Acid catalysed Rearrangement of Bis-(*p*-methoxyphenylcyclopropyl) Ketone. Application of *X*-Ray Crystallography and Nuclear Overhauser Effect Difference Spectra to the Structural Elucidation of the Epimeric Hexahydrobenzindenones[1]

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When treated with tin(IV) chloride in nitromethane the bis-(*p*-methoxyphenylcyclopropyl) ketone (**2b**) rearranged rapidly to a 1:1 mixture of epimeric hexahydrobenzindenones (**3**) and (**4**). The structure of (**3**) was determined by *X*-ray crystallography. Comparison between the nuclear Overhauser effect of difference spectra (NOEDS) of the two products led to the unambiguous assignment of the structure of (**4**). ^{1}H N.m.r. decoupling experiments provided the evidence that both epimers adopt an identical conformation in solution.

The importance of substituted cyclopropanes,[2] cyclopropylcarbinols,[3] and cyclopropyl ketones in synthesis[4] is well established and is in part related to the facility with which they undergo acid-catalysed ring cleavage. Intramolecular trapping of the cation so formed has been the basis of a number of new methods of cyclisation.[5] We have found that aryl cyclopropyl ketones undergo the expected ring cleavage with tin(IV) chloride and rapidly cyclise to tetralones.[6] This methodology was employed in the synthesis of picropodophyllotoxin.[7]

Although ring-fused biscyclopropyl ketones have been investigated[8] under acid conditions in the context of homoaromaticity, to our knowledge acyclic biscyclopropyl ketones have not been investigated previously. We have now initiated such a study by investigating the acid-catalysed reactions of bis-(*p*-methoxyphenylcyclopropyl) ketone (**2b**).

Results

The ketones (**2a** and **b**) were readily obtained from *E,E*-1,5-diarylpenta-1,4-dien-3-ones (**1a** and **b**).[9] Although the *meso*- and DL-isomers of ketone (**2a**) were separable on t.l.c., only one stereoisomer of ketone (**2b**) was detected. Diastereoisomeric mixtures of (**2a**) were used in this study. Treatment of ketone (**2a**) with a wide variety of protic and non-protic acids caused slow decomposition. No identifiable products were detected and (**2a**) was invariably recovered in good yield. However, ketone (**2b**) reacted rapidly when treated with tin(IV) chloride in nitromethane at ambient temperature. Reaction was complete within 10 min. A 1:1 mixture of epimers (**3**) and (**4**), which were very difficult to separate, was isolated in *ca.* 50% yield by means of p.l.c. Other, more polar products were also formed in variable yields. Unfortunately, we have so far been unable to separate these products. Careful recrystallisation of (**3**) provided crystals suitable for *X*-ray crystallography. However, crystals of (**4**) invariably twinned and were unsuitable.[10] This problem was exacerbated by our inability to separate the final traces of (**3**) from (**4**).

The crystal structure of (**3**) consists of discrete molecules separated by normal van der Waals distances. Our *X*-ray analysis unequivocally established the relative stereochemistry of (**3**) as shown in Figure 1.† The product (**3**) is 1,2,*r*-3a,4,5,*c*-9b-hexahydro-7-methoxy-*t*-5-(*p*-methoxyphenyl)-3*H*-benz[*e*]inden-3-one. The five-membered ring has a C(1)-envelope conformation [C(1) is 0.602(1) Å below the C(2)–C(9b) plane]. The six-membered ring, which is *cis*-fused to the five-membered ring, has a half-chair conformation with C(4) 0.717(1) Å below the C(5)–C(3a) plane. The *p*-methoxyphenyl ring is equatorially attached to C(5) with the hydrogen atom of C(5) *cis* to the hydrogen atoms on C(3a) and C(9b). The phenyl ring C(1′)–C(6′) is rotated about the C(5)–C(1′) bond [C(5a)C(5)-C(1′)C(2′) torsion angle −58.2(5)°] to relieve strain due to intromolecular N···H interactions. Both aromatic rings are individually planar (deviations −0.003 to +0.004 and −0.003 to +0.003 Å, respectively). The two methoxy groups O(7)C(71) and O(4′)C(41′) adopt conformations such that they are close to being coplanar with the appropriate ring system [torsion angles C(8)C(7)O(7)C(71) 0.1(4)° and C(5′)C(4′)O(4′)C(41′) −2.4(5)°].

The molecular dimensions in (**3**) are unexceptional, mean values being: C_{sp^3}–C_{sp^3} 1.531(4), C_{sp^3}–C_{sp^2} 1.514(5), aromatic C–C 1.389(4), C_{sp^3}–O 1.423(5), C_{sp^2}–O 1.375(4), and C=O 1.225(5) Å.

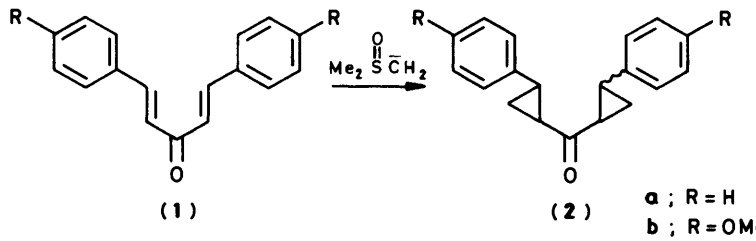
^{1}H *N.m.r. Spectra of Ketones* (**3**) *and* (**4**).—*Structure of ketone* (**4**). A preliminary spectroscopic investigation (see Experimental section) indicated a close structural relationship between the isomeric ketones (**3**) and (**4**). Both ketones were separately heated overnight in acid. No change occurred in either case. We therefore concluded that ketone (**4**) was also *cis*-fused and that it was probably a C-5 epimer of ketone (**3**).

The ^{1}H n.m.r. spectra of both isomers are presented in Figure 2 (see also Tables 1 and 2). Fortunately, the resonances of the protons at most of the chiral centres are observable.

Decoupling[12] and NOEDS[13] results at 250 MHz for isomer (**3**) are given in Table 1. The position of the methoxy group as at C-7 and not at C-8 (**5**; R^1 = H, R^2 = *p*-$MeOC_6H_4$) was confirmed by irradiating the *m*-coupled aryl proton doublet, *i.e.* H-6 in (**3**) or H-9 in (**5**). NOE[14] enhancement of both the C-7 methoxy and H-5 occurred. This result was not consistent with structure (**5**) since H-9 is too far removed from H-5α. This observation was confirmed by irradiating H-5. H-6 then underwent NOE enhancement. The *cis*-relationship of H-5 and H-3a was confirmed by enhancement of H-3a as a consequence of H-5 irradiation and *vice versa*. Finally the *cis*-relationship of H-3a and H-9b was demonstrated by the large NOE enhancement of one following irradiation of the other.

In like manner NOEDS permitted the structural assignment

† Prepared with the graphics segment of the NRC Crystal Structures Package.[11]



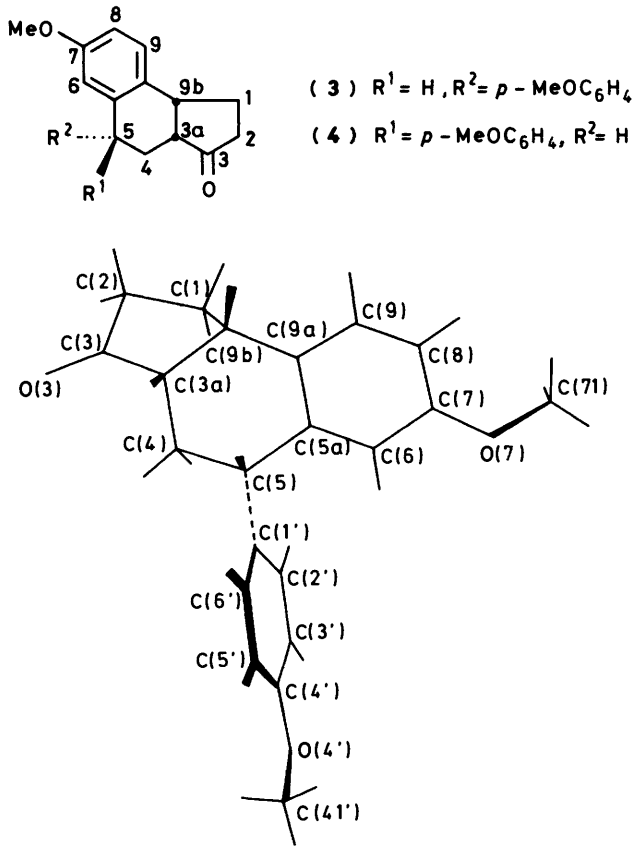


Figure 1. A view of molecule (3) with the numbering scheme

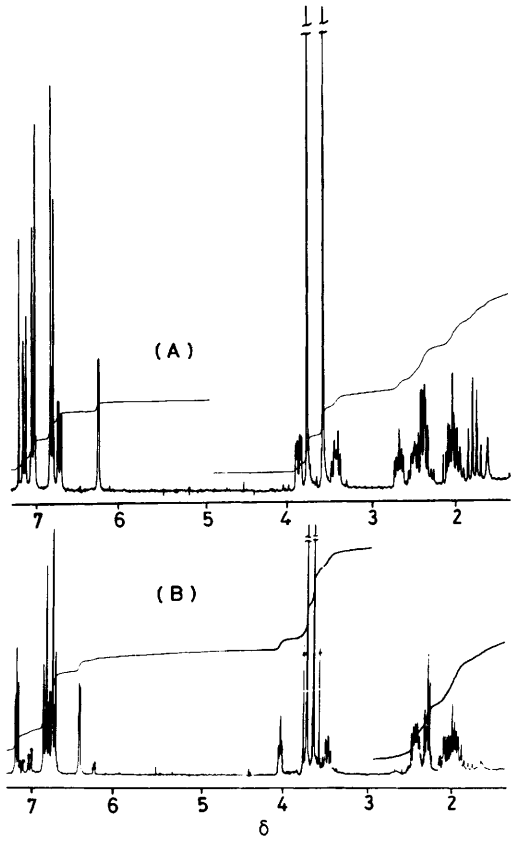


Figure 2. The 250 MHz ^{1}H n.m.r. spectrum of (3) (A) and of (4) (B)

of ketone (4) (Table 3). The position of the methoxy group was established as at C-7 in the same manner as isomer (3). Additionally, it was found that H-5 was α and *trans* to H-3a. The *cis*-relationship of H-3a and H-9b was indicated in this way also.

The preferred conformation of both isomers is $(3)_c/(4)_c$ in which the cyclohexene ring adopts a flattened-chair conformation and not a pseudo-boat conformation $(3)_b/(4)_b$. This was readily deduced from the multiplicities and J values obtained from the 250 MHz ^{1}H n.m.r. spectra (Tables 2 and 4). For example, H-5 in isomer (3) was observed as a doublet of doublets (J 12.1 and 4.2 Hz), consistent with dihedral angles 180 and 60° with H-4α and H-4β, respectively, as in $(3)_c$. In conformation $(3)_b$ there is a dihedral angle of 60° between H-5 and *both* H-4α and H-4β. The remaining coupling constants observable (Table 2) are consistent with conformation $(3)_c$. In the case of isomer (4), H-5 is observed as a triplet (J 4.9 Hz) which is consistent only with conformation $(4)_c$ in which there is a dihedral angle of 60° between H-5 and *both* H-4α and H-4β. From an inspection of Dreiding models, it would seem that both isomers adopt the conformation $(3)_c/(4)_c$ in order to relieve non-bonded interactions between C-3 and R^2(H or *p*-methoxyphenyl).

The 500 MHz ^{1}H n.m.r. spectra of both isomers were also obtained and served to confirm the earlier assignments, particularly the aryl substitution patterns. However, although essentially first-order multiplets were obtained for the nine sp^3 protons of (3), the spectrum of (4) remained complex with much overlapping of multiplets.

Mechanisms of Formation of Ketones (3) *and* (4).—The initiation of this rearrangement is probably the tin(IV) chloride-catalysed cleavage of one cyclopropyl ring (**2b**) ⟶ (**6**), by analogy with our results[6,15] for related systems, followed by a 5-*exo-trig*-cyclisation to (7). Consistent with this hypothesis is the effect of substituents. When the aryl groups are unactivated as in (**2a**), the rate of reaction is reduced dramatically. However, an analogue of this reaction is provided by Stork's[16] investigation of the reaction (**8**) ⟶ (**9**). He considered that since the stereo chemistry was preserved in the product, then attack by the phenyl group was concerted with cyclopropyl ring cleavage.

Table 1. Isomer (3) connectivities established by decoupling and NOEDS experiments

Proton irradiated[a]	Decoupling	NOEDS[b] (%)[c]
3a	9b	5(8), 9b(14)
5		6(6), 3a(8)
		H'_2 (7)
6		5(3), 7-MeO(2)
9		8(12), 9b(4)
9b	3a	9(9), 3a(12)

[a] Absence of entries is because of signal proximity or overlap. [b] Enhancement of other unassigned protons also observed. [c] Per proton.

Table 2. Chemical shifts and coupling constants for ketone (3)

Proton[a]	Chemial shift δ	Multiplicity	J/Hz	
2',3',5',6'	6.97	m	$J_{6.8}$	2.5
3a	2.70	ddd	$J_{8.9}$	8.4
5	3.90	dd	$J_{4\alpha.5}$	12.1[b]
6	6.30	d	$J_{4\beta.5}$	4.2
8	6.76	dd	$J_{3a.9b}$	6.5
9	7.18	d	$J_{3\alpha.4\alpha}$	10.8
9b	3.45	dt	$J_{3a.4\beta}$	5.1
7-MeO	3.61	s		
7'-MeO	3.80	s		

[a] Absence of entries is because of signal proximity or overlap. [b] Not possible to assign unambiguously due to overlap of resonances.

Table 3. Isomer (4) connectivities established by decoupling and NOEDS experiments

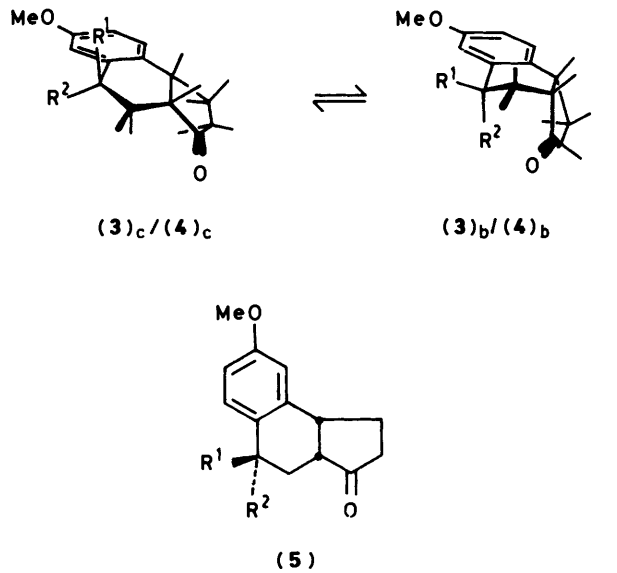
Proton irradiated[a]	Decoupling	NOEDS[b] (%)[c]
3a	9b	9b(14)
5		6(16)
6		7-MeO(3), 5(9)
9		8(17), 9b(5)
9b	3a	3a(21), 9(9)

[a] Absence of entries is because of signal proximity or overlap. [b] Enhancement of other unassigned protons also observed. [c] Per proton.

Table 4. Chemical shifts and coupling constants for ketone (4)

Proton[a]	Chemical shift δ	Multiplicity	J/Hz	
2',3',5',6'	6.84	m	$J_{6.8}$	2.7
3a	2.46	m[b]	$J_{8.9}$	8.9
5	4.06	t	$J_{4\alpha.5}$	4.9
6	6.47	d	$J_{4\beta.5}$	4.9
8	6.82	dd	$J_{9b.3a}$	4.9
9	7.23	d		
9b	3.51	q		
7-MeO	3.68	s		
7'-MeO	3.76	s		

[a] Absence of entries is because of signal proximity or overlap. [b] Complex due to overlap.



(5)

Similarly, Grieco[17] observed π-involvement when a related alkene was investigated. Alternatively, then, since the cyclopropyl ring has π-character,[2] formation of (7) from (**2b**) may involve a concerted step as in (**10**). Substituent effects could be expected to operate in (**10**) as effectively as in (**6**). Since we have been unable to detect an hydroxy ketone[6] derived from (**6**), neither pathway can be ruled out, at this point.

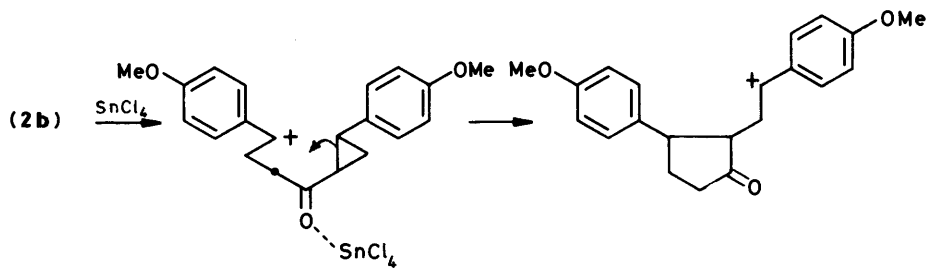
Intermediate (7) may exist in either the *cis*- or *trans*-form. Although geometrically favourable, Ar_2-6 cyclisation[18] of (7) is unlikely due to the location of the methoxy group and also in the light of related cyclisation studies.[19-21] The more probable[19,20] alternative is an Ar_1-5 *ipso*-cyclisation. An examination of Dreiding models indicates that this cyclisation is possible only in the case of the *cis*-(7) intermediate. This rationale provides an explanation for the *cis*-fusion observed in both final products. Assuming that the spiro-intermediate (**11**) is involved, it may now undergo the well established rearrangement,[19-22] related to the Hayashi rearrangement,[23] by either benzyl migration (bond *a*) or alkyl migration (bond *b*). The formation of (**5**), and hence the latter rearrangement, was disproved by NOEDS studies (see above). Additionally, it is clear from molecular models that owing to steric interaction between R^1 and the cyclopentanone ring in *cis*-(7), a preference for the formation of (**4**), in which R^1 = H, could be anticipated. Although a *ca.* 1:1 ratio of (**3**):(**4**) is observed in nitromethane, in benzene this ratio is increased to 1:2 (see Table 5). Similar solvent effects have been noted by others.[17,24]

Experimental

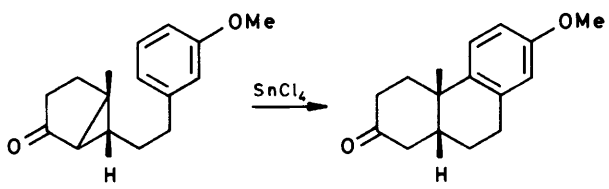
^{1}H N.m.r. spectra were obtained using a Brüker (model WM-250) 250 MHz or Hitachi–Perkin-Elmer R20A 60 MHz instrument with deuteriochloroform as solvent and tetramethylsilane as reference. The 500 MHz spectra were recorded on a Brüker 500 MHz spectrometer through the courtesy of Professor P. E. Eaton, University of Chicago. ^{13}C N.m.r. spectra were recorded in $CDCl_3$ on a JEOL FX60 instrument. Mass spectra were obtained on a VG Micromass 7070 H high-resolution double-focusing mass spectrometer coupled to a INCOS 2400 data system at 70 eV. I.r. spectra were recorded as KBr discs.

Crystal Data.—$C_{21}H_{22}O_3$, M_r = 322.4. Orthorhombic, a = 18.013(4), b = 5.546(2), c = 17.224(3) Å, V = 1 720.7 Å^3, D_c = 1.24 g cm^{-3}, Z = 4, $F(000)$ = 688, Mo-K_α radiation, λ = 0.710 69 Å, μ(Mo-K_α) = 0.5 cm^{-1}. Space group $Pna2_1$ or $Pnam$ from systematic absences: $0kl$, $k + l = 2n + 1$; $h0l$, $h = 2n + 1$; $Pna2_1$ from refinement.

Data were collected to a maximum θ of 25° on an Enraf–Nonius CAD4 diffractometer using the ω–2θ scan technique with monochromatized Mo-K_α radiation. A total of 1 580 unique reflections were collected, of which the 1 426 which have



(6) (7)



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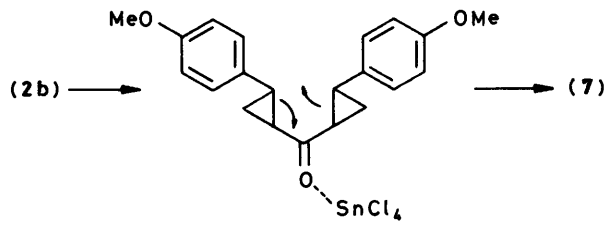

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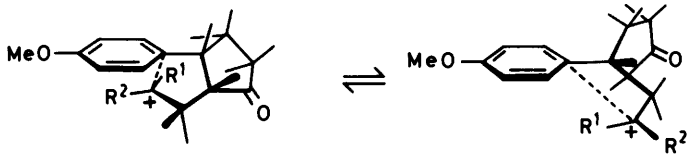
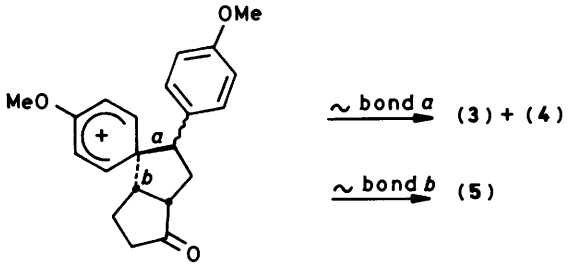


cis-(7) *trans*-(7)



(11)

$I > 3\sigma(I)$ were used in structure solution and refinement after correction for Lorentz and polarization factors.

The structure was solved by direct methods using MULTAN '80[25] and refined by full-matrix least-squares calculations[26] with anisotropic thermal parameters in a manner similar to that described previously.[27] Hydrogen atoms (from difference maps) were included with idealized geometry (C–H 0.95 Å) but not refined in the final rounds of calculations. At convergence, R = 0.040 and $R_w = [\Sigma\Delta^2/\Sigma wF_0^2]^{\frac{1}{2}} = 0.043$. A final difference map was devoid of any significant features. Tables of thermal parameters, molecular dimensions, and final fractional co-ordinates for (3) have been deposited as Supplementary Publication No. SUP 56314 (8 pp.).*

* For details of Supplementary Publications see Instructions for Authors in *J. Chem. Soc., Perkin Trans. 2*, 1985, Issue 1.

Bis(phenylcyclopropyl) Ketone (**2a**).—The ketone (**2a**) was prepared from *E,E*-1,5-diphenylpenta-1,4-dien-3-one[28] by the method of Corey and Chaykovsky[9] as detailed by us previously.[7] The *ketone* (**2a**) obtained as a mixture of diastereoisomers was recrystallised from ethanol; yield 95%; m.p. 61—81 °C (Found: C, 86.8; H, 6.8. $C_{19}H_{18}O$ requires C, 87.0; H, 6.9%); $\nu_{max.}$ 1 660, 1 615, 1 515, 1 250, and 815 cm^{-1}; δ 7.36—6.99 (10 H, m, 2 × Ph), 2.75—2.18 (4 H, m, 2 × CH-CH), and 1.90—1.22 (4 H, m, 2 × CH_2); δ_C 206.88 (s), 140.41 (s), 128.52 (d), 126.50 (d), 126.05 (d), 33.27 (d), 29.24 (d), and 19.23 p.p.m. (t).

Bis-(p-*methoxyphenylcyclopropyl*) *Ketone* (**2b**).—This ketone (**2b**) was prepared from *E, E*-1,5-bis-(*p*-methoxyphenyl)penta-1,4-dien-3-one[29] as above. The *ketone* (**2b**) was obtained as a single diastereoisomer.† It was recrystallised from absolute ethanol to give needles, yield 91%; m.p. 57—59 °C (Found: C, 78.4; H, 7.1. $C_{21}H_{22}O_3$ requires C, 78.2; H, 6.9%); $\nu_{max.}$ 1 665, 1 250, and 820 cm^{-1}; δ 7.0—6.75 (8 H, m, 2 × Ph), 3.73 (6 H, s, 2 × OCH_3), 2.60—2.10 (4 H, m, 2 × CH-CH), and 1.82—1.15 (4 H, m, 2 × CH_2); δ_C 207.14 (s), 158.47 (s), 132.48 (s), 127.22 (d), 113.96, (d), 55.29 (q), 33.14 (d), 28.85 (d), and 18.97 p.p.m. (t).

Acid-catalysed Reaction of Biscyclopropyl Ketone (**2b**). *General Procedure.*—To *ca.* 0.05—0.1M solution of the biscyclopropyl ketone (**2b**) in the indicated solvent was added tin(IV) chloride (1.1—1.5 mol equiv.) at room temperature under nitrogen. The resulting mixture was stirred at room

† No attempt was made to assign the stereochemistry. In related studies we found[6] that identical products were obtained from either diastereoisomer.

Table 5. Reaction of biscyclopropyl ketone (**2b**) with acid at room temperature

Entry	Conditions[a] solvent	time	Identified product yield (%)	isomer ratio (3):(4)		Unidentified product (%)
1	C_6H_6	30 min	66	30	70	15
2		2 h	57	35	65	15
3	CH_2Cl_2	15 min	45	40	60	29
4	$MeNO_2$	20 min	53	50	50	26
5		12 h	37	48	52	36

[a] The concentration of reactant was 0.05—0.1M. Tin(IV) chloride (1.1—1.5 equiv.) was used in each reaction.

temperature for the time indicated. It was then poured into water and neutralised with 5% sodium hydroxide, and extracted with ether. The ether extracts were combined and washed with brine, dried ($MgSO_4$), and evaporated to give an oil. Column chromatography on silica gel with ethyl acetate–light petroleum (1:1) as eluant gave two bands. The top band was a mixture of the two isomers (**3**) and (**4**). The lower band was a solid, m.p. 88—102 °C; $\nu_{max.}$ 1 745br, 1 615, 1 515, and 1 250 cm^{-1}; δ_C *inter alia* 221.69, 220.45, and 219.40 p.p.m.; M^+ 644. Both the ^1H and ^{13}C n.m.r. spectra were very complex, consistent with a mixture. All attempts to separate this highly polar mixture failed.

The top band was separated by p.l.c. (ethyl acetate–light petroleum, 1:9), developed several times, and gave the two isomers. *Isomer* (**4**) had the higher R_F, m.p. 119—122 °C (Found: C, 78.3; H, 7.0%; M^+, 322. $C_{21}H_{22}O_3$ requires C, 78.2; H, 6.9%; *M*, 322); $\nu_{max.}$ 1 730, 1 615, 1 500, 1 250, 1 030, and 840 cm^{-1}; δ_C 221.17 (s), 157.82 (s), 157.69 (s), 137.30 (s), 136.58 (s), 130.47 (s), 129.23 (d), 129.04 (d), 113.90 (d), 113.51 (d), 113.31 (d), 54.97 (q), 43.53 (d), 42.75 (d), 38.27 (d), 38.07 (t), 30.21 (t), and 26.63 p.p.m. (t). This isomer could not be separated from the last traces of isomer (**3**). The lower R_F *isomer*, (**3**), had m.p. 141—142 °C (Found: C, 78.2; H, 7.0%; M^+, 322. $C_{21}H_{22}O_3$ requires C, 78.2; H, 6.9%; *M*, 322); $\nu_{max.}$ 1 735, 1 610, 1 510, 1 250, 1 040, and 840 cm^{-1}; δ_C 220.19 (s), 158.41 (s), 157.82 (s), 141.06 (s), 136.71 (s), 130.40 (s), 129.69 (d), 129.17 (d), 114.02 (d), 113.77 (d), 112.47 (d), 55.23 (q), 47.63 (d), 45.27 (d), 39.18 (d), 38.20 (t), 30.60 (t), and 30.54 p.p.m. (t).

Attempted Reaction of the Biscyclopropyl Ketone (**2a**).—To the solution of biscyclopropyl ketone (**2a**) (1.0 g, 3.8 mmol) in nitromethane (40 ml) was added tin(IV) chloride (1.49 g, 5.7 mmol) at room temperature under nitrogen. The reaction was monitored by t.l.c. for 70 h. After the usual work-up a crude oil (0.97 g) was isolated. This oil was purified by p.l.c. (ethyl acetate–light petroleum, 1:4) and gave two major bands. The band of higher R_F was a solid (80 mg), m.p. 83—85.5 °C (Found: C, 86.6; H, 6.9. Calc. for $C_{19}H_{18}O$: C, 87.0; H, 6.9%); $\nu_{max.}$ 1 665, 1 610, 1 350, and 695 cm^{-1}; δ 7.43—7.0 (10 H, m, ArH), 2.70—2.17 (4 H, m, 2 × CH-CH), and 1.88—1.20 (4 H, m, 2 × CH_2). The ^{13}C n.m.r. spectrum was identical with that of the starting material. The band of lower R_F was a solid (0.3 g), m.p. 56—57.5 °C (Found: C, 86.7; H, 6.8. Calc. for $C_{19}H_{18}O$: C, 87.0; H, 6.9%); $\nu_{max.}$ 1 670, 1 410, 1 350, and 700 cm^{-1}; δ 7.48—7.15 (10 H, m, ArH), 2.80—2.22 (4 H, m, 2 × CH-CH), and 1.88—1.27 (4 H, m, 2 × CH_2). The ^{13}C n.m.r. spectrum was identical with that of the starting material. These products were accompanied by some decomposition and high-polarity products at the base line (0.54 g). All attempts to isolate products from this mixture by p.l.c. were unsuccessful. Various mixtures of light petroleum, chloroform, ethyl acetate, ether, and methanol were used.

When this reaction was monitored *in situ* by ^{13}C n.m.r. spectroscopy, starting material was observed accompanied by only small absorptions at various positions in the course of one week in the n.m.r. tube. The reaction mixture had blackened. This indicated some decomposition. The spectra showed no major product.

Attempted Epimerisation of Isomers (**3**) *and* (**4**).—Components (**3**) and (**4**) (80 mg each) were separately heated to reflux in a mixture of glacial acetic acid (4 ml) and 1M-hydrochloric acid (4 ml), overnight. After cooling, each mixture was filtered, and the precipitate dissolved in chloroform and washed with water, dried ($MgSO_4$), and evaporated to dryness and gave only starting material. The absence of epimerisation was confirmed by t.l.c., ^1H, and ^{13}C n.m.r. spectra.

Acknowledgements

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References

1 Preliminary communication, K. Hantawong, W. S. Murphy, N. Russell, and D. R. Boyd, *Tetrahedron Lett.*, 1984, **25**, 999.
2 A. de Meijere, *Angew. Chem., Int. Ed. Engl.*, 1979, **18**, 809; D. Seebach, *ibid.*, p. 239.
3 M. Julia, S. Julia, and R. Guegan, *Bull. Soc. Chim. Fr.*, 1960, 1072, M. Julia, S. Julia, and S. Y. Tchen, *ibid.*, 1961, 1849.
4 E. Wenkert, *Acc. Chem. Res.*, 1980, **13**, 27.
5 R. L. Danheiser, J. M. Morin, M. Yu, and A. Basak, *Tetrahedron Lett.*, 1981, **22**, 4205 and references therein.
6 W. S. Murphy and S. Wattanasin, *J. Chem. Soc., Perkin Trans. 1*, 1982, 1029.
7 W. S. Murphy and S. Wattanasin, *J. Chem. Soc., Perkin Trans. 1*, 1982, 271.
8 M. A. G. El-Fayoumy, H. M. Bell, M. A. Ogliaruso, and B. H. Arison, *J. Org. Chem.*, 1981, **46**, 1603.
9 E. J. Corey and M. Chaykovsky, *J. Am. Chem. Soc.*, 1962, **84**, 3782.
10 P. G. Jones, *Chem. Br.*, 1981, **17**, 222.
11 A. C. Larson and E. J. Gabe, in 'Computing in Crystallography,' eds. H. Schenk, R. Olthof-Hazekamp, H. van Koningsveld, and G. G. Bassi, Delft University Press, Delft, 1978, p. 81.
12 See for example L. D. Hall and J. K. M. Sanders, *J. Am. Chem. Soc.*, 1980, **102**, 5703.
13 See for example M. P. Williamson and D. H. Williams, *J. Am. Chem. Soc.*, 1981, **103**, 6580.
14 J. H. Noggle and R. E. Schirmer, 'The Nuclear Overhauser Effect,' Academic Press, New York, 1971.
15 W. S. Murphy and S. Wattanasin, *J. Chem. Soc., Perkin Trans. 1*, 1981, 2920.
16 G. Stork and M. Gregson, *J. Am. Chem. Soc.*, 1969, **91**, 2373.
17 G. Stork and P. A. Grieco, *J. Am. Chem. Soc.*, 1969, **91**, 2407; *Tetrahedron Lett.*, 1971, 1807; P. A. Grieco and R. S. Finkelhor, *ibid.*, 1974, 527.
18 B. Capon, *Chem. Soc. Rev.*, 1964, **18**, 90.
19 L. M. Jackman and V. R. Haddon, *J. Am. Chem. Soc.*, 1974, **96**, 5130.
20 M. Gates, D. L. Frank, and W. C. von Felten, *J. Am. Chem. Soc.*, 1974, **96**, 5138.
21 R. Heck and S. Winstein, *J. Am. Chem. Soc.*, 1957, **79**, 3105.
22 L. E. Friedrich and S. Winstein, *Tetrahedron Lett.*, 1962, 475.
23 See M. Newman, *Acc. Chem. Res.*, 1972, **5**, 254.
24 A similar solvent effect has been observed in a biomimetic cyclisation study: G. D. Abrams, W. R. Bartlett, V. A. Fung, and W. S. Johnson, *Bioorg. Chem.*, 1971, **1**, 243.

25 P. Main, S. J. Fiske, S. Hull, L. Lessinger, G. Germain, J.-P. Declerq, and M. M. Woolfson, Multan-80, Universities of York and Louvain, 1980.
26 G. M. Sheldrick, SHELX-76, Programs for Crystal Structure Determinations, Cambridge, 1976.
27 J. F. W. Keana, J. S. Bland, P. J. Boyle, M. Erion, R. Hartling, J. R. Husman, R. D. Roman, G. Ferguson, and M. Parvez, *J. Org. Chem.*, 1983, **48**, 3627.
28 G. R. Conard and M. A. Dolliver, *Org. Synth.*, 1946, Coll. vol. 2, 167.
29 A. Baeyer and V. Villiger, *Chem. Ber.*, 1902, **35**, 1189.

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