714. *Aspects of Stereochemistry. Part XV.* Catalytic Hydrogenation of Cyclic Allylic Alcohols in the Presence of Sodium Nitrite.*

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In the hydrogenation of cholest-4-en-3β-ol (I) at platinum, small amounts of some sodium salts, including those used (nitrate) or formed (nitrite) in the preparation of Adams catalyst, cause hydrogen to add *cis* to the hydroxyl group mainly at the expense of hydrogenolysis. Hydrogenation of cholest-4-ene (ethanol, platinum, and sodium nitrite) gave coprostane (55%) and cholestane (45%); hydrogenations of its 3β-hydroxy- and -methoxy-derivatives were faster, more β-addition occurring with the former compound and more α-addition with the latter. Hydrogen adds *cis* to the hydroxyl group in both piperitols, but specific addition did not occur with various related compounds.

1-Methylcyclohexanol (6—10%) was formed when 3-methylcyclohex-2-enol was hydrogenated at platinum in ethanol containing an organic acid. Two other allylic alcohols did not rearrange during hydrogenation.

For cyclic olefins, the direction of the metal-catalysed addition of hydrogen often parallels that of the formation of epoxides by peracids; in both reactions the direction of attack can be controlled by steric factors imposed by nearby substituents. Recent work in these laboratories has shown that polar substituents can exert other directing effects on the addition of reagents to double bonds. For example, *cis*-hydroxy-epoxides are formed as the main products in reactions of cyclohex-2-enols with peracids.[1] It seemed possible that polar substituents might also exert special directing effects on the addition of hydrogen to cyclic olefins, and cyclohex-2-enols and related compounds were chosen for initial study.

Seventeen examples have been found in the literature of the hydrogenation of cyclic allylic alcohols in which the degree of alkylation of the double bond enables the direction of hydrogen addition to be ascertained (without the use of isotopic hydrogen). It is not profitable to discuss these in detail at the moment as the reaction mixtures were generally incompletely analysed and a variety of experimental conditions was used. However, there are more examples of *cis*-addition of hydrogen to an allylic hydroxyl group than of *trans*-.

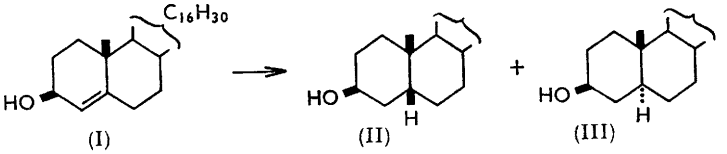
Δ^4-*Steroids*. In 1936, Schoenheimer and Evans [2] described the isolation of coprostanol (II) in unstated yield on hydrogenation of cholest-4-en-3β-ol (I) at platinum in pentyl ether. This reaction has been re-investigated with ethanol as solvent and chromatographic techniques for the separation and analysis of the products. A mixture of coprostanol (II), cholestanol (III), and hydrocarbon (hydrogenolysis product) was obtained in each reaction (Table).

* Part XIV, *J.*, 1959, 4136.

[1] Henbest and Wilson, *J.*, 1957, 1958.

[2] Schoenheimer and Evans, *J. Biol. Chem.*, 1936, **114**, 567.

Variations in the conditions caused large changes in the coprostanol : hydrocarbon yield ratio but had very much less effect on the yield of cholestanol (usually 20—35%). It was found that the coprostanol : hydrocarbon ratio was influenced by the procedure used



(I) (II) (III)

for preparing the Adams catalyst, especially by the ratio of hexachloroplatinic acid to sodium nitrate. These observations led to experiments showing that small amounts of certain alkali salts cause the yield of coprostanol to increase largely at the expense of the hydrocarbon. In discussing the way by which this conclusion was reached it should be remembered that the " platinic dioxide " obtained from Adams's fusion process contains

Hydrogenation of cholest-4-en-3β-ol (I) *using Adams's catalyst.*

	Coprostanol (%)	Cholestanol (%)	Hydrocarbon (%)
1. Commercial catalyst (note 1)	21	33	46
2. ,, ,,	15	28	57
3. Catalyst 1 : 10, prepared at 300° (note 2)	14	22	64
4. Catalyst 1 : 10, prepared at 400°	8	19	73
5. Catalyst 1 : 10, prepared at 400°	10	20	70
6. Catalyst 1 : 20, prepared at 420°	71	20	9
7. Catalyst 1 : 20, prepared at 420°	67	25	8
8. As 6 and 7, but further washed	63	21	16
9. As 6 and 7, but pre-reduced	11	15	74
10. As 6 and 7, but pre-reduced	23	24	53
11. As 9 and 10 + $NaNO_3$ (note 3)	57	34	9
12. As 9 and 10 + $NaNO_2$	65	32	3
13. As 9 and 10 + $LiNO_3$	34	34	32
14. As 9 and 10 + KNO_3	42	34	24
15. As 9 and 10 + NaCN	63	30	7
16. As 9 and 10 + NaCN	57	31	12
17. As 9 and 10 + NaCl	19	30	51
18. As 9 and 10 + NaOH	63	36	1
19. Catalyst 1 : 50, prepared at 420°	70	24	66
20. As 19, but pre-reduced	19	22	59 *
21. As 20 + $NaNO_2$	66	27	7

Note 1: Johnson, Matthey & Co. Note 2: The ratios 1 : 10 (expts. 3 to 5), 1 : 20 (expts. 6, 7), and 1 : 50 (expt. 19) refer to the relative weights of hexachloroplatinic acid to sodium nitrate used for fusion. Note 3: Each of the salts (1% of weight of " platinum dioxide ") was added dissolved in a drop of water. * This hydrocarbon was mainly cholestane by infrared analysis.

sodium salts that are not completely removed by washing with water.[3] When such dioxide (expt. 6 and 7) was added to the solution of cholest-4-en-3β-ol for hydrogenation, coprostanol was formed in more than 65% yield. However, when this dioxide was pre-reduced with hydrogen and the platinum washed with water (thus removing sodium salts more effectively), the yield of coprostanol fell to about 20% and the yield of hydrocarbon rose correspondingly (expts. 6, 7, 9, 10, 19, 20). Addition of a small amount of sodium nitrite, cyanide, or hydroxide (expts. 12, 15, 16, 18, 21) to the reduced, washed platinum reconstituted the properties of the original Adams catalyst, coprostanol again being formed in 65% yield.[4] The effectiveness of these salts of weak acids suggests that they may diminish the amount of hydrocarbon formed by exerting some kind of buffering

[3] Adams and Shriner, *J. Amer. Chem. Soc.*, 1923, **45**, 2171; Keenan, Giesemann, and Smith, *ibid.*, 1954, **76**, 229; Wicker, *J.*, 1956, 2165.

[4] Preliminary account: Dart and Henbest, *Nature*, 1959, **183**, 817.

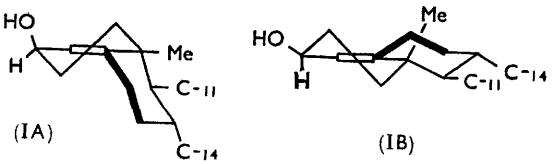
effect, perhaps by neutralising traces of strong acid that are known to promote hydrogenolysis of allylic compounds.[5] For example, cholestane (90%) was shown by Shoppee *et al.*[6] to be formed when the allylic alcohol (I) is hydrogenated at platinum in the presence sulphuric or perchloric acid[6] [these authors also reported that coprostanol and cholestanol were formed in the ratios 54 : 42 and 78 : 14 on hydrogenation of the cholestenol (I) in ethyl acetate, and ethyl acetate containing acetic acid, respectively, with platinum oxide of unspecified origin as the source of catalyst].

The lower yield of hydrocarbon obtained by decreasing the hexachloroplatinic acid : sodium nitrate ratio may be noted. The salt (sodium chloride) of a strong acid gave more than 50% of hydrocarbon (expt. 17) whereas sodium hydroxide only gave a trace (expt. 18). Nitrates were intermediate in behaviour (? reduced to nitrites), and different ratios were obtained with different cations (expts. 11, 13, 14).

Cholest-4-ene (I; OH replaced by H) is fairly rapidly reduced at palladium in acetic acid at 75°, giving nearly pure cholestane;[7] neutral solvents slow down the reaction and coprostane is obtained.[7,8] The last result is often quoted, although an actual yield of coprostane has not apparently been determined. We have found that the reduction of cholest-4-ene in ethanol (containing sodium nitrite) at 20° at platinum is only slightly stereoselective, coprostane and cholestane being formed in the ratio 55 : 45 (analysis by infrared methods). Hydrogenation of the bicyclic analogue, 10-methyl-$\Delta^{1(9)}$-octalin, in ethanol at palladium gives the same ratio of β : α-addition.[9]

This hydrogenation of cholest-4-ene was slow, in contrast to the rapid reduction of the alcohol (I) and its methyl ether under the same conditions. The main product (60%) from the methyl ether was 3β-methoxycholestane, in accord with other work[6] where ethyl acetate was the solvent. Thus, apart from increasing the rates of hydrogenation, the 3β-hydroxyl group causes β-addition of hydrogen to be slightly increased (55 ⟶ 70%) (cf. piperitols below), and the 3β-methoxyl group increases the proportion of α-attack (45 ⟶ 60%), perhaps for steric reasons.

In discussing the hydrogenation of Δ^4-steroids in more detail, it should be noted that they may exist in two conformations. This is illustrated with the 3β-hydroxy-compound (I), where the hydroxyl group is quasi-axial and quasi-equatorial respectively in the conformations (IA and IB).



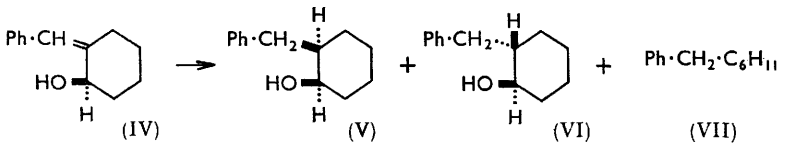
Monocyclic Cyclohexanols.—Hydrogenation of 2-benzylidenecyclohexanol (IV) (platinum–charcoal catalyst) gives[10] a mixture of *cis*-2-benzylcyclohexanol (V; 47%), its *trans*-isomer (VI; 1%), and the hydrogenolysis product, 2-benzylcyclohexane (VII; 37%). Repetition of this hydrogenation using Adams catalyst containing sodium salts changed the yields to 38, 35, and 8% respectively. Thus, as in the steroid series, the presence of sodium salts increases the yield of the compound (*i.e.*, VI) in which hydrogen has added *cis* to the hydroxyl group and decreases the amount of hydrogenolysis.

A catalyst surface with adsorbed hydrogen can cause double bonds to migrate.[11] The possibility that hydrogenation of the allylic alcohol (IV) might proceed *via* the enol of 2-benzylcyclohexanone was checked by preparing the alcohol (IV) with deuterium

[5] McQuillin and Ord, *J.*, 1959, **3169**.
[6] Shoppee, Agashe, and Summers, *J.*, 1957, 3107.
[7] Windaus, *Ber.*, 1919, **52**, 170.
[8] Mauthner, *Monatsh.*, 1909, **30**, 635.
[9] Sondheimer and Rosenthal, *J. Amer. Chem. Soc.*, 1958, **80**, 3999.
[10] Russell, *J.*, 1954, 1771.
[11] Cf. Bream, Eaton, and Henbest, *J.*, 1957, 1974.

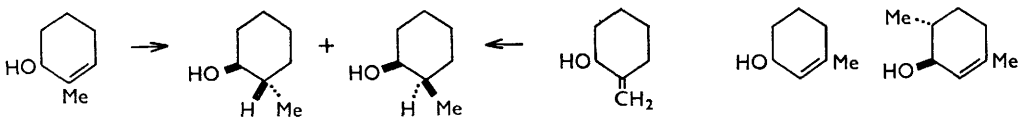
replacing the hydrogen on $C_{(1)}$. The *cis*- and *trans*-saturated alcohols were obtained in the same yields as before; their infrared absorptions showed one atom of deuterium in each isomer, and hydrogen apparently adds directly to the exocyclic double bond in the starting material.

Other cyclohex-2-enols were hydrogenated (at platinum) in ethanol containing sodium nitrite, good yields of saturated alcohols usually being obtained. No directing effect by



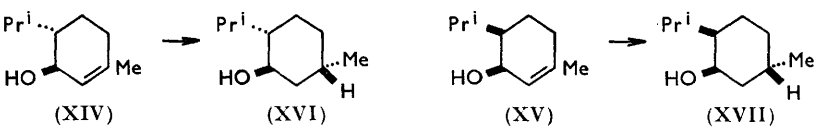
(IV) (V) (VI) (VII)

the hydroxyl group was apparent in the hydrogenation of 2-methylcyclohex-2-enol (VIII) or 2-methylenecyclohexanol (IX), equal parts of *trans*- and *cis*-2-methylcyclohexanol (X and XI) being obtained. Approximately equal amounts of the respective *trans*- and *cis*-isomers were also obtained on hydrogenations of 3-methylcyclohex-2-enol (XII) and (±)-3,6α-dimethylcyclohex-2-en-1β-ol (XIII).



(VIII) (X) (XI) (IX) (XII) (XIII)

In contrast, hydrogenations of racemic *trans*- (XIV) and *cis*-piperitol (XV) gave good yields (>80%) of the products (XVI and XVII) formed by addition of hydrogen *cis* to the allylic hydroxyl groups. [Macbeth and Shannon [12] obtained these alcohols in lower yields (50% and 30% respectively) on hydrogenation of the piperitols at Raney nickel.] Thus, the replacement of methyl in (XIII) by isopropyl (⟶ XIV) increases the proportion of attack *cis* to hydroxyl or *trans* to the alkyl group; the steric effect of the isopropyl group is probably the more important factor. The hydroxyl group in *cis*-piperitol (XV) is probably quasi-axial and effective in promoting *cis*-additions despite the presence of a *cis*-isopropyl group. In cyclohexenols (I, IV, VIII, IX, XII, XIII) giving less specific addition, the hydroxyl group is more likely to be in an equatorial or quasi-equatorial conformation.

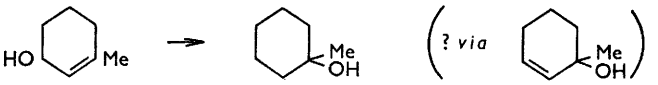


(XIV) (XVI) (XV) (XVII)

Rearrangement of a Hydroxyl Group during Hydrogenation.—As Adams platinic oxide contains sodium salts, the experiment was tried of removing these with acetic acid. The catalyst was dried under reduced pressure and then used for the hydrogenation of 3-methylcyclohex-2-enol (XII). The product contained about 10% of the tertiary alcohol, 1-methylcyclohexanol (XVIII), detected by gas chromatography and isolated as its *p*-nitrobenzoate. A similar result was obtained by hydrogenating the allylic alcohol (VIII) with unwashed catalyst in ethanol containing pivalic acid. The formation of the alcohol (XVIII) may be explained by postulating that the allylic alcohol (XII) partially undergoes an acid-catalysed anionotropic rearrangement to the isomer (XIX) that contains a *cis*-disubstituted,

[12] Macbeth and Shannon, *J.*, 1952, 2852; 1953, 901.

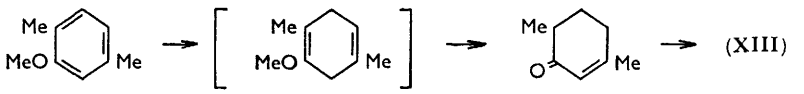
easily hydrogenated double bond. The starting alcohol (XII) was recovered unchanged after treatment with an ethanol solution of pivalic acid; it appears therefore that the presence of the catalyst and hydrogen is necessary for, or promotes, the rearrangement.



(XII) (XVIII) (XIX)

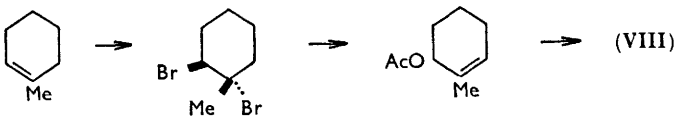
The reaction is restricted in scope, for no tertiary alcohol could be detected when either the homologue (XIII) or the acyclic compound, $Me_2C{=}CH{\cdot}CH_2{\cdot}OH$, was hydrogenated in ethanol containing pivalic acid.

Starting Materials.—The dimethylcyclohexenol (XIII) was prepared from 2,5-dimethylanisole. This was reduced with lithium in ammonia to a dihydro-compound (not



(XX) (XXI)

isolated), that gave a conjugated ketone on acid-hydrolysis. This ketone is assigned the structure (XXI), being derived from the most highly substituted [13] dihydro-compound (*i.e.*, XX) and showing light absorption much closer to the values for 3-methylcyclohex-2-enone than for 2-methylcyclohex-2-enone. Reduction of the ketone (XXI) gave an alcohol formulated as the quasi-equatorial compound (XIII), in line with the general steric course of reduction of relatively unhindered carbonyl groups in six-membered rings.



2-Methylcyclohex-2-enol (VIII) was prepared from 1-methylcyclohexene by addition of bromine, followed by reaction with sodium acetate in acetic acid and hydrolysis.

Experimental

M. p.s were determined on a Kofler block. Alumina (P. Spence, Grade H) was deactivated with acetic acid.[14] Light petroleum refers to the fraction of b. p. 60—80°.

Preparation of Catalysts.—Hexachloroplatinic acid (2 g.) and sodium nitrate (see Table) were dissolved in the minimum amount of distilled water, evaporated, and then melted. The stirred melt was kept at a constant temperature for an appropriate time (below). Cooling and extraction with distilled water gave the dioxide, which was washed repeatedly on a glass filter with water (1 l.) and then dried *in vacuo* over phosphorus pentoxide at 20°.

Temp.	420°	400°	300°
Time (hr.)	1	1·5	3

In expt. 8 (Table) the dioxide was washed further with water (2 l.).

Cholest-4-en-3β-ol (I).—This compound was hydrogenated in the presence of various catalysts and additives. The general procedure was to shake a solution of the steroid (0·542 g.) and catalyst (50 mg.) in " AnalaR " ethanol (50 c.c.) in hydrogen at 20°. An average time for

[13] Cf. Birch, *Quart. Rev.*, 1950, **4**, 69.
[14] Farrar, Hamlet, Henbest, and Jones, *J.*, 1952, 2657.

uptake of hydrogen to cease was 30 min.; starting material was nevertheless still present in many experiments. Filtration and evaporation gave material that was dissolved in benzene (20 c.c.) and re-evaporated to remove traces of ethanol that would affect the subsequent chromatographic separation. The product, in the minimum amount of light petroleum, was introduced on to deactivated alumina (50 g.). Elution with light petroleum gave hydrocarbon. Elution with benzene (500 c.c.) gave coprostanol (II), m. p. and mixed m. p. 101—102°, $[\alpha]_D$ +28°. Further elution with benzene (1 l.) gave cholestanol (III), usually containing some cholest-4-en-3β-ol. This mixture was dissolved in ethanol (5 c.c.); concentrated hydrochloric acid (0·05 c.c.) was added and the solution heated under reflux for 30 min. The product was isolated with benzene as before and chromatographed on alumina (20 g.). Elution with light petroleum (50 c.c.) gave cholesta-3,5-diene, m. p. and mixed m. p. 79—81°. Elution with ether–benzene (1 : 10) gave cholestanol, m. p. and mixed m. p. 140—142°.

The yields of products are given in the above Table.

Cholest-4-ene.—A solution of the olefin (0·2 g.) in ethanol (50 c.c.) containing sodium nitrite (0·3 mg.) was shaken with hydrogen for 20 hr. Filtration and evaporation gave material ($[\alpha]_D$ +25°) that was dissolved in pyridine (5 c.c.) and treated with osmium tetroxide (20 mg.) (to remove traces of unchanged olefin) in ether (20 c.c.), the mixture then being kept overnight. Solvent was removed under reduced pressure and the residue was dissolved in ether containing lithium aluminium hydride (50 mg.). After an hour the product was isolated in the usual way. Filtration of a solution of the product in light petroleum through alumina gave the saturated hydrocarbon mixture (0·192 g.). Analysis by infrared absorption indicated that the mixture contained cholestane (45%) and coprostane (55%); characteristic bands at 900 and 1070 $cm.^{-1}$ respectively were used for this analysis.

3β-*Methoxycholest-4-ene.*—This compound (0·5 g.) was hydrogenated in the presence of sodium nitrite (0·5 mg.) and catalyst (50 mg.). Absorption ceased after 30 min., whereafter the product was isolated and chromatographed on alumina (50 g.). Elution with light petroleum (50 c.c.) gave hydrocarbon (0·18 g.). Further elution with light petroleum (250 c.c.) gave material (0·32 g.), m. p. 79—83°, that on crystallisation from acetone gave 3β-methoxycholestane, m. p. and mixed m. p. 82—83°.

2-*Benzylidenecyclohexanol* (IV).—This (0·94 g.) in ethanol (6 c.c.) was hydrogenated in the presence of catalyst (60 mg., containing sodium salts from its method of preparation). The product isolated in the usual way was chromatographed on alumina (100 g.). Elution with light petroleum–benzene (4 : 1; 1 l.) gave benzylcyclohexane (VII) (0·24 g.). Elution with ether–benzene (1 : 5; 1 l.) gave *cis*-2-benzylcyclohexanol (V) (0·36 g.) as an oil [3,5-dinitrobenzoate, m. p. 125—126° (lit.,[10] m. p. 129°)]. Elution with ether–benzene (1 : 2; 1·5 l.) afforded *trans*-2-benzylcyclohexanol (VI) (0·33 g.), m. p. 76—77° (lit.,[10] m. p. 77°).

Similar hydrogenation of 2-benzylidene-1-deuterocyclohexanol (0·78 g.) yielded 2-benzylcyclohexane (0·22 g.), (±)-2β- (0·27 g.) (band at 2140 $cm.^{-1}$ in CCl_4) (3,5-dinitrobenzoate, m. p. 127°) and (±)-2α-benzyl-1α-deuterocyclohexan-1β-ol (0·275 g.), m. p. 75—77° (band at 2130 $cm.^{-1}$ in CCl_4). The intensities of the C–D bands in the two products were almost identical with that of the starting allylic alcohol.

The deuterated allylic alcohol was made by treating 2-benzylidenecyclohexanone (1·4 g.) in dry ether (20 c.c.) with lithium aluminium deuteride (88 mg.) in ether (20 c.c.), the mixture being stirred at 20° overnight. The product was isolated with ether and crystallised from pentane to give 2-benzylidene-1-deuterocyclohexanol (1·3 g.), m. p. 60—61° (band in CCl_4 at 2140 $cm.^{-1}$). 2-Benzylidenecyclohexanol (IV) (m. p. 60—61°), prepared similarly by using lithium aluminium hydride, did not give a band near 2140 $cm.^{-1}$.

3-*Methylcyclohex-2-enol* (XII).—A solution of this compound (1·2 g.) in ethanol (7 c.c.) containing sodium nitrite (0·3 mg.) was shaken with hydrogen and catalyst (50 mg.) until absorption ceased. The mixture was filtered, an excess of benzene was added to the filtrate, and ethanol was removed by azeotropic distillation. The solution of methylcyclohexanols in benzene was heated with 1-naphthyl isocyanate (1·8 g.) and triethylamine (0·1 g.) under reflux for 2 hr. Filtration and evaporation under reduced pressure gave material (1·82 g.) that was chromatographed on deactivated alumina (200 g.). Elution with light petroleum–benzene (1 : 4; 2·5 l.) gave *cis*-3-methylcyclohexanol 1-naphthylurethane (0·82 g.), m. p. 125—129° (m. p. 129—130°, after crystallisation from light petroleum) (lit.,[15] m. p. 130°). Further elution with the same mixture (3 l.) yielded *trans*-3-methylcyclohexanol 1-naphthylurethane

[15] Macbeth and Mills, *J.*, 1945, 709.

(0·832 g.), m. p. 96—114° (m. p. 117—118° after crystallisation from light petroleum) (lit.,[15] m. p. 118°).

2-*Methylcyclohex-2-enol* (VIII).—This compound (0·5 g.) in ethanol (4 c.c.) containing sodium nitrite (0·3 mg.) was shaken with hydrogen and catalyst (25 mg.). The product was isolated with ether and treated with 1-naphthyl isocyanate (0·75 g.) as in the previous experiment, and chromatographed on deactivated alumina (150 g.). Elution with light petroleum–benzene (2 : 1; 1200 c.c.) gave *trans*-2-methylcyclohexanol (X) 1-naphthylurethane (0·37 g.), m. p. 150—156° (m. p. 156—157° after crystallisation from light petroleum) (lit.,[15] m. p. 156°). Further elution with the same mixture (3·5 l.) gave the *cis*-1-naphthylurethane (cf. XI) (0·372 g.), m. p. 108—112° (m. p. 113° after crystallisation from light petroleum) (lit.,[15] m. p. 112°).

2-*Methylenecyclohexanol* (IX).—This (0·7 g.) was hydrogenated and then esterified as in the preceding experiments, to give the 1-naphthylurethanes of *trans*- (0·77 g.) and *cis*-2-methylcyclohexanol (0·815 g.).

(±)-3,6α-*Dimethylcyclohex-2-en*-1β-*ol* (XIII).—This compound (0·423 g.) in ethanol (3 c.c.) was hydrogenated in the presence of sodium nitrite (0·3 mg.) and catalyst (21 mg.). Isolation as above gave material that was esterified with phenyl isocyanate (0·45 g.) in boiling light petroleum (b. p. 80—100°; 25 c.c.) containing triethylamine (0·1 c.c.). The phenylurethane mixture was chromatographed on deactivated alumina (100 g.). Elution with light petroleum–benzene (3 : 1; 1 l.) gave (±)-2α,5α-dimethylcyclohexan-1β-ol phenylurethane (0·412 g.), m. p. 110—115° (m. p. 116° * after crystallisation from light petroleum). Further elution with the same mixture (1·5 l.) gave (±)-2α,5β-*dimethylcyclohexan*-1β-*ol phenylurethane* (0·415 g.), m. p. 60—65° (m. p. 65—66° after crystallisation from light petroleum) (Found: C, 73·2; H, 8·5. $C_{15}H_{21}O_2N$ requires C, 72·9; H, 8·6%). The order of elution should be the same as that for the urethanes of *cis*- and *trans*-3-methylcyclohexanol, the axial urethane being eluted first.

(±)-5α-*Isopropyl*-3-*methylcyclohex*-2-*en*-1β-*ol* (trans-*Piperitol*) (XIV).—This compound (0·501 g.) in ethanol (4 c.c.) was hydrogenated with sodium nitrite (0·6 mg.) and catalyst (10 mg.). The menthol mixture was isolated and chromatographed on deactivated alumina (50 g.). Elution with ether–light petroleum (1 : 200; 1·6 l.) gave (±)-5α-isopropyl-3α-methylcyclohexan-1β-ol (XVI) (isomenthol) (0·451 g.), m. p. and mixed m. p. 50—53°.

(±)-5β-*Isopropyl*-3-*methylcyclohex*-2-*en*-1β-*ol* (cis-*Piperitol*) (XV).—Hydrogenation of this (0·5 g.), as in the preceding experiment, gave (±)-5β-isopropyl-3α-methylcyclohexan-1β-ol (XVII) (neomenthol) (0·42 g.) (phenylurethane, m. p. and mixed m. p. 110—112°).

1-*Methylcyclohexanol* (XVIII) *from* 3-*Methylcyclohex*-2-*enol* (XII).—The latter compound (1·18 g.) in ethanol (7 c.c.) was hydrogenated in the presence of commercial Adams catalyst (50 mg.) that had been kept overnight in 10% acetic acid and then washed thoroughly with water and dried *in vacuo*. Ethanol was removed azeotropically with benzene as before. The product in benzene was treated with dry pyridine (10 c.c.) and pure *p*-nitrobenzoyl chloride (2 g.), and the mixture was kept at 20° overnight. A part (1·6 g.) of the *p*-nitrobenzoate mixture was chromatographed on deactivated alumina (150 g.). Elution with light petroleum (300 c.c.) gave 1-*methylcyclohexyl* p-*nitrobenzoate* (0·159 g., 6%), m. p. and mixed m. p. 111—112° (from methanol) (Found: C, 64·2; H, 6·4. $C_{14}H_{17}NO_4$ requires C, 63·85; H, 6·5%) (the authentic sample was made by esterifying 1-methylcyclohexanol). Elution with light petroleum–benzene (10 : 1) gave a gum (1·2 g.).

3-Methylcyclohex-2-enol (0·306 g.) in ethanol (1 c.c.) containing pivalic acid (60 mg.) was hydrogenated over commercial Adams catalyst (7 mg.). Analysis of a sample of the total product by vapour-phase chromatography (stationary phase of dinonyl phthalate at 116°) showed that it contained 1-methylcyclohexanol (*ca.* 10%).

Starting Materials.—2-Methylenecyclohexanol (IX) was prepared by the method of Dreiding and Hartmann,[17] and 3-methylcyclohex-2-enol (XII) by the method of Bowman, Ketterer, and Dinga.[18]

2-*Methylcyclohex*-2-*enol* (VIII). Bromine (33 g.) was added dropwise to a stirred solution of 1-methylcyclohexene (20 g.) in ether (100 c.c.). Removal of solvent under reduced pressure

* A phenylurethane, m. p. 116—117°, has been obtained [16] from the hydrogenation product of 2,5-dimethylphenol. The authors tentatively assigned the (±)-2α,5β-dimethylcyclohexan-1β-ol structure to their product.

[16] Ungnade and McLaren, *J. Amer. Chem. Soc.*, 1944, **66**, 118.
[17] Dreiding and Hartmann, *J. Amer. Chem. Soc.*, 1953, **75**, 939.
[18] Bowman, Ketterer, and Dinga, *J. Org. Chem.*, 1952, **17**, 563.

gave the crude dibromo-compound which was then heated in acetic acid (150 c.c.) and acetic anhydride (30 c.c.) containing sodium acetate (50 g.) at 100° for 24 hr. Isolation with ether gave 2-methylcyclohex-2-enyl acetate (20 g.), b. p. 100°/30 mm., n_D^{23} 1·4606 (lit.,[19] b. p. 84°/25 mm., n_D^{23} 1·4645). A solution of the acetate (20 g.) in ethanol (50 c.c.) and water (500 c.c.) containing potassium hydroxide (10 g.) was heated under reflux for 1·5 hr. Isolation with ether gave 2-methylcyclohex-2-enol (16 g.), b. p. 79°/17 mm., n_D^{22} 1·4848 (lit.,[19] b. p. 80°/18 mm., n_D^{20} 1·4855).

3,6-*Dimethylcyclohex-2-enone* (XXI). Finely cut lithium (6 g.) was added during 10 min. to a stirred solution of 2,5-dimethylanisole (15 g.) in dry ammonia (200 c.c.) and dry ether (50 c.c.). The mixture was stirred for 10 min. and dry ethanol (45 g.) was then added with stirring during 45 min. When the blue colour had gone, the product was isolated with ether. It was immediately hydrolysed by refluxing with 10% sulphuric acid for 4 hr. Isolation with ether gave the ketone (XXI) (10 g.), b. p. 80°/10 mm., n_D^{21} 1·4845 (C=O band at 1670 cm.$^{-1}$). Its ultraviolet absorption (in EtOH) ($\lambda_{max.}$ 2330 Å; ε 15,100) was similar to that of 3-methylcyclohex-2-enone ($\lambda_{max.}$ 2340 Å; ε 15,150) but different from that of 2-methylcyclohex-2-enone ($\lambda_{max.}$ 2350 Å; ε 10,600).

Its 2,4-*dinitrophenylhydrazone* was obtained as a mixture (m. p. 130—150°) of two forms, probably geometrical isomers. Chromatography on bentonite–kieselguhr (elution with benzene) gave an *isomer*, m. p. 171—172° (vermilion plates from ethanol) (Found: C, 55·1; H, 5·35. $C_{14}H_{16}N_4O_4$ requires C, 55·2; H, 5·3%). Further elution with benzene gave the second *isomer*, m. p. 161—162° (vermilion needles from ethanol) (Found: C, 55·3; H, 5·4%). On being heated in ethanol solution containing 10% of concentrated hydrochloric acid, each was isomerised to a mixture of needles and plates, m. p. 132—145°, which could again be resolved into the two isomers by chromatography.

(±)-3,6α-*Dimethylcyclohex-2-en-1β-ol* (XIII). The foregoing ketone (9 g.) in dry ether (50 c.c.) was added to a stirred slurry of lithium aluminium hydride (1·8 g.) in ether (100 c.c.) and the mixture was stirred for 2 hr. at 20°. The product, isolated with ether, was dissolved in light petroleum (150 c.c.) containing dry pyridine (6·8 c.c.) and treated with a solution of 3,5-dinitrobenzoyl chloride (16 g.) in dry benzene (100 c.c.) below 30°. After being kept for 2·5 hr. at 20° the mixture was shaken successively with dilute sulphuric acid and aqueous 5% sodium hydroxide solution. The organic solution was dried ($MgSO_4$) and evaporated and the residue (19 g.) was crystallised from propan-2-ol, to give the pure *dinitrobenzoate* (9 g.), m. p. 112—114° (Found: C, 56·0; H, 5·2. $C_{15}H_{16}N_2O_6$ requires C, 56·25; H, 5·05%). Solutions of the pure ester (8 g.) in ether (100 c.c.) and potassium hydroxide (4 g.) in methanol (50 c.c.) were mixed and heated under reflux for 15 min. Potassium 3,5-dinitrobenzoate was filtered off, and the filtrate was evaporated to quarter-bulk. Isolation with ether gave 3,5α-*dimethylcyclohex-2-en-1β-ol* (XIII) (2·3 g.), b. p. 132°/15 mm., n_D^{22} 1·4723 [*phenylurethane*, m. p. 84—84·5° (Found: C, 73·2; H, 7·8. $C_{15}H_{19}NO_2$ requires C, 73·5; H, 7·8%)].

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[19] Urion, *Compt. rend.*, 1934, **199**, 363.