exo-norbornanol). By nmr integration of the 2-*exo*-hydrogen signal at 4.15 ppm for *endo*-norbornanol and of the 2-*endo*-hydrogen signal at 3.67 ppm for *exo*-norbornanol, the solid was shown to be composed of *ca.* 89% *endo*-norbornanol and *ca.* 11% *exo*-norbornanol.

Attempted Reduction of Camphor.—The procedure was that described above except for the following modifications. Since the camphor did not appear to dissolve appreciably and would sublime and clog the reflux condenser, 25 ml of dioxane was added which eliminated the problem. The quantities of material employed were 30.4 g (0.200 mole) of *d*-camphor, 25.0 g of potassium hydroxide, and 500 ml of ethylene glycol. Only a light orange tint developed after 7 days of refluxing. After cooling, the solution was added to ice water, and the white solid that formed was washed repeatedly with water and dried to give 25.6 g of solid, the infrared spectrum of which was not appreciably different from that of pure *d*-camphor except for weak absorption at 2.9 μ. We plan on attempting to reduce camphor under further modified conditions to see whether a successful reduction can be obtained. Perhaps a reaction time longer than 7 days is required.

Registry No.—Ethylene glycol, 107-21-1; 3-*endo*-phenyl-2-norbornanone, 7485-53-2; benzophenone, 119-61-9; 1-phenyl-2-norbornanone, 7485-54-3; norbornane, 279-23-2; camphor, 76-22-2.

On the Preparation of (3*S*)-2,3-Dimethylpentanal by Reaction of (+)-Tris[(2*S*)-1,2-dimethylbutoxy]methane (I) with Carbon Monoxide and Hydrogen[1]

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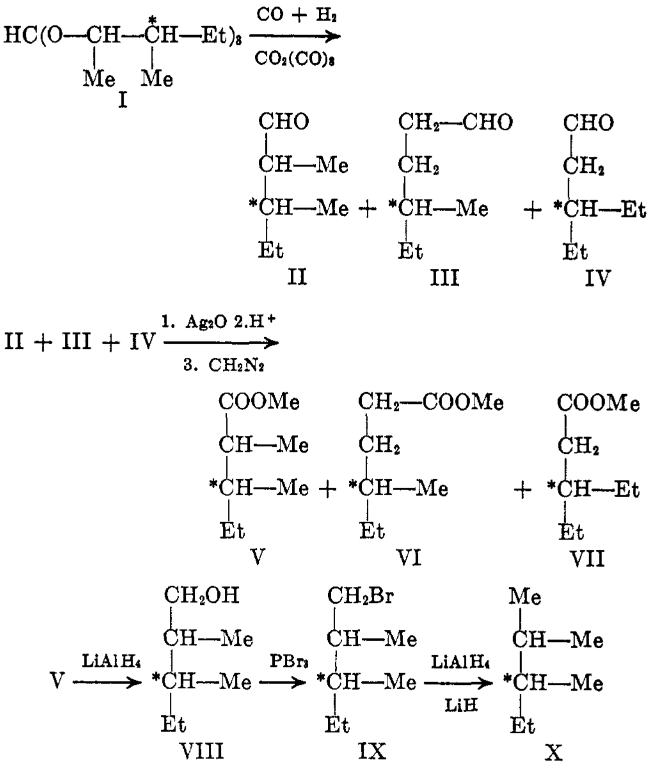
We wish to report and discuss the results obtained in developing a convenient method to prepare a diastereoisomeric mixture of (3*S*)-2,3-dimethylpentanal (II) and its derivatives with a high optical purity with respect to the 3*S* center of asymmetry by the reaction of I with CO and H_2 in the presence of a cobalt catalyst[2,3] (Chart I). Poor results were in fact obtained in the synthesis of II by the usual techniques. By treating I with CO and H_2 in the presence of $Co_2(CO)_8$ in benzene solution[3] a mixture of isomeric aldehydes was obtained which was converted into the corresponding methyl esters (Chart I)[4] further separated by rectification, and identified by comparison of their physical properties with those of authentic samples.

The diastereoisomeric methyl 2,3-dimethylpentanoates (V) and methyl 4-methylhexanoate (VI) were thus obtained in pure form while an intermediate fraction was a 68:32 mixture (vpc analysis) of VI and a third isomeric component. To this third product the structure of VII was assigned on the basis of vpc retention time and the infrared spectrum of a 68:32 mixture of authentic samples of VI and VII. No definite evidence of the presence of 2-ethyl-2-methylbutanoic acid methyl ester has been obtained either from vpc or infrared analysis. We conclude therefore that the above component may be present only in very small amounts if any.

CHART I



The isomeric distribution of the aldehydes obtained by reaction of I with CO and H_2 thus resulted II:III:IV = 39.5:52.0:8.5.[4]

The optical purity of VI, evaluated by comparison of its optical rotatory power with the one of a sample of VI of known optical purity,[5] was 13.6%.

The minimum optical purity of V, with reference to the 3*S* center of asymmetry, evaluated by conversion into (−)-(*S*)-2,3-dimethylpentane (X) (Chart I),[6] was 80.9%.

Thus by assigning to I, with reference to the 2*S* center of asymmetry, an optical purity of 90.0%,[7] the optical yield, with respect to the 3*S* center of asymmetry in the formation of VI results in 15.2%, while it is 90.0% in the formation of V.

The formation of III and IV may be interpreted as owing to the hydroformylation of intermediate olefin,[2,3] in our case (+)-(*S*)-3-methylpent-1-ene (XII)

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[1] This research was supported in part by Consiglio Nazionale delle Ricerche, Roma.

[2] F. Piacenti, *Gazz. Chim. Ital.*, **92**, 225 (1962).

[3] P. Pino, F. Piacenti, and P. P. Neggiani, *Chim. Ind.* (Milan), **44**, 1367 (1962).

[4] F. Piacenti, P. Pino, R. Lazzaroni, and M. Bianchi, *J. Chem. Soc.*, 488 (1966).

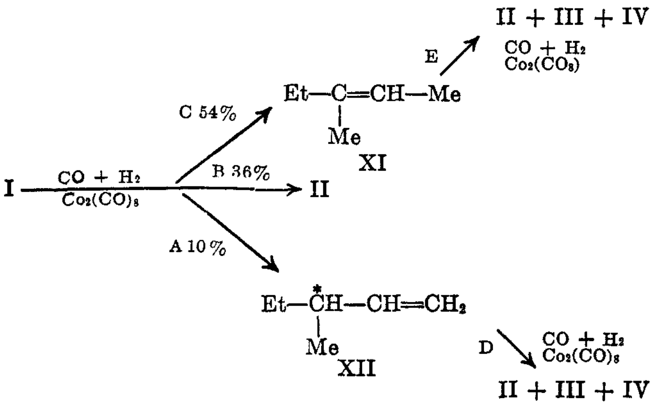
[5] By treating CH_2N_2 with a sample of (+)-(*S*)-4-methylhexanoic acid of 86.6% optical purity [L. Lardicci and P. Pino, *Gazz. Chim. Ital.*, **91**, 441 (1962)], methyl (+)-(*S*)-4-methylhexanoate having $[\alpha]^{25}_{D}$ + 8.77 was obtained.

[6] K. Freudenberg and W. Lwowski, *Ann.*, **587**, 223 (1954).

[7] An enolization equilibrium, which only could determine racemization while preparing (−)-(3*S*)-3-methylpentan-2-ol by treating (+)-(*S*)-2-methylbutanal with CH_3MgBr, must be considered irrelevant in the conditions adopted, as CH_4 evolution was never observed. No racemization was encountered either in the subsequent transesterification between $HC(OEt)_3$ and (−)-(3*S*)-3-methylpentan-2-ol as the same diastereoisomeric composition and optical activity were observed both for the starting alcohol and the recovered one by hydrolysis of I. It is thus reasonable to attribute to I the same optical purity, with respect to the 2*S* center of asymmetry, of (+)-(*S*)-2-methylbutanal (90.0%) [L. Lardicci and R. Rossi, *Atti Soc. Toscana-Sci. Nat. Pisa, Proc. Verbali Mem.*, **68A**, 23 (1961)].

and 3-methylpent-2-ene (XI) (Chart II). On the basis of the isomeric distribution of the hydroformylation products of XI and XII and the corresponding optical yields,[8] the minimum optical yield (15.2%) encountered in obtaining III from I, CO, and H_2 suggests that 16.7% of III was formed by hydroformylation of XII while the remaining 83.3% was due to the hydroformylation of XI. Thus of a total of 52% III, 8.6% is due to reactions A + D and the remaining 43.4% is due to reactions C + E (Chart II).

CHART II



On the basis of these data and of the distribution of isomeric products obtained by hydroformylation of the two intermediate olefins, the amounts of II and IV derived from reactions A + D and C + E may be evaluated. Thus of a total of 39.5% II, 0.33% is due to reaction D and 1.62% to reaction E. Analogous considerations may be made for IV. By subtracting the amounts of II owing to reactions D and E calculated in this way (from total II), the amount of II derived from reaction B is 37.54%.

If the optical purity of II, formed by reactions A and D, as far as the 3*S* center of asymmetry is concerned, is very high,[9] the amount of optically pure II owing to reaction B is 31.73% of total aldehydes, and the racemization of the 3*S* center encountered in this last synthesis is 7%.

Such a low racemization has been evaluated by indirect analysis and may thus be affected by some errors.

The high optical yield obtained in preparing II from I, CO, and H_2 shows that the reaction of CO and H_2 with orthoformic esters of secondary alcohols having an asymmetric center in the β position to the oxygen of the ester is a good method of synthesizing optically active aldehydes having an asymmetric carbon atom β to the carbonyl group.

Experimental Section[10]

(+)-Tris[(2*S*)-1,2-dimethylbutoxy]methane (I).—(−)-(3*S*)-3-Methylpentan-2-ol[11] (316 g, 0.9 mole), having $[\alpha]^{25}D$ −11.50°, was mixed with ethyl orthoformate (123.9 g, 0.9 mole) and distillation was started. Ethyl alcohol was first separated (145 ml), then (−)-(3S)-3-methylpentan-2-ol in excess (102 g), and finally 203.3 g of I (76.4% yield): bp 108° (0.5 mm), $n^{25}D$ 1.4323, $d^{25}{}_4$ 0.8684, $[\alpha]^{25}D$ +8.15°.

Anal. Calcd for $C_{19}H_{40}O_3$: C, 72.09; H, 12.73. Found: C, 71.91; H, 12.46.

Reaction of I with CO and H_2 in the Presence of $[Co(CO)_4]_2$.—A solution of I (43.5 g, 0.137 mole) and $[Co(CO)_4]_2$ (2.8 g) in 160 ml of benzene was introduced by suction in an autoclave having a capacity of 485 ml, then carbon monoxide up to 30 atm was added. The autoclave was heated to 110°; then hydrogen was introduced to 120 atm and finally a mixture of carbon monoxide and hydrogen (1:1) to a pressure of 240 atm. As soon as the autoclave was rocked reaction commenced. Gas adsorption was complete after 7 hr. After cooling, 175 g of liquid products was collected. The carbonyl compounds present in the reaction products, determined according to Smith and Mitchell,[12] were 0.086 mole (67% yield).

Ag_2O Oxidation of the Reaction Products of I with CO and H_2 and Conversion of the Acids into Methyl Esters.—The reaction products of I with carbon monoxide and hydrogen (0.086 mole of aldehydes) were added at 0° to an aqueous suspension of Ag_2O (0.15 mole) prepared from 51 g of $AgNO_3$, 25 g of NaOH, and 200 ml of H_2O. After mixing for 16 hr at room temperature and 3 hr at 40°, the mixture was worked up in the usual manner. By distillation 10.3 g (91.6% yield) of acids was recovered: bp 122–123° (21 mm), $n^{25}D$ 1.4232–1.4245, $d^{25}{}_4$ 0.9220, $[\alpha]^{25}D$ −0.82°, neut equiv 131.0.

The acids recovered from seven such experiments (70.9 g, 0.545 mole) were treated in ether solution with CH_2N_2 in excess at 0°. By distillation 76.5 g of methyl esters was recovered: bp 111–122° (176 mm), $n^{25}D$ 1.4115–1.4118. Besides small amounts of impurities, vpc analysis indicated the presence of three compounds in the ratio 39.5:52:8.5 having retention times equal to those of authentic samples of V, VI, and VII.

This mixture of esters (76.5 g) was distilled through a 90-cm column filled with glass helices and the liquid separated into 35 fractions.

Fractions 5–16 (12.25 g, $[\alpha]^{25}D$ −6.48°) contained (−)-(3*S*)-methyl 2,3-dimethylpentanoate (V) (99% pure by vpc) as shown by comparing their infrared spectra with that of an authentic sample.[13]

Fractions 31–35 (20.97 g, $[\alpha]^{25}D$ +1.38°) were shown by the same method to contain (+)-(*S*)-methyl 4-methylhexanoate (VI, 99% pure by vpc).

Reduction of V to VIII.—A solution of 12.95 g of V (0.0899 mole, $[\alpha]^{25}D$ −6.48°) in 20 ml of ethyl ether was added slowly, under nitrogen, to a suspension of 2.0 g $LiAlH_4$ (0.0525 mole) in 50 ml of anhydrous ethyl ether. After refluxing for 3 hr and standing for 14 more hr at room temperature, the product was hydrolyzed with ice and sulfuric acid and extracted with ether. By distillation of the extracts 10.38 g of VIII (93.8% yield) was obtained: bp 73.5–74° (17 mm), $n^{25}D$ 1.4277, $[\alpha]^{18}D$ −2.91° (*c* 1.443, *n*-pentane) [lit.[11] bp 75° (17 mm), $[\alpha]^{11}D$ −0.97°, pure liquid].

(+)-(3*S*)-1-Bromo-2,3-dimethylpentane (IX).—To a solution of 10.24 g of VIII (0.088 mole), at 0°, 16.4 g of PBr_3 (0.0607 mole) was added in 20 min.

The mixture was heated at 100° for 2 hr then cooled, hydrolyzed with water, and extracted with ether. The extract, after elimination of the solvent, was shaken first with concentrated sulfuric acid, then with water, sodium bicarbonate solution, and water again.

After drying 10.2 g of IX (64.7% yield) was obtained by distillation: bp 58.5° (15 mm), $n^{25}D$ 1.4510, $[\alpha]^{26}D$ +1.95° (*c* 2.040, *n*-butyl ether) [lit.[13] bp 67° (25 mm), $[\alpha]^{23}D$ +2.99° (pure liquid)].

(−)-(*S*)-2,3-Dimethylpentane (X).—A solution of 10.2 g of IX (0.0571 mole) in 6 ml of *n*-butyl ether was added, with stirring under nitrogen, to a suspension of 0.96 g of LiH (0.139 mole) and 0.65 g of $LiAlH_4$ (0.017 mole) in 20 ml of *n*-butyl ether.

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[8] The isomeric distribution of the hydroformylation products of (+)-(*S*)-3-methylpent-1-ene was assumed as III, 90%, IV, 6.5%, II, 3.5%, and the racemization in the formation of III to be 9.4% [P. Pino, S. Pucci, and F. Piacenti, *Chem. Ind.* (London), 294 (1963)]; in the case of 3-methylpent-2-ene, it was III, 80%, IV, 17%, II, 3% (unpublished results).

[9] P. Pino, S. Pucci, and F. Piacenti, *ibid.*, 294 (1963).

[10] All boiling points are uncorrected. Microanalyses were carried out by A. Bernhardt, Mikroanalytische Laboratorium in Max Planck Institut, Mülheim, Ruhr, Germany; vpc was performed on a Perkin-Elmer Model 154 B instrument using a 4-m column filled with polyethylene glycol (400) monostearate on Chromosorb and He as carrier gas. Infrared spectra were recorded on a Perkin-Elmer Model 221 spectrophotometer equipped with a grating prism interchange; nmr spectra were measured on a Varian DP-60 instrument (60 Mc); the high-pressure equipment used is the same as we described in previous papers.[2,3]

[11] L. Lardicci and R. Rossi, *Atti Soc. Toscana Sci. Nat. Pisa, Proc. Verbali Mem.*, **69B**, 1 (1962).

[12] D. M. Smith and J. Mitchell, Jr., *Anal. Chem.*, **22**, 750 (1950).

[13] P. A. Levene and R. E. Marker, *J. Biol. Chem.*, **91**, 405 (1931).

After the addition was finished the temperature was raised to 90° and kept at this value for 3 hr.

The mixture was then cooled to $-10°$ and hydrolyzed with ice and H_2SO_4. The organic layer after drying was distilled. Thus were collected 3.86 g of X: bp 89.5°, $n^{25}D$ 1.3900, $[\alpha]^{25}D$ $-9.23°$ (pure liquid) (lit.[14] bp 89.7°, $n^{25}D$ 1.38945, $[\alpha]^{25}D_{max}$ -11.4,[6] pure liquid).

Registry No.—II, 7492-94-6; I, 7492-89-9; V, 7540-78-5; VI, 7492-90-2; IX, 7485-44-1; X, 7485-45-2; VIII, 7485-46-3.

[14] F. D. Rossini, "Selected Values of Physical and Thermodynamic Properties of Hydrocarbons and Related Compounds," API Research Project 44, New York, N. Y., Oct 31, 1952, Table 8a.

The Acid-Catalyzed Rearrangement of *cis*-2,3-Dimethyl-*endo*-2-norborneol[1]

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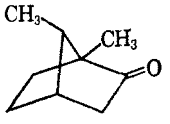
Received September 16, 1966

In the course of another study the need arose for samples of α- and β-santenone (**1** and **2**) and the formation of α-santenyl acetate (**3b**), reported to occur when *cis*-2,3-dimethyl-*endo*-2-norborneol (**5**) is treated with sulfuric acid in acetic acid, appeared to offer a convenient entry to the α series.[3,4] In our hands, however, this reaction furnished substantial amounts of the β isomer (**4b**), as well as the α isomer. The esters were separated by preparative vpc, and identified as described below. Actually, the formation of both isomers is not surprising since it has been shown that the rearrangement of *exo*-isosantene (**6**), *endo*-isosantene (**7**), and santene (**8**) with sulfuric acid in acetic acid gives a mixture of α- and β-santenyl acetate.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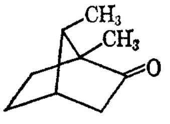
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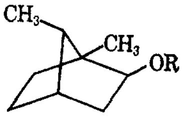
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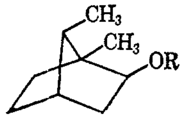
b, R = Ac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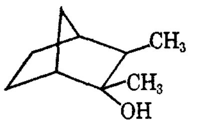
b, R = Ac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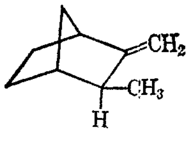
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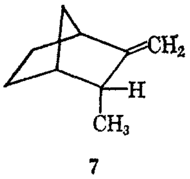
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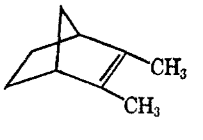
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Steric interference between the *syn*-C-7 methyl group and the acetoxyl group would be expected to decrease the stability of the β isomer. This is borne out by the results presented in Table I, where it is seen that the proportion of the β acetate decreases with increasing duration of acid treatment.

TABLE I

COMPOSITION OF MIXTURE OF α- AND β-SANTENYL ACETATES FROM REARRANGEMENT OF 5[a]

	Compn of mixture,[b] %	
Time, hr	α-Santenyl acetate	β-Santenyl acetate
0.5	51	43
2	54	39
3	59	35
12	74	21
3[c]	76	19

[a] Reactions were carried out by mixing 0.25 g of **5**, 1 ml of glacial acetic acid, and 1 drop of concentrated sulfuric acid, and heating for the specified period of time at 55–60° unless noted otherwise. The mixtures were poured over ice and extracted with ether, and the extracts were washed thoroughly and dried. Analyses were performed by vpc on a 3.8-m column containing LAC-446 on Chromosorb, and operated at 150°. [b] In addition to the santenyl acetates, approximately 5% of an unidentified compound and 1% of 1-methyl-*exo*-2-norbornyl acetate were also present. Formation of the last-named compound indicates that the starting alcohol (**5**) may have contained a small amount of *exo*-2-methyl-*endo*-2-norborneol as an impurity. [c] Reaction temperature was 100°.

The isomeric santenols were obtained by saponification of the acetates, and the melting point of the α isomer and its 3-nitrophthalate ester agreed well with literature values. Correspondingly good agreement was observed for the melting point of the 3-nitrophthalate ester of β-santenol, but the melting point of the free alcohol (108–108.5°) is substantially higher than the literature value 97–98°.[5] The β-santenol used in the earlier studies was separated from the α isomer by fractional crystallization of the 3-nitrophthalate esters, and it is possible that the separation was incomplete. Analysis by vpc of the β-santenol obtained in the present study showed less than 1% of the α isomer to be present.

The nmr spectra of the acetate esters and the free alcohols substantiate the structural assignments. In the β isomers the methyl group at C-7 is more deshielded than it is in the α isomers. The proton at C-2 shows fine splitting owing to long-range coupling ($J \sim 1$ cps) with the *anti*-C-7 proton in the β isomers.[6,7]

Oxidation of the alcohols with chromium(VI) oxide in acetic acid gave the corresponding ketones. The melting points of both ketones as well as their semicarbazones agreed well with literature values. Both ketones exhibit a carbonyl stretching mode at 5.70 μ. It has been observed that the carbonyl group in camphor shields the *syn*-C-7 methyl group to a greater extent than the *anti*-C-7 methyl group.[8] The same effect is observed with the santenones; the C-7 methyl doublet is centered at τ 9.07 in α-santenone and at 9.15 in β-santenone.

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[1] Taken from the Ph.D. Dissertation of L. D. Hatfield, Aug. 1966.

[2] To whom inquiries should be addressed.

[3] O. Diels and K. Alder, *Ann.*, **486**, 202 (1931).

[4] N. J. Toivonen and E. Wuolejoki, *Suomen Kemistilehti*, **33B**, 119 (1960); *Chem. Abstr.*, **55**, 1471 (1961).

[5] S. Beckmann and A. Durkop, *Ann.*, **594**, 205 (1955).

[6] S. I. Musher, *Mol. Phys.*, **6**, 93 (1963); F. A. L. Anet, *Can. J. Chem.*, **39**, 789 (1961).

[7] A. F. Thomas and B. Willhalm, *Tetrahedron Letters*, 1309 (1965); F. G. Bordwell and M. L. Douglass, *J. Am. Chem. Soc.*, **88**, 993 (1966).

[8] J. O. Connolly and R. McCrindle, *Chem. Ind.* (London), 379 (1965).