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The Absolute Configurations of Some Simple Norbornane Derivatives. A Test of the "Conformational Asymmetry" Model[1a]

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Absolute configurations and maximum rotations are deduced for forty-six norbornane derivatives by conversion of 2-*endo*-norborneol to fenchone and of the 2-methyl-5-norbornene-2-carboxylic acids to camphenilane. Optical resolutions of both epimeric 2-methyl-5-norbornene-2-carboxylic acids are described, that of the *exo*-acid being apparently virtually complete. The conformational asymmetry model correctly predicts the signs of rotation for a number of these substances, but gives incorrect predictions for six norbornane derivatives, the configurations of which can be deduced from information in the literature.

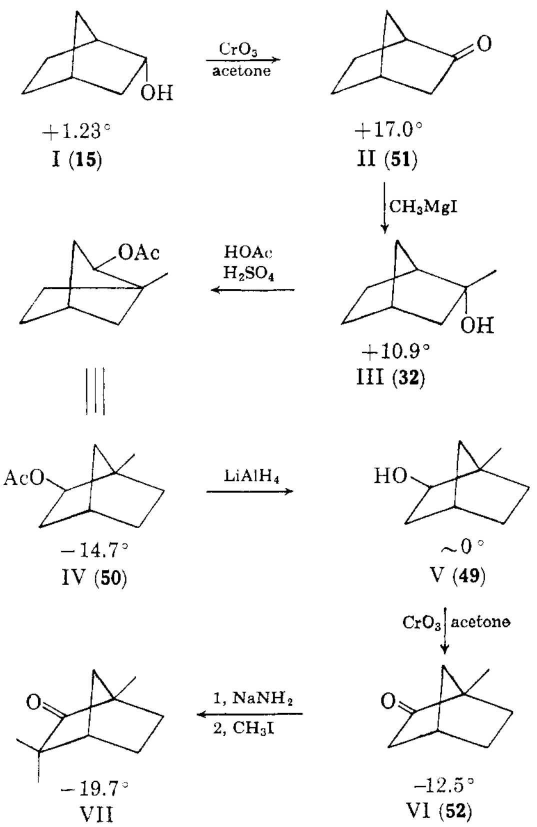
In the course of other studies, we have established the relative and absolute configurations of a number of norbornane derivatives. We anticipated that these correlations would be useful in studies of reaction mechanism in this series and also in providing a test of recently proposed methods of relating absolute configuration and sign of optical rotation. The present paper summarizes our stereochemical results.

Our assignments of absolute configuration were based upon conversions of simple norbornanes to derivatives of naturally-occurring terpene substances for which absolute configurations had already been deduced. The transformations were effected in two separate series, one leading from 2-monosubstituted norbornanes to fenchone and the other from 2,2-disubstituted norbornanes to camphenilane.

Correlation of 2-Monosubstituted Norbornanes with Fenchone.—The stereochemical correlations of the natural monoterpenoids with glyceraldehyde had been established by a network of internally consistent relationships involving, in the final stages, both physical[2] and chemical[3] evidence. Chart 1 outlines the steps by which we converted (+)-*endo*-norborneol (I) to (−)-fenchone (VII), thereby establishing the absolute configurations of I, the intermediate substances II–VI and a series of other norbornane derivatives already related to I (the arabic numbers refer to Table I). The configurations shown are absolute for the indicated enantiomers.

The optically active (+)-*endo*-norborneol (I) used as starting material was prepared by resolution of the corresponding acid phthalate *via* the brucine and cinchonidine salts, according to the procedure of Winstein and Trifan.[4a] Our starting material was incompletely resolved, the resolution being pursued only to acid phthalate of $[\alpha]_D$ $-3.21°$, 64% of the highest rotation reported.[4] The manipulations involved in the steps of Chart 1 were carried out without recrystallization of any of the intermediates, and consequently optical fractionations were not a factor. The identity and purity of each product were established by comparison of the infrared spectrum and vapor chromatographic retention time with those of authentic racemic material obtained by carrying through the entire scheme in the racemic series.

CHART 1



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(2) (a) A. Fredga and J. K. Miettinen, *Acta Chem. Scand.*, **1**, 371 (1947); (b) J. Porath, *Arkiv Kemi*, **1**, No. 60 (1950).

(3) (a) K. Freudenberg and W. Hohmann, *Ann.*, **584**, 54 (1954); (b) D. S. Noyce and D. B. Denney, *J. Am. Chem. Soc.*, **76**, 768, 3630 (1954); D. S. Noyce and J. H. Canfield, *ibid.*, **76**, 3630 (1954). (c) For a summary of *relative* configurations within the terpene series, see W. Hückel, *J. prakt. Chem.*, **157**, 225 (1941). For summaries of *absolute* configuration, see (d) J. A. Mills and W. Klyne in "Progress in Stereochemistry," W. Klyne, ed., Butterworths Scientific Publications, London, 1954, p. 177; (e) A. J. Birch, *Ann. Reports Prog. Chem.*, **47**, 191 (1950).

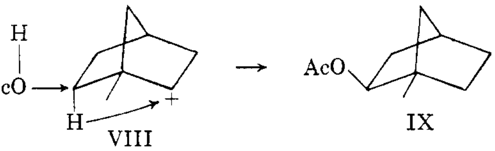
(4) (a) S. Winstein and D. Trifan, *J. Am. Chem. Soc.*, **74**, 1147 (1952); (b) **74**, 1154 (1952).

Each of the steps in the racemic series had been described by others, and our procedures followed those reported except for minor but important modifications. Three steps of the scheme were potentially troublesome: the oxidations of *endo*-norborneol (I) and 1-methyl-*exo*-norborneol (V) to 2-norbornanone (II) and 1-methyl-2-norbornanone (VI), and the Wagner–Meerwein rearrangement of 2-*exo*-methyl-2-*endo*-norborneol (III) to 1-methyl-2-*exo*-norbornyl acetate.

The oxidation of optically active 2-*exo*-norborneol with dichromate and sulfuric acid had been reported[4] to give 2-norbornanone with partial loss of optical purity, presumably[4] because of prior partial racemization of the very sensitive *exo*-alcohol in the strongly acidic medium. Under the same conditions, 2-*endo*-norborneol gave ketone with higher retention of optical purity.[4] The maximum optical rotation of the ketone had not been established, however, and therefore it was not clear that the latter oxidation gave complete retention of optical purity. Since we feared that a later step (III → IV) might also produce partial racemization, it was necessary to conserve our hard-won optical activity. Accordingly, we investigated other methods for carrying out the oxidation. Oppenauer oxidation (quinone–aluminum *t*-butoxide–benzene[5]) of optically active I gave optically active II in 51% yield. Oxidation with chromium trioxide–sulfuric acid–acetone[6] gave II with the same amount of retention of optical purity observed in the Oppenauer procedure; after careful scrutiny of the conditions for the chromium trioxide oxidation, the yield was raised to 85%. Racemization in the Oppenauer oxidation was inherently improbable; even less probable was the possibility that partial racemization occurred in the Oppenauer oxidation to exactly the same extent as in the chromium trioxide oxidation. Accordingly, both oxidations must have occurred with complete retention of optical purity. This desirable result combined with the high yield and convenience made the chromium trioxide procedure the method of choice. In the oxidation of V to VI, the Oppenauer and chromium trioxide methods again gave identical amounts of retention of optical purity, indicating the absence of racemization.

The conversion of 2-methyl-2-*endo*-norborneol (III) to 1-methyl-2-*exo*-norbornyl acetate (IV) by Wagner–Meerwein rearrangement was potentially hazardous to the scheme because of the possibility of rapid 6,2-hydrogen shift and/or tricyclene formation which would cause racemization. In fact, the rearrangement of optically active III to IV did result in extensive (but fortunately incomplete) racemization. Since recrystallization of the product or a derivative could not be relied upon for fear of optical fractionation, conditions that assured complete conversion of III to IV had to be chosen so that the sacrifice of this method of purification would cause no difficulty. The conditions finally used were dangerously close to those under which complete racemization would have occurred; a control experiment showed that when optically active IV was re-exposed to the reaction conditions, it lost all optical activity. The fraction of optical activity lost in the rearrangement step can be calculated on the assumptions that (i) the reported highest rotations for *endo*-norbornyl acid phthalate[4] and fenchone[7] correspond to optically pure materials and (ii) that no other steps of Chart 1 produce racemization. On this basis, the rearrangement occurred with loss of 55% of optical purity.[8]

An ambiguity is present in the scheme of Chart 1 if one admits the possibility that 6,2-hydrogen shift in the cationic intermediate (VIII or a bridged non-classical variant) in the III → IV rearrangement can occur *in concert* with attack of solvent (*cf.* VIII → IX). If this hypothetical process were faster than direct attack of solvent at the cationic site of VIII, the predominant product would be IX, the enantiomer of IV, and all the configurations of the scheme would be reversed. We feel that this possibility can be dismissed as unlikely, primarily on the grounds that in the single analogous case for which direct evidence is available, the process, if present at all, at least does not control the stereochemical result. Thus, (+)-α-pinene (X) can be converted[11] to esters of (+)-borneol (XII), the indicated relative configurations being assigned on the assumption that direct conversion of the intermediate cation XI to product of retained configuration (XII, path a) is faster than concerted reaction with solvent and hydrogen migration to product of inverted configuration (XIII, path b). That this assumption must be correct is established by the independent correlation of α-pinene and borneol through α-terpineol (XIV).[12] By analogy, we assume the reaction



VIII IX

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[5] *Cf.* P. D. Bartlett and W. P. Giddings, *J. Am. Chem. Soc.*, **82**, 1240 (1960).

[6] (a) R. G. Curtis, I. Heilbron, E. R. H. Jones and G. F. Woods, *J. Chem. Soc.*, 457 (1953); (b) A. Bowers, T. G. Halsall, E. R. H. Jones and A. J. Lemin, *ibid.*, 2548 (1953); (c) T. G. Halsall, R. Hodges and E. R. H. Jones, *ibid.*, 3019 (1953); (d) C. Djerassi, R. R. Engle and A. Bowers, *J. Org. Chem.*, **21**, 1547 (1956). (e) We are indebted to Dr. R. R. Engle for calling this procedure to our attention.

[7] O. Wallach and P. Vivck, *Ann.*, **362**, 174 (1908).

[8] It is not entirely clear that the resolution[4a] of *endo*-norborny acid phthalate was complete.[9,10] Accordingly, this figure may require revision when the maximum rotation of the acid phthalate is established.

[9] J. A. Berson and S. Suzuki, *J. Am. Chem. Soc.*, **81**, 4088 (1959).

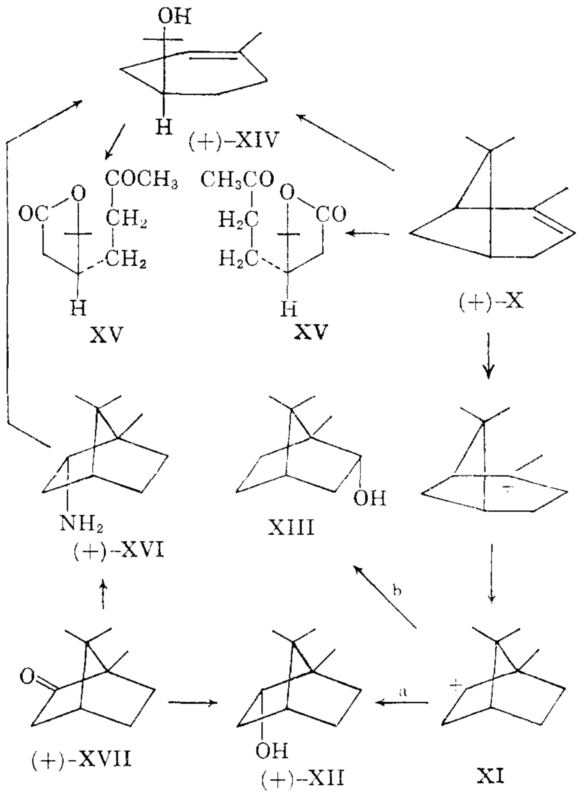
[10] (a) J. A. Berson and D. A. Ben-Efraim, *ibid.*, **81**, 4094 (1959); (b) **81**, 4083 (1959).

[11] J. Reisman, *Bull. soc. chim. France*, [4] **41**, 94 (1927); M. Délépine, J. Reisman and E. Suau, *ibid.*, [4] **47**, 966 (1930).

[12] (+)-α-Pinene (X) is converted by acids to (+)-α-terpineol (XIV).[3c] It can hardly be doubted that the relative configurations of these two substances are as shown and, in any case, the matter is settled independently by the observation[13,3e] that X and XIV can be oxidized to enantiomeric forms of the same ketolactone XV. Nitrous acid deamination of (+)-bornylamine (XVI) gives (+)-α-terpineol (XIV).[2c] In this reaction, the concerted solvent attack and hydride migration cannot be a factor. But (+)-bornylamine and (+)-borneol are configurationally correlated[3c] without ambiguity through (+)-camphor (XVII). Therefore, (+)-borneol, (+)-α-terpineol and (+)-α-pinene have the relative configurations indicated by XII, XIV and X.

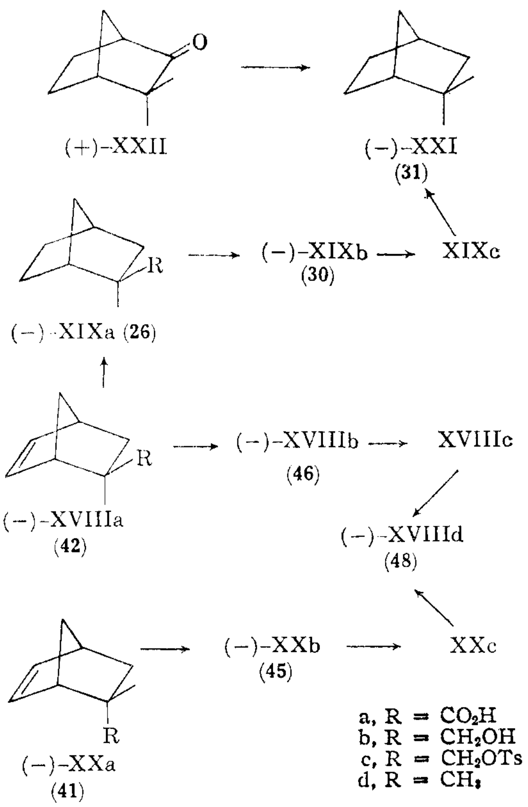
[13] M. Délépine, *Compt. rend.*, **179**, 980 (1924); *Bull. soc. chim. France*, [4] **35**, 1655 (1924).

VIII → IX does not control the stereochemistry of the Wagner–Meerwein rearrangement III → IV and that consequently the configurations shown in Chart 1 are correct.



Correlations with Camphenilane.—Resolution of *endo*-2-methyl-5-norbornene-2-*exo*-carboxylic acid (XVIIIa) was achieved readily *via* the quinine salt. Six recrystallizations of the salt sufficed to give an acid that appeared to be essentially optically pure. Conversion of the acid to camphenilane (XXI) gave material having a rotation that corresponded to that of a sample obtained[14] from camphenilone (XXII). The conversions are outlined in Chart 2.

CHART 2



a, R = CO_2H
b, R = CH_2OH
c, R = CH_2OTs
d, R = CH_3

Partial resolution of the epimeric unsaturated acid XXa and conversion of the latter to camphenilene (XVIIId) related the configurations of the *exo*-(XVIII) and *endo*-(XX) unsaturated series to each other. Since (+)-camphenilone has[3] the absolute configuration XXII, the absolute configurations of all the substances of Chart 2 are as shown.

By a set of straightforward transformations described in the Experimental section, the 2-monosubstituted substances **1–12** and **35–40** were configurationally correlated with the norbornane- and 5-norbornene-2-carboxylic acids. The latter acids already had been correlated with each other, with *endo*-norbornylamine, with *exo*-norborneol and with *exo*-2-acetylnorbornane[9,10]; *exo*-norborneol had been correlated with *endo*-norborneol (I) through 2-norbornanone (II).[4h] The transformations of Chart 1 thus establish the absolute configurations of the entire set of 2-monosubstituted compounds.

The absolute configurations and maximum rotations of both the 2-monosubstituted and 2,2-disubstituted series are collected in Table I.

Tests of the "Conformational Asymmetry" Model of Optical Activity.—A recently proposed[15a–c] model predicts the sign and magnitude of optical rotation for a wide variety of substances. This approach assumes that the optical activity of cyclic substances is, in many cases, largely attributable to "conformational asymmetry," the total rotational effect being an algebraic sum of individual bond conformational contributions. The bicyclo[2.2.1]heptane system, in which the conformations of the individual bonds are rigidly locked, appeared to us to offer a useful testing ground for the model. In substances based on this skeleton, there is no doubt (such as arises in flexible systems) about the relative weights to be assigned to the various conformations, since the shape of the molecular framework is fixed.

In Table I are collected the signs and magnitudes of optical rotation, predicted on the basis of the

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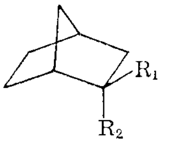
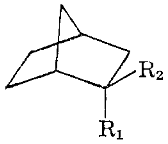
(14) (a) Camphenilane of $[\alpha]_D$ −12.3° (benzene) is obtained[14b] from camphenilone prepared from camphene of $[\alpha]_D$ +107.1° (benzene). Assuming a negligible temperature coefficient, the latter rotation corresponds to $[\alpha]_D$ +102.5° (ether)[14b,14c] whereas the highest reported[14d] rotation is 113.5° (ether). Optically pure camphenilane thus has $[\alpha]_D$ 13.6° (benzene). The value calculated from our correlation on the assumption that the resolution of the starting acid was complete is 13.4° (benzene). (b) W. Hückel, W. Doll, S. Eskola and H. Weidner, *Ann.*, **549**, 186 (1941); (c) J. Houben and E. Pfankuch, *ibid.*, **501**, 219 (1933); (d) J. P. Bain, A. H. Best, B. L. Hampton, G. A. Hawkins and L. J. Kitchen, *J. Am. Chem. Soc.*, **72**, 3124 (1950).

(15) J. H. Brewster, *ibid.*, **81**, (a) 5475 (1959); (b) 5483 (1959); (c) 5493 (1959); *cf.* also D. H. Whiffen, *Chemistry & Industry*, 964 (1956). (d) Personal communication from Professor J. H. Brewster, whom we thank for an expression of his views and for the suggestion that they be presented here.

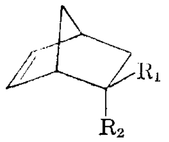
TABLE I

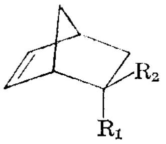
ABSOLUTE CONFIGURATIONS AND MAXIMUM ROTATIONS, [M]D, OF SOME NORBORNANE DERIVATIVES



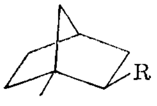


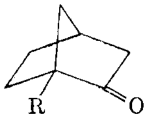
Compd.	R_1	R_2	[M]D, degrees Found	[M]D, degrees Calcd.[a]	[M]D, degrees, Found	[M]D, degrees, Calcd.[a]	$\Delta[M]_{D_{ep}}$ Found	$\Delta[M]_{D_{ep}}$ Calcd.
1,2	H	CO_2H	1, $-42.8^{b,i}$	0	2, $-39.0^{b,i}$	0		
3,4	H	CO_2CH_3	3, $-30.5^{b,i}$	0	4, $-52.6^{b,i}$	0		
5,6	H	CH_2OH	5, $+9.70^{b}$	0	6, -13.7^{b}	0		
7,8	H	CH_2OTs	7, -15.0^{b}	0	8, -37^{b}	0		
9,10	H	$CH_2N(CO)_2C_6H_4$	9	0	10 ...	0		
11,12	H	$CH_2NH_3{}^+Cl^-$	11, $+11.9^{b}$	0	12, -26.1^{b}	0		
13,14	H	OAc	13, $-21.6^{j,h,k}$	0	14, $-18.5^{f,h,i}$	0		
15,16	H	OH	15, $-2.1^{e,h,k}$	0	16, $+3.2^{e,h,i}$	0		
17,18	H	OBs	17, $-39.0^{e,h,k}$	0	18, $-6.25^{e,h,i}$	0		
19,20	H	$OCOC_6H_4CO_2H$	19, $+11.4^{e,h,k}$	0	20, $-22.8^{e,h,i}$	0		
21,22	H	NH_2	21, $+28.4^{b,i}$	0	22 ...	0		
23,24	H	$COCH_3$	23 ...	0	24, $-103^{g,l}$	0		
25,26	CH_3	CO_2H	25 ...	0	26, -8.95^{b}	0		
27,28	CH_3	CO_2CH_3	27 ...	0	28, -11.7^{b}	0		
29,30	CH_3	CH_2OH	29 ...	0	30, -19.2^{b}	0		
31	CH_3	CH_3	31, $-16.6^{d,q}$	0				
32	CH_3	OH	32, -18.8^{e}	0				





33,34	H	CO_2H	33, -199^{b}	-120^{m}	34, -23.6^{b}	0	-175	-120
35,36	H	CO_2CH_3	35, -214^{b}	-120^{m}	36, -43.6^{b}	0	-170	-120
37,38	H	CH_2OH	37, -95^{b}	-80	38, -23.9^{b}	0	-71	-80
39	H	CH_2OBs	39, -173	-80	...	0	...	-80
40	H	CH_3	40, -97.6	-80	...	0	...	-80
41,42	CH_3	CO_2H	41, -161^{b}	-120^{m}	42, -102^{b}	-80^{n}	-59	-40
43,44	CH_3	CO_2CH_3	43, -159^{b}	-120^{m}	44, -108^{b}	-80^{n}	-51	-40
45,46	CH_3	CH_2OH	45, -63.6^{b}	-80^{n}	46, -94^{b}	-80^{n}	$+30$	0
47	CH_3	CH_2OAc	47, -75.8^{b}	-80^{n}	...	-80^{n}	...	0
48	CH_3	CH_3	48, -59.5^{d}	-80^{n}				





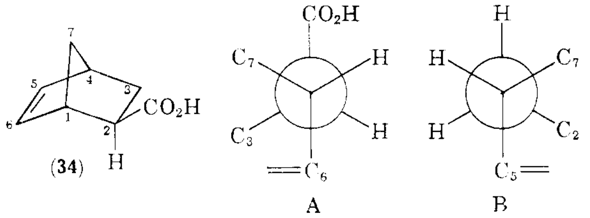
49	OH		49, 0^{e}	-50^{p}	...			
50	OAc		50, -83.0^{e}	-50^{p}	...			
51	H		...		51, $-29.2^{e,k}$			
52	CH_3		...		52, $-52.0^{e,k}$			

[a] By the method of Brewster,[15] assuming only conformational asymmetry effects. [b] In 95% ethanol. [d] In benzene. [e] In chloroform. [f] Neat. [g] Neat, density assumed to be 1.000. [h] For relative configuration, see ref. 4. [i] For relative configuration, see refs. 9 and 10. [j] In acetic acid. [k] See footnote 8 of text. [l] Rotatory effect of $COCH_3$ assumed to be the same as for CO_2H. [m] $-k(\text{X–H})(\text{C–H}) - \frac{(\text{X–H})(\text{C–H})(\overset{\text{C}}{\overset{\|}{\text{C}}}\text{–H})(\text{C–H})}{(\text{C–H})^2}$. [n] $k[(\text{C–H})^2-(\overset{\text{C}}{\overset{\|}{\text{C}}}\text{–H})(\text{C–H})]$. [p] $-k[(\text{X–H})(\text{C–H})]$. [q] For relative and absolute configuration, see ref. 3 and 14.

conformational asymmetry model, for the series of substances we have studied. The calculations involved the assumptions made by Brewster[15] and employed his numerical values for the individual conformational rotatory contributions. The algebraic form of the predicted net rotation (in terms of the individual contributions) for each substance expected to have a rotation other than zero is given in the footnotes to Table I.

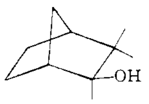
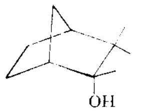
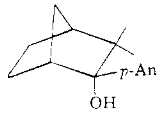
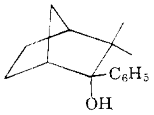
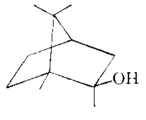
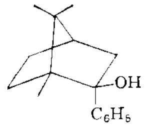
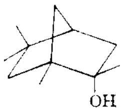
A comparison of the calculated and observed values for the unsaturated series (**33–48**) shows mediocre to good agreement in the magnitudes of the observed rotations; perfect agreement in the signs is observed in each case for which the calculation predicts a rotation other than zero. The observed effects of epimerization, $\Delta[M]_{D_{ep}}$, in the unsaturated series also roughly confirm the predictions. Perhaps the most satisfactory correlation is achieved for the effect of structural change in the series. With the exception of **39**, which seems to be out of line, the predicted fall in rotation accompanying the reduction of a carboxyl group in the 2-monosubstituted cases is observed (*cf.* **33**, **35** → **37**, **40**); this pattern holds very well for the *endo*-2,2-disubstituted cases (*cf.* **41**, **43** → **45**, **47**, **48**) also. In the *exo*-2,2-disubstituted cases, the model predicts that no change in rotation should result from reduction of a carboxyl, and the observed drop (**42**, **44** → **46**) is certainly less than is found in the epimeric cases. Within this limited series, the method seems to work rather well.

On the other hand, the cases for which zero rotations are predicted (**34**, **36**, **38**) show substantial rotations. It must be emphasized that the model[15a–c] used in these calculations assigns rotatory contributions on the basis of "attachment atoms"; thus, the *same* rotatory contribution is assigned to the interaction of a given type of substituent with *any* saturated carbon atom. An obvious refinement of the method of calculation would take into account the structural environment of each type of saturated carbon. For example, a refined calculation as applied to **34** would assign different weights to the interactions C_3:C_6 and C_2:C_5 (*cf.* A and B) which in the zeroth approximation treatment used here handled as if they were *equal* in magnitude (and opposite in sign). The neglect of this kind of weighting may also account for the large discrepancies between calculated and observed values in **33** and **35**.



In those members of the saturated series (**1–32**) for which zero rotation is predicted, discrepancies appear in many of the cases (**1–4**, **17**, **21**, and especially **24**). In **49**, for which a rotation of −50° is predicted, the substance shows a rotation too low to measure (at least at the level of optical purity at our disposal), although the corresponding acetate **50** is levorotatory. Discrepancies like this are also observed in the application of the conformational asymmetry rule to other series.[15] Particularly pertinent are the cases of the bornyl halides[15b]: the chloride, bromide and iodide have rotations of +58°, +67° and +96°, respectively, while the conformational asymmetry model predicts rotations of +170°, +180° and +250°. Evidently, conformational asymmetry effects alone do not account for the observed rotations. While it is true that one would not attempt to assign configuration on the basis of observed rotation to a substance for which the model predicts zero rotation, effects similar to those which cause the above discrepancies presumably are also present in the substances for which the model predicts non-zero rotation. It seems to us, therefore, that these cases in which good numerical agreement between observed and calculated rotations occurs must involve fortuitous balancing of the neglected factors.

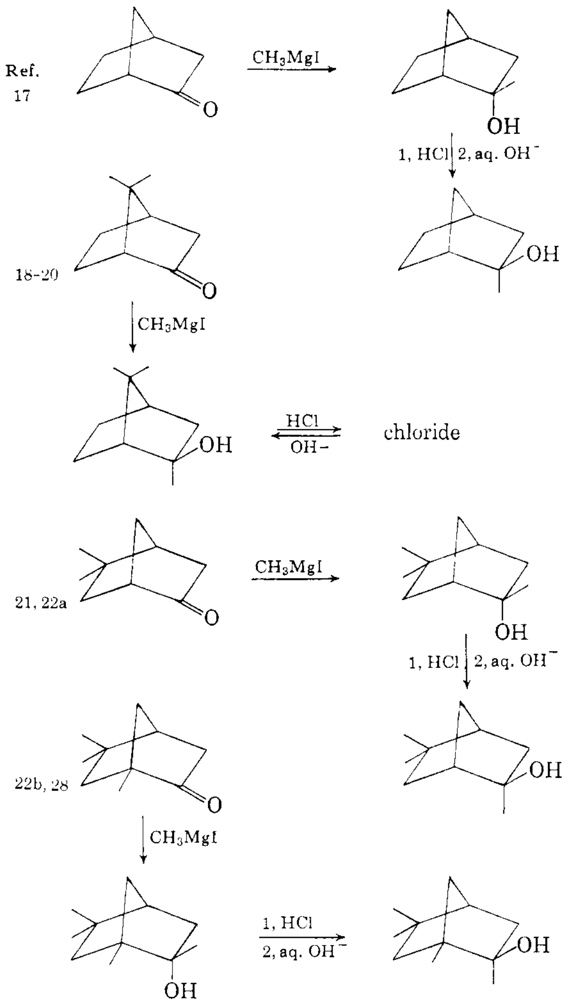
TABLE II

	M_D, degrees	
	Found	Calcd.
 XXIII, (+)-camphene hydrate	+41(alc.)	−10[a]
 XXIV, (−)-2-methylcamphenilol	−40(alc.)	+10[b]
 XXV, (−)-2-*p*-anisylcamphenilol	−63(C_6H_6)	+90[c]
 XXVI, (−)-2-phenylcamphenilol	−115(neat)[d]	+90[c]
 XXVII, (−)-2-methylborneol	−21(alc.)	+10[b]
 XXVIII, (−)-2-phenylborneol	−116(C_6H_6)	+90[c]
 XXIX, (−) 2-methylisofenchol	−17[e]	−10[a]

[a] $k[(X\text{–}H)(C\text{–}H) - (C\text{–}H)^2] = +50\text{–}60$. [b] $k[(C\text{–}H)^2 - (X\text{–}H)(C\text{–}H)] = +60 - 50$. [c] $k[(C{=}C\text{—}H)(C\text{–}H) - (X\text{–}H)(C\text{–}H)] = +140\text{–}50$. [d] (+)-Camphenilone, $[\alpha]_D$ +12.4° (ether), 22.8% optically pure,[23] gave[25] (+)-2-phenylcamphenilol, $[\alpha]_D$ +11.2°. [e] Solvent unspecified.

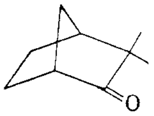
A more serious shortcoming of the model is apparent in its prediction of the *wrong sign* of rotation in some cases. In a search of the literature, we have found six bicyclo[2.2.1]heptanes to which configurations can be assigned with

CHART 3

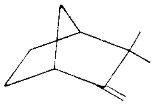


confidence on chemical grounds and to which the application of the model assigns configurations incorrectly. We do not claim completeness for our search, and it is possible that other examples exist. The calculated and observed rotations for these compounds (XXIII–XXVIII) are given in Table II. In the calculation for XXV, the rotatory effect of interactions involving the *p*-anisyl group was assumed to be the same as those involving phenyl and alkenyl groups[15a–c] (*i.e.*, $k(\underset{\substack{\|\\ \mathrm{C}}}{\mathrm{C{-}H}})(\mathrm{C{-}H}) = 140^\circ$).

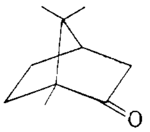
The stereochemical assignments of Table II depend upon the previous assignments[2,3] of absolute configuration to the common bicyclic monoterpenoid substances and upon two additional rules: (i) additions of Grignard reagents to 2-bicycloheptanones (like hydride reductions[16a]) occur from the less hindered side (*exo*, unless a *syn*-7-alkyl group is present), and (ii) kinetically controlled carbonium ion reactions in this series generally lead to *exo*-products. Part of the experimental basis for these rules is given[16b] by the reactions outlined in Chart 3.[17–22] Rule (i) is presumably attributable to steric hindrance, while rule (ii) is a consequence of the occurrence of configuration-maintaining, non-classical cationic intermediates. Accordingly, (−)-2-methylcamphenilol (XXIV), the product of the reaction of (−)-camphenilone (XXX[2,3]) with methyl Grignard reagent,[23] has the absolute and epimeric configuration shown; the epimer is (+)-camphene hydrate (XXIII), which is formed[24] by the path camphene → camphene hydrochloride → camphene hydrate, and which is dehydrated[23] to (−)-camphene (XXXI[2,3]). The alcohols XXV[16c] and XXVI[25] (from (−)-camphenilone XXX[2,3]), XXVII[26] and XXVIII[27] (from (+)-camphor XXXII[2,3]) and XXIX[28] (from (−)-isofenchone XXXIII[29]) are assigned the configurations shown. With the possible exception of XXVI, which is reported[25] to be a liquid, there is no reason to doubt that the substances of Table II are essentially homogeneous.



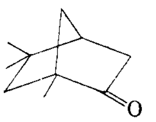
(−)-XXX



(−)-XXXI



(+)-XXXII



(−)-XXXIII

In six of the cases of Table II the predictions of the model conflict with the assignments. It might be argued that, since all of these substances

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[16] (a) *Cf. inter alia*, S. Beckmann and R. Mezger, *Chem. Ber.*, **89**, 2738 (1956). (b) More complete documentation will be available in the chapter by J. A. Berson in a forthcoming book, "Molecular Rearrangements," to be edited by P. de Mayo and published by Interscience Publishers, Inc. *Cf.* also P. R. Schleyer, Thesis, Harvard University, 1956. (c) For a recent application of these rules, see P. D. Bartlett, E. R. Webster, C. E. Dills and H. G. Richey, Jr., *Ann.*, **623**, 217 (1959).

[17] (a) N. J. Toivonen, E. Siltanen and K. Ojala, *Ann. Acad. Sci. Fennicae*, **Ser. A II**, No. 64 (1955); *C. A.*, **51**, 7329 (1957); (b) N. J. Toivonen, Abstracts of the XIVth International Congress of Pure and Applied Chemistry, Zürich, 1955, p. 45; (c) S. Beckmann, R. Schaber and R. Bamberger, *Chem. Ber.*, **87**, 997 (1954); (d) R. R. Sauers, *J. Am. Chem. Soc.*, **81**, 4873 (1959).

[18] G. Komppa and R. H. Roschier, *Ann. Acad. Sci. Fennicae*, **A10**, No. 3 (1917).

[19] G. Komppa and S. Beckmann, *Ann.*, **508**, 205 (1934).

[20] G. Komppa and G. A. Nyman, *ibid.*, **543**, 111 (1940).

[21] G. Komppa and R. H. Roschier, *Ann. Acad. Sci. Fennicae*, **A10**, No. 15 (1917).

[22] (a) G. Komppa and S. Beckmann, *Ann.*, **503**, 130 (1933); **509**, 51 (1934); (b) G. Komppa, *ibid.*, **472**, 179 (1929).

[23] *Cf.* (+)-camphenilone → (+)-2-methylcamphenilol; W. Hückel, W. Doll, S. Eskola and H. Weidner, *Ann.*, **549**, 186 (1941).

[24] H. Meerwein and K. van Emster, *Ber.*, **53**, 1815 (1920); H. Meerwein and L. Gérard, *Ann.*, **435**, 174 (1924).

[25] M. Bredt-Savelsberg, *Ber.*, **56**, 554 (1923).

[26] A. I. Shavrygin, *J. Gen. Chem. U. S. S. R.*, **7**, 2668 (1937); *C. A.*, **32**, 2100 (1938).

[27] J. Bredt, *J. prakt. Chem.*, [2] **98**, 96 (1918).

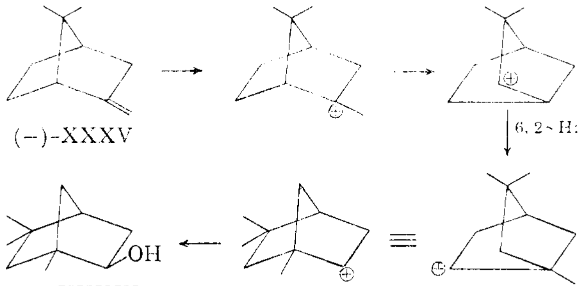
[28] G. Komppa and G. A. Nyman, *Ann.*, **523**, 87 (1936).

[29] The absolute configuration of (−)-isofenchone may be deduced from that of its precursor (−)-α-isofenchol (XXXIV), which is a product[7,30] of the hydration of (−)-α-fenchene (XXXV), the absolute configuration of which is known.[2,3] The hydration is explicable[31,32] in terms of 6,2-hydrogen shift (shown here without specification of the non-classical nature of the intermediates).

[30] J. Bertram and J. Helle, *J. prakt. Chem.*, [2] **61**, 293 (1900).

[31] W. von E. Doering and A. P. Wolf, *Perfumery and Essential Oil Record*, **42**, 414 (1951); *C. A.*, **46**, 7080 (1952); Abstracts of the XIIth International Congress of Pure and Applied Chemistry, New York, N. Y., 1951, p. 437.

[32] A. P. Wolf, Dissertation, Columbia University, 1952.



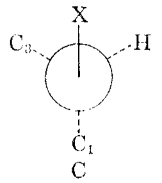
are tertiary alcohols with similar structural features, the model contains a systematic error arising from some inadequacy to deal with structures of this type, but this conflicts with the correct prediction in the case of XXIX. It should be noted that in each of the cases of discrepancy, an incorrect assignment of either absolute or epimeric configuration would bring the observed rotation into accord with prediction. We feel, however, that the absolute configurations are firmly established[2,3] and that in order for the epimeric configurations assigned here to be in error, an inexplicable inconsistency in the steric course of Grignard additions to 2-norbornanones would be required.

"Permolecular" and Side-chain Effects.—In addition to atomic and conformational asymmetry, Brewster[15a–c] postulates a "permolecular," long-range effect. Although this effect is explicitly treated[15b] in the carbohydrate series, it is not invoked in other cases. Since the "permolecular" effect is not sharply defined for the general case (except by exclusion, *i.e.*, the "permolecular" effect consists of those rotational effects which are not caused by atomic and conformational asymmetry), the circumstances in which it is important and the structural features that contribute to it are not clear.

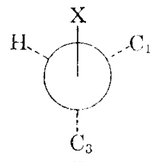
The bond conformational constants used in this paper (and previously by Brewster[15]) are those associated with four-atom skew chains with angular separations of 60° or 120° between substituents. Using the assumption[15b] that the contributions of such chains have a sinusoidal dependence on angle of separation, Brewster[15d] has now calculated rotations for several substances of Table I. The model of the norbornane skeleton used[15d] assumed that the conformations around bonds C_1–C_2, C_3–C_4, C_4–C_5 and C_6–C_1 are twisted by 10° from a completely staggered one. The new calculations,[15d] in which allowance is made for bond angle distortions, predict that the 2-monosubstituted norbornanes **1**, **2**, **15**, **16** and **21** should all have small negative rotations ranging between about −4° and −10°. The distortions thus do not account completely for the observed rotations (see Table I): compounds **16** and **21** have signs of rotation opposite to those predicted, and there are still substantial numerical discrepancies in the cases of compounds **1** and **2**. Note that the distortions cannot account for the discrepancies mentioned above in the cases of the bornyl halides either, since, as has been pointed out,[15d] the conformational asymmetry effect of bond C_1–C_2 vanishes when C_1 bears a saturated alkyl substituent (the bridge-head methyl group).

In the norbornene series, calculations[15d] that allow for bond angle distortions give predicted values for the *endo* series (**33**, **35**, **37**, **39**, **40**, **41**, **43**, **45**, **47**, **48**) which differ only slightly, on the average, from those given in Table I. For the *exo* series, a general improvement is noted, the calculated values being about 20–30° more levorotatory than those derived on the basis of the treatment in Table I.

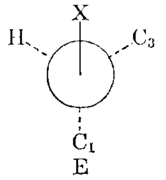
Brewster[15d] also has suggested the possibility that, in some of the cases of Table I, the presence of flexible side-chains may lead to additional rotational effects which derive from the preference of an unsymmetrical substituent for a particular conformation. Thus, the hydrogen atom at C_1 offers slightly more steric hindrance to a C_2 *exo*-substituent than does the *exo*-hydrogen atom at C_3.[15d] To the extent that this is significant, an *exo*-substituent will show a slight preference for the levorotatory conformation C over the dextrorotatory conformation D; the same reasoning applied to 2-*endo*-substituents suggests a preference for the dextrorotatory conformation E over the levorotatory conformation F. The influence of side-chain asymmetry on the rotation should disappear when, in addition to the substituent X, there is an alkyl group at C_2, since conformations C–F will have zero rotatory power derived from conformational asymmetry. Calculations[15d] for the 2,2-disubstituted norbornanes **25–32**, based on the assumption that side-chain asymmetry effects are absent and that bond angle distortions account for the rotational effects, predict the signs and approximate magnitudes correctly. In the monosubstituted series of norbornanes, where side-chain asymmetry can be a factor, the direction of the effect can be predicted[15d] in some cases (Table III). Comparison of the observed rotations with those calculated[15d] from the bond-angle distortion assumption shows that in nine of the twelve cases, the discrepancy is in the direction predicted for a side-chain asymmetry effect. Brewster[15d] notes that in each of the three cases of discrepancy, the substituent is unsaturated. Nevertheless, the two norbornyl phthalates conform to prediction.[15d]



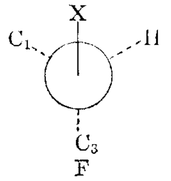
C



D



E

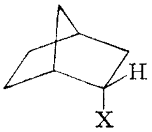


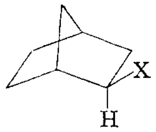
F

In the cases of the monosubstituted norbornane- and norbornenecarboxylic acids, Brewster suggests[15d] that side-chain asymmetry may arise from differing steric requirements of the carbonyl and hydroxyl oxygens. This side-chain asymmetry should disappear in the salts of the acids, since the

TABLE III

$[M]_D$ OF NORBORNANES IN WHICH SIDE-CHAIN CONFORMATIONAL ASYMMETRY IS POSSIBLE





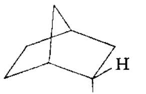
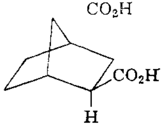
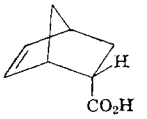
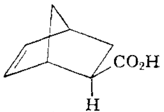
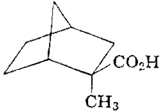
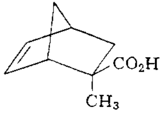
X	Calcd.[a]	Predicted side-chain effect	Obsd.	Calcd.[a]	Predicted side-chain effect	Obsd.
CH_2OH	−5.1°	Pos.	+ 9.70°	−6.9°	Neg.	−13.7°
CH_2NH_3Cl	−5.1	Pos.	+11.9	−6.9	Neg.	−26.1
OPhth	−4.25	Pos.	+11.4	−5.75	Neg.	−22.8
OAc	−4.25	Pos.	−21.6	−5.75	Neg.	−18.5
OBs	−4.25	Pos.	−39.0	−5.75	Neg.	− 6.2
CH_2OTs	−5.1	Pos.	−15.0	−6.9	Neg.	−37

[a] Assuming no side-chain asymmetry effects.

oxygens of the carboxylate ion would be equivalent.[15d] Thus, the rotations of the salts of the secondary acids should be much closer to the values calculated than those of the free acids; in the tertiary series, where the side-chain asymmetry effect cannot contribute, ionization should produce little change.[15d] We have now tested this matter (Table IV), but the predictions[15d] are not confirmed. With all of the acids examined, both secondary and tertiary, ionization increases the discrepancy between observed and calculated values. The shift is in the opposite direction from that predicted for three of the four secondary acids. We conclude that if side-chain asymmetry is a factor in these acids at all, it is obscured by some other effect.

TABLE IV

EFFECT OF IONIZATION ON THE ROTATIONS OF CARBOXYLIC ACIDS

	$[M]_D$, degrees		
	Calcd.[a]	Obsd.(RCO_2H)[b]	Obsd.(RCO_2M)[c]
	− 7.7	− 42.9	− 59.8[e]
	− 10.3	− 39.0	− 42.9[d]
	−113	−199	−230[e]
	− 33	− 23.6	− 70[d]
	− 15.4	− 8.95	− 19[d]
	−109	−102	−138[d], −155[e]

[a] On the assumption that side-chain asymmetry effects are absent. [b] In 95% ethanol. [c] In 95% ethanol containing slightly more than one equivalent of sodium or potassium hydroxide. Larger excesses of alkali produced no change. [d] Sodium salt. [e] Potassium salt.

Brewster suggests[15d] that the large discrepancies observed in the series of tertiary alcohols (Table II) are attributable to "permolecular" effects arising from restricted rotation of the phenyl groups in the phenylated compounds and from the steric environment of the hydroxyl group which, in his view, must be essentially frozen in one conformation if it is to act as a donor in hydrogen bonding. We note, however, that in the bornyl halide series discussed above, in which neither these effects nor the bond distortion and side-chain effects can play a role, very large discrepancies are still observed.

Conclusions.—The results make it clear that conformational asymmetry is not the sole cause of optical activity in the series of substances studied in this paper. Although such additional factors as "permolecular" asymmetry and side-chain asymmetry may be present, it is not yet clear how these can be disentangled and put on a quantitative basis. From the practical point of view, some suggestive correlations emerge from the data. Since, however, the net rotation is interpreted[15] as the resultant of several independent effects, prediction of the sign and/or magnitude of rotation of a substance of known absolute configuration (or the converse, assignment of configuration on the basis of sign of rotation) requires an accurate knowledge of the signs and magnitudes of all the hypothetical contributions. Until these become available, it would seem imprudent to assign configurations in the norbornane series on the basis of the conformational asymmetry rule alone.

Experimental[33]

Conversion of *endo*-Norborneol (I,15) to Fenchone (VII) (see Chart 1).—The entire sequence was carried out with both optically inactive and optically active materials. Experimental details are given only for the optically active series, but pertinent physical properties of the racemates are reported.

Preparation of Active I.—Racemic *endo*-norbornyl acid phthalate (**19**), m.p. 110–111° (reported[4a] m.p. 109–110°), was partially resolved *via* the brucine and cinchonidine salts.[4a] From the brucine salt there was obtained the (−)-isomer, $[\alpha]^{24}\text{D}$ −3.21° ($CHCl_3$, *c* 4.897), and from the cinchonidine salt the (+)-isomer, $[\alpha]^{30}\text{D}$ + 2.55° ($CHCl_3$, *c* 5.433), m.p. 105–106.5°. The infrared spectra of both samples were identical with that of the racemate. Steam distillation of the (−)-isomer above from 25% sodium hydroxide gave (+)-*endo*-norborneol (I), m.p. 151–151.5°, $[\alpha]^{29}\text{D}$ +1.23° ($CHCl_3$, *c* 4.854). These results are in excellent agreement with those of Winstein and Trifan,[4a] who also observed the change of sign and a ratio of the magnitudes of rotations of acid phthalate to alcohol of 2.65; our ratio is 2.61.

Oxidation of (+) *endo*-Norborneol (I, 15) to (+)-2-Norbornanone (II, 51). A. Oppenauer Method.—The procedure was based upon that used by Bartlett and Giddings[5] for oxidation of benzonorborneol to benzonorbornanone.

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[33] Melting points are corrected. Boiling points are uncorrected. Optical rotations were measured with a Rudolph model 80 high precision polarimeter. The analyses are by Dr. Adelbert Elek, Elek Microanalytical Laboratories, Los Angeles, Calif., and by Dr. Joseph Alicino, Metuchen, N. J. The vapor chromatograms were taken using a 6.4 mm. × 1.8 m. tri-(β-cyanoethoxy)-propane-on-Chromosorb column in the Perkin–Elmer model 154C instrument at 105° with a flow rate of 78 ml./min., 10 lb. pressure, helium carrier, unless otherwise indicated. Substances designated with roman numerals are shown in the text in Charts 1 and 2; those designated with boldface arabic numerals are shown in Table I. The numbering schemes are cross-referenced where appropriate.

A sample of optically active (+)-*endo*-norborneol (rotation not measured, 1.1 g.), 1.24 g. of *p*-quinone and 4.92 g. of aluminum *t*-butoxide in 75 ml. of dry benzene was heated under reflux for 23 hours. After being cooled, the reaction mixture was decanted from a small amount of black residue, the residue was leached with ether and the combined ether and benzene solutions washed successively with cold 5% sulfuric acid, cold 5% sodium hydroxide, water, and saturated brine, and dried over sodium sulfate. The solvent was removed carefully under an efficient fractionating column (finally at aspirator pressure) to give 0.55 g. (51%) of crude norbornanone, m.p. 80–82°, $[\alpha]^{26}\mathrm{D}$ +9.05° ($\mathrm{CHCl_3}$, *c* 5.207).

B. $\mathrm{CrO_3}$–$\mathrm{H_2SO_4}$–Acetone Method.—The oxidant was prepared according to the directions of ref. 6. It consisted of a solution of 26.72 g. of chromic anhydride in 23 ml. of concentrated sulfuric acid diluted to 100 ml. with distilled water. To a stirred, ice-cold solution of 20.6 g. of *endo*-norborneol, $[\alpha]\mathrm{D}$+1.23°, in 320 ml. of acetone (freshly distilled from potassium permanganate) was added dropwise during 5 minutes 52.0 ml. (theoretical, 45.95 ml.) of the above oxidizing solution. After the completion of the addition, the supernatant layer contained excess oxidant (red-brown color) and a green precipitate had formed. After an additional 2.5 minutes, the reaction mixture was diluted with 2 l. of water, treated with a large quantity of salt, and extracted with seven portions of ether (total 1500 ml.). After having been washed with water and saturated brine, the ether layer was dried over sodium sulfate and evaporated under an efficient fractionating column to give 17.2 g. (85%) of crude norbornanone, m.p. 88–90°. Sublimation gave 16.5 g. of pure material, m.p. 90–91°, infrared spectrum identical with that of an authentic sample (m.p. 109–110°, reported m.p. 93–94°,[34a] 96°[34b]) of the racemate, $[\alpha]^{30}\mathrm{D}$ +17.0°($\mathrm{CHCl_3}$, *c* 4.368), homogeneous by vapor chromatography.

Under the same conditions as above, a sample of the same batch of norborneol used in the Oppenauer oxidation was oxidized to norbornanone of $[\alpha]^{26}\mathrm{D}$ +9.39° ($\mathrm{CHCl_3}$, *c* 4.360).

The conditions used in the chromic anhydride oxidation were those found to be most suitable after several trial experiments in the racemic series. The yield and purity of the ketone are very sensitive to small changes in experimental procedure.

Conversion of Norbornanone to *exo*-2-Methyl-*endo*-norborneol (III, 32).—The procedure was based upon that reported[17] for this reaction in the racemic series. From 16.0 g. of norbornanone, $[\alpha]^{30}\mathrm{D}$+17.0° and excess methylmagnesium iodide in ether, there was obtained, after decomposition of the reaction mixture with ammonium chloride and distillation of the product, 15.0 g. (82%) of III, b.p. 70.5–71° (10 mm.), m.p. 46–47°, $[\alpha]^{30}\mathrm{D}$ +10.9°($\mathrm{CHCl_3}$, *c*. 2.994), vapor chromatographically homogeneous, infrared spectrum identical with that of the racemate (b.p. 66–67° (9.5 mm.), m.p. 26–34°; reported[17] b.p. 72–73° (11 mm.), m.p. 34°). The infrared spectrum of both preparations indicated the absence of carbonyl impurity.

Wagner–Meerwein Rearrangement of III (32) to IV (50).—This reaction had been described in the racemic series.[17] The following conditions were chosen, after several trial experiments, as representing the best compromise between complete rearrangement and complete racemization. To a solution of 14.0 g. of III in 40 ml. of glacial acetic acid was added 10 drops of 75% sulfuric acid. The mixture was warmed for 1 hour on the steam-bath, cooled, and diluted with water to a volume of 500 ml. The sulfuric acid was neutralized with sodium bicarbonate, the mixture was extracted with seven portions of ether (total 350 ml.), the ether layer was washed with water and brine solution and dried over sodium sulfate. The solvent was carefully removed under a fractionating column and the residual oil was distilled under vacuum to give 16.6 g. (89%) of IV, b.p. 75–77° (12.5 mm.). (The substance foamed vigorously when heated, and distillation was difficult.) The infrared spectrum was identical with that of an authentic sample of the racemate. It showed a strong acetate absorption band and no hydroxyl absorption. This material had $[\alpha]^{30}\mathrm{D}$ −14.7°($\mathrm{CHCl_3}$, *c* 3.978).

When a small sample of the optically active acetate was re-exposed to acetic acid–sulfuric acid under the rearrangement conditions, optically inactive acetate was recovered.

1-Methyl-2-*exo*-norborneol (V, 49).—To a stirred suspension of 3.6 g. of lithium aluminum hydride in 100 ml. of dry ether was added dropwise during 1 hour a solution of 16.0 g. of the above optically active acetate in 75 ml. of dry ether. The mixture was heated at reflux for 6 hours and stirred overnight at room temperature. Fifty ml. of ice-cold 5% sulfuric acid was added dropwise with stirring, the ether layer was separated and the residue was triturated thrice with ether. The combined ethereal solutions were washed with water and brine, dried over sodium sulfate, and carefully evaporated under a fractionating column (finally *in vacuo*) to give 11.5 g. of V, infrared spectrum identical with that of the racemate, vapor chromatographically *ca*. 99% homogeneous. The rotation of the optically active sample (*c* 4.6 in chloroform) was too small to measure. Re-acetylation of a small sample (0.3783 g.) in 1.7 ml. of acetic acid, 0.6 g. of acetic anhydride and 4 drops of pyridine for 21 hours on the water-bath gave a reaction mixture which when made up to 10 ml. in acetic acid was optically active. Assuming 100% reaction, the rotation of the regenerated acetate was $[\alpha]^{30}\mathrm{D}$ −14.0° (acetic acid, *c* 5.04).

In the racemic series, the alcohol V when crude contained about 5% of impurities, as indicated by vapor chromatography. Most of these were removed by solution chromatography on alumina followed by conversion to the acid phthalate and regeneration. Thus obtained, racemic V was 99% homogeneous by vapor chromatography (at 115° and a flow rate of 112 ml./min.), m.p. 75–76° (reported[35] m.p. 76°).

1-Methyl-2-norbornanone (VI,52).—To a stirred, ice-cooled solution of 10.1 g. of the above optically active sample of V in 140 ml. of acetone (freshly distilled from potassium permanganate) was added dropwise during 3.5 minutes 35 ml. (theoretical, 20 ml.) of chromium trioxide–sulfuric acid solution (prepared as described above). After an additional 10 minutes, the mixture was diluted to a volume of 1500 ml. with water, salted heavily and extracted with 7 portions of ether (total 800 ml.). The ether solution was worked up as in the preparation of II and the ketone VI was distilled to give 6.7 g. (67.5%) of VI, b.p. 61.5–63° (15 mm.), vapor chromatographically 99% homogeneous, infrared spectrum identical with that of the racemate, $[\alpha]^{30}\mathrm{D}$ −12.5° ($\mathrm{CHCl_3}$, *c* 2.408). The racemic ketone gave a semicarbazone, m.p. 212–213°, reported[36] m.p. 209°.

Methylation of VI to Fenchone (VII).—The procedure was similar to that of Ruzicka.[36] To a stirred suspension of 5.3 g. of freshly powdered sodium amide in 100 ml. of sodium-dried ether under a nitrogen atmosphere was added in one portion a solution of 4.8 g. of the above optically active ketone VI in 25 ml. of dry ether. The mixture was agitated violently with a powerful stirrer for 22 hours. Ammonia was evolved. The resulting yellow mixture was treated with a solution of 50 g. of methyl iodide in 40 ml. of dry ether in one portion and heated at reflux for 3 hours. After being cooled to room temperature, the mixture was treated with an additional 5.0 g. of sodium amide and the stirring treatment with more methyl iodide, and boiling steps repeated as above. A third portion of 50 g. of methyl iodide was added, and boiling was continued an additional 2.5 hours. The solvent and excess methyl iodide were removed by distillation, the residue was treated in the cold with 200 ml. of ice-cold 2% sulfuric acid and the resulting oil extracted with ether. The ethereal solution, after being washed successively with sodium thiosulfate solution, water and brine, was dried over sodium sulfate and carefully evaporated under a fractionating column. The residual material, a pleasant-smelling oil, was largely fenchone, as judged by the infrared spectrum and vapor chromatographic behavior. The major peak in the vapor chromatogram emerged with the same retention time as an authentic sample of fenchone and represented >97% of the total area of the chromatogram. There were three small peaks, one corresponding in position to unmethylated starting material VI and two incompletely resolved ones intermediate in position between fenchone and VI, which presumably represented the two epimers of monomethylated product. The crude product was treated with semicarbazide hydrochloride and sodium acetate in aqueous methanol, according to Ruzicka,[36] to remove incompletely methylated materials, filtered (only a small amount of semicarbazone was formed), and the filtrate steam distilled.

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(34) (a) S. V. Hintikka and G. Komppa, *Ann. Acad. Sci. Fennicae*, **A10**, No. 22 (1918), (b) K. Alder and G. Stein, *Ber.*, **67**, 613 (1934).

(35) S. Beckmann and R. Schaber, *Ann.*, **585**, 154 (1954).

(36) L. Ruzicka, *Ber.*, **50**, 1362 (1917).

The distillate was salted heavily, extracted thoroughly with ether, the ethereal solution was washed with water and brine, dried over sodium sulfate, and evaporated. The residual oil (4.3 g.) was fractionally distilled to give the fractions: (1) 0.43 g., b.p. 59–60° (10 mm.); (2) 1.02 g., b.p. 61–62° (10 mm.); (3) 1.15 g., b.p. 62–63° (10 mm.); (4) 1.40 g., b.p. 63–64° (10 mm.) (total recovery 4.0 g.). Fractions 3 and 4 were essentially pure fenchone. The infrared spectra were identical with that of an authentic sample except for three extremely weak absorptions (which were somewhat stronger in fractions 1 and 2). Fraction 3 had $n^{25}\mathrm{D}$ 1.4600, fraction 4 had $n^{25}\mathrm{D}$ 1.4611, reported for fenchone[30b] $n^{18}\mathrm{D}$ 1.4636. Vapor chromatograms showed fraction 3 to be 99.1% and fraction 4 to be 98.1% homogeneous. Fraction 3 had $[\alpha]^{30}\mathrm{D}$ −19.23° (ethanol, c 3.255); fraction 4 had $[\alpha]^{30}\mathrm{D}$ −19.65° (ethanol, c 3.464), $[\alpha]^{30}\mathrm{D}$ −19.51° ($CHCl_3$, c 2.695). Authentic optically pure *d*-fenchone (Fluka) in our hands had $[\alpha]^{25}\mathrm{D}$ + 65.6° (ethanol, c 2.12), $[\alpha]^{25}\mathrm{D}$ +65.7° ($CHCl_3$, c 3.03); reported[30b,37] $[\alpha]^{18}\mathrm{D}$ +68.43° (ethanol, c 13.76), $[\alpha]^{28}\mathrm{D}$ +51.8° ($CHCl_3$, c 8).

2-*endo*-Hydroxymethyl-5-norbornene (37).—A solution of 35 g. of (+)-2-*endo*-5-norbornenecarboxylic acid (**33**), $[\alpha]\mathrm{D}$ +27.3° (c 2.59 in 95% ethanol, l 1), 19% optically pure,[10b] in 150 ml. of ether was slowly added to a mixture 14.5 g. of lithium aluminum hydride in 250 ml. of ether during 4 hours. After an additional 9 hours at room temperature and 45 minutes at reflux, the mixture was cooled and treated successively with 150 ml. of water and 250 ml. of 20% hydrochloric acid. The ether layer was separated, combined with the ether layer from extraction of the aqueous layer, washed with 10% sodium hydroxide, water, and saturated brine, and dried over calcium sulfate. Evaporation and distillation gave 28.3 g. of the carbinol **37**, b.p. 90–90.6° (11.2 mm), $n^{25}\mathrm{D}$ 1.4972, $[\alpha]\mathrm{D}$ +14.6° (95% ethanol, l 1). Similarly, (−)-acid, $[\alpha]\mathrm{D}$ −37.0°, gave (−)-carbinol, $[\alpha]\mathrm{D}$ −19.6°, $n^{26}\mathrm{D}$ 1.4962. The racemate of the carbinol, reported[38] to have b.p. 92–95° (13 mm.), has been prepared from cyclopentadiene and allyl alcohol. We have now prepared it by lithium aluminum hydride reduction of pure racemic *endo*-unsaturated acid as above. The carbinol thus prepared had b.p. 97–98° (20 mm.), $n^{18}\mathrm{D}$ 1.4999.

Anal. Calcd. for $C_8H_{12}O$: C, 77.42; H, 9.65. Found: C, 77.44; H, 9.69.

The phenylurethan had m.p. 123–124° (from methanol). A mixture m.p. with the phenylurethan of the *exo*-unsaturated alcohol was depressed to 113–119°.

Anal. Calcd. for $C_{15}H_{17}O_2N$: C, 73.90; H, 6.98; N, 5.76. Found: C, 73.97; H, 7.01; N, 5.73.

The *p*-bromobenzenesulfonate (**39**) was prepared by treating a solution of 9.7 g. of (−)-carbinol **37**, $[\alpha]\mathrm{D}$ −19.6°, in 21 ml. of pyridine with 30.9 g. of *p*-bromobenzenesulfonyl chloride, added in several portions while cooling the reaction mixture. Pyridine hydrochloride began to precipitate immediately. After 2 hours at room temperature and 8 days in the refrigerator, the mixture was poured onto a mixture of 200 g. of cracked ice and 15 ml. of concentrated hydrochloric acid. Extraction with ether, successive washing of the ether layer with 10% sodium bicarbonate, water and brine, drying over calcium sulfate, and evaporation gave a thick oil which crystallized from cold methanol to give a first crop of 23.1 g. of **39**, m.p. 79.8–80.8°, and a second crop, 1.30 g., m.p. 78–79.6°. The crops were combined (total yield 91%), and mixed thoroughly; this material had $[\alpha]\mathrm{D}$ −13.0° (c 4.1 in chloroform, l 1). In the text, it is assumed for the calculations that no fractionation occurred. The high yield obtained makes it unlikely that the rotation given is seriously in error. A sample of crop 1 was recrystallized from absolute methanol to give material of m.p. 80.2–80.8°.

Anal. Calcd. for $C_{14}H_{15}O_3SBr$: C, 48.99; H, 4.41. Found: C, 49.10; H, 4.49.

The racemic *p*-bromobenzenesulfonate had m.p. 80–81°, infrared spectrum identical with that of the above sample.

2-*endo*-Methyl-5-norbornene (40).—A sample of 16.1 g. of (−)-2-*endo*-norbornene-5-carboxylic acid of $[\alpha]\mathrm{D}$ −76.1° (95% ethanol) was reduced to the carbinol **37** as above. The latter was converted to the *p*-bromobenzenesulfonate, which was not crystallized but reduced in the dried ether solution obtained after extraction. This solution (400 ml.) was added during 1 hour to a stirred solution of lithium aluminum hydride (10.5 g.) in 200 ml. of ether. The solution was stirred and heated at reflux for 34 hours, cooled in ice, and treated dropwise with 30 ml. of water followed by 375 ml. of 20% sodium hydroxide solution. The resulting emulsion slowly separated, the ether layer was removed, and the aqueous layer, after having been acidified with hydrochloric acid, was extracted with fresh ether. The combined ether layers were washed with N sodium hydroxide, water, and saturated brine and dried over calcium sulfate. Careful distillation gave 5.65 g. of the hydrocarbon, b.p. 114.5–115.5°, $[\alpha]\mathrm{D}$ −47.8° (c 8.95 in chloroform, l 1), $n^{27}\mathrm{D}$ 1.4550, infrared spectrum identical with that of the racemate.

The racemic hydrocarbon was prepared by the same procedure from crystalline racemic *p*-bromobenzenesulfonate. It had b.p. 114–114.8°, $n^{24}\mathrm{D}$ 1.4562.

Anal. Calcd. for C_8H_{12}: C, 88.82; H, 11.18. Found: C, 88.61; H, 11.27.

Resolution of 2-*exo*-Norbornene-5-carboxylic Acid (34).—A solution of 142 g. of pure racemic acid[39a] and 320 g. of cinchonidine in 1800 ml. of hot absolute ethanol was allowed to cool to room temperature and stored overnight in the refrigerator. The solution was concentrated and triturated until crystallization began. The first crop of salt (260 g.), from which acid of $[\alpha]\mathrm{D}$ +6.64° (ethanol) could be regenerated, was recrystallized once from absolute ethanol to give 127 g. of salt from which acid of $[\alpha]\mathrm{D}$+10.0° (ethanol) was regenerated. The mother liquors from the salt recrystallizations were subjected to systematic triangular fractionation. From the tail fraction there was obtained salt (140 g.) which gave acid of $[\alpha]\mathrm{D}$ −11.7° (ethanol) (68% optically pure[10b]), m.p. 37–39°, after bulb-to-bulb distillation. The infrared spectrum was identical with that of a sample of the racemate. We have observed that samples of the *exo*-methyl ester, prepared from either optically active or racemic acid and diazomethane, sometimes contain a few per cent. of an impurity which is not the *endo*-ester and is not readily removed by distillation. Pure ester can be obtained by preparative gas chromatography. In this way, *exo*-acid of $[\alpha]\mathrm{D}$+13.6° (ethanol) gave ester of $[\alpha]\mathrm{D}$ +22.8° (ethanol). This requires a minor revision of the maximum rotation of the ester previously[10b] reported from 26.5° to 28.7°.

2-*exo*-Hydroxymethyl-5-norbornene (38) was prepared from pure racemic *exo*-acid by lithium aluminum hydride reduction in the same manner used for preparation of the *endo* isomer. The racemic **38** had b.p. 101–101.5° (22 mm.), $n^{22}\mathrm{D}$ 1.4974. It was vapor chromatographically homogeneous (tri-β-cyanoethoxypropane-on-firebrick column at 130°, helium carrier). The *endo*-alcohol described above was also homogeneous by this criterion, and there was sufficient difference in the retention times of the two epimers to allow detection of 1% of cross-contamination. The preparation of these epimers has been described by others,[40] although no physical properties are reported in the brief abstract.

Anal. Calcd. for $C_8H_{12}O$: C, 77.42; H, 9.65. Found: C, 77.28; H, 9.57.

The racemic *exo*-carbinol gave a **phenylurethan**, m.p. 123–124.5° (from methanol).

Anal. Calcd. for $C_{15}H_{17}O_2N$: C, 73.90; H, 6.98; N, 5.76. Found: C, 74.18; H, 7.07; N, 5.72.

The optically active *exo*-carbinol was prepared from (−)-*exo*-5-norbornene-2-carboxylic acid, $[\alpha]\mathrm{D}$ −11.0° (c 6.38 in 95% ethanol), 64.3% optically pure,[10b] by the same procedure used in the racemic series. It had $n^{17}\mathrm{D}$ 1.4994, $[\alpha]\mathrm{D}$ −12.4° (c 5.59 in 95% ethanol). Its infrared spectrum was identical with that of the racemic compound.

2-*endo*-Hydroxymethylnorbornane (5) had been reported by Alder and Stein,[39b] but the methods of preparation did not assure epimeric purity. We have prepared it by lithium aluminum hydride reduction of pure *endo*-2-norbornanecarboxylic acid. The carbinol thus prepared gave a

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(37) P. Walden, *Ber.*, **38**, 345 (1905).

(38) K. Alder and E. Windemuth, *ibid.*, **71**, 1939 (1938).

(39) (a) C. D. ver Nooy and C. S. Rondestvedt, *J. Am. Chem. Soc.*, **77**, 3583 (1955); (b) K. Alder and G. Stein, *Ann.*, **525**, 247 (1936).

(40) P. Resnick and J. G. Pucknat, Abstracts of Papers, American Chemical Society Meeting, Atlantic City, N. J., Sept. 13–18, 1959; p. 95-P.

phenylurethan, m.p. 131–132°, in 99% yield. Two recrystallizations from absolute methanol gave material of m.p. 133–134° and further recrystallization did not change the m.p.; reported[39b] m.p. 134°. In the optically active series, acid of [α] +16.1° (*c* 0.664 in 95% ethanol), 52.4% optically pure,[10b] gave carbinol of [α]D −4.04° (*c* 0.515 in 95% ethanol), infrared spectrum identical with that of the racemate.

The racemic **p-toluenesulfonate 7** had m.p. 44–45° (from methanol).

Anal. Calcd. for $C_{15}H_{20}O_3S$: C, 64.26; H, 7.19. Found: C, 64.30; H, 7.32.

The (−)-carbinol above gave a solid *p*-toluenesulfonate (7) which, without recrystallization, had an infrared spectrum identical with that of the pure racemate. It showed [α]D +2.81° (*c* 0.663 in 95% ethanol).

2-*endo*-Phthalimidomethylnorbornane (9) was prepared by the general method of Sakellarios[41] as modified by Sheehan and Bolhofer.[42] A solution of 95.8 g. of racemic 2-hydroxymethylnorbornyl *p*-toluenesulfonate in 200 ml. of freshly distilled dimethylformamide was treated with 150 g. of potassium phthalimide. The mixture was diluted with another 120 ml. of dimethylformamide and stirred at reflux for 24 hours. Ice was added, the solid material was filtered off, washed with water, air-dried, and dissolved in ether. After having been washed with bicarbonate solution, water, hydrochloric acid, and brine, the ether solution was dried and evaporated to give 80.2 g. (92%) of 9, which had m.p. 85–85.5° (from methanol).

Anal. Calcd. for $C_{16}H_{17}O_2N$: C, 75.27; H, 6.71; N, 5.49. Found: C, 75.35; H, 6.67; N, 5.45.

In the same manner, the optically active *p*-toluenesulfonate gave phthalimide 9.

2-*endo*-Aminomethylnorbornane hydrochloride (11) was prepared by the general method of Ing and Manske,[43] as modified.[42] A solution of 44 g. of the phthalimide in 300 ml. of methanol was treated with 70 ml. of 85% hydrazine and heated at reflux for 4 hours. After most of the methanol had been distilled off through a Vigreux column, the residue was treated with 300 ml. of water and 350 ml. of concentrated hydrochloric acid. After having been heated and stirred under reflux for 3 hours, the mixture was cooled in an ice–salt-bath and filtered. The filtrate was cooled, made basic with potassium hydroxide, and the amine was extracted with ether. After having been washed with brine and dried over magnesium sulfate, the ether solution was treated with a stream of dry hydrogen chloride until no further precipitate appeared. The hydrochloride thus obtained (17 g. 63%) had no definite m.p., but gradually turned dark above 250°.

The benzoyl derivative had m.p. 99.5–101°, reported[44] m.p. 99–100°.

In the optically active series, the hydrochloride obtained from the above phthalimide had [α]D −3.87° (*c* 0.538 in 95% ethanol).

2-*exo*-Hydroxymethylnorbornane (6) was prepared (i) by lithium aluminum hydride reduction of the corresponding acid, as in the *endo* series, and (ii) by catalytic hydrogenation of the corresponding unsaturated carbinol (38) (prepared above and there shown to be at least 99% epimerically pure) in ethanol over 10% palladium-on-charcoal. The infrared spectra of both samples were identical. The substance had b.p. 99–100° (15–16 mm.), $n^{26.5}$D 1.4858. Alder[39b] had reported the preparation of this carbinol by methods that did not assure epimeric purity. His sample had b.p. 89–90° (11 mm.); it gave a phenylurethan, m.p. 118°. It seems likely that this material was epimerically impure. The phenylurethan prepared from our sample of epimerically pure carbinol had m.p. 110–110.5° (from methanol). The m.p. was unchanged by further recrystallization. Admixture with pure phenylurethan of the epimeric *endo*-carbinol, m.p. 133–134°, did not cause a depression, the 1:1 mixture melting at 119–122.5°.

Anal. Calcd. for $C_{15}H_{19}O_2N$: C, 73.44; H, 7.81. Found: C, 73.52; H, 7.94.

From (−)-2-*exo*-hydroxymethyl-5-norbornene, [α]D −12.4°, there was obtained (−)-2-*exo*-hydroxymethylnorbornane (6), [α]D −6.96° (*c* 5.59 in 95% ethanol), b.p. 103–105° (20–21 mm.); infrared spectrum identical with that of the racemate.

The racemic **p-toluenesulfonate 8** was prepared by adding a solution of 126 g. of *p*-toluenesulfonyl chloride in 150 ml. of dry pyridine to a cold solution of 42 g. of carbinol in 100 ml. of pyridine while the temperature was kept below 20°. After having been stored at a temperature below 30° for 89 hours, the mixture was cooled and treated with small portions of cracked ice. After the reaction had subsided, ice-water was added. The precipitated oil gradually crystallized. The mixture was extracted with hexane, washed with dilute hydrochloric acid, bicarbonate solution, and water, and dried over magnesium sulfate. Evaporation gave 87 g. (94%) of solid which after recrystallization from pentane and then from methanol had m.p. 41–42°. A mixture with the *endo*-*p*-toluenesulfonate 7 was liquid at room temperature.

Anal. Calcd. for $C_{15}H_{20}O_3S$: C, 64.26; H, 7.19. Found: C, 64.10; H, 7.11.

From (−)-2-*exo*-hydroxymethylnorbornane, the *p*-toluenesulfonate 8, after chromatography on acid-washed alumina in 10% ether-in-pentane (no recrystallizations), had [α]D −8.57° (*c* 7.51 in 95% ethanol).

2-*exo*-Phthalimidomethylnorbornane (10) was prepared from *p*-toluenesulfonate by the same procedure used in the *endo* series. The racemic phthalimide had m.p. 98–100° (from methanol).

Anal. Calcd. for $C_{16}H_{17}O_2N$: C, 75.29; H, 6.66; N, 5.49. Found: C, 75.20; H, 6.74; N, 5.50.

Optically active material was prepared by the same route, and was used without recrystallization for the preparation of optically active amine.

2-*exo*-Aminomethylnorbornane hydrochloride (12), prepared from the phthalimide by the procedure used in the *endo* series, gradually decomposed and darkened above 250°. The benzoyl derivative had m.p. 116–117° after recrystallization from pentane–ether and from methanol; reported[44] m.p. 117–118°. The free base was a liquid, b.p. 63.5–64° (12–13 mm.), The optically active hydrochloride 12, prepared from alcohol 6 of [α]D −6.96°, had [α]D −10.4° (*c* 2.31 in 95% ethanol).

Resolution of 5-Norbornene-2-*endo*-methyl-2-*exo*-carboxylic Acid (42).—To a solution of 76.2 g. of pure racemic acid, m.p. 81.5–83° (from aqueous acetic acid), reported 79–80°,[45] 83°,[46] in 4500 ml. of acetone was slowly added (from a Soxhlet extractor) 194.7 g. of quinine trihydrate. Crystals formed during the addition of the alkaloid. After all the quinine had been added, the solution was allowed to cool to room temperature. The crystals were filtered off and successively recrystallized from acetone six times, using a Soxhlet extractor. The course of the resolution was followed by regenerating small samples of acid at each stage with ether–10% sulfuric acid. The third, fourth, fifth and sixth recrystallizations of the salt gave acid of [α]D +57.3°, +61.5°, +64.9° and +66.0°. The salt from a seventh recrystallization gave 6.0 g. of acid of [α]D +67.3°, m.p. 47–48°. The infrared spectrum was identical with that of the pure racemic acid. This material was assumed to be optically pure, a point that is supported below. All rotations for this substance are in 95% ethanol.

Anal. Calcd. for $C_9H_{12}O_2$: C, 71.10; H, 7.90. Found: C, 71.18; H, 8.00.

From the early mother liquors, 10.3 g., [α]D −45.4°, of partially resolved levo acid was obtained; the mother liquors from the middle of the fractionation gave 5.0 g. of the racemate, and those from the late mother liquors gave 8.0 g., [α]D +32.1°, of partially resolved dextro isomer.

With ethereal diazomethane a sample of acid [α]D +62.5° gave methyl ester 44, [α]D +60.4°, vapor chromatographically homogeneous, infrared spectrum identical with that of the racemate.

Partial Resolution of 5-Norbornene-2-*exo*-methyl-2-*endo*-carboxylic Acid (41).—The racemic acid had m.p. 108–110° after recrystallization from aqueous ethanol and vacuum

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[41] E. J. Sakellarios, *Helv. Chim. Acta*, **29**, 1675 (1946).

[42] J. C. Sheehan and W. Bolhofer, *J. Am. Chem. Soc.*, **72**, 2786 (1950).

[43] H. R. Ing and R. H. F. Manske, *J. Chem. Soc.*, 2348 (1926).

[44] K. Alder, K. Heimbach and R. Reubke, *Chem. Ber.*, **91**, 1516 (1958).

[45] J. S. Meek and W. B. Trapp, *J. Am. Chem. Soc.*, **79**, 3909 (1957).

[46] S. Beckmann, R. Schaber and R. Bamberger, *Chem. Ber.*, **87**, 997 (1954).

sublimation; reported m.p. 94–95°,[45] m.p. 109°.[46] The m.p. is very sensitive to traces of impurity and the iodolactone precursor must be carefully recrystallized (aqueous ethanol is a suitable solvent) or chromatographed before reduction. To 130 g. of acid in 750 ml. of boiling 95% ethanol was added 258 g. of cinchonidine. Cooling at 0° for 2–3 hours gave the salt which was recrystallized eight times more from 95% ethanol, using steadily decreasing volumes of solvent. Regeneration of the acid with ether–10% sulfuric acid gave 22.5 g. of material of $[\alpha]_D + 58.9°$, m.p. 106–109°, infrared spectrum identical with that of the racemate. This material was 55.3% optically pure.

Anal. Calcd. for $C_9H_{12}O_2$: C, 71.10; H, 7.90. Found: C, 71.09; H, 8.03.

The above acid, $[\alpha]_D +58.9°$, was esterified with ethereal diazomethane to give vapor chromatographically homogeneous methyl ester **43**, $[\alpha]_D +53.4°$, infrared spectrum identical with that of the racemate. Rotations for the above acid and ester are in 95% ethanol.

2-*exo*-Methyl-2-*endo*-hydroxymethyl-5-norbornene (45) was prepared by lithium aluminum hydride reduction of the corresponding acid by methods similar to those described in the un-methylated series. The racemate had m.p. 95–96° after vacuum sublimation.

Anal. Calcd. for $C_9H_{14}O$: C, 78.25; H, 10.15. Found: C, 78.15; H, 10.21.

The α-**naphthylurethan** had m.p. 119.5–120° from heptane.

Anal. Calcd. for $C_{20}H_{21}O_2N$: C, 78.10; H, 6.84; N, 4.56. Found: C, 78.21; H, 6.87; N, 4.64.

From acid of $[\alpha]_D +58.9°$ there was obtained alcohol, **45**, $[\alpha]_D +25.5°$ (95% ethanol), a white waxy solid after sublimation. The infrared spectrum was identical with that of the racemate. The acetate **47** was a liquid, n^{25}_D 1.4652, $[\alpha]_D +23.2°$ (95% ethanol).

2-*endo*-Methyl-2-*exo*-hydroxymethyl-5-norbornene (46) was prepared by lithium aluminum hydride reduction of the corresponding acid. After recrystallization from aqueous ethanol and sublimation, the racemate was a white waxy solid, m.p. 61–68°.

Anal. Calcd. for $C_9H_{14}O$: C, 78.25; H, 10.15. Found: C, 78.08; H, 10.32.

Similarly, reduction of the (—)-acid, $[\alpha]_D -41.4°$ (95% ethanol), gave alcohol of $[\alpha]$ −41.7° (95% ethanol), m.p. 59–68°. The infrared spectrum was identical with that of the racemate.

Camphenilene (48). A. From 45.—To a solution of the above optically active alcohol **45** in 120 ml. of pyridine was added, at 0°, 18.8 g. of *p*-toluenesulfonyl chloride. The solution was kept at 0° for 2 hours and then at room temperature for 10 hours. Small chips of ice were added and the product was isolated in the manner described above for **8**. Evaporation of the ether left 16.0 g. of a clear viscous oil. This material was reduced, without further purification, with lithium aluminum hydride in ether as described for **40**. The reduction mixture was concentrated under a Vigreux column, the excess lithium aluminum hydride was filtered off under nitrogen and the filtrate was carefully evaporated under a Vigreux column. Distillation of the residue through a Vigreux column gave the crude hydrocarbon, b.p. 128–131°. Vapor chromatographic analysis using the Perkin-Elmer C column (silicone oil DC-200 on firebrick) at a flow rate of 102 ml./min. with helium carrier showed this material to be about 90% pure; the major impurity was ether, although about 1–3% of higher boiling substances also were present. Preparative vapor chromatography under the same conditions was achieved by successively passing many samples of 30–50 microliters each through the chromatograph and trapping the emergent stream under monitoring by the recorder response. The product was a white solid, m.p. 27–28°, homogeneous by vapor chromatography, $[\alpha]_D +27.0°$(benzene). The infrared spectrum was identical with that of a sample prepared from the *exo*-alcohol **46**.

B. From 46.—Similarly, conversion of the above optically active alcohol **46** to the *p*-toluenesulfonate, reduction, distillation and preparative vapor chromatography gave camphenilene, m.p. 27–28°, $[\alpha]_D -30.0°$ (benzene).

Anal. Calcd. for C_9H_{14}: C, 88.50; H, 11.50. Found: C, 88.22; H, 11.39 (prepared by method A); C, 88.21; H, 11.39 (prepared by method B).

2-*endo*-Methyl-2-*exo*-norbornanecarboxylic Acid (26).—Hydrogenation of the unsaturated acid 42, $[\alpha]_D -41.4°$, in anhydrous methanol over platinum oxide followed by bulb-to-bulb distillation gave the saturated acid, m.p. 52–70°, $[\alpha]_D -3.57°$ (95% ethanol).

Anal. Calcd. for $C_9H_{14}O_2$: C, 70.10; H, 9.08. Found: C, 70.17; H, 9.01.

Ethereal diazomethane gave the methyl ester **28** which was a liquid. It was purified by bulb-to-bulb distillation and had n^{25}_D 1.4631, $[\alpha]_D -4.32°$ (95% ethanol). It contained less than 0.1% of the saturated ester by vapor chromatographic analysis.

Anal. Calcd. for $C_{10}H_{16}O_2$: C, 71.40; H, 9.52. Found: C, 71.51; H, 9.65.

2-*endo*-Methyl-2-*exo*-hydroxymethylnorbornane (30) was prepared by lithium aluminum hydride reduction of the above active acid 26 in the usual manner. Bulb-to-bulb distillation gave a waxy solid melting below 38°, $[\alpha]_D -8.44°$ (95% ethanol).

Anal. Calcd. for $C_9H_{16}O$: C, 77.10; H, 11.40. Found: C, 77.17; H, 11.32.

Camphenilane (31) was prepared by lithium aluminum hydride reduction of the crude *p*-toluenesulfonate of the above alcohol **30** in the usual manner. The crude hydrocarbon contained about 15% of impurities which were removed by preparative vapor chromatography using the same procedure as for camphenilene (**48**). The pure hydrocarbon was a liquid, $[\alpha]_D$ −8.20° (benzene), vapor chromatographically homogeneous, infrared spectrum identical with that of a sample of the racemate prepared by Wolff–Kishner reduction[47] of racemic camphenilone semicarbazone.

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[47] (a) By the general method of A. H. Cook and R. P. Linstead, *J. Chem. Soc.*, 956 (1934). (b) Racemic camphenilane also has been prepared by Wolff–Kishner reduction of camphenilone hydrazone by S. Nametkin, *Ann.*, **438**, 185 (1924), and by G. Komppa and T. Hasselström, *ibid.*, **496**, 164 (1932).