounds during allylic bromination has been reported on a number of occasions. Bruylants¹ found that the same isomeric mixture of 4-bromobut-2-enonitriles was produced by the interaction of *N*-bromosuccinimide and either *trans*- or *cis*-but-2-enonitrile. The bromination² of both methyl elaidate and methyl oleate is accompanied by geometric isomerisation, giving rise, in both cases, to the same *cis,trans* mixture of allylic brominated product and unbrominated esters. Reaction of *cis*-hex-3-ene with *N*-bromosuccinimide is accompanied by rapid isomerisation of the starting material to *trans*-hex-3-ene.³ Korte and Behner⁴ claim, however, that no *cis* to *trans* isomerisation is observed when either methyl angelate or methyl tiglate is brominated with *N*-bromosuccinimide.

We report here a study of the allylic bromination of two pairs of geometrically isomeric unsaturated esters. In agreement with earlier observations,¹⁻³ our results show that, during allylic bromination of a *cis*- or a *trans*-isomer, rapid isomerisation of the unsaturated compound occurs, giving an equilibrium mixture of the two geometrical isomers. This rapid isomerisation is followed by slower allylic bromination. These results fit the current theories on the free radical mechanism of allylic bromination.^{5,6}

The products of the reaction of *N*-bromosuccinimide with methyl *trans*- and *cis*-but-2-enoates [(1) and (3), respectively] and with methyl *cis*- and *trans*-3-phenylbut-2-enoates [(2) and (4), respectively] have been studied by means of gas-chromatographic analysis of samples withdrawn from the reaction mixture at suitable intervals of time from the start of the reaction, and of observation of the rate of isomerisation of the starting ester, and of the variation, during the course of the reaction, of the ratio of starting ester to bromo-ester.



¹ A. Bruylants, *Bull. Soc. chim. belges.*, 1950, **59**, 107.

² E. Ucciani, J. Chouteau, and M. Naudet, *Bull. Soc. chim. France*, 1960, 1511.

³ B. P. McGrath and J. M. Tedder, *Proc. Chem. Soc.*, 1961, 80.

⁴ F. Korte and O. Behner, *Chem. Ber.*, 1956, **89**, 2675.

⁵ J. Adam, P. A. Gooselain, and P. Goldfinger, *Nature*, 1953, **171**, 704; *Bull. Soc. chim. belges.*, 1956, **65**, 523.

⁶ G. F. Bloomfield, *J.*, 1944, 114.

added, and the time at the completion of the addition was taken as the start of the reaction. Heating of the mixture to maintain reflux was continued until no unreacted *N*-bromosuccinimide remained at the bottom of the flask.

All gas-chromatographic analyses were carried out by using a 6-ft. stainless-steel column packed with 30% w/w silicone oil (D.C. 550) on 42—60 mesh firebrick. The column was attached to a thermal-conductivity detector, and the carrier gas was hydrogen. The flow-rate was 30 ml. per min. at an inlet pressure of 6 p.s.i. To determine rates of bromination, *ca.* 0.1-ml. samples were withdrawn from the reaction mixture at set intervals of time, and then cooled to 0°. Traces of *N*-bromosuccinimide, withdrawn with the samples, were allowed to settle before 0.01 ml. of each sample was injected into the gas chromatograph. Samples of the products of bromination were prepared for infrared (i.r.) analysis and micro-analysis by filtration of the reaction products, to remove succinimide, followed by distillation of the filtrate, first at atmospheric pressure, to remove the carbon tetrachloride solvent, and then at reduced pressure. Yields of bromo-esters are based on the *N*-bromosuccinimide used.

Bromination of Methyl trans-But-2-enoate—(a) The ester, prepared by esterification of the acid with methanol—concentrated sulphuric acid, was brominated completely in 6 hr., after which time, the area of the gas-chromatography peak corresponding to methyl 4-bromobut-2-enoate (retention time at 160°, 42 min.) became constant.

(b) Using ester prepared as for (a), but purified by passing it through a bed of chromatographic-grade alumina, the area of the methyl 4-bromobut-2-enoate peak became constant after 4½ hr. The product of the reaction was isolated to yield methyl 4-bromobut-2-enoate (56%), b. p. 83.5—85.5°/15 mm., n_D^{20} 1.5017 (lit.,¹¹ b. p. 78—82°/8 mm., n_D^{20} 1.5021) (Found: Br, 44.5. Calc. for C₅H₇BrO₂: Br, 44.7%). The ester had an i.r. band at 980 cm.⁻¹, indicating *trans* geometry at the double bond.

(c) Using ester, b. p. 120°/753 mm., n_D^{22} 1.4304, prepared by treating the recrystallised acid with diazomethane, complete reaction occurred within 45 min.

Bromination of Methyl cis-But-2-enoate.—The ester required 90 min. for complete bromination and gave the same methyl 4-bromobut-2-enoate (retention time at 160°, 42 min.) as was obtained by brominating the *trans*-ester. The product of the reaction was isolated to give methyl 4-bromobut-2-enoate (58%), b. p. 88—91°/15 mm., n_D^{20} 1.5018 (Found: Br, 44.9. Calc. for C₅H₇BrO₂: Br, 44.7%); it had an i.r. band at 980 cm.⁻¹, indicating mainly *trans* geometry about the double bond.

Isomerisation of Methyl trans-But-2-enoate in the Presence of Initiator and N-Bromosuccinimide.—The ester (2.0 g., 1 mol.) and azobisisobutyronitrile (0.02 g., 6 × 10⁻³ mol.) in carbon tetrachloride (10 ml.) were heated to reflux. *N*-Bromosuccinimide (2.5 g., 0.7 mol.) was then added. The composition of the reaction mixture, with respect to the ratio of *trans* to *cis* unbrominated ester, was determined by gas-chromatographic analysis of samples. The following results were obtained:

Time (sec.)	0	10	30	45	60	90	120	240
$\frac{[\textit{trans-Ester}]}{[\textit{cis-Ester}]}$	∞	24.2	11.6	10.8	10.6	10.2	10.0	10.1

Isomerisation of Methyl cis-But-2-enoate in the Presence of Initiator and N-Bromosuccinimide.—The same quantities and reaction conditions as for the isomerisation of the *trans*-isomer were used:

Time (sec.)	0	15	60	120	240	360	480
$\frac{[\textit{trans-Ester}]}{[\textit{cis-Ester}]}$	0	0.175	0.455	9.6	10.0	10.2	10.0

Isomerisation of Methyl cis-But-2-enoate with N-Bromosuccinimide in the Absence of Initiator.—The experiment described above was repeated with the same quantities and conditions, but in the absence of any initiator:

Time (min.)	0	1.5	3	7	15
$\frac{[\textit{trans-Ester}]}{[\textit{cis-Ester}]}$	0	0.14	1.19	7.8	9.9

Unsuccessful Attempt to Isomerise Methyl cis-But-2-enoate with Initiator in the Absence of N-Bromosuccinimide.—The ester (2.0 g., 1 mol.) was refluxed in carbon tetrachloride (10 ml.) with

¹¹ L. N. Owen and M. U. S. Sultanbawa, *J.*, 1949, 3101.

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azobisisobutyronitrile ($0.02 \text{ g.}, 6 \times 10^{-3} \text{ mol.}$) for 30 min. Gas-chromatographic analysis of samples of the refluxing solution showed the complete absence of the *trans*-isomer.

Methyl trans-3-Phenylbut-2-enoate.—*trans*-3-Phenylbut-2-enoic acid was prepared by the method of Lindenbaum¹² from acetophenone and ethyl bromoacetate. The acid, m. p. 98° (lit.,¹² m. p. 98.5°), was esterified either with diazomethane, to yield the methyl ester, b. p. $120\text{--}122^\circ/9 \text{ mm.}$, m. p. $28\text{--}30^\circ$, $n_D^{21} 1.5592$, or by the method of Stoermer *et al.*,¹³ using dimethyl sulphate, to yield the methyl ester, b. p. $125\text{--}127^\circ/9 \text{ mm.}$, m. p. $24\text{--}27^\circ$, $n_D^{21} 1.5595$ (lit.,¹³ b. p. $127\text{--}128^\circ/10 \text{ mm.}$, m. p. 29°).

Methyl cis-3-Phenylbut-2-enoate.—*cis*-3-Phenylbut-2-enoic acid was prepared by irradiating a solution of *trans*-3-phenylbut-2-enoic acid (20 g.) in anhydrous benzene (100 ml.) with ultraviolet light from a mercury-discharge lamp for 7 days.¹³ The *cis*-acid (1 g., 5%), m. p. 132° (lit.,¹³ m. p. 131°), so obtained, was esterified with diazomethane. The purity of the ester was checked by means of gas chromatography. Assuming the ratio of *cis*- to *trans*-ester to be equal to the ratio of the area of the peak due to the *cis*- to that due to the *trans*-ester, the ester was found to contain 95% of the *cis*-isomer. (Retention times at 190° : methyl *trans*-3-phenylbut-2-enoate, 84 min.; methyl *cis*-3-phenylbut-2-enoate, 57 min.)

Bromination of Methyl trans-3-Phenylbut-2-enoate.—The *trans*-ester was brominated in the usual manner, but more initiator [*ca.* $(1.5\text{--}2) \times 10^{-2} \text{ mol.}$] and *N*-bromosuccinimide (0.9 mol.) were used than with the unsubstituted but-2-enoates. Bromination was shown, by gas-chromatographic analysis, to have proceeded to the extent of 90% in 6 hr. The product yielded a methyl 4-bromo-3-phenylbut-2-enoate (17.3 g., 60%) as a pale green liquid, b. p. $138\text{--}143^\circ/4.5 \text{ mm.}$, $n_D^{23} 1.5906$ (lit.,¹⁴ b. p. $100\text{--}102^\circ/0.01 \text{ mm.}$, $n_D^{31} 1.5785$), which partly solidified on standing; this was recrystallised three times from light petroleum (b. p. $40\text{--}60^\circ$) as hexagonal plates (7.5 g.), m. p. $53\text{--}54^\circ$ (Found: C, 51.9; H, 4.3; Br, 31.6. Calc. for $C_{11}H_{11}BrO_2$: C, 51.8; H, 4.4; Br, 31.4%). The purity of this bromo-ester was checked by means of thin-layer chromatography, using silica-silver nitrate plates¹⁵ and dry chloroform-glacial acetic acid (99:1) as solvent. The esters were located by spraying the plates with aqueous alkaline potassium permanganate. The mother liquors from the crystallisation of the bromo-ester gave two spots, and the crystalline solid only one spot. The approximate R_F values are:

Mother liquors: (a) 0.7; and (b) 0.55. Crystalline solid: 0.7 only.

Spot (a) was larger than spot (b), and spot (b) did not coincide with the spot due to methyl *trans*-3-phenylbut-2-enoate (R_F , 0.75). The bromo-ester (m. p. $52\text{--}53^\circ$), in carbon tetrachloride solution, gave only decomposition peaks of short retention time on gas chromatography at 190° .

Bromination of Methyl cis-3-Phenylbut-2-enoate.—The *cis*-ester was brominated in the usual manner for 8 hr. A sample of the reaction mixture was removed $1\frac{1}{2}$ min. after the addition of the *N*-bromosuccinimide; gas-chromatographic analysis showed the presence of 2 components, methyl *trans*-3-phenylbut-2-enoate and methyl *cis*-3-phenylbut-2-enoate in the ratio 12.5:1, indicating that isomerisation of the *cis*- to the *trans*-ester occurs rapidly. On completion of the reaction, the product was isolated. It was semi-solid (0.2 g.) and was crystallised from light petroleum (b. p. $40\text{--}60^\circ$) as hexagonal plates, m. p. $49\text{--}51^\circ$, which gave no depression of m. p. when mixed with methyl 4-bromo-3-phenylbut-2-enoate (m. p. $53\text{--}54^\circ$) obtained from the bromination of the *trans*-ester. Thin-layer chromatography of the semi-solid residue showed the main component present to have the same R_F value (0.7) as the crystalline product from the bromination of methyl *trans*-3-phenylbut-2-enoate.

Methyl 3-(p-Methoxyphenyl)but-2-enoate.—This compound, m. p. $39.5\text{--}40^\circ$ (Found: C, 69.5; H, 7.0. $C_{12}H_{14}O_3$ requires C, 69.9; H, 6.9%), was prepared by reaction of 3-(*p*-methoxyphenyl)but-2-enoic acid,¹² m. p. $153\text{--}155^\circ$ (lit.,¹² m. p. 153°), with excess of diazomethane.

Reaction of N-Bromosuccinimide with Methyl 3-(p-Methoxyphenyl)but-2-enoate.—Methyl 3-(*p*-methoxyphenyl)but-2-enoate (10.8 g., 1 mol.) in dry carbon tetrachloride (60 ml.) was refluxed with *N*-bromosuccinimide (8.9 g., 1.1 mol.) and azobisisobutyronitrile ($0.2 \text{ g.}, 2.4 \times 10^{-2} \text{ mol.}$). After 1 hr., the reaction mixture did not cause liberation of iodine from potassium iodide solution, and the reaction was assumed to be complete. Succinimide was filtered off, and the carbon tetrachloride was evaporated from the reaction mixture to leave a brown oil (15 g.). A

¹² S. Lindenbaum, *Ber.*, 1917, **50**, 1270.

¹³ R. Stoermer, F. Grimm, and E. Laage, *Ber.*, 1917, **50**, 968.

¹⁴ M. U. S. Sultanbawa, P. Veeravagu, and T. Padmanathan, *J.*, 1960, 1267.

¹⁵ C. B. Barrett, M. S. J. Dallas, and F. B. Padley, *Chem. and Ind.*, 1962, 1050.

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portion of this oil (3 g.) was chromatographed on activated alumina, and the fraction which was eluted with benzene-ether (1:1) was crystallised from benzene-cyclohexane (3:1) as white needles of the γ -lactone (0.4 g., 21%) of 4-hydroxy-3-(*p*-methoxyphenyl)but-2-enoic acid, m. p. 121—123° (Found: C, 69.3; H, 5.4. $C_{11}H_{10}O_3$ requires C, 69.4; H, 5.3%). The nuclear magnetic resonance spectrum of this compound, using tetramethylsilane as an internal standard, was kindly measured by Dr. R. Foster; it showed: a group of lines between τ 2.4 and 3.1, which could correspond to 4 aromatic protons; a line at τ 3.8, corresponding to one CH proton; a line at τ 4.8, corresponding to two CH_2 protons; and a line at τ 6.1, corresponding to three OCH_3 protons. The main bulk of the reaction product partly solidified when seeded with the crystals of this lactone, but the other products of the reaction have yet to be identified.

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