crystallization of the crude alcohol from *n*-hexane gave colorless prisms of (-)-**5**: mp 78.3–79.9 °C (racemate; oil); $[\alpha]_{589}$ -39.9° (*c* 0.490); NMR δ 0.87 (s, *tert*-butyl), 1.33 (s, hydroxyl), 3.57–4.10 (m, methylene and methine), 7.23–7.88 (m, 6 H, aromatic), 8.05–8.33 (m, 1 H, aromatic); IR 3550, 3370 cm^{-1} (ν_{OH}).

Anal. Calcd for $C_{16}H_{20}O$: C, 84.16; H, 8.83. Found: C, 84.06; H, 8.82.

(-)-2-*tert*-Butyl-1-chloro-2-(α-naphthyl)ethane (6). A mixture of (-)-**5** (10.7 g), triphenylphosphine (14.8 g), and CCl_4 (300 mL, previously dried over molecular sieves 3A) was refluxed with stirring for 70 h. Methanol (5 mL) was added, and the mixture was refluxed for 3 h to decompose excess triphenylphosphine. The solvent was evaporated, *n*-hexane was added, and the precipitates were filtered. The residue obtained on evaporating the filtrate was dissolved in *n*-hexane and passed through a column of silica gel (80 g). The eluate was concentrated to yield crystals of **6** which were recrystallized from methanol to give colorless prisms (8.8 g, 76%): mp 79.0–80.4 °C (racemate; mp 61.8–63.5 °C); $[\alpha]_{589}$ -7.9° (*c* 1.414, isooctane); NMR δ 0.96 (s, *tert*-butyl), 3.78–4.26 (m, methylene and methine), 7.32–7.97 (m, 6 H, aromatic), 8.08–8.30 (m, 1 H, aromatic).

Anal. Calcd for $C_{16}H_{19}Cl$: C, 77.87; H, 7.76; Cl, 14.37. Found: C, 77.86; H, 7.84; Cl, 14.15.

(+)-*tert*-Butyl-3-(α-naphthyl)propionic Acid (7). A mixture of (-)-6 (2.997 g), ethylene dibromide (0.428 g), well-dried magnesium sands (0.350 g), and absolute THF (40 mL) was refluxed with stirring for 32 h under dry N_2 gas. The Grignard reagent was carboxylated in a similar manner as that used in the case of **4**. Recrystallization of the resulting acid from *n*-hexane yielded colorless rods of **7** (2.201 g, 71%): mp 99.4–100.7 °C (racemate; mp 179.8–180.4 °C); $[\alpha]_{589}$ +33.2° (*c* 0.849); NMR δ 0.88 (s, *tert*-butyl), 2.80, 2.87 (AB part of ABX pattern, $|J_{AB}|$ = 15.8 Hz, $|J_{AX}|$ = 12.2 Hz, $|J_{BX}|$ = 3.5 Hz, methylene), 4.02 (X part of ABX pattern, $|J_{AX} + J_{BX}|$ = 15.7 Hz, methine), 7.28–7.88 (m, 6 H, aromatic), 8.08–8.38 (m, 1 H, aromatic), 9.50 (bs, carboxyl).

Anal. Calcd for $C_{17}H_{20}O_2$: C, 79.65; H, 7.86. Found: C, 79.65; H, 7.87.

(-)-3-*tert*-Butyl-3-(1′,2′,3′,4′-tetrahydro-5′-naphthyl)-propionic Acid (8). A mixture of (+)-**7** (1.245 g), platinum dioxide (0.3 g), ethyl acetate (24 mL), and acetic acid (6 mL) was stirred vigorously under a hydrogen atomsphere for 19.5 h. The catalyst was removed, and the oil obtained on evaporating the solvent was chromatographed on silica gel (10 g). Benzene and benzene–ether (1:1) eluates were concentrated to give an oil which crystallized on trituration with *n*-pentane. Recrystallization from *n*-pentane afforded colorless rods of **8** (1.072 g, 85%): mp 104.3–106.0 °C (racemate; mp 161.0–163.6 °C); $[\alpha]_{589}$ -18.8° (*c* 0.821); NMR δ 0.92 (s, *tert*-butyl), 1.55–1.90 (m, 4 H, methylenes), 2.58–2.97 (m, 6 H, methylenes), 3.42 (dd, $|J_{AX} + J_{BX}|$ = 15 Hz, methine), 6.90–7.03 (m, aromatic), 8.75 (bs, carboxyl); IR 1705 cm^{-1} ($\nu_{C=O}$).

Anal. Calcd for $C_{17}H_{24}O_2$: C, 78.42; H, 9.29. Found: C, 78.17; H, 9.27.

Resolution of *tert*-Butylphenylacetic Acid (9). (±)-**9**[12] (80 g) was mixed with brucine dihydrate (124.5 g) in warm methanol (2.15 L), and 0.85 L of methanol was removed by distillation. The salt deposited on cooling (126.8 g) was recrystallized twice from methanol to afford 115.4 g of pure salt: mp 110 °C dec; $[\alpha]_{589}$ -58.7° (*c* 0.358). Regeneration with 2 N HCl and recrystallization from *n*-hexane afforded 31.7 g of colorless needles: mp 140.8–141.5 °C; $[\alpha]_{589}$ -48.2° (*c* 2.351).

The mother liquor of the first crop of resolution was concentrated and acidified with HCl to give 39.8 g of crude (+)-**9**, $[\alpha]_{589}$ +43.4° (*c* 2.478), which was mixed with 60.9 g of cinchonine in warm methanol (0.8 L), and 0.25 L of hot water was added. The salt deposited on cooling was recrystallized from methanol–water (5:2), giving 72.5 g of pure crystals: mp 198 °C dec; $[\alpha]_{589}$ -142.8° (*c* 1.094). Regeneration with HCl and recrystallization from *n*-hexane gave 28.75 g of (+)-**9**: $[\alpha]_{589}$ + 48.0° (*c* 2.279), lit.[12] $[\alpha]_{589}$ +47.7°.

(-)-**10** (mp 96.8–98.1 °C, $[\alpha]_{589}$ -16.4° (*c* 2.216)), (-)-**11** (bp 76–78 °C (1 mm), $[\alpha]_{589}$ -30.7° (*c* 2.215, *n*-hexane)), and (-)-**12** (mp 95.8–96.8 °C, $[\alpha]_{589}$ -15.8° (*c* 0.820))[13] were prepared starting from (+)-**9** according to Mosher's procedure.[12]

(+)-Dimethyl *tert*-Butylsuccinate (13). A. From (-)-8. To a yellow solution of ruthenium tetroxide prepared from ruthenium dioxide (307 mg), sodium periodate (2 g), acetone (50 mL), and water (12 mL) was added a solution of (-)-**8** (507 mg) in acetone (30 mL) at room temperature. The mixture was stirred for 66 h, during which time sodium periodate (28 g) in water (140 mL) and acetone (140 mL) was added portionwise to keep the reaction mixture light yellow whenever darkening occurred. After the precipitates were removed on a Celite column, most of the acetone was evaporated, and the residue was extracted with ether. The acidic materials were isolated in the usual manner to give 642 mg of crude acid, which was treated with an excess amount of ethereal diazomethane. The resulting ester was chromatographed twice on silica gel (20 g), eluting with *n*-hexane–ethyl acetate (9:1). The eluate was concentrated to afford 123 mg (31%) of pure ester (NMR and TLC), $[\alpha]_{589}$ +12.3° (*c* 1.108), which was distilled to give an analytical sample of **13**: bp 120 °C (bath temperature, 2 mm); $[\alpha]_{589}$ +12.4°, $[\alpha]_{405}$ +36.8° (*c* 0.582); NMR δ 0.99 (s, *tert*-butyl), 1.96–2.93 (m, methylene and methine), 3.69, 3.72 (s each, methyls); IR 1740 cm^{-1} ($\nu_{C=O}$).

Anal. Calcd for $C_{10}H_{18}O_4$: C, 59.38; H, 8.97. Found: C, 59.29; H, 9.04.

B. From (*S*)-(-)-12. (*S*)-(-)-**12** (377 mg) was degraded by the action of ruthenium tetroxide reagent, and the resulting acid was esterified in a similar manner as that used in A. Purification by chromatography yielded 234 mg (63%) of pure **13** (NMR and TLC), $[\alpha]_{589}$ +12.7° (*c* 2.339), which was distilled to afford 112 mg of an analytical sample: $[\alpha]_{589}$ +12.4° (*c* 1.213).

Registry No. **1**, 66-77-3; **2**, 57573-88-3; **3**, 71185-36-9; (±)-**4**, 71185-37-0; (*S*)-(+)-**4**, 71214-34-1; (*S*)-(+)-**4** brucine salt, 71214-41-0; (*R*)-(-)-**4**, 71214-35-2; (*S*)-(-)-**5**, 71185-38-1; (*S*)-(-)-**6**, 71185-39-2; (±)-**6**, 71214-42-1; (*S*)-(+)-**7**, 71185-40-5; (±)-**7**, 71214-43-2; (*S*)-(-)-**8**, 71185-41-6; (±)-**9**, 13490-70-5; (+)-**9**, 13490-71-6; (-)-**9** brucine salt, 71185-51-8; (*R*)-(-)-**9**, 13491-16-2; (*S*)-(-)-**10**, 54321-15-2; (*S*)-(-)-**11**, 54321-14-1; (*S*)-(-)-**12**, 24425-68-1; (*S*)-(+)-**13**, 71185-42-7; brucine, 357-57-3; *tert*-butyl chloride, 507-20-0; 1-*tert*-butyl-1-phenylethane, 71214-36-3; methyl α-*tert*-butylphenylacetate, 71214-37-4; methyl β-*tert*-butylphenylpropanoate, 71214-38-5; 1,3-bis(*tert*-butylphenylmethyl)-3-(methoxycarbonyl)propane, 71185-43-8; 1,3-bis(*tert*-butylphenylmethyl)-2-carboxypropane, 71185-44-9; 1,2,3,4-tetrahydro-5-(1-*tert*-butylethyl)naphthalene, 71185-45-0; 3-*tert*-butyl-3-(1′,2′,3′,4′-tetrahydro-5′-naphthyl)propionic acid, 71214-39-6; 2-*tert*-butylpropionic acid, 19910-29-3; monomethyl 2-*tert*-butylpropanedioate, 71185-46-1; dimethyl 2-*tert*-butylbutanedioate, 71214-40-9; dimethyl 3-*tert*-butyl-2-oxopentanedioate, 71185-47-2; 2,6-di-*tert*-butyl-4-(methoxycarbonyl)heptanedioic acid, 71185-48-3; dimethyl 2,6-di-*tert*-butyl-4-(methoxycarbonyl)-7-oxooctanedioate, 71185-49-4; dimethyl 2,6-di-*tert*-butyl-4-(methoxycarbonyl)heptanedioate, 71185-50-7; ruthenium tetraoxide, 20427-56-9.

Quantitative Studies in Stereochemistry. 16. The Ratio of Diastereomeric Pinacols Produced in the Aluminum Amalgam Bimolecular Reduction of Acetophenone

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A report of the almost stereospecific bimolecular reduction of acetophenone employing aluminum amalgam in refluxing methylene chloride has appeared.[1] An earlier series of studies from the present authors' laboratory

(1) A. P. Schriebmann, *Tetrahadron Lett*, 4271 (1970). The author reports yields of 21–38% of this pinacol of which less than 1% is the meso form. An unspecified amount of *trans*-α,α′-dimethylstilbene was also found; no simple carbinol was observed (both items in contrast to the present study). Since experimental details for the methylene chloride studies did not include amounts or reaction times, it is not possible to offer any reasonable rationale for the discrepancies between the present and the earlier reports. It can only be assumed that some combination of reagent sources, reagent amounts, or reaction conditions could account for the observed differences. No report subsequent to this communication appears to have been made by this author.

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Table I. Reduction of Acetophenone by Various Techniques

entry no.	media	concn, g/mL (M)	reflux time, h	yields,[a] % carbinol	pinacol (*dl*/meso)	recov acetophenone
		Photochemical in Protic Media				
1[b]	2-PrOH			0	100 (1.1)	0
		Electrochemical in Protic Media				
2[c]	80% EtOH			0	60 (1.1)	0
		Aluminum Amalgam in Protic Media				
3	C_6H_6/EtOH, 1:1	0.5/50 (0.08)	4	0	95 (1.1)	5
4	CH_2Cl_2/EtOH, 1:1	1/50 (0.17)	5	0	90 (1.1)	5
5	C_6H_6/2-PrOH, 1:1	1/10 (0.83)	4	0	88 (1.1)	10
		Aluminum Amalgam in Aprotic Media				
6	CH_2Cl_2	0.5/100 (0.04)	4	10	15 (2.0)	75
7	CH_2Cl_2	0.5/25 (0.17)	4	0	35 (2.0)	15
8	CH_2Cl_2	0.5/25 (0.17)	4	10	53 (1.9)	20
9	CH_2Cl_2	1/10 (0.83)	4	<5	61 (2.0)	17
10	C_6H_6	0.5/100 (0.04)	4	0	<5	70
11	C_6H_6	0.5/25 (0.17)	4	0	35 (2.2)	11
12	C_6H_6	0.5/25 (0.17)	4	0	23 (2.2)	50
13	C_6H_6	1/10 (0.83)	4	0	65 (2.2)	25
14	C_6H_6	1/10 (0.83)	1	0	65 (2.2)	10
15	C_6H_6	1/10 (0.83)	0.25	0	7 (~2)	90
16	xylene	1/10 (0.83)	0.75	0	*d* (2.0)	(<5)[d]
17	xylene	1/10 (0.83)	4	0	*e* (1.8)	35
		Preformed Aluminum 2-Propoxide				
18	C_6H_6/2-PrOH, 1:1	1/10 (0.83)	4	95	0	0

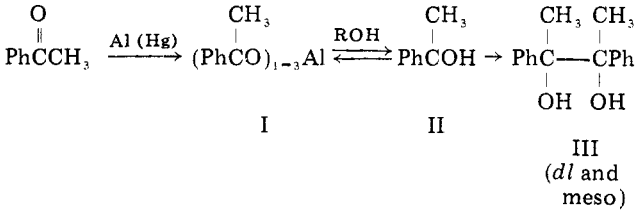
[a] Yields estimated to be accurate to 5-10%. [b] Representative example, neutral or acidic media, see ref 13. [c] Average result, neutral or acidic media, see ref 14. [d] Overzealous removal of the solvent resulted in low mass balance reflecting appreciable loss of unreacted acetophenone. This should not affect isomer ratio but does lead to an unreasonably high percent yield of pinacols. [e] Incomplete removal of solvent resulted in high mass balance and an unreasonably low figure for percent yield. Diastereomeric ratio is not affected.

describing the attendant stereochemistry of the photopinacolization[2] and electropinacolization[2] of this compound in protic media indicated a common but rather low level of stereoselectivity to these reactions.[3] A careful search of the literature disclosed only one other report of the stereochemical aspects of this reaction.[4] Since a pinacolization process of this mildness and high stereoselectivity could have appreciable synthetic utility, we have made a more quantitative study, with the representative ketone acetophenone, and report the results below. Regretably, it does not support the earlier study's promise. Variations in reflux time, concentration, and, particularly, solvent were considered. A comparative study employing a preformed aluminum alkoxide (Meerwein–Pondorf–Verley) was also carried out.

The first reported exploitation of this pinacolic reductive technique was by Newman,[6] who observed diastereomeric mixtures but did not characterize them. The Newman choice of solvent, benzene and an alcohol, usually ethanol, is the medium customarily associated with this technique.[7]

The present work, reported in Table I, shows the reaction to have a very low stereoselectivity in protic media, slightly in favor of the *dl* form, essentially identical with that observed in neutral/acidic protic media in both photopinacolization and electropinacolization studies.[2] An increase to 2:1 *dl* preference is observed in aprotic media. The yield, but not the stereoselectivity, is clearly concentration dependent in the latter studies. While the methylene chloride appears to slightly improve the yields in the aprotic studies, there is no evidence that either solvent plays a distinctive role in diastereomer determination.

There have been a number of mechanistic proposals to explain this type of reduction.[9] It is usually agreed that there is a transfer of one electron from the metal to the carbonyl to produce a radical anion which may be bonded to the metal, with varying degrees of covalency, via either the oxygen or the carbon atom. It seems simplest to view the present case as:



Dimerization of II[10] to yield III has been demonstrated[2] to yield the product diastereomers in the ratio presently

(2) J. H. Stocker, R. M. Jenevein, and D. H. Kern, *J. Org. Chem.*, **34**, 2810 (1969), and references cited therein.

(3) A somewhat higher level of stereoselectivity was subsequently observed in aprotic media (cf. J. H. Stocker and R. M. Jenevein, *Collect. Czech. Chem. Commun.*, 36, 925 (1970)); this higher value still did not approach the specificity inferred in ref 1.

(4) A conformational study[5] of the pinacolic diastereomers from isobutyrophenone and its *p*-dimethylamino derivative, prepared incidentally by the Newman technique, reported that the *crystallized* product from these preparations, by NMR analysis, showed about a 60:40 meso:*dl* ratio for the pinacols from the simple phenone and a 55:45 meso:*dl* ratio for the substituted one. It should be pointed out that the meso form is usually appreciably less soluble than the racemate.

(5) A. Vigevani, R. Pasqualucci, G. G. Gallo, and G. Pifferi, *Tetrahedron*, **25**, 573 (1969).

(6) M. S. Newman, *J. Am. Chem. Soc.*, **62**, 1683 (1940); cf. also M. S. Newman, *J. Org. Chem.*, **26**, 582 (1961).

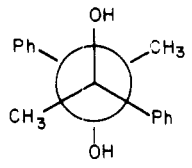
(7) The use of aluminum amalgam in other media for ketone reduction is appreciably older, the products being simple alcohols rather than pinacols, e.g., in ether, diethyl oxaloacetate produced diethyl malate.[8]

(8) H. Wislicenus and L. Kaufmann, *Chem. Ber.*, **28**, 1323 (1895).

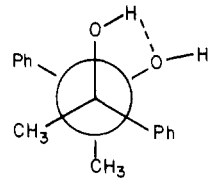
(9) A good, brief summary appears in H. O. House, "Modern Synthetic Reactions", W. A. Benjamin, San Francisco, Calif., 2nd ed., 1962, pp 155–169.

(10) A referee has pointed out that the neutral ketyl radical II would be more acidic than the solvent alcohol.[11] Although the indicated equilibrium between I and II would be correspondingly unfavorable, the huge preponderance of solvent alcohol should, on a mass action basis, lead to an unspecified but appreciable amount of II.

observed; this ratio has been explained[2,12] as that due to conformational control via interspecies hydrogen bonding at the time of combination.



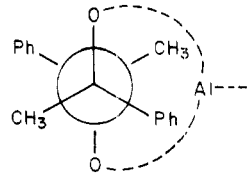
A
(all like groups opposed, major route to meso)



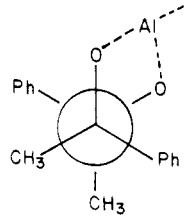
B
(phenyl groups opposed, a major route to *dl*)

In aprotic media, the formation of II would be minimal, and the "dimerization", presumably intramolecularly from I, would predominate.

Reasoning similar to that proposed for the ketyl radical dimerization would be invoked to explain *dl* predominance, i.e.,



A'
(major route to meso)



B'
(phenyl groups opposed, a major route to *dl*)

Some combination of oxygen–aluminum bond distances and/or bond strengths would increase the utilization of pathway B′ relative to B and increase the preference for the *dl* product.

Another aspect of the problem deserves comment. Utilization of the *components* of an aluminum alkoxide in a protic medium is associated with the production of pinacol while a preformed alkoxide (Merwein–Pondorf–Verley reaction) is employed to produce simple carbinol. A comparison of the two pathways, using the alcohol/alkoxide preferred in MPV reactions (2-PrOH), would permit the observation of whether the readily interacting alcohol and aluminum together produce any alkoxide in situ which, if formed, should give rise to some simple carbinol. No carbinol was observed under such circumstances (entry 5 in Table I). The preformed alkoxide studies gave only carbinol (entry 18, 2-PrOH) or a neglible reaction (EtOH).

Experimental Section

The procedures employed by Newman[6] and by Schriebmann[1] were adapted as follows (variation in amounts and times will be found in Table I [13,14]). The acetophenone (Eastman Reagent), aluminum foil (Baker purified, 18 in.^{2} × 0.001 in., ~0.75 g cut in small squares), solvent (simple or 1:1 with alcohol), and 0.1 g of $HgCl_2$ were added to a flask in that order. The reaction mixture was cooled and hydrolyzed with a 0.5 M HCl/ice slurry, after the appropriate reflux. The organic layer was separated, the aqueous layer was thoroughly extracted with the common solvent, and the combined organic layers were washed successively with 0.5 M HCl, 5% $NaHCO_3$, and saturated NaCl and dried over $MgSO_4$. The dried material was concentrated to the complete removal of solvent, and the residue was weighed (material balance) and dissolved in $CDCl_3$. Yields and diastereomeric ratios were determined by NMR.[15]

The preformed aluminum alkoxide studies differed only in the replacement of the components of aluminum amalgam with the preformed reagent; e.g., 4.1 g of freshly distilled aluminum 2-propoxide,[16] 0.122 g of acetophenone, 10 mL of 2-propanol, and 10 mL of benzene refluxed 4 h produced a nearly quantitative yield of methylphenylcarbinol and no pinacol.

Registry No. Acetophenone, 98-86-2; α-methylbenzyl alcohol, 98-85-1; *dl*-2,3-diphenyl-2,3-butanediol, 22985-90-6; *meso*-2,3-diphenyl-2,3-butanediol, 4217-65-6.

(11) E. Hayon and M. Simic, *Acc. Chem. Res.*, 7, 114 (1974).
(12) While the arguments are somewhat lengthy and have been provided in detail elsewhere,[2] it might be helpful to note that simple dimerization of any such radicals (or radical anions) would be expected to produce a predominance of the meso form as argued from the viewpoint that only when all like groups are opposed do we have a minimum of nonbonded interactions. Accordingly, some other influence(s) must be controlling.
(13) J. H. Stocker and D. H. Kern, *J. Org. Chem.*, 31, 3755 (1966).
(14) J. H. Stocker and R. M. Jenevein, *J. Org. Chem.*, 33, 294 (1968).
(15) J. H. Stocker, D. H. Kern, and R. M. Jenevein, *J. Org. Chem.*, 33, 412 (1968).
(16) Preformed according to T. Bersin, "Newer Methods of Preparative Organic Chemistry", Interscience, New York, 1948, p 132.

Conformational Analysis of *cis*- and *trans*-2,6-Diphenyl-5,6-dihydro-2*H*-thiopyran

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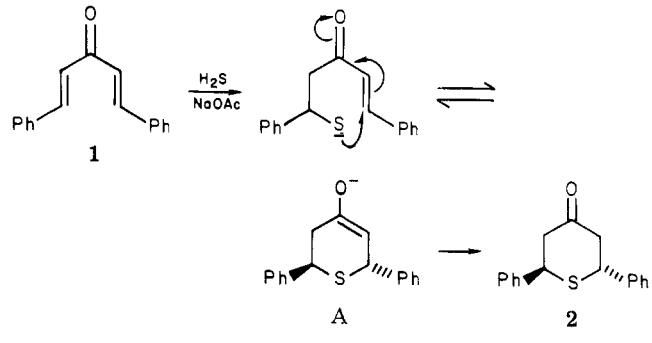
Not much is known of the conformation of 4-heterosubstituted cyclohexene rings.[1] Such a ring has been invoked as a conformational model, however, to explain the preferential formation of the less stable trans isomer of 2,6-diphenyltetrahydro-1-thiopyran-4-one (2) from reaction of dibenzylideneacetone (1) and sodium acetate in 90% aqueous ethanol saturated with hydrogen sulfide.[2]



1 A 2

The proposed reaction mechanism required that both the trans and cis intermediate enols prefer a boat conformation. The trans isomer of the intermediate enolate A, having both phenyl groups equatorial, was expected to be more stable than the cis isomer, having one phenyl axial and the other equatorial. With the assumption that the transition state for the formation of the enolate A is similar to A, the conformational differences accounted for the preferential formation of the trans isomer.

(1) Conformational studies were reported recently on some simple 5,6-dihydro-2*H*-pyran systems: O. Achmatowicz, Jr., M. Chmielewski, J. Jurczak, and L. Kozerski, *Rocz. Chem.*, 48, 481 (1974); O. Achmatowicz, Jr., M. Chmielewski, J. Jurczak, L. Kozerski, and A. Zamojski, *Org. Magn. Reson.*, 4, 537 (1972); O. Achmatowicz, Jr., A. Ejchart, J. Jurczak, L. Kozerski, J. S. Pyrek, and A. Zamojski, *Rocz. Chem.*, 46, 903 (1972); O. Achmatowicz, Jr., J. Jurczak, A. Konowal, and A. Zamojski, *Org. Magn. Reson.*, 2, 55 (1970).
(2) C. A. R. Baxter and D. A. Whiting, *J. Chem. Soc. C*, 1174 (1978).

0022-3263/79/1944-3591$01.00/0