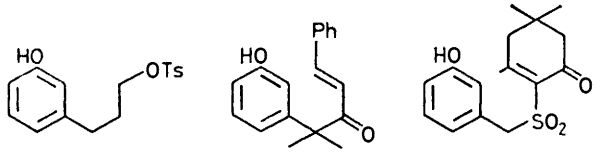
Intramolecular Alkylation of Phenols. Part 5.[1] A Regiospecific Anionic Ring Closure of Phenols *via* Quinone Methides [2]

By **William S. Murphy** * and **Sompong Wattanasin**, Department of Chemistry, University College, Cork, Ireland

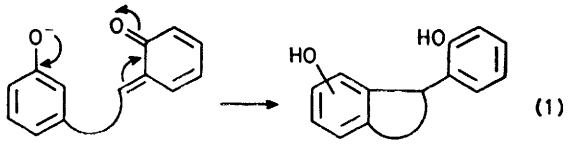
The bis-magnesium salts of the triols (6a) and (6h) cyclise when heated in benzene with high *ortho*-regiospecificity to the corresponding bis-phenols (7) and (8). The triols (6k) and (6o) under the same conditions cyclise with high *para*-regiospecificity to the corresponding bis-phenols (7) and (8). Both (6a) and (6h) cyclise *via* *o*-quinone methides, and (6k) and (6o) *via* *p*-quinone methides. Results from the use of, *inter alia*, 18-crown-6, indicate that the high *ortho*-regiospecificity of the cyclisation of (6a) and (6h) is due to intramolecular Mg(II) bridging of the intermediate *o*-quinone methides. The high *para*-regiospecificity of cyclisation of (6k) and (6o) is due to steric hindrance towards *o*-cyclisation of the intermediate *p*-quinone methides presented by the Mg(II) cation. The unexpected facility with which (6a) and (6k) undergo ring closure is discussed.

THE participation of an aromatic nucleus to form a fused ring system is an important tactic in organic synthesis. Many methods for cyclisation have been developed.[3] However, in most of these, cationic alkylation and acylation is involved with the consequence that problems of regioselectivity are often encountered.[4] The anionic counterpart, of interest to us, is limited for stereoelectronic reasons.[1] Thus the ring closure of the phenols (1)—(3), for example, was not observed under basic conditions.[1,3d]



(1) (2) (3)

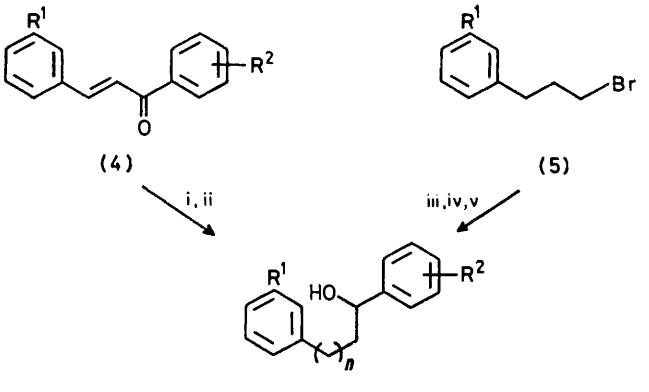
We now report a new anionic cyclisation of phenols with high regiospecific control. The reaction is an aryl–benzyl coupling and is based on the intramolecular interaction between the phenoxide and the *o*- (and *p*-) quinone methide groups [reaction (1)].



(1)

Quinone methides were chosen as likely substances for our cyclisation study because (*a*) the precursors are readily available,[5] (*b*) cyclisation could be expected, with aromatisation of the quinonoid ring coupled with high reactivity [6] as driving force, (*c*) the cyclisation would involve a permissible [1,7] 5 or 6-*Exo-Trig* mode, and (*d*) the possibility that intramolecular chelation [8] could lead to highly regiospecific cyclisations.

Synthesis of Starting Materials.—A number of alcohols were prepared as models for this study, as outlined (Scheme 1). The alcohols (6a—g, 6k—n) were prepared from the corresponding chalcones (4) as follows (Scheme 1). Hydrogenation of the chalcones over Adams catalyst in ethyl acetate gave the corresponding dihydrochalcones in high yield. Reduction of the ketones with lithium aluminium hydride in ether at room or reflux temperature gave the alcohols (6a—g, k—n) in good yield. The synthesis of the alcohols (6i, j, p, and q) was



	n	R¹	R²
a;	1	OH	*o*-OH
b;	1	OMe	*o*-OH
c;	1	OCH_2Ph	*o*-OH
d;	1	OH	*o*-OMe
e;	1	OMe	*o*-OMe
f;	1	H	*o*-OH
g;	1	OH	H
h;	2	OH	*o*-OH
i;	2	OCH_2Ph	*o*-OCH_2Ph
j;	2	OMe	*o*-OMe
k;	1	OH	*p*-OH
l;	1	OMe	*p*-OH
m;	1	OH	*p*-OMe
n;	1	OMe	*p*-OMe
o;	2	OH	*p*-OH
p;	2	OCH_2Ph	*p*-OCH_2Ph
q;	2	OMe	*p*-OMe

SCHEME 1 *Reagents:* i, H_2–Pt; ii, $LiAlH_4$–Et_2O; iii, Mg–Et_2O; iv, $R^2C_6H_4CHO$; v, H_2–Pd–C, NaOH

accomplished by reaction of the Grignard reagent derived from (5) with the corresponding benzaldehyde. Removal of the benzyl groups from the alcohols (6i and p) was effected by catalytic hydrogenation with Pd–C catalyst in the presence of sodium hydroxide, which inhibited oxygen hydrogenolysis.[9] The corresponding compound (7) was also invariably formed.[9]

RESULTS AND DISCUSSION

Cyclisation via o-*Quinone Methides*.—The bisphenoxymagnesium bromide [5] of the alcohol (6a) was heated under reflux in benzene for 20 h. The cyclised product, the bisphenol (7a), and the alkene (9a) were isolated in effect cyclisation. It had been reported [10] that replacement of the Mg(II) cation with alkali metals (K^+, Na^+, Li^+) prevented intermolecular reaction of phenols with ketals and aldehydes. The marked effect of Mg(II) is probably due to the greater chelating ability and Lewis-

Cyclisation and attempted cyclisation reactions

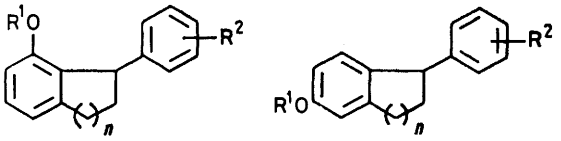
Entry	Starting material	Method	Solvent	Temperature (Time/h)	Product (yield, [%])	Ratio [a] *ortho* (7)	Ratio [a] *para* (8)
1	6a	2EtMgBr	PhH	reflux (20)	7a (71),[b] 9a (11) [b]	100	
2	6a	2EtMgBr, 18-crown-6 (Cat. amount)	PhH	reflux (20)	7a (21),[b] 9a (12),[b] 19 + 20 (25) [b]	100	
3	6a	2EtMgBr, 2 18-crown-6	PhH	reflux (20)	9a (66),[b] 19 + 20 (6) [b]		
4	6a	2NaH	PhH	reflux (20)	6a (75) [b]		
5	6a	2Bu^{n}Li	PhH	reflux (20)	6a (80) [b]		
6	6a	2NaH 2 18-crown-6	PhH	reflux (20)	6a (82),[b] 9a (<5) [b]		
7	6a	$SnCl_4$	CH_2Cl_2	ambient (1.5)	7a + 8a (72) [b]	5	95
8	6b	2EtMgBt	PhH	reflux (20)	6b (93) [c]		
9	6b	5EtMgBr	PhH	reflux (20)	6b (85) [b]		
10	6b	20EtMgBr	PhH	reflux (20)	6b (85) [b]		
11	6b	2EtMgBr ethyl vinyl ether	PhH	reflux (20)	6b (95) [c]		
12	6c	2EtMgBr	PhH	reflux (20)	6c (94) [c]		
13	6c	5EtMgBr	PhH	reflux (20)	6c (90) [c]		
14	6c	2EtMgBr ethyl vinyl ether	PhH	reflux (20)	6c (73) [c]		
15	6d	2EtMgBr	PhH	reflux (20)	6d (94) [c]		
16	6e	$SnCl_4$	CH_2Cl_2	ambient (1.5)	7b + 8b (76) [b]	10	90
17	6f	2EtMgBr, ethyl vinyl ether	PhH	reflux (20)	18 (55) [b]		
18	6g	2EtMgBr	PhH	reflux (20)	6g (96) [c]		
19	6h	2EtMgBr	PhH	reflux (20)	7c + 8c (90) [b]	12	88
20	6h	2EtMgBr, 2 18-crown-6	PhH	reflux (20)	7c + 8c (90) [b]	38	62
21	6j	$SnCl_4$	CH_2Cl_2	ambient (1.5)	7d + 8d (70) [b]	5	95
22	6k	2EtMgBr	PhH	reflux (20)	7e + 8e (43),[b] 9e (2) [b]	10	90
23	6k	2EtMgBr	PhH	reflux (20)	7e + 8e (31),[b] 9e (12) [b]	12	88
24	6k	2EtMgBr 2 18-crown-6	PhH	reflux (20)	6k (25),[b] 9e (46) [b]		
25	6k	2NaH, 2 18-crown-6	PhH	reflux (20)	6k (17),[d] 9e (70) [d]		
26	6k	2.6NaH	PhH	reflux (20)	6k (31),[d] 9e (61) [d]		
27	6k	2NaOMe	PhH	reflux (20)	6k (80)[b]		
28	6l	2EtMgBr	PhH	reflux (20)	9g (84) [b]		
29	6m	2EtMgBr	PhH	reflux (20)	6m (92) [d]		
30	6n	$SnCl_4$	CH_2Cl_2	ambient (1)	7f + 8f (71) [b]	15	85
31	6o	2EtMgBr	PhH	reflux (20)	7g + 8g (90) [b]	7	93
32	6o	2 EtMgBr, 2 18-crown-6	PhH	reflux (20)	7g + 8g (83) [b]	40	60
33	6q	$SnCl_4$	CH_2Cl_2	ambient (1.5)	7h + 8h (71) [b]	10	90
34	9a	2EtMgBr	PhH	reflux (20)	9a (90) [b]		

[a] Determined by g.l.c. of the purified dimethyl ethers using a 2 m column of 2½% CEMS on Chromosorb G programmed at 150—200 °C. [b] Isolated yield (preparative t.l.c.). [c] Crude product yield. [d] Determined from n.m.r. of the crude product.

71 and 11% yield respectively. The cyclised product was shown to be exclusively the *ortho*-isomer (7a) by comparison (n.m.r. and g.l.c.), after methylation to (7b), with an authentic sample prepared by $SnCl_4$-catalysed cyclisation of the alcohol (6e) where a mixture of (7b) and (8b) was formed in the ratio 1 : 9.

A mechanism involving attack of phenoxide on the *o*-quinone methide group (see Scheme 2) was supported by the following results. (*a*) No cyclisation occurred when either the alcohols (6b, c, d, f, or g) or the alkene (9a) were treated under the same conditions as for (6a). Unchanged starting materials only were recovered in each case. (*b*) Other bases, *e.g.* NaH or Bu^{n}Li, did not acid character of magnesium which permit the formation of the complex (10) and facilitate the reaction of it to the quinone methide complex (11) (Scheme 2). (*c*) Trapping experiments with ethyl vinyl ether [11] were effective. Attempts to trap an *o*-quinone methide (16) analogous to (11; $n = 1$) generated from the alcohols (6b) or (6c) (see Scheme 3) by means of an excess of ethylmagnesium bromide or ethyl vinyl ether were unsuccessful, mainly starting materials being recovered. In addition, the alcohol (6b), as noted above in paragraph (a) (Entry 8, Table), was recovered when subjected to standard conditions. We reasoned that the alkoxy-groups (OMe) in (6b) and (OCH_2Ph) in (6c) complexed

with magnesium to form a bridged intermediate (16, Scheme 3) analogous to (11; $n = 1$) and that this bridge sterically hindered cycloaddition to ethyl vinyl ether. Consistent with this is the finding that when the alcohol (6f) was heated under the same conditions with

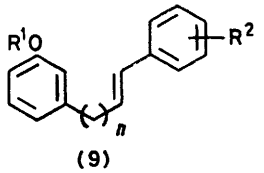


(7) (8)

	n	R^1	R^2
a;	1	H	*o*-OH
b;	1	Me	*o*-OMe
c;	2	H	*o*-OH
d;	2	Me	*o*-OMe
e;	1	H	*p*-OH
f;	1	Me	*p*-OMe
g;	2	H	*p*-OH
h;	2	Me	*p*-OMe

ethyl vinyl ether, the 2-ethoxychroman (18) was isolated (55%). No starting alcohol was detected (t.l.c.). The recovery of both (6b) and (6c) from a reaction performed under the same conditions as those in which (6f) forms a quinone methide, strongly indicates that the reaction (6) ⟶ (16) (Scheme 3) is reversible. It appears that Mg(II) bridging of the two aryl groups as in (11; $n = 1$) and (16) is a requirement for reversibility, since (6l) (see below and Scheme 3) under standard conditions is not recovered. Instead the alkene (9g) is formed. (*d*) Crown ether affected the reaction. Although the regiospecificity of the cyclisation did not change when the alcohol (6a) was treated under standard conditions in the presence of a catalytic amount of 18-crown-6, the yield decreased. Thus (7a) was isolated (21%) along with the alkene (9a, 12%) and the dimers provisionally assigned the structures (19) and (20) (25%).

The reaction of (6a) was then carried out in the presence of 2 mol of 18-crown-6 when the alkene (9a) was isolated (66%). No cyclisation products were formed. However, when the bis-sodium salt of (6a) was treated

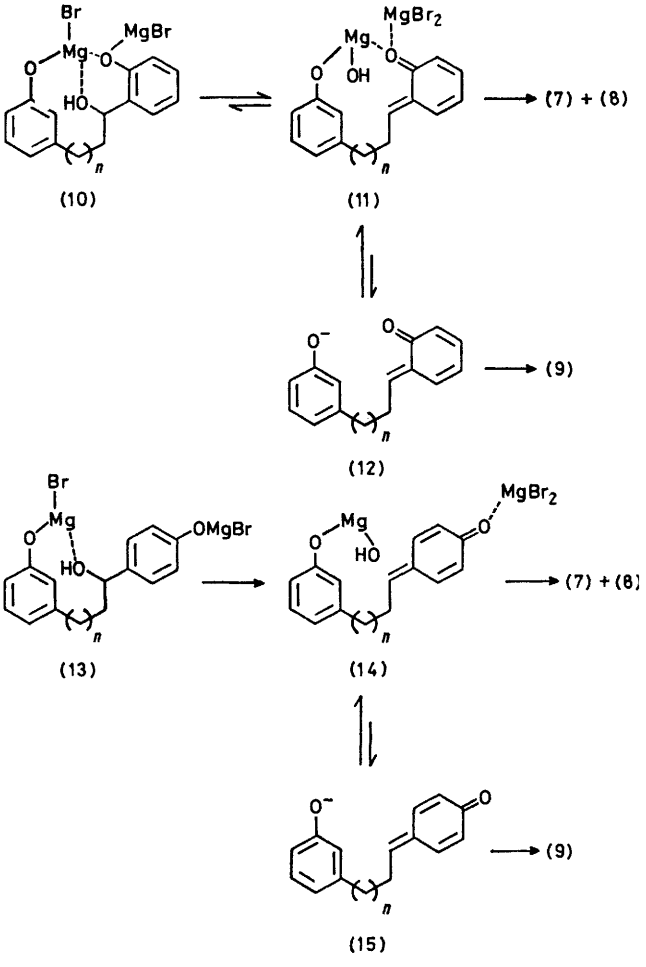


(9)

	n	R^1	R^2
a;	1	H	*o*-OH
b;	1	Me	*o*-OMe
c;	2	H	*o*-OH
d;	2	Me	*o*-OMe
e;	1	H	*p*-OH
f;	1	Me	*p*-OMe
g;	1	Me	*p*-OH

under the same conditions, in the presence of 18-crown-6 and in the absence of Mg(II), only trace quantities of (9a) were formed and the alcohol (6a) was recovered in high yield.

These results are consistent with the following scheme. Cyclisation of (6a) requires magnesium chelation of the intermediate *o*-quinone methide (11; $n = 1$) to increase both the nucleophilicity of the phenol and the electrophilicity of the *o*-quinone methide group. In addition, formation of this complex favours the entropy of cyclisation. Cyclisation will be inhibited by the crown ether because although the complex (10; $n = 1$) (Scheme 2) must be of at least comparable stability to the 18-crown-6-Mg(II) complex,[12] the reverse must be the case with the *o*-quinone methide complex (11; $n = 1$). This complex (11; $n = 1$) once formed dissociates to (12; $n = 1$) in the presence of the crown ether. Cyclisation of



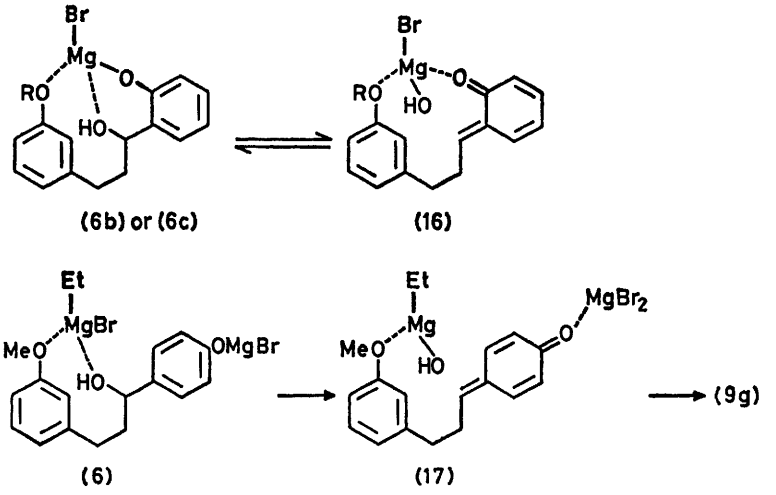
SCHEME 2

(12; $n = 1$) will now be retarded by the absence of Mg(II) chelation. Instead the alkene (9a) is formed by intermolecular proton abstraction by the phenoxide group [13] of a second molecule, the reactivity of which is enhanced by the crown ether.

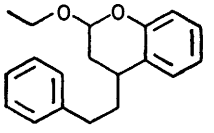
Although magnesium bridging within the *o*-quinone methide complex (11; $n = 1$) should favour the entropy of cyclisation it is not a necessity. Thus the *p*-quinone methide (14; $n = 1$) cyclises (see below and Scheme 2) even though magnesium bridging is not possible. However, it may be, although we have no evidence for it at present, that the *o*-quinone methide complex (11; $n = 1$)

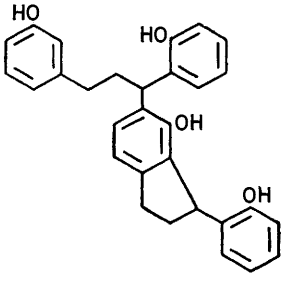
cyclises faster than the *p*-quinone methide complex (14; $n = 1$).

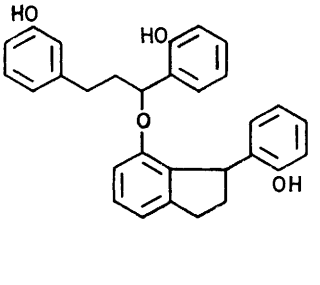
The homologue (6h) also cyclised under standard conditions. A mixture of (7c) and (8c) in the ratio 88 : 12 was formed (90%). Formation of an *o*-quinone methide complex (11; $n = 2$), albeit less stable than (11; $n = 1$), was again indicated by the product ratio. This cyclisation contrasts with the $SnCl_4$-catalysed cyclisation of the alcohol (6j) where a mixture of (7d) and (8d) was formed (70%) in the ratio 5 : 95 respectively. In the presence of 18-crown-6, (6h) cyclised (90%) to a mixture of (7c) and (8c) in the ratio 38 : 62 respectively. None of the alkene (9c) was observed. These results are consistent with (*a*) the mechanism outlined in Scheme 2 and (*b*) the greater ease of six-membered than five-membered ring formation.[3b]



SCHEME 3

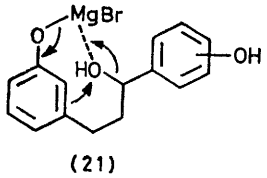

(18)


(19)


(20)

Cyclisation via p-*Quinone Methides*.—The alcohol (6k) cyclised (43%) to give a mixture of (7e) and (8e) in the ratio 1 : 9 together with the alkene (9e) (2%). We consider that this ratio is due to steric hindrance presented by the chelated phenyl substituent *ortho* to the point of ring closure. This ratio also disproves an S_N2-like (Ar_2^--5) mechanism for the cyclisation of (6a) and (6k) in which a concerted displacement by the phenoxide of the benzylic hydroxy-group (21) could occur without involvement of a quinone methide. Predominance of the *ortho*-cyclised product would be predicted. This is not however observed. In contrast, the $SnCl_4$-catalysed cyclisation of (6h) gave (7f) and (8f) in the ratio 15 : 85. The mechanism for the cyclisation of (6k) is as shown in Scheme 2 wherein magnesium chelation between the phenolic and alcoholic oxygen atoms (13; $n = 1$) assists departure of the latter hydroxy-group, to generate the non-bridged *p*-quinone methide (14; $n = 1$).

In addition, the following observations were made. (*a*) In the reaction of (6k) the yields and ratio of (7e) and (8e) and the yield of alkene (9c) were sensitive to the reaction conditions (see Table). (*b*) Treatment of the alcohol (6l), from which formation of the *p*-quinone methide complex (17) (see Scheme 3) is possible, gave under standard conditions, the alkene (9g) (84%). No cyclised product was observed. (*c*) The alcohol (6m), which cannot form a quinone methide, was recovered unchanged when treated under standard conditions. (*d*)



(21)

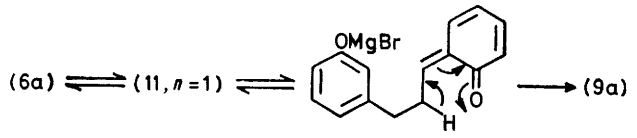
When NaH and NaOMe were used in place of EtMgBr,[9] no cyclisation occurred. (*e*) In the presence of 2 mol of 18-crown-6, no cyclisation of (6k) occurred and the alkene (9e) was obtained (46%). This result disproved the intramolecular mechanism, involving (22), for the formation of (9a) from the alcohol (6a).

Ring closure was also observed in the case of (6o)

(Table). G.l.c., after methylation, showed that the cyclised product consisted of (7g) and (8g) in the ratio 7 : 93. In contrast, $SnCl_4$-catalysed cyclisation of (6q) gave (7h) and (8h) in the ratio 1 : 9 (71%).

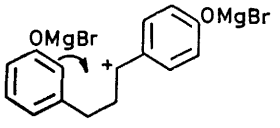
The ratio of (7g) to (8g), just as in the case of (6k), seems to be another example of the effect of steric hindrance. Thus in the presence of 2 mol of 18-crown-6, the alcohol (6o) cyclised to give (7g) and (8g) (83%) in the ratio 2 : 3 respectively.

Although cyclisation of the alcohols (6h) and (6o) was expected, cyclisation of the lower homologues (6a) and



(22)

(6k) was not. Molecular models indicate that if in-line attack [7] by the phenoxide ring on the quinone methide group coupled with overlap by the phenoxide ring [3b,14] are requirements [1] for reaction, then a highly strained transition state would be involved even though the cyclisations constitute the favoured *5-Exo-Trig* [7] ring closure. However, these stereoelectronic requirements may not be necessary, for two reasons. First, the inherent reactivity of quinone methides [6] suggests instead the involvement of an early transition state. Secondly, a planar transition state is suggested on the following basis. It was noted that neither (6a) nor (6k) cyclise unless the respective quinone methide is co-ordinated to Mg(II). The effect of Mg(II) could be to induce strong cationic character in the quinone methide, *e.g.* (23), leading effectively to an anionic–cationic ring



(23)

closure. Since there is evidence that cationic aromatic ring closures have, on occasion,[7] planar transition states, *e.g.* the acid-catalysed cyclisation of phenanthrene-4-carboxylic acid [15] which has no alternative, it is possible that a planar transition state may also prevail in the course of cyclisation of (6a) and (6k). In addition, this theory offers an explanation for the reluctance of the phenol (1) [3d] to cyclise under basic conditions.

It is evident that the steric requirements for phenoxide cyclisations are still unclear. They have been discussed elsewhere.[1]

EXPERIMENTAL

M.p.s were determined on a Thomas-Hoover melting-point apparatus. T.l.c. was carried out on plates coated with silica gel HF_{254} (Merck). Preparative layer chromatography on plates coated with Kiesel gel PF_{254} (Merck) were employed. G.l.c. was performed on a Perkin-Elmer F 11 chromatograph coupled to a Perkin-Elmer 159 recorder. I.r. spectra were determined as liquid films or KBr discs with a Perkin-Elmer 257 spectrometer. ^1H N.m.r. spectra, unless otherwise stated, were determined for solutions in deuteriochloroform with tetramethylsilane as internal standard on a Perkin-Elmer R20A spectrometer. Benzene was distilled from calcium hydride under nitrogen. Ether was distilled from lithium aluminium hydride. Methanol was dried by distillation from magnesium methoxide. Light petroleum refers to that fraction of boiling range 40—60 °C.

1-(2-Hydroxyphenyl)-3-(3-hydroxyphenyl)propan-1-ol (6a).—To a solution of *o*-hydroxyacetophenone (3.78 g, 0.03 mol) and *m*-hydroxybenzaldehyde (3.76 g, 0.03 mol) in ethanol (95%, 40 ml) was added aqueous potassium hydroxide (3.8 g, 0.07 mol, in 20 ml water). The reaction mixture was stirred for 12 h at room temperature. The cooled mixture was acidified with aqueous hydrochloric acid (10%). The resulting precipitate was recrystallised from aqueous ethanol to give a first crop of 2′,3-dihydroxychalcone (4; R^1 = OH, R^2 = 2-OH) (4.4 g), m.p. 150—153 °C (lit.,[16] 132 °C) (Found: C, 74.9; H, 5.4. Calc. for $C_{15}H_{12}O_3$: C, 75.0; H, 5.0%); $\nu_{max.}$ 3 390, 1 635, and 970 cm^{-1}; δ[$(CD_3)_2$CO] 6.80—8.15 (m).

To a solution of the chalcone (4; R^1 = OH, R^2 = 2-OH) (3.2 g) in ethyl acetate (75 ml) was added Adams catalyst (310 mg) and the reaction mixture was shaken under hydrogen (40 lbf in^{-2}) for 5 min at room temperature. The mixture was filtered and the solid was washed with more ethyl acetate. Removal of the solvent *in vacuo* gave *2′,3-dihydroxy-αβ-dihydrochalcone* (3 g, 93%), m.p. 106—108 °C (from ether–hexane) (Found: C, 74.3; H, 5.9. $C_{15}H_{14}O_3$ requires C, 74.4; H, 5.8%); $\nu_{max.}$ 3 350 and 1 670 cm^{-1}; δ 2.80—3.51 (4 H, m, $ArCH_2CH_2CO$) and 6.65—7.80 (8 H, m, ArH). Use of longer reaction times produced many products.

To a solution of the above dihydrochalcone (370 mg) in ether (20 ml) was added lithium aluminium hydride (400 mg) and the reaction mixture was heated at reflux 30 h under nitrogen. The cooled mixture was quenched by the slow addition of water, acidified with aqueous hydrochloric acid (10%), and the ether layer was separated. The aqueous layer was extracted with ether, and the combined organic layers were washed with brine and dried (magnesium sulphate). Removal of the solvent *in vacuo* gave a colourless oil. Preparative t.l.c. (ether–light petroleum, 2 : 3) gave the *alcohol* (6a) (347 mg, 98%), m.p. 117—119 °C (Found: C, 73.7; H, 6.5. $C_{15}H_{16}O_3$ requires C, 73.8; H, 6.6%); $\nu_{max.}$ 3 300 and 1 590 cm^{-1}; δ[$(CD_3)_2CO$] 1.90—2.41 (2 H, m, CH_2), 2.70 (2 H, t, *J* 7 Hz, $ArCH_2$), 4.55 (1 H, br s, aliphatic OH, exchanged with D_2O), 4.90 (1 H, t, *J* 7 Hz, CH), 6.65—7.40 (8 H, m, ArH), 7.70 (1 H, br s, ArOH exchanged with D_2O), and 8.68 (1 H, br s, ArOH, exchanged with D_2O).

1-(2-Hydroxyphenyl)-3-(3-methoxyphenyl)propan-1-ol (6b).—To a solution of the chalcone (4; R^1 = OH; R^2 = 2-OH) (1 g, 4.16 mmol) in acetone (20 ml) was added potassium carbonate (0.6 g, 4.34 mmol) and methyl iodide (1 ml). The reaction mixture was heated at reflux for 5 h. The acetone was removed *in vacuo* and the residue was diluted with water, acidified with aqueous hydrochloric acid (10%), and extracted with dichloromethane. The extracts were washed with water and dried (sodium sulphate). Removal of the solvent *in vacuo* gave an oil which was purified by preparative t.l.c. (ether–light petroleum, 2 : 3) to give 2′

hydroxy-3-methoxychalcone (4; R^1 = OMe, R^2 = 2-OH) (900 mg, 86%), m.p. 85—87 °C (lit.,[17] 94—95 °C) (Found: C, 75.7; H, 5.6. Calc. for $C_{16}H_{14}O_3$: C, 75.6; H, 5.5%); $\nu_{max.}$ 3 000 and 1 640 cm^{-1}; δ[$(CD_3)_2CO$] 3.85 (3 H, s, OMe) and 6.81—7.90 (10 H, m).

To a solution of the chalcone (4; R^1 = OMe, R^2 = 2-OH) (340 mg) in ethyl acetate (10 ml) was added Adams catalyst (30 mg) and the reaction mixture was shaken under hydrogen (40 lbf in^{-2}) for 5 min at room temperature. The mixture was filtered and the solid was washed with more ethyl acetate. Removal of the solvent *in vacuo* gave 2′-*hydroxy*-3-*methoxy*-αβ-*dihydrochalcone* (330 mg, 96%); $\nu_{max.}$ 3 000 and 1 640 cm^{-1}; δ 3.20 (4 H, symmetrical m, $ArCH_2CH_2CO$), 3.82 (3 H, s, OMe), and 6.70—7.91 (8 H, m, ArH).

To a solution of the above dihydrochalcone (261 mg) in ether (15 ml) was added lithium aluminium hydride (300 mg) and the reaction mixture was heated at reflux for 24 h under nitrogen. The cooled mixture was quenched by the slow addition of water, acidified with aqueous hydrochloric acid (10%), and the ether layer separated. The aqueous layer was extracted with ether. The combined ether extracts were washed with brine and dried (magnesium sulphate). Removal of the solvent *in vacuo* gave a colourless oil which was purified by preparative t.l.c. (ether–light petroleum, 2 : 3) to afford the *alcohol* (6b) (216 mg, 82%) (Found: C, 74.5; H, 7.0. $C_{16}H_{18}O_3$ requires C, 74.4; H, 7.0%); $\nu_{max.}$ 3 300 and 1 580 cm^{-1}; δ 2.21 (2 H, m, CH_2), 2.70 (2 H, t, *J* 6 Hz, $ArCH_2$), 3.82 (3 H, s, OMe), 4.71 (1 H, t, *J* 6 Hz, CH), and 6.60—7.51 (8 H, m, ArH).

3-(3-*Benzyloxyphenyl*)-1-(2-*hydroxyphenyl*)*propan*-1-*ol* (6c).—To a solution of the chalcone (4; R^1 = OH, R^2 = 2-OH) (540 mg, 2.25 mmol) in ethanol (20 ml) was added potassium carbonate (320 mg, 2.32 mmol) and benzyl chloride (285 mg, 2.25 mmol). The reaction mixture was heated at reflux for 12 h. The alcohol was removed *in vacuo* and the residue was diluted with water and acidified with aqueous hydrochloric acid (10%). The aqueous phase was extracted with dichloromethane and the combined organic layers were washed with water and dried (magnesium sulphate). Removal of the solvent *in vacuo* gave an oil which was hydrogenated as above to give a colourless oil. Purification of the crude oil by preparative t.l.c. (ether–light petroleum, 2 : 3) gave 2′-*hydroxy*-3-*benzyloxy*-αβ-*dihydrochalcone* (510 mg, 68%); $\nu_{max.}$ 3 000 and 1 640 cm^{-1}; δ 3.22 (4 H, symmetrical m, $ArCH_2CH_2CO$), 5.11 (2 H, s, $PhCH_2$), and 6.78—7.61 (13 H, m, ArH).

Reduction of the above dihydrochalcone (420 mg) in ether (40 ml) with lithium aluminium hydride (500 mg) at reflux (25 h) as above gave a colourless oil of the *alcohol* (6c) (420 mg, 99%) (Found: C, 79.1; H, 6.5. $C_{22}H_{22}O_3$ requires C, 79.0; H, 6.6%); $\nu_{max.}$ 3 200 and 1 580 cm^{-1}; δ 2.21 (2 H, m, CH_2), 2.75 (2 H, m, $ArCH_2$), 4.80 (1 H, m, CH), 5.10 (2 H, s, $PhCH_2$), and 6.81—7.60 (13 H, m, ArH).

3-(3-*Hydroxyphenyl*)-1-(2-*methoxyphenyl*)*propan*-1-*ol* (6d).—To a solution of *o*-methoxyacetophenone (4.3 g, 0.03 mol) and *m*-hydroxybenzaldehyde (3.76 g, 0.03 mol) in ethanol (95%, 30 ml) was added aqueous potassium hydroxide [1.8 g, 0.032 mol, in water (10 ml)]. The mixture was heated at 80 °C for h and allowed to stir at room temperature for 2 d. The cooled mixture was acidified with aqueous hydrochloric acid (10%) and the yellow gummy oil (6 g) was separated. Catalytic hydrogenation of the crude oil (3 g) in ethyl acetate (10 ml) containing Adams catalyst (250 mg) as above followed by preparative t.l.c. (ether–light petroleum, 2 : 3) gave 2′-*methoxy*-3-*hydroxy*-αβ-*dihydrochalcone* (1.88 g); $\nu_{max.}$ 3 400 and 1 660 cm^{-1}; δ 3.12 (4 H, symmetrical m, $ArCH_2CH_2CO$), 3.77 (3 H, s, OCH_3) and 6.70—7.95 (8 H, m, ArH).

Reduction of the above dihydrochalcone (700 mg) in ether (15 ml) with lithium aluminium hydride (500 mg) at reflux (6 h) as above gave a colourless oil. Purification by preparative t.l.c. (ether–light petroleum, 2 : 3) afforded the *alcohol* (6d) (605 mg, 86%) (Found: C, 74.3; H, 7.0. $C_{16}H_{18}O_3$ requires C, 74.4; H, 7.0%); $\nu_{max.}$ 3 300 and 1 580 cm^{-1}; δ 2.10 (2 H, m, CH_2), 2.62 (2 H, m, $ArCH_2$), 3.80 (3 H, s, OMe) and 6.60—7.50 (8 H, m, ArH).

1-(2-*Methoxyphenyl*)-3-(3-*methoxyphenyl*)*propan*-1-*ol* (6e).—To a solution of the chalcone (4; R^1 = OH; R^2 = 2-OH) (500 mg, 2.08 mmol) in acetone (10 ml) was added potassium carbonate (600 mg, 4.34 mmol) and methyl iodide (2 ml). The reaction mixture was heated at reflux for 6 h. Work-up as above gave an oil which was purified by preparative t.l.c. (ether–light petroleum, 2 : 3) to give two bands. The band of higher R_F afforded the chalcone (4; R^1 = OMe; R^2 = 2-OH) (121 mg, 23%), identical (i.r., n.m.r., and t.l.c.) with the previously prepared specimen. The band of lower R_F gave 2′,3-*dimethoxychalcone* (4; R^1 = OMe, R^2 = 2-OMe) (361 mg, 65%) (Found: C, 76.0; H, 5.9. $C_{17}H_{16}O_3$ requires C, 76.1; H, 6.0%); $\nu_{max.}$ 1 640 cm^{-1}; δ 3.82 (3 H, s, OMe), 3.90 (3 H, s, OMe), and 6.80—7.91 (10 H, m, CH=CH and ArH). Use of longer reaction time (20 h) gave only dimethylated product.

Catalytic hydrogenation of the chalcone (4; R^1 = OMe, R^2 = 2-OMe) (350 mg) in ethyl acetate (5 ml) containing Adams catalyst (30 mg) as above (5 m) gave a colourless oil by the usual work-up. Preparative t.l.c. (ether–light petroleum, 2 : 3) afforded 2′,3-*dimethoxy*-αβ-*dihydrochalcone* (316 mg, 90%); $\nu_{max.}$ 1 670 cm^{-1}; δ 2.90—3.50 (4 H, m, $ArCH_2CH_2CO$), 3.82 (3 H, s, OMe), 3.91 (3 H, s, OMe), and 6.71—7.90 (8 H, m, ArH).

Reduction of the above dihydrochalcone (300 mg) in ether (15 ml) with lithium aluminium hydride (250 mg) at reflux (6 h) gave a colourless oil by usual work-up. Preparative t.l.c. (ether–light petroleum, 2 : 3) gave the *alcohol* (6e) (290 mg, 96%) (Found: C, 75.1; H, 7.3. $C_{17}H_{20}O_3$ requires C, 75.0; H, 7.4%); $\nu_{max.}$ 3 320 and 1 580 cm^{-1}; δ 1.90—2.31 (2 H, m, CH_2), 2.60 (1 H, br s, OH, exchanged with D_2O), 2.65—3.01 (2 H, m, $ArCH_2$), 3.75 (6 H, s, 2 × OMe), 4.95 (1 H, t, *J* 7 Hz, CH), and 6.60—7.51 (8 H, m, ArH).

1-(2-*Hydroxyphenyl*)-3-*phenylpropan*-1-*ol* (6f).—Similar condensation of *o*-hydroxyacetophenone (3.78 g, 0.028 mol) and benzaldehyde (2.97 g, 0.028 mol) in ethanol (95%, 40 ml) with aqueous potassium hydroxide [3.14 g, 0.056 mol, in water (20 ml)] at room temperature for 10 h gave a pale yellow solid by usual work-up. Recrystallisation from ethanol (95%) gave pale yellow crystals of 2′-hydroxychalcone (4; R^1 = H, R^2 = 2-OH) [18] (3.6 g, 57%), m.p. 86—87 °C (Found: C, 80.3; H, 5.3. Calc. for $C_{15}H_{12}O_2$: C, 80.4; H, 5.4%); $\nu_{max.}$ 3 300 and 1 635 cm^{-1}; δ 6.71—8.10 (m).

Catalytic hydrogenation of the above chalcone (800 mg) in ethyl acetate (30 ml) containing Adams catalyst (70 mg) as above (10 min) gave a colourless oil of the corresponding dihydrochalcone (only one spot as indicated by t.l.c.) (801 mg) by usual work-up. Reduction of the crude ketone (600 mg) in ether (40 ml) with lithium aluminium hydride (600 mg) at reflux for 17 h, followed by preparative t.l.c. (ether–light petroleum, 2 : 3) of the crude product gave a colourless oil of the *alcohol* (6f) (566 mg, 94%) (Found: C,

78.9; H, 7.0. $C_{15}H_{16}O_2$ requires C, 79.0; H, 7.0%); $\nu_{max.}$ 3 200 and 1 580 cm^{-1}; δ 2.21 (2 H, m, CH_2), 2.74 (2 H, m, $ArCH_2$), 4.79 (1 H, m, CH), and 6.80—7.59 (9 H, m, ArH).

3-(3-*Hydroxyphenyl*)-1-*phenylpropan*-1-*ol* (6g).—To a solution of acetophenone (3 g, 0.027 mol) and *m*-hydroxybenzaldehyde (3.3 g, 0.027 mol) in ethanol (95%, 20 ml) was added aqueous potassium hydroxide [(3.1 g, 0.055 mol, in water (10 ml)] and the reaction mixture was stirred for 12 h at room temperature. Isolation as above gave a yellow solid which was recrystallised from ethanol (95%) to give yellow crystals of 3-hydroxychalcone (4; R^1 = OH, R^2 = H) (3.9 g, 65%), m.p. 156—158 °C (lit.,[19] 161—163 °C) (Found: C, 80.3; H, 5.4. Calc. for $C_{15}H_{12}O_2$: C, 80.4; H, 5.4%); $\nu_{max.}$ 3 350 and 1 660 cm^{-1}; δ[$(CD_3)_2CO$] 6.90—8.31 (m).

Catalytic hydrogenation of the above chalcone (818 mg) in ethyl acetate (15 ml) containing Adams catalyst (80 mg) as above (15 min) gave a colourless oil of 3-*hydroxy*-αβ-*dihydrochalcone* (808 mg, 98%); $\nu_{max.}$ 3 300 and 1 680 cm^{-1}; δ 3.15 (4 H, symmetrical m, $ArCH_2CH_2CO$) and 6.60—7.41 (9 H, m, ArH).

Reduction of the above dihydrochalcone (700 mg) in ether (20 ml) with lithium aluminium hydride (700 mg) at reflux for 1.5 h gave a colourless oil by usual work-up. Preparative t.l.c. (ether–light petroleum, 2 : 3) afforded a white solid of the *alcohol* (6g) (590 mg, 84%), m.p. 81—82 °C (Found: C, 79.0; H, 7.2. $C_{15}H_{16}O_2$ requires C, 79.0; H, 7.0%); $\nu_{max.}$ 3 300 and 1 585 cm^{-1}; δ 2.10 (2 H, m, CH_2), 2.62 (2 H, m, $ArCH_2$), 4.70 (1 H, m, CH), and 6.60—7.41 (9 H, m, ArH).

The Bromides (5; R = OCH_2Ph, OH, *and* OMe).—To a suspension of lithium aluminium hydride (3 g, 0.075 mol) in ether (100 ml) was added a solution of ethyl 3′-(*m*-benzyloxyphenyl)propionate [3d] (15.6 g, 0.055 mol) in ether (50 ml) dropwise (1.5 h) with stirring. After the addition was complete, the reaction mixture was heated at reflux for 1 h and the cooled mixture was quenched by the slow addition of water. The ether layer was separated. The aqueous layer was acidified with aqueous hydrochloric acid (10%) and extracted with ether. The combined ether layers were washed with water and brine and dried (magnesium sulphate). Removal of the solvent *in vacuo* gave a colourless oil of 3-(*m*-benzyloxyphenyl)propan-1-ol (only one product was indicated by t.l.c.) (12 g, 90%); $\nu_{max.}$ 3 320 and 1 600 cm^{-1}; δ 2.18 (2 H, m, CH_2), 2.69 (2 H, 2 × d, *J* 6 Hz, $ArCH_2$), 3.61 (2 H, t, *J* 6 Hz, OCH_2), 4.0 (1 H, br s, OH, exchanged with D_2O), 5.01 (2 H, s, $ArCH_2O$), and 6.59—7.30 (9 H, m, ArH).

To a solution of 3-(*m*-benzyloxyphenyl)propan-1-ol (7.5 g) in ether (50 ml) was added phosphorus tribromide (4 ml) slowly and the reaction mixture was stirred at room temperature for 21 h. The mixture was poured into cold saturated sodium hydrogencarbonate solution and the ether layer was separated. The aqueous layer was extracted with ether and the combined ether layers were washed twice with aqueous sodium hydroxide (10%) and dried (magnesium sulphate). After removal of solvent, the residue was distilled to give benzyl bromide (1.9 g), followed by *benzyl* 3-(3-*bromopropyl*)*phenyl ether* (5; R = OCH_2Ph) (4.6 g, 45%) (Found: C, 62.9; H, 5.5; Br, 26.1. $C_{16}H_{17}BrO$ requires C, 63.0; H, 5.6; Br, 26.0%); $\nu_{max.}$ 1 600 cm^{-1}; δ 2.16 (2 H, m, CH_2), 2.75 (2 H, t, *J* 7 Hz, $ArCH_2$), 3.37 (2 H, t, *J* 6 Hz, CH_2Br), 5.07 (2 H, s, $ArCH_2O$), and 6.70—7.61 (9 H, m, ArH). The sodium hydroxide layers were acidified with aqueous hydrochloric acid (10%) and extracted with ether. The ether extracts were washed with water and brine and dried (magnesium sulphate). Removal of the solvent *in vacuo* gave an oil of 3-(3-*bromopropylphenol* (5; R = OH) (2.6 g, 36%); $\nu_{max.}$ 3 330 and 1 600 cm^{-1}; δ 2.15 (2 H, m, CH_2), 2.73 (2 H, t, *J* 7 Hz, $ArCH_2$), 3.36 (2 H, t, *J* 6 Hz, CH_2Br), and 6.60—7.41 (4 H, m, ArH).

Methylation (potassium carbonate, excess of methyl iodide, acetone, reflux, 12 h) of the bromide (5; R = OH) (1.6 g, 7.44 mmol) followed by chromatography on silica gel (30 g) (ether–light petroleum, 2 : 3) gave a colourless oil of 3-(3-bromopropyl)anisole (5; R = OMe) (1.5 g, 88%) (Found: C, 52.3; H, 5.5; Br, 34.6. Calc. for $C_{10}H_{13}BrO$: C, 52.4; H, 5.7; Br, 34.9%); $\nu_{max.}$ 1 600 cm^{-1}; δ 2.15 (2 H, CH_2), 2.72 (2 H, t, *J* 7 Hz, $ArCH_2$), 3.18 (2 H, t, *J* 6 Hz, CH_2Br), 3.80 (3 H, s, OMe), and 6.68—7.51 (4 H, m, ArH).

1-(2-*Benzyloxyphenyl*)-4-(3-*benzyloxyphenyl*)*butan*-1-*ol* (6i).—To a mixture of magnesium (161 mg, 0.006 7 mol) and a few crystals of iodine in ether (5 ml) was added ethyl bromide (3 drops) at room temperature. After the reaction had started and progressed for a few minutes, a solution of the bromide (5; R = OCH_2Ph) (2 g, 0.006 6 mol) in ether (20 ml) was added dropwise. The addition was completed over a 30 min period and the mixture was allowed to stir for an additional 1 h at room temperature. To the stirring solution was added dropwise a solution of *o*-benzyloxybenzaldehyde (1.4 g, 0.006 6 mol) in ether (30 ml) at room temperature. After the addition was completed, the mixture was stirred for an additional 12 h and poured into saturated aqueous ammonium chloride. This mixture was thoroughly extracted with ether. The ether layers were dried (brine and magnesium sulphate) and evaporated to give an oil. Preparative t.l.c. (ether–light petroleum, 2 : 3) gave a colourless oil of the *alcohol* (6i) (860 mg, 30%) (Found: C, 82.0; H, 6.5. $C_{30}H_{30}O_3$ requires C, 82.2; H, 6.8%); $\nu_{max.}$ 3 360 and 1 600 cm^{-1}; δ 1.78 (4 H, m, 2 × CH_2), 2.40 (1 H, br s, OH, exchanged with D_2O), 2.56 (2 H, m, $ArCH_2$), 4.75 (1 H, m, CH), 5.01 (2 H, s, OCH_2Ph), 5.04 (2 H, s, OCH_2Ph), 6.60—7.3 (8 H, m, ArH), and 7.40 (10 H, s, PhH).

1-(2-*Hydroxyphenyl*)-4-(3-*hydroxyphenyl*)*butan*-1-*ol* (6h).—A solution of the alcohol (6i) (600 mg, 1.37 mmol) and aqueous sodium hydroxide [164 mg, 4.11 mmol, in water (2 ml)] in methanol (20 ml) containing palladium–charcoal catalyst (5%; 240 mg) was shaken under hydrogen (40 lbf in^{-2}) at room temperature for 26 h. After filtration, the methanol was removed *in vacuo*, ether and water were added, and the mixture was neutralised with aqueous hydrochloric acid (5%). The ether layer was separated and the aqueous phase was extracted with ethyl acetate. The combined organic layers were dried (brine and magnesium sulphate) and the solvent was removed *in vacuo* to give an oil. Preparative t.l.c. (ether–light petroleum, 1 : 1) afforded two bands. The band of higher R_F gave a mixture of (7c) and (8c) (159 mg, 48%) which were identical (i.r., n.m.r., and t.l.c.) with known samples. The band of lower R_F gave the *alcohol* (6 h) (144 mg, 41%) (Found: C, 74.2; H, 6.8. $C_{16}H_{18}O_3$ requires C, 74.4; H, 7.0%); $\nu_{max.}$ 3 300 and 1 590 cm^{-1}; δ[$(CD_3)_2CO$] 1.72 (4 H, m, 2 × CH_2), 2.51 (2 H, m, $ArCH_2$), 3.20 (1 H, br s, OH, exchanged with D_2O), 4.90 (1 H, m, CH), 6.50—7.35 (8 H, m, ArH), and 7.51 (2 H, br s, 2 × OH, exchanged with D_2O).

1-(2-*Methoxyphenyl*)-4-(3-*methoxyphenyl*)*butan*-1-*ol* (6j).—The *alcohol* (6j) was prepared from the bromide (5; R = OMe) (1.4 g, 6.1 mmol) and *o*-methoxybenzaldehyde (830 mg, 6.1 mmol) in a manner similar to that described

for the synthesis of the alcohol (6i). The crude oil was purified by preparative t.l.c. (ether–light petroleum, 1 : 4) to afford the alcohol (6j) (561 mg, 32%) (Found: C, 75.1; H, 7.4. $C_{18}H_{22}O_3$ requires C, 75.5; H, 7.7%); $\nu_{max.}$ 1 600 cm^{-1}; δ 1.75 (4 H, m, 2 × CH_2), 2.50 (1 H, br s, OH, exchanged with D_2O), 2.61 (2 H, m, $ArCH_2$), 3.78 (3 H, s, OMe), 3.83 (3 H, s, OMe), 4.91 (1 H, m, CH), and 6.65—7.55 (8 H, m, ArH).

1-(4-*Hydroxyphenyl*)-3-(3-*hydroxyphenyl*)*propan*-1-*ol* (6k).—To a solution of *p*-hydroxyacetophenone (2 g, 0.014 7 mol) and *m*-hydroxybenzaldehyde (1.8 g, 0.148 mol) in ethanol (95%, 10 ml) was added aqueous sodium hydroxide [1.70 g, 0.044 mol, in water (10 ml)] and the reaction was heated at 80 °C for 2 h and allowed to stir at room temperature for 3 d. The cooled mixture was acidified with aqueous hydrochloric acid (10%). The resulting yellow precipitate was recrystallised from aqueous ethanol to give yellow needles of 3,4-dihydroxychalcone (4; R^1 = OH, R^2 = 4-OH) (2.9 g, 82%), m.p. 236—239 °C (lit.,[19] 237—239 °C) (Found: C, 74.6; H, 5.1. Calc. for $C_{15}H_{12}O_3$: C, 75.0; H, 5.0%); $\nu_{max.}$ 3 350 and 1 630 cm^{-1}; δ[$(CD_3)_2CO$] 6.71—8.41 (m).

Catalytic hydrogenation of the chalcone (4; R^1 = OH, R^2 = 4-OH) (1.2 g) in ethyl acetate (20 ml) containing Adams catalyst (110 mg) under hydrogen (40 lbf in^{-2}) for 20 min at room temperature gave an oil by usual work-up. Preparative t.l.c. (ethyl acetate–light petroleum, 2 : 3) afforded 3,4′-*dihydroxy*-αβ-*dihydrochalcone* (980 mg, 81%) (Found: C, 74.3; H, 5.9. $C_{15}H_{14}O_3$ requires C, 74.4; H, 5.8%); $\nu_{max.}$ 3 350 and 1 650 cm^{-1}; δ[$(CD_3)_2CO$] 3.10 (4 H, symmetrical m, $ArCH_2CH_2CO$), 6.65—8.20 (8 H, m, ArH), and 8.50 (2 H, br s, OH, exchanged with D_2O).

To a solution of 3,4′-dihydroxy-αβ-dihydrochalcone (800 mg) in ether (50 ml) was added lithium aluminium hydride (800 mg) slowly in small portions and the resulting mixture was allowed to stir at room temperature for 3 h. Work-up in the usual manner gave a pale yellow oil which was purified by preparative t.l.c. (ethyl acetate–light petroleum, 1 : 1) to give white crystals of the *alcohol* (6k) (460 mg, 57%), m.p. 131—133 °C (Found: C, 74.1; H, 6.5. $C_{15}H_{17}O_3$ requires C, 73.8; H, 6.6%); $\nu_{max.}$ 3 300 and 1 600 cm^{-1}; δ[$(CD_3)_2CO$] 2.0 (2 H, m, CH_2), 2.70 (2 H, m, $ArCH_2$), 4.71 (1 H, m, CH), 4.35 (1 H, br s, OH, exchanged with D_2O), 6.61—7.50 (8 H, m, ArH), and 8.35 (2 H, br s, 2 × OH, exchanged with D_2O). Use of higher temperature and a longer reaction time produced many products.

1-(4-*Hydroxyphenyl*)-3-(3-*methoxyphenyl*)*propan*-1-*ol* (6l) —Condensation of *p*-hydroxyacetophenone (3 g, 0.022 mol) and *m*-methoxybenzaldehyde (3 g, 0.022 mol) in ethanol (95%; 10 ml) with aqueous sodium hydroxide (2.1 g, 0.053 mol, in water 10 ml) as described above for the chalcone (4; R^1 = OH, R^2 = 4-OH), followed by recrystallisation of the crude solid from aqueous ethanol gave yellow crystals of 3-*methoxy*-4′-*hydroxychalcone* (4; R^1 = OMe, R^2 = 4-OH) (3.8 g, 68%), m.p. 138—141 °C (Found: C, 75.6; H, 5.4. $C_{16}H_{14}O_3$ requires C, 75.6; H, 5.5%); $\nu_{max.}$ 3 300 and 1 630 cm^{-1}; δ[$(CD_3)_2CO$] 3.90 (3 H, s, OMe), 7.10—8.32 (10 H, m, CH=CH and ArH), and 9.40 (1 H, br s, OH, exchanged with D_2O).

Catalytic hydrogenation of the above chalcone (1 g) in ethyl acetate (10 ml) containing Adams catalyst (100 mg) as above (10 min) gave an oil of 3-*methoxy*-4′-*hydroxy*-αβ-*dihydrochalcone* (910 mg, 90%); $\nu_{max.}$ 3 300 and 1 640 cm^{-1}; δ[$(CD_3)_2CO$] 3.20 (4 H, symmetrical m, $ArCH_2CH_2$-CO), 3.78 (3 H, s, OMe), and 6.60—8.11 (8 H, m, ArH).

Reduction of the above dihydrochalcone (400 mg) in ether (15 ml) with lithium aluminium hydride (300 mg) at room temperature for 3 h gave an oil by usual work-up. Preparative t.l.c. (ethyl acetate–light petroleum, 1 : 1) afforded an oil of the *alcohol* (6l) (239 mg, 59%) (Found: C, 74.3; H, 6.9. $C_{16}H_{18}O_3$ requires C, 74.4; H, 7.0%); $\nu_{max.}$ 3 350 and 1 600 cm^{-1}; δ[$(CD_3)_2CO$] 2.11 (2 H, m, CH_2), 2.65 (2 H, m, $ArCH_2$), 4.60 (1 H, m, CH), 6.60—7.51 (8 H, m, ArH), 8.10 (1 H, br s, OH, exchanged with D_2O).

3-(3-*Hydroxyphenyl*)-1-(4-*methoxyphenyl*)*propan*-1-*ol* (6m).—Condensation of *p*-methoxyacetophenone (2 g, 0.013 mol) and *m*-hydroxybenzaldehyde (1.8 g, 0.015 mol) in ethanol (95%; 10 ml) with aqueous sodium hydroxide [2 g, 0.050 mol, in water (10 ml)] at 80 °C for 2 h and room temperature for 3 d gave a yellow solid after usual work-up. Recrystallisation from aqueous ethanol gave yellow needles of 2-hydroxy-4′-methoxychalcone (4; R^1 = OH; R^2 = 4-OMe) (2.9 86%), m.p. 150—153 °C (lit.,[19] 162—164 °C) (Found: C, 75.1; H, 5.2. Calc. for $C_{16}H_{14}O_3$: C, 75.6; H, 5.5%); $\nu_{max.}$ 3 300 and 1 640 cm^{-1}; δ[$(CD_3)_2CO$] 3.90 (3 H, s, OMe), 6.90—8.41 (10 H, m, CH=CH and ArH), and 9.30 (1 H, br s, OH, exchanged with D_2O).

Catalytic hydrogenation of the above chalcone (2 g) in ethyl acetate (12 ml) containing Adams catalyst (200 mg) as above (3 min) gave an oil (2 g) after usual work-up. Purification of the crude oil (1g) by preparative t.l.c. (ether–light petroleum, 2 : 3) gave a colourless oil of 3-*hydroxy*-4′-*methoxy*-αβ-*dihydrochalcone* (765 mg, 76%); $\nu_{max.}$ 3 350 and 1 650 cm^{-1}; δ 3.15 (4 H, symmetrical m, $ArCH_2CH_2$-CO), 3.82 (3 H, s, OMe), and 6.70—8.21 (8 H, m, ArH).

Reduction of the above dihydrochalcone (500 mg) in ether (10 ml) with lithium aluminium hydride (300 mg) at room temperature for 3 h followed by usual work-up gave an oil. Preparative t.l.c. (ether–light petroleum, 2 : 3) afforded a white solid of the *alcohol* (6m) (400 mg, 79%), m.p. 108—110 °C (Found: C, 74.2; H, 7.0. $C_{16}H_{18}O_3$ requires C, 74.4; H, 7.0%); $\nu_{max.}$ 3 330 and 1 600 cm^{-1}; δ[$(CD_3)_2CO$] 2.08 (2 H, m, CH_2), 2.75 (2 H, m, $ArCH_2$), 3.80 (3 H, s, OMe), 4.70 (1 H, m, CH), 6.60—7.60 (8 H, m, ArH), and 8.31 (1 H, br s, OH, exchanged with D_2O).

1-(4-*Methoxyphenyl*)-3-(3-*methoxyphenyl*)*propan*-1-*ol* (6n).—To a solution of the chalcone (4; R^1 = OH; R^2 = 4-OH) (380 mg, 1.58 mmol) in acetone (10 ml) was added potassium carbonate (436 mg, 3.16 mmol) and methyl iodide (1 ml) and the reaction mixture heated at reflux for 9 h. Work-up as usual gave a yellow oil of 3,4′-dimethoxychalcone (4; R^1 = OMe; R^2 = 4-OMe) [20] (390 mg, 92%); $\nu_{max.}$ 1 660 cm^{-1}; δ 3.85 (6 H, s, 2 × OMe) and 6.95—8.20 (10 H, m, CH=CH and ArH).

Catalytic hydrogenation of the chalcone (4; R^1 = OMe; R^2 = 4-OMe) (370 mg) in ethyl acetate (5 ml) containing Adams catalyst (39 mg) as above (5 min) gave an oil of 3,4-*dimethoxy*-αβ-*dihydrochalcone* (358 mg, 96%); $\nu_{max.}$ 1 670 cm^{-1}; δ 3.10 (4 H, m, $ArCH_2CH_2CO$), 3.75 (3 H, s, OMe), 3.78 (3 H, s, OMe), and 6.71—8.10 (8 H, m, ArH).

Reduction of the above dihydrochalcone (350 mg) in ether (5 ml) with lithium aluminium hydride (160 mg) at room temperature for 2 h (the reaction was shown to be complete by t.l.c.) afforded an oil by usual work-up. Preparative t.l.c. (ether–light petroleum, 2 : 3) gave a colourless oil of the *alcohol* (6n) (314 mg, 89%) (Found: C, 75.0; H, 7.2. $C_{17}H_{20}O_3$ requires C, 75.0; H, 7.4%); $\nu_{max.}$ 3 400 and 1 600 cm^{-1}; δ 2.15 (2 H, m, CH_2), 2.65 (2 H, m, $ArCH_2$), 3.80 (6 H, s, 2 × OMe), 4.65 (1 H, m, CH), and 6.70—7.51 (8 H, m, ArH).

1-(4-*Benzyloxyphenyl*)-4-(3-*benzyloxyphenyl*)*butan*-1-*ol* (6p).—The alcohol (6p) was prepared from the bromide (5; R = OCH_2Ph) and *p*-benzyloxybenzaldehyde in a manner similar to that described for the alcohol (6i). Preparative t.l.c. (ether–light petroleum, 2 : 3) of the crude oil gave the *alcohol* (6p) (43%) (Found: C, 81.9; H, 6.4. $C_{30}H_{30}O_3$ requires C, 82.2; H, 6.8%); $\nu_{max.}$ 3 360 and 1 600 cm^{-1}; $\delta(CCl_4)$ 1.59 (4 H, m, 2 × CH_2), 2.18 (1 H, br s, OH, exchanged with D_2O), 2.51 (2 H, m, $ArCH_2$), 4.45 (1 H, m, CH), 4.98 (4 H, s, 2 × OCH_2Ph), 6.61—7.35 (8 H, m, ArH), and 7.40 (10 H, s, ArH).

1-(4-*Hydroxyphenyl*)-4-(3-*hydroxyphenyl*)*butan*-1-*ol* (60).—A solution of the alcohol (6p) (400 mg, 0.91 mmol) and aqueous sodium hydroxide [109 mg, 2.73 mmol, in water (2 ml)] in methanol (20 ml) was shaken under hydrogen at room temperature for 24 h. Work-up as previously described for the alcohol (6h) and preparative t.l.c. (ether–light petroleum, 1 : 1) gave two bands. The band of higher R_F gave a mixture of (7g) and (8g) (88 mg, 40%), identical (i.r., n.m.r., and t.l.c.) with known samples (described below). The band of lower R_F afforded the *alcohol* (6o) (94 mg, 40%) (Found: C, 74.2; H, 7.1. $C_{16}H_{18}O_3$ requires C, 74.4; H, 7.0%); $\nu_{max.}$ 3 300 and 1 600 cm^{-1}; $\delta[(CD_3)_2CO]$ 1.64 (4 H, m, 2 × CH_2), 2.55 (2 H, m, $ArCH_2$), 4.65 (1 H, m, CH), 6.60—7.51 (8 H, m, ArH), and 8.21 (2 H, br s, 2 × OH, exchanged with D_2O).

1-(4-*Methoxyphenyl*)-4-(3-*methoxyphenyl*)*butan*-1-*ol* (6q).—The *alcohol* (6q) was prepared from the bromide (5; R = OMe) and *p*-methoxybenzaldehyde in a manner similar to that described for the synthesis of the alcohol (6i). Preparative t.l.c. (ether–light petroleum, 1 : 4) gave a colourless oil of the *alcohol* (6q) (39%) (Found: C, 75.2; H, 7.3. $C_{18}H_{22}O_3$ requires C, 75.5; H, 7.7%); $\nu_{max.}$ 3 400 and 1 600 cm^{-1}; $\delta(CCl_4)$ 1.50 (4 H, m, 2 × CH_2), 1.98 (1 H, br s, OH, exchanged with D_2O), 2.41 (2 H, m, $ArCH_2$), 3.59 (6 H, s, 2 × OMe), 4.31 (1 H, br s, CH), and 6.41—7.25 (8 H, m, ArH).

1-(2-*Methoxyphenyl*)-3-(3-*methoxyphenyl*)*prop*-1-*ene* (9b).—A solution of the alcohol (6e) (100 mg) in dimethyl sulphoxide (0.8 ml) was heated at 180—190 °C for 0.5 h. Chloroform was added and the solution was washed several times with water and dried (brine and sodium sulphate). Removal of the solvent *in vacuo* gave an oil (only one spot was indicated by t.l.c.). Preparative t.l.c. (ether–light petroleum, 2 : 3) gave the *olefin* (9b) (80 mg, 86%) (Found: C, 80.1; H, 7.0. $C_{17}H_{18}O_2$ requires C, 80.3; H, 7.1%); $\nu_{max.}$ 1 620 and 970 cm^{-1}; δ 3.60 (2 H, d, *J* 8 Hz, $ArCH_2$), 3.82 (3 H, s, OMe), 3.87 (3 H, s, OMe), and 6.41—7.71 (10 H, m, CH=CH and ArH).

1-(4-*Methoxyphenyl*)-3-(3-*methoxyphenyl*)*prop*-1-*ene* (9f).—Similar dehydration of the alcohol (6n) by heating in dimethyl sulphoxide as above followed by preparative t.l.c. (ether–light petroleum, 2 : 3) gave the *olefin* (9f) (84%) (Found: C, 80.0; H, 6.9. $C_{17}H_{18}O_2$ requires C, 80.3; H, 7.1%); $\nu_{max.}$ 1 620 and 960 cm^{-1}; δ 3.51 (2 H, d, *J* 6 Hz, $ArCH_2$), 3.80 (6 H, s, 2 × OMe), 6.40 (2 H, m, CH=CH), and 6.70—7.51 (8 H, m, ArH).

Reactions of Ethylmagnesium Bromide with Alcohols.—General method. To a solution of ethylmagnesium bromide (3.0 mmol) [from magnesium (3.0 mmol) and ethyl bromide (3.0 mmol) in ether (5 ml)] was added dropwise to a solution of the alcohol (6) (14 mmol) in ether (5 ml) at room temperature. After the addition was complete, the mixture was allowed to stir for an additional 10 min and the ether was removed *in vacuo* under nitrogen. Benzene (25 ml) was added (when 18-crown-6 or ethyl vinyl ether was required; it was dissolved in benzene and added all at once during this period) and the reaction mixture was heated at reflux for 20 h. The cooled mixture was quenched by the addition of saturated aqueous ammonium chloride and extracted with ether. The organic layers were washed with water and brine and dried (magnesium sulphate). Removal of the solvent *in vacuo* gave an oil.

The alcohol (6a). The Grignard reagent (3.0 mmol) and the alcohol (6a) (342 mg, 1.4 mmol) in benzene (25 ml) gave, after work-up, a pale yellow oil. Preparative t.l.c. (ether–light petroleum, 1 : 1) afforded two main bands. The band of higher R_F gave 3-(2-*hydroxyphenyl*)*indan*-4-*ol* (7a) (224 mg, 71%), m.p. 131—133 °C (Found: C, 79.2; H, 5.9. $C_{15}H_{14}O_2$ requires C, 79.6; H, 6.2%); $\nu_{max.}$ 3 300 and 1 600 cm^{-1}; δ 2.10—2.91 (2 H, m, CH_2), 3.25 (2 H, t, *J* 7 Hz, $ArCH_2$), 4.81 (1 H, m, CH), and 6.60—7.51 (7 H, m, ArH). The band of lower R_F gave the *olefin* (9a) (35 mg, 11%); $\nu_{max.}$ 3 300, 1 620, and 960 cm^{-1}; δ 3.51 (2 H, d, *J* 8 Hz, $ArCH_2$), 6.30—7.61 (10 H, m, CH=CH and ArH), and 5.70 (2 H, br s, 2 × OH).

Methylation of the cyclised product (7a) (2 mol equiv. potassium carbonate, excess of methyl iodide, acetone, reflux, 24 h) followed by preparative t.l.c. (ether–light petroleum, 1 : 4) gave 7-*methoxy*-1-(2-*methoxyphenyl*)*indan* (7b) (92%) (Found: C, 80.1; H, 6.8. $C_{17}H_{18}O_2$ requires C, 80.3; H, 7.1%); $\nu_{max.}$ 1 580 cm^{-1}; δ 1.70—2.61 (2 H, m, CH_2), 2.91 (2 H, m, $ArCH_2$), 3.68 (3 H, s, OMe), 4.88 (1 H, m, CH), and 6.51—7.50 (7 H, m, ArH).

Methylation of the olefin (9a) as above followed by preparative t.l.c. (ether–light petroleum, 2 : 3) gave the olefin (9b) (90%) identical (i.r., n.m.r., and t.l.c.) with the previously prepared specimens.

The alcohol (6h). Ethylmagnesium bromide (1.5 mmol) and the alcohol (6h) (180.6 mg, 0.70 mmol) in benzene (15 ml) gave, after work-up, an oil (only one product was indicated by t.l.c.) which on preparative t.l.c. (ether–light petroleum, 1 : 1) gave a mixture of the cyclised alcohols (7c) and (8c) (151 mg, 90%); $\nu_{max.}$ 3 300 and 1 600 cm^{-1}; $\delta[(CD_3)_2CO]$ 1.75 (4 H, m, 2 × CH_2), 2.79 (2 H, m, $ArCH_2$), 4.69 (1 H, m, CH), and 6.50—7.51 (7 H, m, ArH).

Methylation of the cyclised products (7c) and (8c) as above followed by preparative t.l.c. (ether–light petroleum, 1 : 4) gave 6- and 8-*methoxy*-1-(2-*methoxyphenyl*)-1,2,3,4-*tetrahydronaphthalene* (7d) and (8d) (91%) (Found: C, 80.2; H, 7.3. $C_{18}H_{20}O_2$ requires C, 80.6; H, 7.5%); $\nu_{max.}$ 1 600 cm^{-1}; δ 1.81 (4 H, m, 2 × CH_2), 2.85 (2 H, t, *J* 6 Hz, $ArCH_2$), 3.80 (3 H, s, OMe), 3.88 (3 H, s, OMe), 4.68 (1 H, t, *J* 6 Hz, CH), and 6.61—7.48 (7 H, m, ArH).

The alcohol (6k). Ethylmagnesium bromide (2.1 mmol) and the alcohol (6k) (244 mg, 1.0 mmol) in benzene (20 ml) gave a yellow oil which was separated by preparative t.l.c. (ethyl acetate–light petroleum 1 : 1) into two components. That of higher R_F comprised the cyclised alcohols (7e) and (8e) (97 mg, 43%); $\nu_{max.}$ 3 300 and 1 600 cm^{-1}; δ 2.41 (2 H, m, CH_2), 2.91 (2 H, t, *J* 7 Hz, $ArCH_2$), 4.20 (1 H, t, *J* 7 Hz, CH), 6.60—7.41 (7 H, m, ArH), and 7.75 (2 H, br s, 2 × OH, exchanged with D_2O). The band of lower R_F afforded the olefin (9e) (4.6 mg, 2%); $\nu_{max.}$ 3 300, 1 620. and 960 cm^{-1}; $\delta[(CD_3)_2CO]$ 3.45 (2 H, d, *J* 6 Hz, $ArCH_2$), 6.41 (2 H, m, CH=CH), and 6.61—7.51 (8 H, m, ArH).

Methylation of a mixture of (7e) and (8e) as previously described for the cyclised product (7a) followed by preparative t.l.c. (ether–light petroleum, 1 : 4) gave 5- and 7-*methoxy*-1-(4-*methoxyphenyl*)*indan* (7f) and (8f) (90%)

(Found: C, 80.0; H, 6.9. $C_{17}H_{18}O_2$ requires C, 80.3; H, 7.1%); $\nu_{max.}$ 1 600 cm^{-1}; δ 2.11 (2 H, m, CH_2), 3.01 (2 H, m, $ArCH_2$), 3.81 (6 H, s, 2 × OCH_3), 4.21 (1 H, m, CH), and 6.70—7.41 (7 H, m, ArH).

Similar methylation of the olefin (9e) gave the olefin (9f), identical (i.r., n.m.r., and t.l.c.) with the previously prepared sample.

The alcohol (6o). Ethylmagnesium bromide (1.92 mmol) and the alcohol (6o) (232 mg, 0.90 mmol) in benzene (17 ml) gave, after work-up, an oil which was purified by preparative t.l.c. (ethyl acetate–light petroleum, 1 : 1) to give the cyclised products (7g) and (8g) (194 mg, 90%), methylation of which, as previously described for (7a), followed by preparative t.l.c. (ether–light petroleum, 1 : 4) gave 6- and 8-*methoxy*-1-(4-*methoxyphenyl*)-1,2,3,4-*tetrahydronaphthalene* (7h) and (8h) (90%) (Found: C, 80.9; H, 7.7. $C_{18}H_{20}O_0$ requires C, 80.6; H, 7.5%), $\nu_{max.}$ 1 600 cm^{-1}; δ 1.81 (4 H, m, 2 × CH_2), 2.80 (2 H, m, $ArCH_2$), 3.72 (6 H, s, 2 × OMe), 3.95 (1 H, m, CH), and 5.58—7.21 (7 H, m, ArH).

Trapping of the o-*quinone methide from the alcohol* (6f). A solution of the alcohol (6f) (180 mg, 0.79 mmol) in ether (5 ml) was treated with ethylmagnesium bromide solution [0.94 mmol, in ether (5 ml)] as described in the general method. The mixture was stirred for 10 min and the ether was removed *in vacuo* under nitrogen. Benzene (15 ml) was added, followed by ethyl vinyl ether (100 mg, 1.39 mmol) in benzene (2 ml) and the mixture was heated at reflux for 20 h. Work-up as above gave an oil. T.l.c. indicated the absence of the starting alcohol. Preparative t.l.c. (ether–light petroleum, 3 : 7) afforded 2-*ethoxy*-4-*phenethylchroman* (18) (123 mg, 55%) (Found: C, 80.8; H, 8.2. $C_{19}H_{22}O_2$ requires C, 80.8; H, 7.9%); $\nu_{max.}$ 1 600 cm^{-1}; δ 1.31 (3 H, m, $CO_2CH_2CH_3$), 2.20 (4 H, m, 2 × CH_2), 2.91 (3 H, m, $ArCH_2$ and ArCH), 3.90 (2 H, m, CO_2CH_2), 5.0 (1 H, m, OCH), 7.11 (4 H, m, ArH), and 7.35 (5 H, s, PhH).

Reactions of Sodium Hydride with Alcohols.—General method. To a solution of the alcohol (1.0 mmol) in ether (6 ml) was added sodium hydride (80% dispersion in mineral oil; 2.2 mmol) under nitrogen. After the mixture had been stirred for 10 min at room temperature, the ether was removed *in vacuo*. Benzene (20 ml) was added and the solution was treated in a manner similar to that previously described for the reaction of the alcohol with ethylmagnesium bromide.

Attempted n-Butyl-lithium-catalysed Cyclisation of (6a).—To a solution of the alcohol (6a) (244 mg, 1.0 mmol) in ether (6 ml) at 0 °C under nitrogen was added n-butyl-lithium (1.7M in hexane, 1.2 ml, 2.0 mmol). The reaction mixture was stirred for 10 min at room temperature and the ether was removed *in vacuo*. Benzene (20 ml) was added and the mixture was heated at reflux for 20 h. The cooled reaction mixture was quenched by the addition of aqueous ammonium chloride (20%). The solution was extracted with ether and the ethereal solution was dried (brine and magnesium sulphate). Removal of the solvent *in vacuo* gave a viscous oil. Preparative t.l.c. (ether–light petroleum, 1 : 1) gave a colourless oil (195 mg, 80%), identical (i.r., n.m.r., and t.l.c.) with the starting material.

Attempted Sodium Methoxide-catalysed Cyclisation of (6k).—Sodium metal (46 mg, 2.0 mmol) was allowed to react with methanol (3 ml) and a solution of the alcohol (6k) (244 mg, 1.0 mmol) in methanol (3 ml) was added at room temperature. The mixture was stirred for 10 min and the solvent was removed *in vacuo*. Benzene (20 ml) was added and the mixture was heated at reflux for 20 h. Work-up as above, followed by preparative t.l.c. (ether–light petroleum, 1 : 1) gave an oil (196 mg, 80%) which was shown to be identical with the starting material (i.r., n.m.r., and t.l.c.).

Stannic Chloride-catalysed Cyclisations of Alcohols.—The alcohol (6a). To a solution of the alcohol (6a) (500 mg, 2.05 mmol) in dichloromethane (50 ml) was added stannic chloride (5.3 g, 20.5 mmol). The mixture was stirred at room temperature under nitrogen for 1.5 h and then poured onto ice–water and the organic phase separated. The aqueous layer was extracted with dichloromethane and the combined extracts were dried (brine, magnesium sulphate). Removal of the solvent *in vacuo* followed by preparative t.l.c. (ether–light petroleum, 1 : 1) afforded a mixture of 5- and 7-*hydroxy*-1-(1-*hydroxyphenyl*)*indan* (7a) and (8a) (340 mg, 72%) (Found: C, 79.5; H, 6.1. $C_{15}H_{14}O_2$ requires C, 79.6; H, 6.2%); $\nu_{max.}$ 3 300 and 1 600 cm^{-1}; δ 2.40 (2 H, m, CH_2), 2.91 (2 H, t, *J* 7 Hz, $ArCH_2$), 4.20 (1 H, t, *J* 7 Hz, ArCH), 6.60—7.41 (7 H, m, ArH), and 7.75 (2 H, s, OH, exchanged with D_2O).

Methylation (2 mol equiv. of potassium carbonate, excess of methyl iodide, acetone, reflux, 24 h) of the above cyclised products (7a + 7b) (140 mg) followed by preparative t.l.c. (ether–light petroleum, 1 : 4) afforded a mixture of the dimethyl ethers (7b) and (8b) (144 mg, 92%) (Found: C, 80.5; H, 7.0. $C_{17}H_{18}O_2$ requires C, 80.3; H, 7.1%); $\nu_{max.}$ 1 600 cm^{-1}; δ 2.55 (2 H, m, CH_2), 3.01 (2 H, t, *J* 8 Hz, $ArCH_2$), 3.81 (3 H, s, OMe), 3.87 (3 H, s, OMe), 4.81 (1 H, t, *J* 8 Hz, ArCH), and 6.50—7.51 (7 H, m, ArH).

The alcohol (6e). Similar cyclisation of the alcohol (6e) (250 mg, 0.92 mmol) in dichloromethane (20 ml) with stannic chloride (2.4 g, 9.2 mmol) at room temperature for 1.5 h followed by preparative t.l.c. (ether–light petroleum, 1 : 4) of the crude product gave a mixture of (7b) and (8b) (177 mg, 76%), identical (i.r., n.m.r., t.l.c., and g.l.c.) with the above known sample.

The alcohol (6j). Similar treatment of the alcohol (6j) (160 mg, 0.56 mmol) in dichloromethane (20 ml) with stannic chloride (1.46 g, 5.60 mmol) gave an oil by usual work-up. Preparative t.l.c. (ether–light petroleum, 1 : 4) afforded a colourless oil which solidified on standing to afford the desired products (7d) and (8d) (105 mg, 70%), m.p. 63—66 °C, identical (i.r., n.m.r., t.l.c., and g.l.c.) with the above known sample.

The alcohol (6n). Similar treatment of the alcohol (6n) (150 mg, 5.5 mmol) in dichloromethane (20 ml) with stannic chloride (1.43 g, 0.55 mmol) followed by preparative t.l.c.-(ether–light petroleum, 1 : 4) of the crude oil gave a mixture of (7f) and (8f) (100 mg, 71%), identical (i.r., n.m.r., t.l.c., and g.l.c.) with the above sample.

The alcohol (6q). In a manner similar to that described for the reaction of the alcohol (6j), the alcohol (6q) (160 mg, 0.56 mmol) was cyclised to give a mixture of (7h) and (8h) (106.5 mg, 71%), identical (i.r., n.m.r., t.l.c., and g.l.c.) with the above sample.

[9/1525 *Received*, 25*th September*, 1979]

REFERENCES

[1] Part 4, W. S. Murphy and S. Wattanasin, preceding paper.
[2] Preliminary communication, W. S. Murphy and S. Wattanasin, *J.C.S. Chem. Comm.*, 1979, 788.
[3] See for example (*a*) W. S. Johnson, *Organic Reactions*, 1947, **2**, 114; (*b*) B. Capon, *Quart. Rev.*, 1964, 45; (*c*) L. R. C. Barclay in G. Olah, ed., 'Friedel Craft and Related Reactions,' Vol. 2,

Part 2, Interscience, New York, 1964, pp. 785—952; (*d*) P. G. Duggan and W. S. Murphy, *J.C.S. Perkin II*, 1975, 1054; (*e*) S. V. Kessar, *Accounts Chem. Res.*, 1978, **11**, 283.

[4] See *e.g.* W. J. Gensler, C. M. Samour, S. Y. Wang, and F. Johnson, *J. Amer. Chem. Soc.*, 1960, **82**, 1714, and references therein; F. Suzuki, S. Trenbeath, R. D. Gleim, and C. J. Sih, *J. Amer. Chem. Soc.*, 1978, **100**, 2272, and references therein.

[5] G. Casiraghi, G. Casnati, M. Cornia, A. Pochini, G. Sartori, and R. Ungaro, *J.C.S. Perkin I*, 1978, 322.

[6] J. A. Hemingson, *J.C.S. Perkin II*, 1977, 616; G. Leary, I. J. Miller, W. Thomas, and A. D. Woolhouse, *ibid.*, p. 1737.

[7] J. E. Baldwin, *J.C.S. Chem. Comm.*, 1976, 734.

[8] G. Casiraghi, G. Casnati, M. Cornia, A. Pochini, G. Puglia, G. Sartori, and R. Ungaro, *J.C.S. Perkin I*, 1978, 318.

[9] W. S. Murphy and S. Wattanasin, in preparation.

[10] G. Casiragni, G. Casnati, G. Puglia, G. Sartori, and G. Terenghi, *J. Chem. Research*, 1977, (*S*) 96; (*M*) 1123.

[11] A. Pochini and R. Ungaro, *J.C.S. Chem. Comm.*, 1976, 309; D. A. Bolon, *J. Org. Chem.*, 1970, **35**, 3666.

[12] G. F. Luteri and W. T. Ford, *J. Organometallic Chem.*, 1976, 139.

[13] J. Gierer and I. Pettersson, *Canad J. Chem.*, 1977, **55**, 593.

[14] R. Heck and S. Winstein, *J. Amer. Chem. Soc.*, 1957, 79, 3114.

[15] K. G. Rutherford and M. S. Newman, *J. Amer. Chem. Soc.*, 1957, **79**, 213.

[16] E. Schraufstötter and S. Deutsch, *Chem. Ber.*, 1948, **81**, 489.

[17] A. Gutzeit and S. V. Kostanecki, *Chem. Ber.*, 1905, **38**, 933.

[18] H. S. Mahal and K. Venkataraman, *J. Chem. Soc.*, 1933, 616.

[19] J. F. Miguel, *Bull. Soc. chim. France*, 1961, 1369.

[20] B. J. F. Hudson, *J. Chem. Soc.*, 1946, 754.