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Reactions of Cyclohexadienes. Part V.[1] A New Synthesis of 4-Substituted Cyclohexenones

By A. J. Birch and J. S. Hill

Addition of some 1-methoxycyclohexa-1,3-dienes to but-3-en-2-one or *trans*-pent-3-en-2-one occurs with the COMe adjacent to the OMe. The adducts are converted by acid initially into diketones with fission of a carbon–carbon bond; aldol ring-closure and dehydration may follow. Other methods of generating a carbonium ion result in similar fissions, and the processes represent new syntheses of 4-substituted cyclohexenones and some derivatives of bicyclo[3,3,1]nonane.

Recently [2] we reported an acid-catalysed rearrangement of the skeletons of adducts from quinones and 1-methoxycyclohexa-1,3-dienes; the present work extends the reaction to products from some non-quinonoid dienophiles, particularly but-3-en-2-one (II). Addition of (II) to 1-methoxycyclohexa-1,3-diene (I; R = H) occurs in one direction only to give (III; R = R′ = H, R″ = Me) in accord with other results and theory.[3] In a kinetically controlled process the COMe of (III; R = R′ = H, R″ = Me) should be found chiefly *endo* to the bridge containing the double bond,[4] although equilibration to the *exo*-isomer can occur. Experimentally, the presence of both forms could be inferred from p.m.r. spectroscopy, the dominant one (usually about 80%) being presumably *endo*. Base-catalysed equilibration resulted in an increase in the proportion of the minor component, so the nature of the product is at least partly kinetically controlled.

Reaction of (I; R = Me) with excess of refluxing but-3-en-2-one (b. p. 78°) or of *trans*-pent-3-en-2-one (b. p. 126°) gave, respectively, (III; R′ = H, R = R″ = Me) or (III; R = R′ = R″ = Me) in 80 and 7% yields based on diene. The yield in the latter case was raised to 20% by heating to 180° in a sealed tube. The deactivating effect, on the addition, of substituents in the dienophile is well known.[4] Addition of methyl

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[1] Part IV, A. J. Birch, J. M. Brown, and F. Stansfield, *J. Chem. Soc.*, 1964, 5343.

[2] A. J. Birch, D. N. Butler, and J. B. Siddall, *J. Chem. Soc.*, 1964, 2932.

[3] K. W. Bentley and J. C. Ball, *J. Org. Chem.*, 1958, **23**, 1720; J. S. Meak, P. H. Monroe, and C. J. Bouboulis, *ibid.*, 1963, **28**, 2572.

[4] J. G. Martin and R. K. Hill, *Chem. Rev.*, 1961, **61**, 537.

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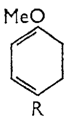
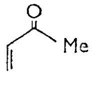
acrylate to (I; R = H) gave the expected ester (III; R = R′ = H, R″ = OMe) in 75% yield.



(I)



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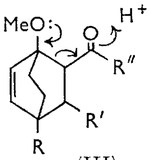

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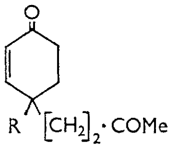


(IV)

The structures assigned to the adducts were supported by spectra: $\nu_{max.}$ (III; R = R′ = H, R″ = Me) 1705 (carbonyl), 1360 (COMe), 1115 (OMe), and 690 cm.$^{-1}$ (=CH); for p.m.r. spectra see Table 1. For (III; R = R′ = H, R″ = Me) the minor resonances of the pairs (Table 1) are attributed to the *exo*-form, the proportion of which (estimated from the relative intensities of the acetyl resonances at τ 7·88, 7·77) was raised from about 20 to 40% of the total mixture by equilibration. Hydrogenation of the double bond in (III; R = R′ = H, R″ = Me), which removes the isomerism, gave a product with undivided resonances at τ 6·83 and 7·80. The other adducts are also steric mixtures (Table 1), the OMe and COMe resonances of the *exo*-isomers being assigned the lower τ-values as for (III; R = R′ = H, R″ = Me). On this basis the *exo*-isomer of (III; R = R′, R″ = Me) predominates, presumably because loss of kinetic control under the more vigorous conditions of formation permits production of what is in this case the more stable isomer. Absorptions at $\nu_{max.}$ *ca.* 1100 cm.$^{-1}$ (C–OMe stretching) and *ca.* 690 cm.$^{-1}$ (olefin C–H bending) are common to all the adducts, and their disappearance was found useful in following the acid-catalysed rearrangements below.

TABLE 1

P.m.r. spectra of Diels–Alder adducts

Adduct	OMe	COMe	CO_2Me	CHMe	CMe	%
(III; R = R′ = H, R″ = Me)	6·64	7·77				20
($CDCl_3$)	6·67	7·88				80
(III; R = R″ = Me, R′ = H)	6·57	7·72			8·82	15
($CDCl_3$)	6·60	7·82			8·78	85
(III; R = R′ = H, R″ = OMe)	6·67		6·35			20
(CCl_4)	6·70		6·44			80
(III; R = R′ = R″ = Me)	6·70	7·88		9·00, 9·11	*	30
($CDCl_3$)	6·64	7·77		9·23, 9·35	8·93	70

* The sample was of insufficient purity for determination of this value.

As previously noted,[2] the structural requirements for acid-catalysed ring-opening (III ⟶ IV) is a bridgehead methoxyl β to a carbonyl. This type of reaction has already been observed with some thebaine adducts and with the adducts of acrylic acid with 9-methoxyanthracene.[3] In the last case, rearrangement occurs only under drastic conditions owing to the low basicity of the carbonyl group.

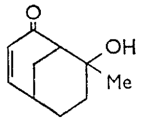
The expected product from both stereoisomers of (III; R = R′ = H, R″ = Me) was (IV; R = H). In trial reactions, development of the αβ-unsaturated ketone chromophore was followed by ultraviolet spectroscopy. A peak at 226 mμ reached ε 7700 after several hours on treatment of (III; R = R′ = H, R″ = Me) with 0·01N-ethanolic hydrochloric acid at spectroscopic dilution. On a preparative scale, rearrangements were effected with perchloric acid in acetic acid. Treatment of (III; R = R′ = H, R″ = Me) and (III; R = R″ = Me, R′ = H) with a 2·5% solution of perchloric acid (60% aqueous) in acetic acid gave 75% yields of the corresponding diketones (IV; R = H) and (IV; R = Me) whose structures were supported by their p.m.r. spectra (Table 2).

Rearrangement of (III; R = R′ = H, R″ = Me) during 5 hr. with 7·5% perchloric–acetic acid, followed by chromatography of the product on acid alumina, gave non-crystalline material (40%) consisting mainly of (IV; R = H) together with two unsaturated hydroxyketones. The first eluted, $C_{10}H_{14}O_2$ (16%), had m. p. 89—92°, $\nu_{max.}$ 3300, 1665 cm.$^{-1}$. The structure (V; R = H) resulting from aldol ring closure of (IV; R = H) is consistent with the p.m.r. spectrum: τ 8·80 (Me); τ 3·91 (doublet), τ 2·8—3·2 (multiplet) (olefinic protons). A second compound, $C_{10}H_{14}O_2$ (6%), m. p. 111—113°, $\nu_{max.}$ 3350, 1660 cm.$^{-1}$, was apparently a stereoisomer of the material of m. p. 89—92°. The possible stereoisomers of (V; R = H) are (VI; R = H) and (VII; R = H). Models indicate the possibility of effective intramolecular hydrogen-bonding between hydroxyl and carbonyl in the former but not in the latter. The isomer of m. p. 89—92°, probably (VI; R = H), has a broad ultraviolet absorption at $\lambda_{max.}$ 220 mμ compared with a sharper band at 228 mμ in the isomer of m. p. 111—113°; the latter is also more strongly adsorbed on alumina and is considered to be the initial product of ring closure (VIII; R = H).

TABLE 2

P.m.r. (τ) assignments of diketones (IV) in carbon tetrachloride solution

(IV; R = H)	(IV; R = Me)	H	Assignment
3·03(d)	3·31(d)	1	$CH_B{=}CH_ACO$ (J_{AB} = 10 c./sec.)
4·07(d)	4·19(d)	1	$CH_B{=}CH_ACO$
7·2—7·8(m)	7·3—7·8(m)	4	CH_2CO
7·86(s)	7·87(s)	3	CH_3CO
7·9—8·5(m)	7·9—8·4(m)	5, 4	CH_2CH_2CO
—	8·83(s)	3	Quaternary CH_3



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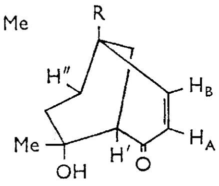

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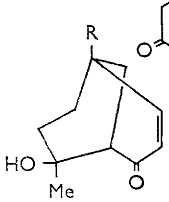

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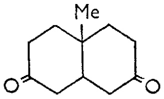

(VIII)

The adduct (III; R = R″ = Me, R′ = H), treated with 7·5% perchloric acid in acetic acid for 20 hr. followed by chromatography of the product, gave three ketones. Elution with benzene gave a saturated ketone, $C_{11}H_{16}O_2$ (10%), m. p. 87—89°, $\nu_{max.}$ 1710 cm.$^{-1}$, the p.m.r. spectrum of which showed one quaternary methyl

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resonance (τ 8·68) compatible with structure (VIII). The stereochemistry of the ring junction has not yet been determined. Benzene–ether afforded two unsaturated hydroxy-ketones, related to (VI; R = H) and (VII; R = H) by comparison of their ultraviolet spectra. The non-crystalline isomer (VI; R = Me) had a broad band $\lambda_{max.}$ 221 mμ [cf. (VI; R = H)] and was eluted first. The second isomer (VII; R = Me), $\lambda_{max.}$ 225 mμ, was crystalline, m. p. 96—98°. The p.m.r. spectra (Table 3) are in agreement with these structures.

TABLE 3

P.m.r. (τ) assignments of (VI; R = Me) and (VII; R = Me) in deuteriochloroform solution

(XI; R = H)	(XI; R = Me)	H	Assignment
3·42(d)	3·41(d)	1	$C\mathit{H}_B{=}CH_ACO$; J_{AB} = 10 (VI; R = Me)
4·02(d)	3·97(d)	1	$CH_B{=}C\mathit{H}_ACO$ and 9·5 c./sec. (VII; R = Me)
7·5—8·5(m)	7·5—8·5(m)	7	$C\mathit{H}_2C\mathit{H}_2$ and $C\mathit{H}_2C\mathit{H}$
8·82(s)	8·63(s)	3	$C(OH)C\mathit{H}_3$
8·87(s)	8·87(s)	3	$C{-}C\mathit{H}_3$

Although the course of the rearrangement of (III; R = R′ = H, R″ = Me) with ethanolic hydrochloric acid was experimentally difficult to reproduce, treatment of (III; R = R″ = Me, R′ = H) for 72 hr. with 0·1N-acid gave the non-crystalline hydroxy-ketone (VI; R = Me) in 50% yield. After some time in solution in light petroleum and isopropyl ether, a small proportion of crystalline material, m. p. 254—257°, was obtained, with an infrared spectrum similar to, but not identical with, that of the gum. A dimeric structure was indicated by the mass spectrum (*m*/*e* 360 compared with 180 for the gum), in accord with its low solubility in chloroform, acetone, and ethanol.

Under drastic conditions, such as refluxing in 5N-methanolic hydrochloric acid, the adduct (III; R = R″ = Me, R′ = H) was converted in 62% yield into the ring-closed and dehydrated product (IX). The ester (III; R = R′ = H, R″ = OMe) was not rearranged under any of the above conditions.

For some synthetic applications it would be advantageous to omit the carbonyl group in the side-chain. The bond-fission is dependent on an internal nucleophilic displacement initiated by protonation of the carbonyl, but other ways of generating the requisite carbonium ion should initiate similar processes. The alcohols (X; R = H) and (X; R = Me) were obtained from the adducts (III; R = R′ = H, R″ = Me) and (III; R = R″ = Me, R′ = H) by addition of methylmagnesium iodide. The isopentenylcyclohexenones (XI; R = H) and (XI; R = Me) were the expected products of acid-catalysed rearrangement. Treatment of (X; R = H) with 2·5% perchloric acid in acetic acid for 2 hr. gave a product having both saturated and unsaturated carbonyl bands in the infrared. The cyclohexenone (XI; R = H) was separable in 75% yield by chromatography. Increase of the reaction time to 4 days caused complete conversion into a saturated ketone, $C_{11}H_{18}O_2$, m. p. 70—72°. The presence of an ether linkage was indicated by physical measurements: $\nu_{max.}$ 1105, 1080, 1070, and 1055 cm.$^{-1}$ (C–O–C stretching); τ 6·25—6·75 (one proton multiplet); *m*/*e* = 182 (small) with intense *m*/*e* —15 peak (C–O–CMe). Furthermore, the p.m.r. spectrum showed two quaternary methyl resonances (τ 8·78 and 8·76) and no olefinic peaks. The tetrahydrochromanone (XII; R = H) resulting from addition of water to (XI; R = H) as indicated fits the above evidence. A similar situation was observed for (X; R = Me), and both (XI; R = Me) and (XII; R = Me) could be isolated in reasonable yields. The stereochemistry of the ketones (XII) has not yet been determined. The p.m.r. spectra of the cyclohexenones (XI) are outlined in Table 4.

Reduction of (III; R = R′ = H, R″ = Me) with sodium borohydride gave the alcohol (XIII) in which the presence of all possible stereoisomers is supported by two methoxyl resonances of approximately equal intensities at τ 6·68 and 6·60, presumably due to the two *endo*-alcohols (peaks due to the *exo*-isomers were not resolved). Conversion into the tosylate gave a gum which would not crystallise, although crystalline material was obtained in several cases after partial rearrangement (see Experimental section). An intense infrared band at 915 cm.$^{-1}$ was useful in following the rearrangement. Heating of the crude tosylate in ethanol or dimethyl sulphoxide produced partial rearrangement, although an elimination product, apparently (XV) from its p.m.r. spectrum, was the major product in the latter case. The ketonic fractions showed infrared bands due to an unsaturated ketone [presumably the expected product (XIV)] and a saturated ketone, possibly the βγ-unsaturated isomer of (XIV) or a bicyclic compound resulting from intramolecular cyclisation of (XIV) involving the two double bonds. Preliminary experiments show that hot acid converts the carbinols (X) or the ketones (XI) into saturated ketones as yet unidentified. More efficient rearrangement of the tosylate was effected by chromatography on silica gel which afforded an oil in 70% yield from the alcohol (XIII). This material had the spectral properties expected for (XIV) and gave a semicarbazone (*ca.* 70%), m. p. 130—132°, having the correct analysis of 4-(but-2-enyl)cyclohex-2-enone. Evidence that the configuration of the new double bond in (XIV) was at least partially *trans* came from the infrared spectrum, $\nu_{max.}$ 970 cm.$^{-1}$. The presence of appreciable amounts of impurity was apparent from the p.m.r. spectrum, and

TABLE 4

P.m.r. (τ) assignments of (XI; R = H) in carbon tetrachloride and (XI; R = Me) in deuteriochloroform solutions

(XI; R = H)	(XI; R = Me)	H	Assignment
3·17(d)	3·25(d)	1	$C\mathit{H}_B{=}CH_ACO$ (J_{AB} = 10 c./sec.)
4·10(d)	4·10(d)	1	$CH_B{=}C\mathit{H}_ACO$
4·6—5·0(t)	4·6—5·0(t)	1	$CH_2C\mathit{H}{=}C$
7·2—8·2(m)	7·4—8·2(m)	6	$C\mathit{H}C\mathit{H}_2C\mathit{H}_2CO$, $C\mathit{H}_2CH{=}C$
8·24(s)	8·25(s)	3	$CH{=}C(C\mathit{H}_3)_2$
8·35(s)	8·37(s)	3	
	8·87(s)	3	$C{-}C\mathit{H}_3$

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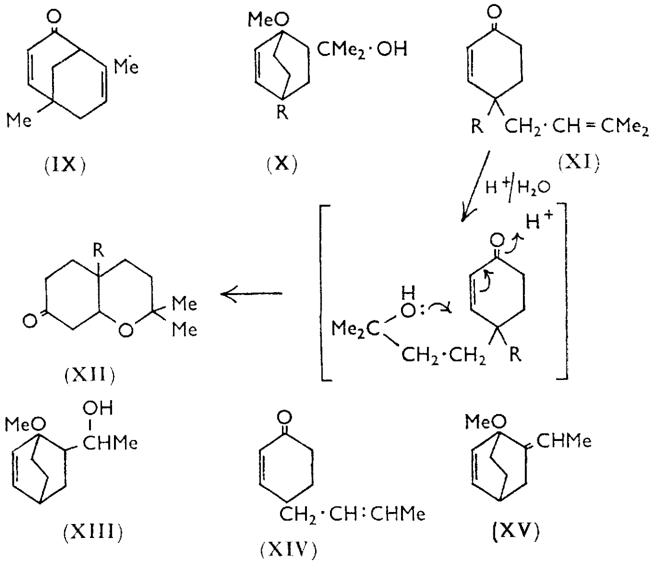

(IX) (X) (XI) (XII) (XIII) (XIV) (XV)

gas-liquid chromatography showed three major components constituting about 20, 10, and 70% of the total mixture in order of elution. Attempts to obtain pure (XIV) have so far been unsuccessful. Hydrogenation of the mixture gave a saturated ketone showing no olefinic peaks in its p.m.r. spectrum. Attempted isolation of 4-butylcyclohexanone as its semicarbazone (m. p. 175°) [5] gave only material of m. p. 145—165° after several recrystallisations.

The reactions described above represent new syntheses of 4-substituted cyclohexenones, including 4,4-disubstituted compounds. Some applications will be described elsewhere.

Proton Magnetic Resonance Spectra.—Some details of the p.m.r. spectra of certain compounds described above are worth noting. The olefinic protons of the ketone (IV; R = H) appeared as an AB quartet, each peak of the quartet having further small splittings (1—2 c./sec.). A similar situation was observed for the corresponding protons of (XI; R = H) and (XIV; R = H). This indicates very low coupling between these protons and the 4-hydrogen atom and can be explained in terms of the dihedral angle between the 3- and 4-hydrogens which is about 90° for conformations having the side-chain equatorial.

Long-range splitting was observed for the rigid structures (VI), (VII), and (IX). For (VI; R = Me), (VII; R = Me), and (IX) the olefinic protons of the αβ-unsaturated carbonyl functions appear as the expected AB quartets but show further small splitting (1—2 c./sec.). Models demonstrate that the pairs of protons H_A,H′ and H_B,H″ [structure (VI)] have the requisite " M " or " W " orientation described by Rassat *et al.*[6]

EXPERIMENTAL

Infrared spectra were determined for liquid films or Nujol mulls, ultraviolet spectra for ethanol solutions, and p.m.r. spectra for deuteriochloroform solutions (unless otherwise stated) with tetramethylsilane as an internal reference.

6-*Acetyl*-1-*methoxybicyclo*[2,2,2]*oct*-2-*ene*.—An equilibrated mixture of 1-methoxycyclohexa-1,4- and -1,3-diene (60% of the latter) (29·5 g.) and methyl vinyl ketone (36 g.) was refluxed for 20 hr. Excess of ketone was removed under reduced pressure and the residue poured into light petroleum (b. p. 60—80°) (200 ml.). The liquid was decanted from the precipitated polymeric material which was washed with more petroleum (4 × 50 ml.). Evaporation of the combined solutions and distillation of the residue gave the *product* (23·5 g.), b. p. 130—132°/27 mm., $\nu_{\text{max.}}$ 1705, 1115, and 690 cm.$^{-1}$ (Found: C, 72·4; H, 9·0; OMe, 17·2. $C_{11}H_{16}O_2$ requires C, 73·3; H, 8·95; OMe, 17·2%). The *semicarbazone* had m. p. 180—181° (from aqueous ethanol), $\lambda_{\text{max.}}$ 228 mμ (ε 15,400) (Found: N, 17·55. $C_{12}H_{19}N_3O_2$ requires N, 17·7%). Later experiments showed that the addition of a little Methylene Blue inhibits polymerisation of methyl vinyl ketone in these reactions.

To epimerise the adduct (500 mg.) it was refluxed for 2 hr. with a solution of sodium (200 mg.) in methanol (8 c.c.); the infrared spectrum was unchanged; the principal difference was an increase of the intensity of resonances at τ 7·77 and 6·64 relative to those at τ 7·98 and 6·67.

Hydrogenation of the adduct over palladium–charcoal in ethyl acetate occurred rapidly. The product, $\nu_{\text{max.}}$ 1705 and 1110 cm.$^{-1}$, τ 8·35, 7·80, and 6·83, gave rise to 2-*acetyl*-1-*methoxybicyclo*[2,2,2]*octane semicarbazone*, m. p. 172—176° (from aqueous ethanol) (Found: C, 60·3; H, 8·8; N, 17·4; OMe, 13·05. $C_{12}H_{21}N_3O_2$ requires C, 60·2; H, 8·8; N, 17·6; OMe, 13·0%).

5-*Acetyl*-4-*methoxy*-1-*methylbicyclo*[2,2,2]*oct*-2-*ene*. — A similar reaction between methyl vinyl ketone and 1-methoxy-4-methylcyclohexa-1,3-diene gave this *product*, b. p. 77—78°/1 mm., $\nu_{\text{max.}}$ 1705, 1100, and 685 cm.$^{-1}$ (Found: C, 74·0; H, 9·5; OMe, 15·6. $C_{12}H_{18}O_2$ requires C, 74·3; H, 9·5; OMe, 16·0%). The *semicarbazone* had m. p. 184—187° (from aqueous ethanol) (Found: C, 62·1; H, 8·35; N, 16·4; OMe, 12·35. $C_{13}H_{21}N_3O_2$ requires C, 62·1; H, 8·4; N, 16·7; OMe, 12·35%).

6-*Acetyl*-1-*methoxy*-4,5-*dimethylbicyclo*[2,2,2]*oct*-2-*ene*. — A mixture of 1-methoxy-4-methylcyclohexa-1,3-diene (1·5 g.) (65% 1,3-diene) and *trans*-pent-3-en-2-one (3 g.) in an evacuated sealed tube were heated in refluxing aniline (b. p. 180°) for 7 hr. Volatile material was removed at 100°/15 mm. and the residue chromatographed on O-alumina in light petroleum (b. p. 60—80°), followed by benzene–light petroleum (3 : 1), then ether–benzene (1 : 3) which eluted the adduct (380 mg.), $\nu_{\text{max.}}$ 1705, 1115, 1095, and 700 cm.$^{-1}$; *semicarbazone*, m. p. 174—176° (from aqueous ethanol) (Found: C, 63·5; H, 8·9; N, 15·7; OMe, 11·8. $C_{14}H_{23}N_3O_2$ requires C, 63·4; H, 8·7; N, 15·8; OMe, 11·7%).

Methyl 1-*Methoxybicyclo*[2,2,2]*oct*-5-*ene*-2-*carboxylate*.—1-Methoxycyclohexa-1,3-diene (2 g.) and methyl acrylate (4 g.) were refluxed for 20 hr., the volatile material was removed, and the residue applied to a silica-gel column in light petroleum (b. p. 60—80°). Final elution with benzene–ether (4 : 1) gave the *product* (1·66 g.), b. p. 148—150°/36 mm., $\nu_{\text{max.}}$ 1735, 1115, and 680 cm.$^{-1}$ (Found: C, 67·2; H, 8·1; OMe, 31·5. $C_{11}H_{16}O_3$ requires C, 67·3; H, 8·2; OMe, 31·6%). The *anilide* was obtained by reaction with anilinomagnesium iodide. This crystallised from aqueous

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[5] J. von Braun, *Annalen*, 1929, **472**, 1.

[6] A. Rassat, C. W. Jefford, J. M. Lehn, and B. Waegell, *Tetrahedron Letters*, 1964, 233.

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ethanol but had m. p. 120—131° and is probably a mixture of *endo*- and *exo*-isomers (Found: C, 74·6; H, 7·8; N, 5·6; OMe, 12·2. $C_{16}H_{19}NO_2$ requires C, 74·7; H, 7·4; N, 5·45; OMe, 12·1%).

Acid Rearrangement of (III; R = R′ = H, R″ = Me).—(*a*) The adduct (III; R = R′ = H, R″ = Me) (9 g.) in acetic acid (90 c.c.) containing perchloric acid (2·25 c.c.; 60% aq.) was left at room temperature for 30 min. Neutralisation with potassium hydrogen carbonate solution, ether extraction, and distillation of the extract gave 4-(3-oxobutyl)cyclohex-2-enone (6·4 g.) as a colourless oil, b. p. 134—136°/2·5 mm., $\nu_{\text{max.}}$ 1710, 1675 cm.$^{-1}$, $\lambda_{\text{max.}}$ 227 mμ (ε 9600) (see Table 2 for p.m.r. spectrum). The product contained some hydroxylic material which could not be removed by distillation. The *semicarbazone* had m. p. 210—211° (decomp.) (from aqueous ethanol) (Found: C, 51·3; H, 7·2; N, 30·0. $C_{12}H_{20}N_6O_2$ requires C, 51·4; H, 7·15; N, 30·0%).

(*b*) The adduct (III; R = R′ = H, R″ = Me) (1 g.) in acetic acid (10 c.c.) containing perchloric acid (0·75 c.c.; 60% aq.) was left at room temperature for 5 hr. Neutralisation with potassium hydrogen carbonate solution and ether extraction gave an oil (730 mg.) which was chromatographed on alumina deactivated with 3% of 10% aqueous acetic acid. After elution of oil (370 mg.) (consisting mainly of the above diketone) with benzene, benzene–ether (4 : 1) gave a solid (145 mg.). The 8-*hydroxy*-8-*methylbicyclo*[3,3,1]*non*-3-*en*-2-*one* (VI; R = H) had m. p. 89—92° (from benzene–light petroleum), $\nu_{\text{max.}}$ 3300 and 1665 cm.$^{-1}$, $\lambda_{\text{max.}}$ 220 mμ (ε 5650), τ 8·80 (s), 3·83 (d), and 2·8—3·2 (m) (Found: C, 71·95; H, 8·4. $C_{10}H_{14}O_2$ requires C, 72·3; H, 8·5%). Further elution with benzene–ether (1 : 1) gave the *isomer* (VII; R = H) (55 mg.), m. p. 111—113° (from benzene–light petroleum), $\nu_{\text{max.}}$ 3350, and 1660 cm.$^{-1}$, $\lambda_{\text{max.}}$ 227 mμ (ε 6650), *m*/*e* 166·0992 (calculated 166·0994) (Found: C, 72·0; H, 8·4%).

Acid Rearrangement of (III; R = R″ = Me, R′ = H).—(*a*) Conversion of the adduct (III; R = R″ = Me, R′ = H) into the diketone (IV; R = Me), $\nu_{\text{max.}}$ 1710, 1675, and 810 cm.$^{-1}$, $\lambda_{\text{max.}}$ 227 mμ (ε 9600) (p.m.r. spectrum in Table 2), was effected as for (IV; R = H). Once again the product contained hydroxyl absorption in the infrared spectrum and was not purified by distillation under reduced pressure. Treatment with a solution of 2,4-dinitrophenylhydrazine in 30% aqueous perchloric acid, chloroform extraction, and chromatography of the extract on bentonite–kieselguhr in chloroform gave the *bis*-2,4-*dinitrophenylhydrazone*, m. p. 195—196° (from ethanol–ethyl acetate) (Found: N, 20·8. $C_{23}H_{24}N_8O_8$ requires N, 20·5%).

(*b*) The adduct (III; R = R″ = Me, R′ = H) (1 g.) in acetic acid (10 c.c.) containing perchloric acid (0·75 c.c.; 60% aq.) was left for 20 hr. at room temperature. After neutralisation with potassium hydrogen carbonate solution, ether extraction gave an oil which was chromatographed on alumina deactivated with 3% of 10% aqueous acetic acid. Elution with benzene removed some oil (40 mg.) followed by crystalline material (96 mg.) considered to be a 10-*methyldecalin*-2,7-*dione*, m. p. 87—89°, $\nu_{\text{max.}}$ 1710 cm.$^{-1}$, τ 8·68 (Found: C, 73·5; H, 8·9. $C_{11}H_{16}O_2$ requires C, 73·3; H, 8·95%). After removal of more oil (80 mg.) with benzene, benzene–ether (1 : 1) gave a gum (230 mg.), $\nu_{\text{max.}}$ 3400 and 1665 cm.$^{-1}$, $\lambda_{\text{max.}}$ 221 mμ (ε 6200), *m*/*e* 180 (p.m.r. spectrum in Table 3), which was assigned structure (VI; R = Me). Further elution with ether gave 8-*hydroxy*-5,8-*dimethylbicyclo*[3,3,1]*non*-3-*en*-2-*one* (VII; R = Me) (133 mg.), m. p. 96—98° (from light petroleum), $\nu_{\text{max.}}$ 3300 and 1665 cm.$^{-1}$, $\lambda_{\text{max.}}$ 225 mμ (ε 7700) (p.m.r. spectrum in Table 3) (Found: C, 73·0; H, 8·85. $C_{11}H_{16}O_2$ requires C, 73·3; H, 8·95%).

(*c*) A solution of the adduct (III; R = R″ = Me, R′ = H) (2 g.) and 5N-hydrochloric acid (0·5 c.c.) in ethanol (20 c.c.) was left at room temperature for 72 hr. Neutralisation with dilute sodium hydroxide solution, dilution with water, and ether extraction gave an oil which was chromatographed on alumina deactivated with 3% of 10% aqueous acetic acid. Oil (650 mg.) was removed with petroleum–benzene before elution of a gum (1·3 g.), $\nu_{\text{max.}}$ 3400 and 1665 cm.$^{-1}$, with benzene–ether (4 : 1). This material was rechromatographed and eluted with benzene, separating into 400 mg. of material contaminated with a saturated ketone and 900 mg. of fairly pure hydroxy-ketone, identical with material having $\lambda_{\text{max.}}$ 221 mμ isolated in (*b*) above. The gum was dissolved in isopropyl ether–light petroleum, and the solvents were allowed to evaporate slowly at room temperature. After several weeks, solid material was separated from gum by washing with ether, chloroform, ethanol, benzene, and ethyl acetate, to give a dimer, m. p. *ca.* 300° (rapid heating), 254—257° (sealed tube), $\nu_{\text{max.}}$ 3450 and 1675 cm.$^{-1}$, τ (pyridine) 8·75 and 8·51 (methyl resonances), *m*/*e* 360. No ultraviolet maximum was observed, however, ε_{225} = 600 (Found: C, 72·4; H, 8·9. $C_{22}H_{32}O_4$ requires C, 73·3; H, 8·95%).

(*d*) A solution of the adduct (III; R = R″ = Me, R′ = H) (5 g.) in methanol (100 c.c.) and concentrated hydrochloric acid (100 c.c.) was refluxed for 2 hr. Dilution with water and ether extraction gave an oil which was filtered through alumina (50 g.) in benzene. The eluted material was distilled, to give 5,8-*dimethylbicyclo*[3,3,1]*nona*-3,7-*dien*-2-*one* (2·51 g.), b. p. 126—128°/26 mm., $\nu_{\text{max.}}$ 1680 cm.$^{-1}$, $\lambda_{\text{max.}}$ 232—233 mμ (ε 5500) (Found: C, 80·7; H, 8·6. $C_{11}H_{14}O$ requires C, 81·4; H, 8·8%). The 2,4-*dinitrophenylhydrazone* had m. p. 151—153° (from ethanol) (Found: C, 59·4; H, 5·3; N, 16·5. $C_{17}H_{18}N_4O_4$ requires C, 59·6; H, 5·3; N, 16·4%). The p.m.r. spectrum (CCl_4) had τ 8·80 (s) (3H; C–CH_3), 7·8—8·5 (m) [7H; $C\mathit{H}_2CHCO$, $C\mathit{H}_2CH{=}C$, and $C\mathit{H}_3C{=}C$ (*ca.* 8·35)], 7·32 (t) (1H; $CH_2C\mathit{H}CO$), 4·62 (m) (1H; $C\mathit{H}{=}CCH_3$), 4·26 (d) (1H; $CH_B{=}C\mathit{H}_ACO$), and 3·52 (d) ($C\mathit{H}_B{=}CH_ACO$) J_{BA} = 10·5 c./sec.

Reduction of (II; R = R′ = H, R″ = Me).—The adduct (III; R = R′ = H, R″ = Me) (14·3 g.) in methanol (200 c.c.) was treated for 12 hr. with sodium borohydride (4 g.) in aqueous N-sodium hydroxide (30 c.c.). Worked up as usual, the 6-(1-*hydroxyethyl*)-1-*methoxybicyclo*[2,2,2]-*oct*-2-*ene* (10·3 g.) had b. p. 140—142°/30 mm., $\nu_{\text{max.}}$ 3400, 1100 , and 690 cm.$^{-1}$ (Found: C, 72·3; H, 9·9; OMe, 17·0. $C_{11}H_{18}O_2$ requires C, 72·5; H, 9·95; OMe, 17·0%). The resonances at τ 6·68 and 6·60 (CCl_4) indicate the presence of epimeric carbinols.

Rearrangement of (XIII).—The above carbinol (4·7 g.) and toluene-*p*-sulphonyl chloride (10 g.) in pyridine (20 c.c.) were left overnight. After dilution with water, the ether extract was washed with *N*-hydrochloric acid and potassium hydrogen carbonate solution, and evaporated to give a gum (8·9 g.) from which crystalline material could be obtained only after partial rearrangement (see below).

(*a*) The crude tosylate (300 mg.) was applied to an alumina column (75 g.) in light petroleum. Some toluene-*p*-sulphonyl chloride was removed with petroleum–benzene (1 : 3) before elution of an oil (163 mg.), $\nu_{\text{max.}}$ 1680 and 915 cm.$^{-1}$, with benzene–ether (4 : 1). This material crystallised

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in part on standing, to give a *tosylate* (74 mg.), m. p. 83—85° (from light petroleum), $\nu_{max.}$ 1595, 1350, 1180, 1165, 1110, and 915 cm.$^{-1}$, $\lambda_{max.}$ 257, 262, 267, and 273 mμ (ε 420, 530, 485, and 425) (Found: C, 64·35; H, 6·9. $C_{18}H_{24}O_4S$ requires C, 64·3; H, 7·2%). The non-crystalline material was presumably the rearranged product (XV). Attempts to repeat this experiment have so far proved unsuccessful, giving only low recoveries of unchanged (non-crystalline) tosylate. Small quantities of crystalline material could be obtained from the crude tosylate by seeding with the crystalline material above.

(*b*) The initial crude tosylate (1·4 g.) was refluxed in ethanol (25 c.c.) containing lithium chloride dihydrate (2 g.) for 2 hr. Distillation of the product at 15 mm. gave an oil (300 mg.), $\nu_{max.}$ 1705, 1680 cm.$^{-1}$, presumably containing (XIV).

(*c*) Crude tosylate (6 g.) in dimethyl sulphoxide (100 c.c.) was heated at 100° for 4 hr. The crude product obtained on dilution and ether extraction was distilled at 15 mm. to give a colourless oil (2 g.), $\nu_{max.}$ 1705, 1680, and 1115 cm.$^{-1}$, with negligible ultraviolet absorption in the region of 225 mμ. The material (250 mg.) was extracted with Girard-T reagent, to give a ketonic fraction (60 mg.), $\nu_{max.}$ 1705, 1680, and 970 cm.$^{-1}$, $\lambda_{max.}$ 223 mμ (ε 3150), and an olefin which was further purified by chromatography on silica gel in benzene to give an oil (120 mg.), $\nu_{max.}$ 1610 (weak), 1110, and 690 cm.$^{-1}$, assigned structure (XV) on the basis of its p.m.r. spectrum: τ 8·3—8·6 (m) (7H; C*H*$_3$C=C, C*H*$_2$C*H*$_2$CH), 7·7—8·1 (m) (2H; C*H*$_2$CH=CHCH$_3$), 7·1—7·5 (m) (1H; CH=CHC*H*), 6·57 (s) (3H; OCH$_3$), 4·35—4·75 (m) (1H; C=C*H*CH$_3$), and 3·5—3·9 (m) (2H; C*H*=C*H*CH).

(*d*) The crude tosylate (4·5 g.) was applied to a column of silica gel (350 g.) in light petroleum. After washing with benzene–light petroleum (3 : 1), elution with benzene–ether (4 : 1) gave an oil which was distilled. The resulting colourless liquid (1·42 g.) had b. p. 72—76°/0·5 mm., $\nu_{max.}$ 1680 and 970 cm.$^{-1}$, τ (CCl$_4$) 4·3—4·6 (m) (CH$_2$C*H*=C*H*CH$_3$), 4·08 (d) (CH$_B$=C*H*$_A$CO), and 3·15 (d) (C*H*$_B$=CH$_A$CO). Absorption at τ *ca.* 9·0 showed the material to be impure; gas–liquid chromatography indicated three components constituting *ca.* 20, 10, and 70% of the total mixture in order of elution. The major component is presumably the expected 4-(but-2-enyl)cyclohex-2-enone. The mixture afforded a *semicarbazone*, m. p. 130—132° (from aqueous ethanol), in *ca.* 70% yield (Found: C, 63·6; H, 8·2; N, 20·5. $C_{11}H_{17}N_3O$ requires C, 63·7; H, 8·3; N, 20·3%).

Hydrogenation of the above mixture (Pd–C) gave an oil, $\nu_{max.}$ 1715 cm.$^{-1}$, showing no olefinic absorption in its p.m.r. spectrum. The expected methyl triplet of 4-n-butylcyclohexanone was superimposed on impurity peaks. The semicarbazone had m. p. 145—165° after several recrystallisations from aqueous ethanol.

(*e*) Treatment of the tosylate as in (*d*) but at an increased concentration on the column (4 g. on 100 g. of silica gel) generally caused partial rearrangement to a mixture of ketones ($\nu_{max.}$ 1710 and 1680 cm.$^{-1}$), and crystalline tosylate, m. p. 83—85°, could be obtained from the eluted oil on dilution with light petroleum. Rearrangement of this material as in (*d*) above may afford purer (XIV).

Rearrangement of (X; R = H) *and* (X; R = Me).—The adduct (III; R = R″ = Me, R′ = H) (8 g.) in ether (25 c.c.) was added to methylmagnesium iodide [from magnesium (2 g.) and methyl iodide (18 g.) in ether (50 c.c.)] and the mixture refluxed for 4 hr. Worked up by addition of aqueous ammonium chloride, the 5-(1-*hydroxy*-1-*methylethyl*)-1-*methyl*-4-*methoxybicyclo*[2,2,2]*oct*-2-*ene* (8 g.) had b. p. 86°/1 mm., $\nu_{max.}$ 3400, 1095, and 690 cm.$^{-1}$, τ 9·02, 8·88, 6·59, 4·15 (d), and 3·70 (d) (*J* = 8·5 c./sec.) (Found: C, 74·3; H, 10·55; OMe, 14·6. $C_{13}H_{22}O_2$ requires C, 74·2; H, 10·5; OMe, 14·8%).

Similarly, (III; R = R′ = H, R″ = Me) gave 6-(1-*hydroxy*-1-*methylethyl*)-1-*methoxybicyclo*[2,2,2]*oct*-2-*ene*, b. p. 80°/0·5 mm., $\nu_{max.}$ 3400, 1100, and 695 cm.$^{-1}$, τ (CCl$_4$) 9·14, 7·5—7·75 (C-4 bridgehead proton), 6·67, and 3·75—4·25 (Found: C, 73·4; H, 10·5. $C_{12}H_{20}O_2$ requires C, 73·4; H, 10·3%).

The carbinol (X; R = H) (2 g.) reacted with perchloric acid (0·5 c.c., 60% aq.) in acetic acid (20 c.c.) during 2 hr. Normal working-up gave an oil (1·67 g.), $\nu_{max.}$ 1715, 1680 cm.$^{-1}$. Chromatography on alumina in toluene allowed separation of fairly pure 4-(2-methylbut-2-enyl)cyclohex-2-enone (1·28 g.), b. p. 69—75°/1 mm., $\nu_{max.}$ 1680 cm.$^{-1}$, $\lambda_{max.}$ 223 mμ (ε 10,000) (p.m.r. spectrum in Table 4). The *semicarbazone* had m. p. 132—133° (from aqueous ethanol) (Found: C, 65·3; H, 8·75; N, 18·8. $C_{12}H_{19}N_3O$ requires, C, 65·1; H, 8·65; N, 19·0%).

Hydrogenation of the ketone (XI; R = H) over Pd–C (5%) in ethyl acetate gave an oil, $\nu_{max.}$ 1715 cm.$^{-1}$, τ (CCl$_4$) 9·09 (d), converted into 4-*isopentylcyclohexanone semicarbazone*, m. p. 169—171° (Found: C, 64·0; H, 10·3; N, 18·55. $C_{12}H_{23}N_3O$ requires C, 64·0; H, 10·3; N, 18·65%).

Rearrangement of (X; R = H) (15 g.) during 4 days in acetic acid (150 c.c.) containing perchloric acid (3·75 c.c., 60% aq.) caused complete conversion into a saturated ketone (9·4 g.) considered to be *tetrahydro*-2,2-*dimethylchroman*-7-*one*, b. p. 140—142°/20 mm., m. p. 70—72° (from light petroleum), $\nu_{max.}$ 1715, 1105, 1080, 1077, 1055, and 970 cm.$^{-1}$, τ 8·78 (s) and 8·76 (s) (quaternary methyls) and 6·25—6·75 (m) (1H; CH–O–C), *m*/*e* 182 (weak) with an intense *m*/*e* — 15 peak. The material appeared to be homogeneous by gas–liquid chromatography (Found: C, 72·5; H, 9·9. $C_{11}H_{18}O_2$ requires C, 72·5; H, 10·0%).

The carbinol (X; R = Me) (1·45 g.), rearranged as for (X; R = H) gave, after 2·5 hr. reaction time, a product free from saturated carbonyl absorption; 4-methyl-4-(2-methylbut-2-enyl)cyclohex-2-enone (900 mg.), b. p. 60—70°/0·25 mm., $\nu_{max.}$ 1680 and 805 cm.$^{-1}$, $\lambda_{max.}$ 223—224 mμ (ε 10,500) (p.m.r. spectrum in Table 4); *semicarbazone*, m. p. 120—122° (from aqueous ethanol) (Found: C, 66·5; H, 8·9; N, 17·9. $C_{13}H_{21}N_3O$ requires C, 66·3; H, 9·0; N, 17·5%).

After 4 days, (X; R = Me) (1·75 g.), treated as above, gave a saturated ketone (1·19 g.) probably *tetrahydro*-2,2,10-*trimethylchroman*-7-*one*, b. p. 150—152°/22 mm., $\nu_{max.}$ 1715, 1095, 1050, and 970 cm.$^{-1}$, τ 8·85 (s) (one methyl), 8·82 (s) (two methyls), and 6·51 (CH$_2$C*H*–O–C; badly defined triplet). Gas–liquid chromatography showed the presence of a trace of slightly less polar material which accounts for the poor analysis (Found: C, 73·8; H, 9·5. $C_{12}H_{20}O_2$ requires C, 73·4; H, 10·3 %). The *semicarbazone* had m. p. 189—191° (from aqueous ethanol) (Found: C, 61·75; H, 9·0; N, 16·4. $C_{13}H_{23}N_3O$ requires C, 61·6; H, 9·15; N, 16·6%).

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