

Iodine-catalysed Stereomutation of Chiral 1,4-Dialkylbutadienes

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The iodine-catalysed (*Z*)-(E)-stereomutation of some optically active 1,4-dialkylbutadienes has been studied in heptane between 25 and 60 °C. The isomerisation rate depends on the substituents of the diene moiety. When it occurs, the isomerisation of (*E,Z*)- and (*E,E*)-dienes is reversible under the experimental conditions adopted, whereas (*Z,Z*)-dienes do not isomerise at all. The stereomutation of (*E,Z*)-(3*S*,8*S*)-3,8-dimethyldeca-4,6-diene to the corresponding (*E,E*)-isomer occurs without racemisation of the chiral centres and follows first-order kinetics. The data obtained are discussed briefly in the light of the mechanisms generally accepted.

DURING work on the synthesis and physical properties of chiral 1,4-dialkylbutadienes,¹ we noted that whilst distilling crude (*E,Z*)-(3*S*,8*S*)-3,8-dimethyldeca-4,6-diene (I) and (*E,Z*)-dodeca-5,7-diene (II), prepared respectively from (*S*)-3-methylpent-1-yne² and hex-1-yne *via* iodination of the corresponding divinylborinate derivatives,³ appreciable isomerisation to the corresponding (*E,E*)-isomers occurred.

In order to widen the investigation of this isomerisation phenomenon, samples of (*E,Z*)-(I) and of (*E,Z*)-(II),

purified by preparative g.l.c., were heated at 70 °C and analysed at intervals by g.l.c. The dienes isomerised only slowly under these conditions. When heated in the presence of small amounts of an iodination by-product,³ such as (*E*)-1-iodoalk-1-ene, the rate increased remarkably. This suggested that the isomerisation of these dienes during distillation depended on the presence of iodine atoms, arising from thermal decomposition of the iodoalkene.

Published kinetic results for the (*Z*)-(E) isomerisation

¹ A. Saba, Thesis, Pisa, 1977.

² L. Lardicci, C. Botteghi, and E. Benedetti, *J. Org. Chem.*, 1966, **31**, 1534.

³ G. Zweifel, N. L. Polston, and C. C. Whitney, *J. Amer. Chem. Soc.*, 1968, **90**, 6243.

of various alkenes⁴⁻⁹ and (*E,Z*)-butadienes,¹⁰⁻¹² induced by thermally or photochemically generated iodine atoms indicate that a mechanism involving intermediate compounds with covalently bonded iodine atoms operates; internal rotation in the intermediate appears to be the rate-determining step. Whereas the isomerisation of butadienes containing phenyl or phenylallyl groups has been studied,^{11,12} to date no isomerisation of aliphatic dialkylbutadienes has been reported.

We have, therefore, carried out an investigation on the iodine-catalysed isomerisation of some dialkylbutadienes to elucidate further details of the reaction mechanism and, in particular, the stereochemistry of the process; the configurational isomers of (I), (II),

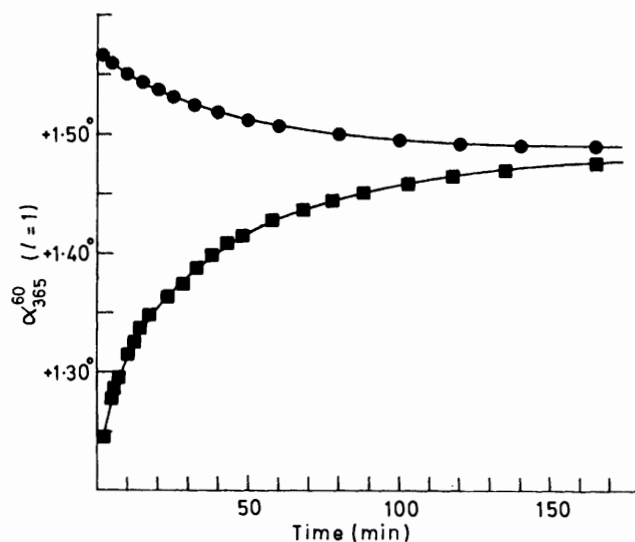


FIGURE. Photochemical stereomutation at 60 °C of (*E,Z*)-(3*S*,8*S*)-3,8-dimethyldeca-4,6-diene (I) (lower curve) and of (*E,E*)-(3*S*,8*S*)-3,8-dimethyldeca-4,6-diene (II) (upper curve): $[\text{diene}]/[\text{I}_2] = 4.9$.

and of (3*S*,8*S*)-2,2,3,8,9,9-hexamethyldeca-4,6-diene (III), have been used.

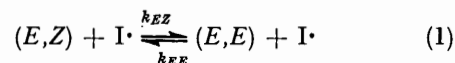
In contrast to published reports for similar cases,^{11,13} (*Z*)-(*E*) isomerisations of these dienes, induced by photochemically generated iodine atoms, are reversible under the experimental conditions adopted; this is shown for (*E,Z*)-(I) and (*E,E*)-(II) (Figure). In fact, in the presence of iodine, (*E,Z*)-(I) is converted into a mixture containing mostly (*E,E*)-isomer [$(E,E)/(E,Z) \simeq 4$] * with no trace of the (*Z,Z*) isomer. The reaction is inhibited by small amounts of 2,5-di-*t*-butyl-*p*-cresol, a

further indication that it proceeds *via* radical intermediates.

Under the experimental conditions adopted, the iodine-induced isomerisation of (I) does not involve the chiral centres in the α -position with respect to the conjugated double bonds: in fact, a sample of (*E,Z*)-(I) (optical purity 90%),¹ after heating at 98 °C for 6 h ($[\text{diene}]/[\text{I}_2] \simeq 5$), isomerised to 75% (*E,E*)-(I) having the same optical purity.¹

Following a literature report,¹¹ the iodine-induced stereomutations of (*E,Z*)-(I) and (*E,E*)-(II) were carried out in heptane at both high and low diene/ I_2 molar ratios ($\simeq 150$ and $\simeq 5$). The course of the reactions was followed by measuring the change of the optical activity of the mixture at 3 650 Å with time. At high diene/ I_2 molar ratios the kinetics of the reactions are very complex, the isomerisation being diffusion-controlled, the diene probably acting as a third body for the recombination of iodine atoms.⁵ At low diene/ I_2 molar ratios the stereomutation reaction exhibits first-order kinetics (Figure) in the range of temperatures investigated.

Under these experimental conditions the isomerisation rate would, therefore, be consistent with the following equation:



where the equilibrium constant is given by:

$$K_e = \frac{k_{EZ}}{k_{EE}} = \frac{[(E,E)]_e}{[(E,Z)]_e} \quad (2)$$

The overall reaction rate is, therefore, given by the equation:

$$\frac{dC_{EZ}}{dt} = k_{EZ}fK_I[\text{I} \cdot][(E,Z)] - k_{EE}fK_I[\text{I} \cdot][(E,E)] \quad (3)$$

where f is a function of the light intensity and of its wavelength and K_I is the dissociation constant of the iodine.¹¹

Equation (3) yields, upon integration:

$$k'_{EZ} = \frac{K_e}{K_e + 1} \frac{1}{t} \ln \frac{\alpha_0 - \alpha_e}{\alpha - \alpha_e} \quad (4)$$

$$k'_{EE} = \frac{1}{K_e + 1} \frac{1}{t} \ln \frac{\alpha_e - \alpha_0}{\alpha_e - \alpha} \quad (5)$$

where $k' = kfK_I[\text{I} \cdot]$, α_0 and α_e are the optical rotations of the mixtures before exposure and after the reaction had reached equilibrium. The first-order rate constants

* The composition of the equilibrium mixture is not changed when the isomerisation is induced by thermally generated iodine atoms.

⁴ M. D. Carr, J. R. P. Clarke, and M. C. Whiting, *Proc. Chem. Soc.*, 1963, 333.

⁵ M. H. Back and R. J. Cvetanovic, *Canad. J. Chem.*, 1963, **41**, 1396.

⁶ S. W. Benson and A. N. Bose, *J. Amer. Chem. Soc.*, 1963, **85**, 1385.

⁷ M. D. Carr, V. V. Kane, and M. C. Whiting, *Proc. Chem. Soc.*, 1964, 408.

⁸ S. W. Benson, K. W. Egger, and D. M. Golden, *J. Amer. Chem. Soc.*, 1965, **87**, 468.

⁹ W. J. Muizebelt and R. J. F. Nivard, *J. Chem. Soc. (B)*, 1968, 913.

¹⁰ K. W. Egger and S. W. Benson, *J. Amer. Chem. Soc.*, 1965, **87**, 3311, 3314.

¹¹ A. J. G. Van Rossum, A. H. M. de Bruin, and R. J. F. Nivard, *J. C.S. Perkin II*, 1975, 1036.

¹² A. J. G. Van Rossum and R. J. F. Nivard, *J. C.S. Perkin II*, 1975, 1042.

¹³ M. Kröner, *Chem. Ber.*, 1967, **100**, 3172.

for both the direct and the reverse stereomutation of (I) at various temperatures together with the equilibrium constants are collected in the Table.

TABLE

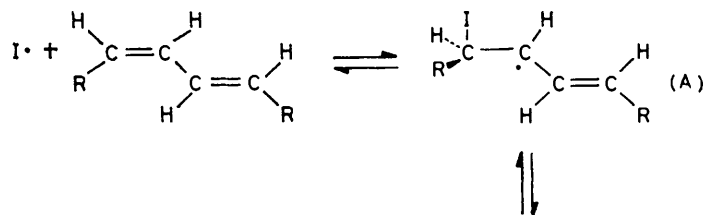
Rate constants for the iodine-induced stereomutation of (*E,Z*)-(I) and (*E,E*)-(I) in heptane at 3 650 Å^a

$\theta_c/^\circ\text{C}$	$k'_{EZ} \cdot 10^4{}^b$ s ⁻¹	$k'_{EE} \cdot 10^5{}^c$ s ⁻¹	$K_e{}^d$
25	1.6	3.7	4.34
35	1.8	4.2	4.30
45	2.9	6.8	4.25
60	3.7	8.8 ^e	4.20
	3.9 ^e	9.3	

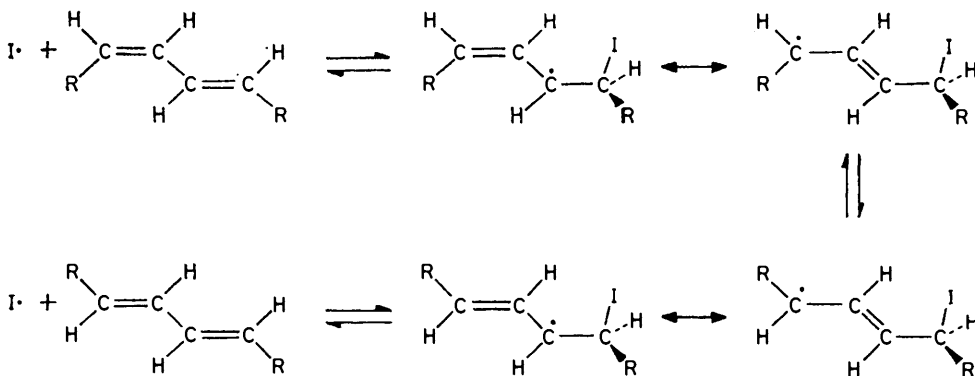
^a Diene concentration ≈ 0.56 g/100 ml, molar ratio diene/I₂ ≈ 4.9 . ^b $k'_{EZ} = (K_e/K_e + 1) \cdot k_{\text{obs}}$. ^c $k'_{EE} = (1/K_e + 1) \cdot k_{\text{obs}}$. ^d Determined by g.l.c. analysis. ^e $k'_{EZ}/k'_{EE} = K_e$.

For the isomerisation of the other dienes, the results we have obtained indicate that the stereomutation rate

dienes investigated might be rationalised through a mechanism involving the addition of an iodine atom to a double bond in the diene system. Subsequent rotation in the adduct radical around the C-C bond, followed by decomposition should lead to the isomer diene (Scheme 1). According this picture, the rate-determining steps would be either the attack of the halogen atom on the double bond or the internal rotation of the intermediate radical (A).^{8,10-12} In our work the addition of iodine is thought to be the rate-determining step since the resulting allyl-type radical is stabilised by resonance.⁹ This suggestion seems, moreover, to fit the observed variation of the isomerisation rate with the structure of the diene and, in particular, the lack of isomerisation of (III). In this last case, owing to the presence of bulky substituents in the α -position with respect to the conjugated double-bonds, the attack of iodine on the diene to form the intermediate radical



SCHEME 1



SCHEME 2

depends strictly on the substituents of the diene moiety. In fact, (*E,Z*)-(II) and (*E,E*)-(II) isomerise *ca.* 6 times faster than the corresponding isomers (I) under the same experimental conditions employed (see Experimental section), whilst (*Z,Z*)-dienes and (III) fail to isomerise, even under more drastic experimental conditions.

In the light of literature suggestions^{8,10-12} and bearing the kinetic results in mind, the stereomutation of the

(A) is strongly resisted. The lack of isomerisation of the (*Z,Z*) dienes may also be explained in these terms, inspection of molecular models showing that these dienes are more sterically compressed than their (*E,Z*) and (*E,E*) counterparts.

These latter findings together with the fact that no (*Z,Z*) isomer is formed in the reaction, might also indicate that iodine attack occurs on the (*E*) double-

bond of the butadiene system. On the basis of this assumption, and taking into account that the allyl-type radical (A) is stabilised by relatively high resonance energy,⁹ the stereomutation of these aliphatic 1,4-dialkylbutadienes might be explained, in principle, by an alternative mechanism (Scheme 2). Thus, the isomerisation might occur not only by rotation around the single C-C bond in the intermediate radical (A) (Scheme 1) but also by rotation of the carbon atom chain not containing the iodine atom (Scheme 2) through shift of the residual double-bond from the terminal to the internal position. On this basis we can also interpret the lack of isomerisation observed in the photoiodination of (*E*)-2,4-dialkylbuta-1,3-dienes, such as (*E*)-(3*S*,7*S*)-3,7-dimethyl-4-methylnon-5-ene,¹⁴ since the non-coplanarity of the double bonds in these kinds of substrates¹⁵ should reliably reduce the resonance stabilisation of the intermediate (Scheme 2) and, consequently, prevent the isomerisation.

Finally, the complete retention of the configuration of the chiral centres in the isomerisation of (*E*,*Z*)-(I) and



(*E*,*E*)-(I) confirms that the iodine atom adds to the terminal diene carbon atoms. In fact, the attack of the iodine atom on the internal carbon atoms would cause the formation of an intermediate radical in the α -position with respect to the chiral tertiary carbon atom with probable consequent racemisation. Moreover, the absence of racemisation indicates once more⁶ that hydrogen atom abstraction from the carbon atom in the α -position with respect to the butadiene system [equation (6)] would be negligibly slow to respect the isomerisation process, although the intermediate radical can be highly stabilised by resonance.

EXPERIMENTAL

Materials.—Heptane was distilled over LiAlH₄ before use and iodine was used without purification. (*E*,*E*)-, (*Z*,*Z*)-, and (*E*,*Z*)-dodeca-5,7-diene (II) were prepared as elsewhere described^{3,16,17} from hex-1-yne. (*E*,*Z*)-(3*S*,8*S*)-3,8-Dimethyldeca-4,6-diene (I), $[\alpha]_D^{25} + 56.60^\circ$ (heptane) and (*E*,*Z*)-(3*S*,8*S*)-2,2,3,8,9,9-hexamethyldeca-4,6-diene (III), $[\alpha]_D^{25} - 70.49^\circ$ (heptane), were obtained *via* hydroboration of (*S*)-3-methylpent-1-yne² and of (*R*)-3,4,4-trimethylpent-1-yne¹⁸ respectively with thexylborane, followed by alkaline iodination,³ while (*E*,*E*)-(3*S*,8*S*)-(I), $[\alpha]_D^{25} + 81.25^\circ$

¹⁴ G. Giacomelli, A. M. Caporusso, and L. Lardicci, *J.C.S. Perkin I*, 1977, 1333.

¹⁵ W. F. Forbes, R. Shilton, and A. Balasubramanian, *J. Org. Chem.*, 1964, **29**, 3527 and references therein.

¹⁶ G. Zweifel and R. L. Miller, *J. Amer. Chem. Soc.*, 1970, **92**, 6678.

(neat), and (*E*,*E*)-(3*S*,8*S*)-(III), $[\alpha]_D^{25} - 88.02^\circ$ (heptane), were obtained by treatment of the alkenyldi-isobutylalanes from the corresponding alk-1-yne^{2,18} with CuCl in tetrahydrofuran.¹⁶ (*Z*,*Z*)-(I) was obtained by reductive hydroboration of the corresponding enyne system¹⁷ from 3-methylpent-1-yne; (*E*)-(3*S*,7*S*)-3,7-dimethyl-4-methylnon-5-ene, $[\alpha]_D^{25} + 61.97^\circ$ (neat), was prepared by a catalytic method.^{14,19}

Apparatus and Procedure.—For the kinetic experiments an iodine solution (0.2 ml, *ca.* 1.5×10^{-5} mol) and a solution of the diene (1 ml, *ca.* 7.5×10^{-5} mol), both in heptane, were pipetted into a polarimeter cell with exclusion of light and the cell was placed into a Perkin-Elmer 142 spectropolarimeter. The course of the isomerization of the optically active dienes was followed by measuring the change of the optical activity of the solution at 3 650 Å, and controlled by withdrawing, at intervals, samples (0.01 μ l) of the reaction mixture and analysing these by g.l.c. The course of isomerization of (II) was followed only by g.l.c. analyses which were performed on a Perkin-Elmer F 30 instrument (flame ionization detectors) equipped with a 200 \times 0.30 cm column packed with 2% SE 30 on 80—100 mesh Chromosorb G AW-DMCS at 120 °C and a nitrogen

flow rate of 10 ml min⁻¹. Measurements of the kinetics were carried out between 25 and 60 °C: the temperature was adjusted by pumping thermostatted water through the cell-holder. At least two runs were performed for all reaction conditions. The first-order rate constants were calculated by computed least-squares analysis of the data obtained, by using an I.B.M. 370/158 computer. For all temperatures, the individual rate constants were reproducible to within 5.0%. For the isomerization of (*E*,*Z*)- and (*E*,*E*)-dodeca-5,7-diene (II) the following rate constants were measured: at 35 °C, $k'_{EZ} = 10.1 \times 10^{-4}$ s⁻¹; at 60 °C, $k'_{EZ} = 23.6 \times 10^{-4}$ s⁻¹, $k'_{EE} = 6.0 \times 10^{-4}$ s⁻¹.

Stereomutation of (*E*,*Z*)-(I) into (*E*,*E*)-(I).—A sample (1.29 g, 7.76 mmol) of (*E*,*Z*)-(3*S*,8*S*)-3,8-dimethyldeca-4,6-diene, $[\alpha]_D^{25} + 56.60^\circ$ (heptane) (optical purity 90%),¹ in heptane (10 ml), was heated with iodine (0.197 g, 1.55 mmol) at 98 °C for 6 h, and then treated with Na₂S₂O₃ until decoloration. The product mixture which contained 75% of (*E*,*E*)-(I), was separated by preparative g.l.c. (300 \times 0.8 cm column filled with 2.5% SE 30 on 60—80 mesh Chromosorb A, 140 °C, nitrogen flow rate 180 ml min⁻¹, Perkin-Elmer F 21 instrument) to yield pure (*E*,*E*)-(3*S*,8*S*)-3,8-dimethyldeca-4,6-diene, $[\alpha]_D^{25} + 81.25^\circ$ (neat) (optical purity 90%).¹

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¹⁷ G. Zweifel and N. L. Polston, *J. Amer. Chem. Soc.*, 1970, **92**, 4068.

¹⁸ A. M. Caporusso, G. Giacomelli, and L. Lardicci, *Atti Soc. Toscana, Sci. Nat., Mem.*, 1973, **A80**, 40.

¹⁹ A. M. Caporusso, G. Giacomelli, and L. Lardicci, *J. Org. Chem.*, 1977, **42**, 914.