

## Chiral 2,2-Disubstituted Cyclohexanones; Annulation *via* Claisen Rearrangement Products

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The methyl enol ether of 2-methylcyclohexanone reacts regiospecifically with the optically active forms of but-3-yn-2-ol and but-3-en-2-ol. (*R*)-But-3-yn-2-ol yields an approximately 4:1 mixture of (*R*)-2-methyl-2-(*R*-buta-1,2-dienyl)cyclohexanone and the corresponding *SR* compound. By contrast the but-3-en-2-ol reaction is *ca.* 96% enantioselective; (*R*)-but-3-en-2-ol gives (*R*)-2-(*trans*-but-2-enyl)-2-methylcyclohexanone and (*S*)-but-3-en-2-ol gives the corresponding (*S*)-cyclohexanone. These Claisen rearrangement products have been transformed into Robinson-type annulated ketones. Cleavage of some highly hindered esters has been carried out efficiently by sodium methylsulphinylmethanide in dimethyl sulphoxide.

We considered it likely that a compound of type (1) would undergo the Claisen rearrangement<sup>1</sup> as shown and the question posed was to what extent the asymmetric centre *R* in (1) would control the stereochemistry of the reaction, in particular the proportions of the two expected diastereoisomers (2) (*R*-allene, *R*-) and (3) (*R*-allene, *S*-). To come within bonding distance to the appropriate carbon atom the acetylene system must bend and it seems likely that the side-chain methyl will become, fleetingly, either *quasi*-equatorial (1; *eq*Me) leading to (2) or *quasi*-axial (1; *ax*Me) leading to (3).

Cyclohexanone enol ethers are tautomeric compounds. The methyl enol ether (4a) has been found by gas chromatography to exist as a mixture of 1-methoxy-2-methylcyclohex-1-ene (39.4%) and 2-methoxy-3-methylcyclohex-1-ene (60.6%).<sup>2</sup> This has been confirmed by <sup>1</sup>H n.m.r. spectroscopy<sup>3</sup> and extended in the present work to compounds (4b) and (4c); the ratios of the 1,2- to the 2,3-isomers were found to be 29:71 (4b) and 38:62 (4c). Despite the tautomerism, the ethers (4a) when heated with racemic but-3-yn-2-ol and a trace of toluene-*p*-sulphonic acid gave a racemic allenic ketone (2) and/or (3) (69%) with no trace of the 2,6-position isomer. The ketone [ $\nu_{\max}$ . 1955 (C=C=C), 1707 (CO);  $\delta_{\text{H}}$  1.16 (3H, s, CH<sub>3</sub>),  $\delta_{\text{C}}$  203.6 (=C=)] appeared to be homogeneous. We envisaged no difficulty in elaborating the side chain for annulation and when the compound was treated with potassium 3-aminopropylamide in propane-1,3-diamine<sup>4</sup> it gave the racemic acetylenic ketone (5) and thence by hydration<sup>5</sup> and cyclisation compounds (6) and (7).

The allenic ketone gave a highly crystalline oxime. A single crystal X-ray diffraction examination of this compound showed conclusively† that the stereochemistry was that of formula (2) (see Figure). It is noteworthy that in the crystal the allene substituent takes up the axial position; the *E*-configuration of the oxime function is dictated by hydrogen bonding in the *RR/SS*-dimer (8) [O—H...N, 2.776 (5) Å] which has a centre of symmetry. Fractional atomic co-ordinates and molecular dimensions are given in Tables 1—4.

To obtain the optically active octalone (7) we required (*R*)-(+)-but-3-yn-2-ol. The optical forms of this alcohol have been prepared many times but absolute values for their rotations have varied widely. Claesson and Olsson<sup>6</sup> resolved the acid phthalate of the racemic alcohol with (*S*)-(–)-1-phenylethylamine and found that the esters of the two alcohols with (*R*)-(–)- $\alpha$ -methoxyphenylacetic acid had n.m.r. signals for the acetylenic hydrogen atoms at  $\delta_{\text{H}}$  2.90 and 2.76 in [<sup>2</sup>H<sub>4</sub>] methanol. In the present work resolution was achieved with (*R*)-(+)-1-phenylethylamine and the progress could be followed very conveniently by observing the <sup>1</sup>H n.m.r. spectrum of the

Table 1. Fractional stomic co-ordinates

Atom	<i>x/a</i>	<i>y/b</i>	<i>z/c</i>
O(1)	0.832 3(2)	0.451 9(2)	0.572 38(8)
N(1)	0.878 7(3)	0.422 5(2)	0.468 23(8)
C(1)	0.779 9(3)	0.354 9(2)	0.442 3(1)
C(2)	0.823 5(3)	0.319 9(2)	0.378 5(1)
C(3)	0.670 3(3)	0.341 7(2)	0.339 3(1)
C(4)	0.513 5(3)	0.289 7(2)	0.363 7(1)
C(5)	0.480 8(3)	0.332 5(3)	0.427 1(2)
C(6)	0.625 5(3)	0.308 4(3)	0.468 6(1)
C(7)	0.968 0(3)	0.388 7(2)	0.353 1(1)
C(8)	0.864 3(3)	0.193 3(2)	0.378 2(1)
C(9)	1.003 1(3)	0.150 2(2)	0.360 0(1)
C(10)	1.142 6(3)	0.108 3(2)	0.342 8(1)
C(11)	1.180 7(4)	0.072 3(3)	0.280 6(1)

Table 2. Bond lengths

O(1)–N(1)	1.414(2)
N(1)–C(1)	1.266(3)
C(1)–C(2)	1.523(3)
C(1)–C(6)	1.490(3)
C(2)–C(3)	1.544(3)
C(2)–C(7)	1.534(3)
C(2)–C(8)	1.516(3)
C(3)–C(4)	1.515(4)
C(4)–C(5)	1.521(4)
C(5)–C(6)	1.524(4)
C(8)–C(9)	1.303(4)
C(9)–C(10)	1.296(4)
C(10)–C(11)	1.480(4)

amine salt. In deuteriochloroform solution a doublet at  $\delta_{\text{H}}$ (250 MHz) 2.46 (*J* 2 Hz, CHC≡CH) was that of the (*R*)-(+)-alcohol; the (*S*)-(–)-alcohol gave a similar doublet at  $\delta_{\text{H}}$  2.49

Treatment of the ether (4a) with (*R*)-(+)-but-3-yn-2-ol gave a dextrorotatory allenic ketone which was converted *via* compounds (5) and (6) into the laevorotatory octalone (7). It was obvious by comparison of its rotation with that of the published value<sup>7</sup> that it was impure. The precursory alkyne (5) was re-examined; it gave a 2,4-dinitrophenylhydrazone which after repeated crystallisation was separated into optically active material, m.p. 112°C, and a smaller amount of the racemate,

† We thank Dr. M. J. Begley and the late Prof. T. J. King (University of Nottingham) for the X-ray diffraction study.

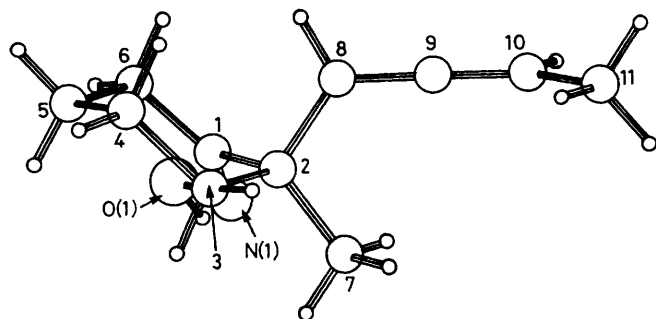
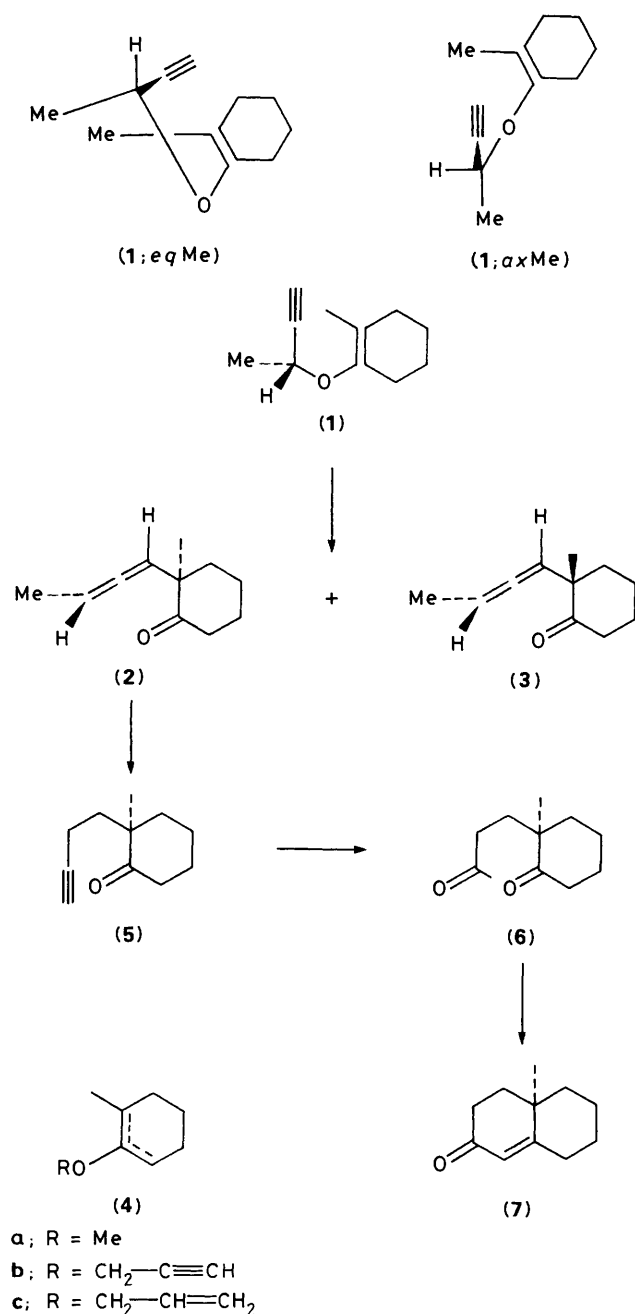


Figure 1. X-Ray molecular structure of the oxime of compound (2)

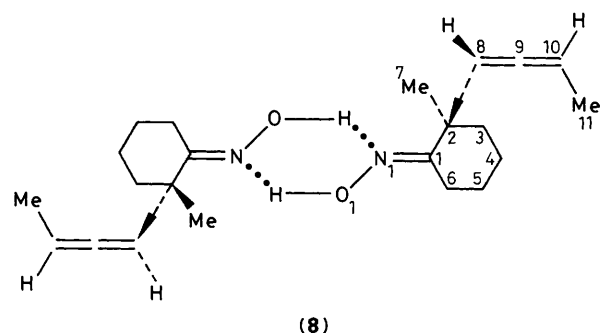


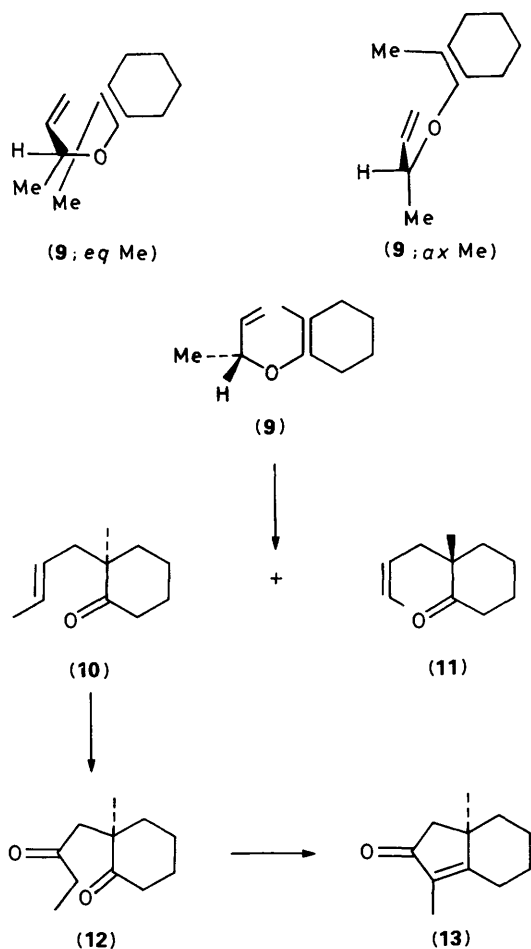
Table 3. Bond angles

O(1)-N(1)-C(1)	114.0(2)
C(1)-C(2)-C(3)	107.2(2)
C(1)-C(2)-C(7)	112.4(2)
C(1)-C(2)-C(8)	108.5(2)
C(3)-C(2)-C(7)	109.0(2)
C(3)-C(2)-C(8)	109.6(2)
C(7)-C(2)-C(8)	110.2(2)
N(1)-C(1)-C(2)	116.4(2)
N(1)-C(1)-C(6)	125.8(2)
C(2)-C(1)-C(6)	117.7(2)
C(1)-C(6)-C(5)	110.4(2)
C(6)-C(5)-C(4)	111.5(2)
C(5)-C(4)-C(3)	110.5(2)
C(2)-C(3)-C(4)	114.3(2)
C(2)-C(8)-C(9)	124.7(2)
C(8)-C(9)-C(10)	178.9(3)
C(9)-C(10)-C(11)	124.6(3)

Table 4. Torsion angles

O(1)-N(1)-C(1)-C(2)	-179.9
C(3)-C(2)-C(1)-C(6)	50.5
C(8)-C(2)-C(1)-N(1)	112.8
C(7)-C(2)-C(3)-C(4)	-173.1
C(3)-C(2)-C(8)-C(9)	121.0
C(2)-C(1)-C(6)-C(5)	-53.1
C(5)-C(4)-C(3)-C(2)	56.3
O(1)-N(1)-C(1)-C(6)	0.8
C(7)-C(2)-C(1)-N(1)	-9.0
C(8)-C(2)-C(1)-C(6)	-67.8
C(8)-C(2)-C(3)-C(4)	66.5
C(7)-C(2)-C(8)-C(9)	1.1
C(1)-C(6)-C(5)-C(4)	53.4
C(2)-C(8)-C(9)-C(10)	64.5
C(3)-C(2)-C(1)-N(1)	-128.8
C(7)-C(2)-C(1)-C(6)	170.3
C(1)-C(2)-C(3)-C(4)	-51.1
C(1)-C(2)-C(8)-C(9)	-122.2
N(1)-C(1)-C(6)-C(5)	126.2
C(6)-C(5)-C(4)-C(3)	-55.9
C(8)-C(9)-C(10)-C(11)	-154.4

m.p. 134 °C; the original ketone must, therefore, have contained isomer (3). Its presence was not detected by chromatography, by 100 and 250 MHz <sup>1</sup>H n.m.r. spectroscopy, or by 25.15 MHz <sup>13</sup>C n.m.r. spectroscopy. The 62.896 MHz <sup>13</sup>C n.m.r. spectrum contained 11 groups of signals of which 3 were symmetrical singlets, 5 slightly distorted singlets, and 3 barely resolved doublets. From intensity ratios of the last three (CO, =C=, and one CH=) the proportions of the epimers (2) and (3) were determined as 80.5 to 19.5. The 250 MHz <sup>1</sup>H n.m.r. spectrum of a deuteriochloroform solution containing a large amount of tris-3-(trifluoromethylhydroxymethylene)-(+)-camphorato-



europium(III) showed distortion of the quaternary methyl singlet. For two different concentrations of Euroshift reagent use of a curve resolver gave good correspondence by assuming the presence of 17 and 21% of compound (3).

The allyl vinyl ether rearrangement of compound (9) was next investigated. In the two possible chair-like transition states<sup>1</sup> the side-chain methyl is *quasi*-equatorial in the one (9; *eq*Me) leading to (10), and *quasi*-axial in the other (9; *ax*Me) leading to (11). ( $\pm$ )-But-3-en-2-ol reacted with the enol ether (4a) to yield (77–84%) predominantly the *trans*-ketone (10) with no trace of the 2,6-position isomer. The pure compound was isolated (62%) by chromatography or equally well by conversion of the reaction product into its semicarbazone and regeneration (64%) with hot 20% aqueous oxalic acid. The 360 MHz <sup>1</sup>H n.m.r. spectrum\* had a quaternary methyl singlet at  $\delta_{\text{H}}$  1.04, a doublet of doublets at 1.64 (3 H, *J* 1.5 and 7 Hz,  $\text{CH}_3\text{CH}=\text{CH}$ ) and multiplets at 5.31 (1 H,  $\text{CH}_3\text{CH}=\text{CH}$ ) and at 5.41 (1 H,  $\text{CH}_3\text{CH}=\text{CH}$ ). On irradiation at  $\delta$  1.61 the 5.41 multiplet became a doublet *J* 15 Hz thereby indicating a *trans*-configuration for the double bond, a conclusion also supported by strong i.r. absorption at 975  $\text{cm}^{-1}$  of the compound.

The presence of the stereoisomer (11) in the Claisen product before purification was readily detected by <sup>13</sup>C n.m.r. spectroscopy at 62.896 MHz. Summation of intensities for the two series of signals gave amounts corresponding to 7% for a reaction at 135 °C and 3% for one at 95 °C.

Wacker oxidation<sup>8</sup> of racemic (10) by oxygen in aqueous dimethylformamide containing catalytic amounts of palladium

chloride and copper(II) chloride gave the ketones (12) and (6) in the ratio 91:9 which were separated and cyclised to produce the corresponding compounds (13) and (7). That the carbonyl function was directing the course of the oxidation followed from the oxidation of (10;  $\text{CH}_2$  in place of CO) prepared by Wolff-Kishner reduction of (10) itself. Two products were obtained in the ratio 16:84. The mass spectrum of the minor product had an ion at  $m/z$  139 ( $M^+ - \text{C}_2\text{H}_5$ ) but no ion at  $m/z$  153 ( $M^+ - \text{CH}_3$ ); the major product had an ion at  $m/z$  153 but no ion at  $m/z$  139. The major product was therefore compound (6;  $\text{CH}_2$  in place of the ring CO). The product ratio reverted (92:8) to that of the ketone when the Wacker reaction was conducted on the dioxolane of (10). Both the ketone and its dioxolane reacted with 9-borabicyclo[3.3.1]nonane (9-BBN) by almost equal attack of the reagent at the two available positions. The result was particularly disappointing since 9-BBN is known to attack simple olefins, e.g. *cis*-4-methylpent-2-ene, at the less hindered carbon.<sup>9</sup>

For the optically active series of compounds, racemic but-3-en-2-ol was resolved as its acid phthalate with the optical forms of 1-phenylethylamine. The purity of the enantiomeric alcohols was easily checked by <sup>1</sup>H n.m.r. spectroscopy. Whereas the Euroshift reagent tris[3-trifluoroacetyl-(+)-camphorato]europium(III) produces no splitting of signals with but-3-en-2-ol,<sup>10</sup> with but-3-en-2-ol the methyl doublet at  $\delta_{\text{H}}$  1.28 (*J* 7 Hz) separates into two doublets of equal intensity in the racemate; in the optically pure forms the doublet remains unsplit. The methyl enol ether (4a) and (*R*)-(–)-but-3-en-2-ol gave (*R*)-(+)-2-methyl-2-(*trans*-but-2-enyl)cyclohexanone,  $[\alpha]_{\text{D}}^{25} + 52.6^\circ$  (ether, *c* 0.3) (10) converted by the Wacker method into the *R* ketones (13)  $[\alpha]_{\text{D}}^{25} - 12^\circ$  (ethanol, *c* 0.3) and (7)  $[\alpha]_{\text{D}}^{25} - 188^\circ$  (ethanol, *c* 0.4). Use of (*S*)-(+)-but-3-en-2-ol gave (*S*)-(–)-2-(*trans*-but-2-enyl)-2-methylcyclohexanone (14a),  $[\alpha]_{\text{D}}^{25} - 53.1^\circ$  (ether, *c* 0.4); after initial work on the racemate it was intended to convert this latter compound specifically into the enantiomer of the octalone (7).

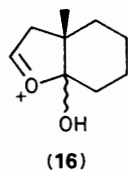


- a; R = O  
 b; R = H, OH  
 c; R = H, OOC-mesityl  
 d; R = H, OOC-1-adamantyl

- a; R = OH  
 b; R = H

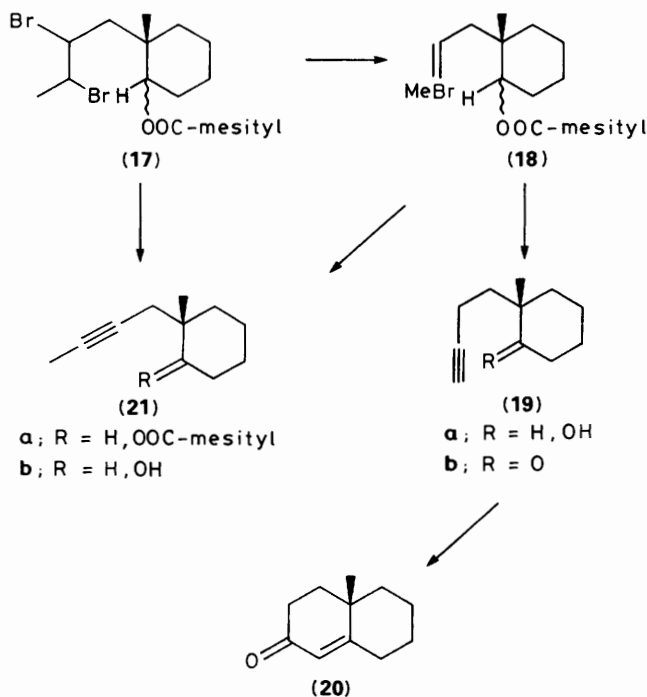
The reaction of racemic (14a) to bromine in carbon tetrachloride was complex. The carbonyl group did not survive and the mass spectrum of the product established that only one bromine atom had entered the molecule. Intramolecular attack by the carbonyl oxygen acting as nucleophile to the electrophilic bromine was suspected and confirmed by using aqueous 1,2-dimethoxyethane-dioxane as solvent. The crystalline product (81%) proved to be compound (15a). The five-membered ring formulation was deduced because the mass spectral base peak,  $m/z$  155 was clearly due to the ion (16). The ethylenedioxy function did not protect the carbonyl function against bromine. Sodium borohydride reduction of (14a) produced a 3:2 stereoisomeric mixture of alcohols (14b) which was readily converted into the methoxymethyl and methyl ethers. Surprisingly bromine in carbon tetrachloride removed the ether groups from both these compounds. The reaction products gave virtually identical spectra and pointed to the formation of compounds of type (15b; H in place of OH). The acetates of (14b) behaved normally in yielding dibromo adducts;

\* We thank Dr. I. Sadler, University of Edinburgh, for this spectrum.



unfortunately the acetate groups were lost, with ensuing complications, on attempted dehydrobromination in hydroxy-containing solvents and with the organic base 1,1,3,3-tetramethylguanidine<sup>11</sup> reaction was incomplete. Clearly it became necessary to use a hindered ester protecting group.

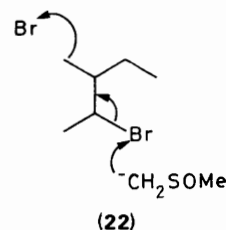
Efficient conversion into the octalone was achieved as follows. The optically active ketone (14a) was reduced to the weakly dextrorotatory mixture of alcohols (14b) (94%) which by the action of mesityl chloride in ether–light petroleum gave the mesitoate esters (14c) (95%), converted by bromine in carbon tetrachloride into the dibromo adducts (100%) (17). The action of sodamide (alone or in liquid ammonia) on this substance was complex. However, on treatment with potassium *t*-butoxide in *t*-butyl alcohol it produced (84%) a stereoisomeric mixture of monobromo esters (18). The location of the bromine atoms at C-3 was deduced from <sup>1</sup>H n.m.r. spectroscopy. For eight compounds encountered during this investigation which pos-



essed the side-chain entity CH<sub>3</sub>CH= the methyl signals were all in the region  $\delta_{\text{H}}$  1.65–1.71. For the compounds (18) the side-chain methyl appears at  $\delta_{\text{H}}$  2.23 which is that expected for the CH<sub>3</sub>CBr= group.<sup>12</sup> The vinylic bromine atoms in (18) are no longer amenable to nucleophilic displacement. The mixture when treated with sodamide at 130 °C produced the terminal acetylenes (19a) (68%) and mesitylene as virtually sole products; the readily separable mesitylene clearly derives from the mesitamide formed during the reaction. Swern oxidation<sup>13</sup> then gave as a single compound the optically pure ketoacetylene (19b) (92%). Its stereochemical purity was checked by examination of the <sup>1</sup>H n.m.r. spectrum in deuteriochloroform containing tris[3-(trifluoromethyl)hydroxymethylene-(+)-camphorato]europium(III); the singlet methyl at  $\delta$  1.08 remained unsplit whereas the racemic compound showed two methyl

singlets. Also the compound on catalytic reduction gave pure (*R*)-(–)-2-butyl-2-methylcyclohexanone, stereochemical purity again being checked by the Euroshift reagent. Conversion of (19b) into the optically active octalone (20) was conducted as for the racemic compound.

When the dibromo adduct (17) was treated with potassium *t*-butoxide in dimethylformamide (as against *t*-butylalcohol) both bromine atoms were removed leading to the internal alkyne ester (21a) (87%). This could also be transformed by sodamide into (19a). As a possible alternative to sodamide, the esters (18) were treated with sodium methylsulphinyllmethanide in dimethyl sulphoxide at 20 °C. The product, formed by dehydrobromination and deacylation was (21b) (64%), *i.e.* the epimeric mixture of alcohols corresponding to (21a). As far as we are aware the ready cleavage of hindered esters by sodium methylsulphinyllmethanide itself, as against alkali metal hydroxides<sup>14</sup> in dimethyl sulphoxide, has not so far been reported. It was confirmed in this series of compounds by the conversions (21a) into (21b), (14c) and (14d) into (14b), and (17) into (14b), debromination (22) being a known<sup>15</sup> property of the reagent. When the dibromo esters (17) were treated with sodium



methylsulphinyllmethanide in dimethyl sulphoxide to which had been added an equivalent amount of water to form sodium hydroxide the product was a complex mixture, the i.r. spectrum of which showed hydroxy and ester carbonyl absorption.

### Experimental

Petroleum refers to light petroleum (b.p. 40–60 °C), which had been stirred with concentrated sulphuric acid for *ca.* 3 h and then washed with water, aqueous sodium carbonate, and water before being dried and distilled. N.m.r. spectra were taken in deuteriochloroform solution.

**1-Methoxy-2-methylcyclohex-1-ene and 2-Methoxy-3-methylcyclohex-1-ene (4a).**—Trimethyl orthoformate (61 g) was added over 5 min to a solution of 2-methylcyclohexanone (44.8 g), methanol (14 ml), and toluene-*p*-sulphonic acid (0.2 g) stirred under a reflux condenser fitted with a variable distillation take-off head. After 2 h the mixture was heated slowly to 140 °C (methyl formate and methanol evolved). The product was then distilled, b.p. 55 °C/18 mmHg or 158 °C/755 mm Hg (39.8 g, 79%).  $\nu_{\text{max}}$  (film) 3 060, 1 688, 1 660, 1 220, and 1 205 cm<sup>-1</sup>;  $\delta_{\text{H}}$  1.12 (2 H, d, *J* 7 Hz, CH<sub>3</sub>CH), 1.2–2.4 (8.3 H), 3.61 (3 H, s, OCH<sub>3</sub>, both tautomers), and 4.75 (0.67 H, t, *J* 4 Hz, CH=). The data indicate a composition of 33% for the 1,2-compound and 67% for the 2,3-compound. 2,4-Dinitrophenylhydrazine reagent produced by hydrolysis and derivatisation (as it did for the two succeeding enol ethers) the 2,4-dinitrophenylhydrazone of 2-methylcyclohexanone, m.p. 135 °C.

**2-Methyl-1-(prop-2-ynoxy)cyclohex-1-ene and 3-Methyl-2-(2-propynyloxy)cyclohex-1-ene (4b).**—These were prepared from the above methyl enol ether, prop-2-ynol alcohol, and a trace of toluene-*p*-sulphonic acid at 70 °C; b.p. 54 °C/0.2 mmHg (42%),  $\nu_{\text{max}}$  (film) 3 285, 3 060, 2 120, 1 688, and 1 662 cm<sup>-1</sup>;  $\delta_{\text{H}}$  1.11 (2.14 H, d, *J* 7 Hz, CH<sub>3</sub>CH), 1.4–2.6 (9H), 4.3 (2 H, s br,

$\text{OCH}_2\text{C}=\text{CH}$ , both tautomers) and 4.68 (0.71 H, t,  $J$  4 Hz,  $\text{CH}=\text{CH}_2$ ). The data agree with a composition 29% of the 1,2-compound and 71% of the 2,3-isomer.

*2-Methyl-1-(prop-2-enyloxy)cyclohex-1-ene and 3-Methyl-2-(prop-2-enyloxy)cyclohex-1-ene (4c)*.—These were prepared from the methyl enol ether, allyl alcohol, and a trace of toluene-*p*-sulphonic acid at 70 °C, b.p. 50 °C/0.2 mmHg (45%);  $\nu_{\text{max}}$  (film) 3 075, 3 010, 1 685, 1 644, and 1 555  $\text{cm}^{-1}$ ;  $\delta_{\text{H}}$  1.12 (1.85 H, d,  $J$  7 Hz,  $\text{CH}_3\text{CH}$ ), 1.2–2.3 (8.75 H), 4.18 (2 H, d,  $J$  5 Hz,  $\text{OCH}_2\text{CH}=\text{CH}_2$  of both tautomers), 4.58 (0.62 H, t,  $J$  4 Hz,  $\text{CH}=\text{CH}_2$ ), 5.0–5.45 (2 H, m,  $\text{CH}=\text{CH}_2$  of both tautomers), and 5.7–6.2 (1 H, m,  $\text{CH}=\text{CH}_2$  of both tautomers). A composition of 38% of 1,2- and 62% of 2,3-compounds is indicated by the above data.

*2-(Buta-1,2-dienyl)-2-methylcyclohexanone (2)*.—Racemic but-3-yn-2-ol (11 g) was added dropwise to a stirred solution of 2-methylcyclohexanone (10 g), its methyl enol ether (21 g), and toluene-*p*-sulphonic acid (0.25 g) under nitrogen. After 30 min the orange brown solution was slowly heated during 4 h to 85 °C and maintained there for a further 8 h. After cooling the mixture was washed with water (40 ml) and aqueous 1M sodium carbonate (40 ml) and extracted with ether. The extracts were dried, evaporated, and distilled to give a pale yellow oil (17.8 g, 69%), b.p. 64 °C/0.3 mmHg. G.c. on both 5% OV-1 and 5% OV-17 at 140 °C gave single peaks:  $m/z$  164 ( $M^+$ ), 149, 136, 122, and 93;  $\nu_{\text{max}}$  (film) 1 955, 1 705, 1 310, and 1 118  $\text{cm}^{-1}$ ;  $\delta_{\text{H}}$  1.16 (3 H, s, quaternary methyl), 1.6–2.6 (11 H containing  $\delta$  1.67 dd,  $J$  6.5, 3.7 Hz,  $\text{CH}_3\text{CH}=\text{C}=\text{CH}$ ), and 5.16 (2 H, m,  $\text{HC}=\text{C}=\text{CH}$ ).

The 2,4-dinitrophenylhydrazone had m.p. 124 °C (from ethanol) (Found: C, 59.15; H, 5.85; N, 16.05  $\text{C}_{17}\text{H}_{20}\text{N}_4\text{O}_4$  requires C, 59.29; H, 5.85; N, 16.27%).

The oxime, m.p. 77 °C, was prepared in the usual way and crystallised from pentane;  $m/z$  180 ( $M^+ + 1$ ), 178 ( $M^+$ ), 179 ( $M^+ - 1$ ), 165, 162, and 126;  $\nu_{\text{max}}$  (KBr) 3 256, 1 965, 1 635, 947, 916, 882, 731, and 660  $\text{cm}^{-1}$ ;  $\delta_{\text{H}}$  1.19 (3 H, s, quaternary methyl), 1.4–3.0 (12 H), and 5.21 (2 H, m,  $\text{HC}=\text{C}=\text{CH}$ ).

*Crystal data*.  $\text{C}_{11}\text{H}_{17}\text{NO}$ ,  $M = 179.3$ . Orthorhombic,  $a = 8.147(1)$ ,  $b = 11.685(1)$ ,  $c = 22.279(3)$  Å,  $U = 2 120.9$  Å<sup>3</sup> (by least-squares refinement of 23 setting angles measured on a Hilger and Watts Y 290 diffractometer), space group  $Pbca$ ,  $Z = 8$ ,  $D_c = 1.12$ ,  $D_m = 1.11$  g  $\text{cm}^{-3}$ . Crystal dimensions  $0.2 \times 0.2 \times 0.15$  mm,  $\mu(\text{Mo-K}\alpha) = 0.88$   $\text{cm}^{-1}$ .

Data were collected using graphite monochromated molybdenum radiation ( $\lambda = 0.710 69$  Å) for reflections with  $\theta \leq 25^\circ$ ; 2 182 independent reflections were counted of which 1 172 had  $I \geq 3\sigma(I)$  and were used in the refinement.

The structure was solved by direct methods using the MULTAN program.<sup>16</sup> Data reduction and subsequent crystallographic calculations were performed using the CRYSTALS program.<sup>17</sup> C, N, and O were refined anisotropically by full-matrix least squares and hydrogens were included in fixed, calculated positions (the 1-OH hydrogen was placed in position found in a difference Fourier calculation). A weighting scheme based on Chebyshev polynomials gave a satisfactory agreement analysis and final  $R$  and  $R_w$  were 0.048 and 0.054. Final atomic co-ordinates are shown in Table 1. Bond lengths, bond angles, and torsion angles are given in Tables 2, 3, and 4 respectively.

*2-(But-3-ynyl)-2-methylcyclohexanone (5)*.—Propane-1,3-diamine (45 ml) (freshly distilled from sodium) was added to powdered potassium hydride (2 g) (from a mineral oil dispersion which had been extracted with petroleum—glove box, nitrogen atmosphere). After hydrogen evolution had ceased (90 min) the stirred pale yellow solution was cooled to  $-5$  °C and the racemic allenic ketone (2 g) in propane-1,3-diamine (3 ml) added rapidly. The solution immediately be-

came dark brown. After 20 min ice (20 g) was added and the mixture was extracted with petroleum (6  $\times$  100 ml). The combined extracts were washed with aqueous hydrochloric acid and water and then dried ( $\text{MgSO}_4$ ). Evaporation gave a pale yellow oil (1.66 g, 83%). T.l.c. (silica gel, 10% ether-petroleum) showed only one spot. A sample was purified by prep. g.c. (10% OV-1, 160 °C), single peak;  $m/z$  164 ( $M^+$ ), 149, 119, 113, 112, 105, and 97;  $\nu_{\text{max}}$  (film) 3 295, 2 110, 1 705, 1 312, 1 122, and 1 094  $\text{cm}^{-1}$ ;  $\delta_{\text{H}}$  1.08 (3 H, s,  $\text{CH}_3$ ), 1.5–2.5 (13 H containing 1.94, t,  $J$  2.5 Hz,  $\text{C}=\text{CH}$ ).

The 2,4-dinitrophenylhydrazone had m.p. 134 °C (from ethanol) (Found: C, 59.35; H, 6.0; N, 16.2.  $\text{C}_{17}\text{H}_{20}\text{N}_4\text{O}_4$  requires C, 59.29; H, 5.85; N, 16.27%).

*9-Methyl-1,2,6,7,8,9-hexahydronaphthalene-3(5H)-one (7)*.—A mixture of yellow mercuric oxide (0.5 g), boron trifluoride-diethyl ether (0.2 g), trichloroacetic acid (0.01 g), and methanol (2 ml) was stirred and heated to 70 °C under dry nitrogen. The ketoalkyne (5) (1.64 g) in methanol (30 ml) was then added dropwise to the cooled (20 °C) suspension. The mixture was stirred for 90 min and then poured into 0.01M sulphuric acid (40 ml); sodium chloride was added to saturation and the whole was extracted with ether (5  $\times$  100 ml). The extract was dried ( $\text{K}_2\text{CO}_3$ ) and evaporated to leave 2-methyl-2-(3-oxobutyl)-cyclohexanone (6) as a pale yellow oil (1.43 g, 78%); t.l.c. (silica gel, 60% ether-petroleum) showed one spot. A portion was purified by prep. g.c. (10% OV-1, 170 °C);  $m/z$  182 ( $M^+$ ), 139, 115, 112, 111, and 97;  $\nu_{\text{max}}$  (film) 1 702, 1 420, 1 360, 1 360, 1 165, 1 122, and 918  $\text{cm}^{-1}$ ;  $\delta_{\text{H}}$  1.06 (3 H, s, quaternary methyl), 1.4–2.0 (8 H), 2.13 (3 H, s,  $\text{CH}_3\text{CO}$ ), 2.2–2.7 (4 H, m, C-6 and C-2 side-chain methylenes). The 2,4-dinitrophenylhydrazone had m.p. 207 °C (from tetrahydrofuran) (Found: C, 51.15; H, 4.55; N, 20.5.  $\text{C}_{23}\text{H}_{26}\text{N}_8\text{O}_8$  requires C, 50.92; H, 4.83; N, 20.66%).

The remaining material was dissolved in methanol (10 ml) and added rapidly to a stirred solution of sodium hydroxide (1.6 g) in boiled out methanol (30 ml)–water (40 ml) under nitrogen at 15 °C. After 3 h the mixture was saturated with sodium chloride and extracted with ether (5  $\times$  150 ml). The extracts were dried ( $\text{K}_2\text{CO}_3$ ) and evaporated to yield 9-methyl-1,2,6,7,8,9-hexahydronaphthalene-3(5H)-one (7) (63% overall); t.l.c. (silica gel, 50% ether-petroleum) one spot. A portion was purified by prep. g.c. (10% OV-1, 170 °C);  $m/z$  165 ( $M^+ + 1$ ), 164 ( $M^+$ ), 149, 136, 112, and 108;  $\nu_{\text{max}}$  (film) 3 020, 1 668, 1 614, 1 328, 1 260, and 1 225  $\text{cm}^{-1}$ ;  $\delta_{\text{H}}$  1.25 (3 H, s,  $\text{CH}_3$ ), 1.4–2.7 (12 H), and 5.74 (1 H, br s,  $\text{CH}=\text{CH}_2$ ). The 2,4-dinitrophenylhydrazone had m.p. 173 °C (from ethanol) (lit., m.p. 173–174 °C) (Found: C, 58.95; H, 5.78; N, 16.15. Calc. for  $\text{C}_{17}\text{H}_{20}\text{N}_4\text{O}_4$ ; C, 59.29; H, 5.85; N, 16.27%).

*(R)-(+)-2-(R-Buta-1,2-dienyl)-2-methylcyclohexanone (2)*.—Pure *(R)-(+)-but-3-yn-2-ol* was prepared as follows. The acid phthalate of the racemic alcohol was prepared from the alcohol (1 mol), phthalic anhydride (1 mol), triethylamine (2.25 mol), and 4-dimethylaminopyridine (0.01 mol). After 16 h, work-up gave the crude compound which was dissolved in chloroform and treated with *(R)-(+)-1-phenylethylamine* (molar ratio 1:0.7). The precipitated salt was collected and crystallised to m.p. 145 °C either from chloroform or from methanol–benzene. The <sup>1</sup>H n.m.r. spectrum showed a doublet ( $J$  2 Hz,  $\text{CHC}\equiv\text{CH}$ ) at  $\delta$  2.463; less pure material showed a second doublet at  $\delta$  2.496 due to the other diastereoisomer. The pure amine salt was treated in the usual way to liberate the crystalline acid phthalate which was steam-distilled from 20% aqueous sodium hydroxide. The distillate was extracted with ether to which was then added a small amount of anhydrous sodium sulphate. The whole was cooled to  $-50$  °C. The liquid decanted from the frozen slurry was further dried with a small amount of anhydrous potassium

carbonate and then evaporated (< 40 °C) to give (*R*)-(+)-but-3-yn-2-ol, b.p. 103 °C/750 mmHg,  $[\alpha]_D^{17} + 55.1^\circ$  (ether, *c* 1.5). The allenic ketone prepared from the above alcohol had  $[\alpha]_D^{17} + 42.2^\circ$  (ether, *c* 0.6);  $\delta_C$ (62.896 MHz) for the major isomer 212.20 (CO), 203.68 (=C=), 95.91 (=CH), 88.34 (=CH), 49.49 (quaternary carbon), 39.78 (CH<sub>2</sub>), 38.90 (CH<sub>2</sub>), 27.39 (CH<sub>2</sub>), 24.20 (CH<sub>3</sub>CH=), 21.59 (CH<sub>2</sub>), 13.93 (CH<sub>3</sub>C) and for the minor isomer 212.29, 203.61, 96.09, 88.34, 49.45, 39.84, 38.83, 27.39, 24.20, 21.63, and 13.85. Comparison of the summed intensities of the first three signals for each isomer gave a product ratio of 80.5 to 19.5.

2-(*trans*-But-2-enyl)-2-methylcyclohexanone (**10**), (**14a**).—Under nitrogen, (±)-but-3-en-2-ol (14.4 g) was added dropwise during 15 min to a stirred mixture of 2-methylcyclohexanone methyl enol ether (**4a**) (43.2 g) and toluene-*p*-sulphonic acid (0.2 g) in a three-necked flask fitted with a reflux condenser and a variable take-off head. The temperature was raised to 95 °C during 4 h (methanol evolved) and maintained there for a further 4 h. To the cooled (50 °C) mixture, 10% aqueous sulphuric acid (50 ml) and dioxane (50 ml) were added (to hydrolyse the methyl enol ether of the product which is also formed) and after 2 h the mixture was cooled to 20 °C and thoroughly extracted with petroleum. Distillation gave a colourless oil (27.7 g, 83%), b.p. 52 °C/0.05 mmHg. The pure *trans*-ketone was obtained (62%) by chromatography on silica gel (0–20% ether—petroleum) and equally well by preparation of the *semicarbazone*, m.p. 201 °C (from ethanol–chloroform) (Found: C, 64.3; H, 9.5; N, 18.8. C<sub>12</sub>H<sub>21</sub>N<sub>3</sub>O requires C, 64.54; H, 9.48; N, 18.82%) and hydrolysis (1 g:10 ml) with hot 20% aqueous oxalic acid (64% yield), g.c. single peak on 10% OV-1 at 165 °C; *m/z* 166 (*M*<sup>+</sup>), 151, 112, 109, 108, and 97; *v*<sub>max</sub> (film) 3 020, 1 704, 1 312, 1 122, and 975 cm<sup>-1</sup>;  $\delta_H$ (360 MHz) 1.04 (3 H, s, quaternary methyl), 1.64 (3 H, dd, *J* 1.5 and 7 Hz, CH<sub>3</sub>CH=CH), 5.31 (1 H, m, CH<sub>3</sub>CH=CH), and 5.41 (1 H, m, CH<sub>3</sub>CH=CH); on irradiation at  $\delta$  1.61, the 5.41 multiplet became a doublet, *J* 15 Hz;  $\delta_C$ (62.986 MHz) 214.45 (CO), 128.20 (CH=), 126.29 (CH=), 48.61 (quaternary carbon), 40.75 (CH<sub>2</sub>), 38.80 (CH<sub>2</sub>), 38.73 (CH<sub>2</sub>), 27.49 (CH<sub>2</sub>), 22.70 (CH<sub>3</sub>CH=), 21.20 (CH<sub>2</sub>), and 17.94 (CH<sub>3</sub>C). The 2,4-dinitrophenylhydrazone had m.p. 152 °C (lit.,<sup>18</sup> prepared by a different route, m.p. 149 °C) (Found: N, 16.1. Calc. for C<sub>17</sub>H<sub>22</sub>N<sub>4</sub>O<sub>4</sub>: N, 16.18%). The *ethylenedioxy ketal* was prepared (81%) from the ketone, ethyleneglycol, and toluene-*p*-sulphonic acid in benzene and a portion purified by prep. g.c. on 10% OV-17 (Found: C, 74.45; H, 10.6. C<sub>13</sub>H<sub>22</sub>O<sub>2</sub> requires C, 74.24; H, 10.54%). The <sup>13</sup>C n.m.r. spectrum (62.896 MHz) of the oil prior to purification showed the following signals for the *cis*-isomer (**11**):  $\delta_C$  212.82, 128.48, 126.87, 50.88, 45.57, 37.52, 34.79, 32.58, 25.65, 17.88, and 14.59.

2-(1-Bromoethyl)-7a-hydroxy-3a-methyl-2,3,3a,4,5,6,7,7a-octahydrobenzofuran (**15a**).—A stirred solution of the racemic *trans*-ketone (**14a**) (1 g) in dioxane (15 ml) and water (3 ml) at 0 °C was treated dropwise with a 10% solution of bromine in 1,2-dimethoxyethane. Uptake was rapid and ceased abruptly at 1 mol. Ethylene was passed through the solution for 1 min. After addition of water the product was extracted into petroleum. Evaporation of the extract and crystallisation of the residue from dioxane, gave the product m.p. 97 °C (1.28 g, 81%) (Found: C, 50.1; H, 7.5; Br, 30.2. C<sub>11</sub>H<sub>19</sub>BrO<sub>2</sub> requires C, 50.20; H, 7.28; Br, 30.36%); *m/z* 263, 261 (*M*<sup>+</sup> - 1), 246, 244, 218, 216, and 155; *v*<sub>max</sub> (KBr) 3 390, 1 180, 1 160, 1 130, 1 085, 980, and 953 cm<sup>-1</sup>;  $\delta_H$  1.10 (3 H, s, quaternary methyl), 1.2–2.3 (13 H containing  $\delta$  1.74, d, *J* 6.5 Hz, CH<sub>3</sub>CH), 2.4 (1 H, br s, OH), and 4.02–4.20 (2 H, m, CHBr and CHO);  $\delta_C$  (62.896 MHz) 106.65 (COH), 79.98 (CHBr), 53.28 (CHO), 44.09 (CH<sub>2</sub>), 43.30 (quaternary carbon), 38.38 (CH<sub>2</sub>), 33.91 (CH<sub>2</sub>), 23.43 (CH<sub>2</sub>), 23.33 (CH<sub>3</sub>CH), 22.13 (CH<sub>2</sub>), and 19.93 (CH<sub>3</sub>C).

*Chiral* 2-(*trans*-But-2-enyl)-2-methylcyclohexanones.—The resolution of racemic but-3-en-2-ol was carried out in similar fashion to that of but-3-yn-2-ol. The (*R*)-(+)-1-phenylethylamine salt of the acid phthalate ester was crystallised to m.p. 152 °C (from acetone) and converted into pure (*R*)-(-)-but-3-en-2-ol, b.p. 96 °C/750 mmHg,  $[\alpha]_D^{20} - 25.0^\circ$  (ether, *c* 0.8). Resolution using (*S*)-(-)-1-phenylethylamine gave (*S*)-(+)-but-3-en-2-ol,  $[\alpha]_D^{18} + 25.2^\circ$  (ether, *c* 0.8) (Kenyon and Snellgrove<sup>19</sup> obtained values of -33.7° and +33.9° for these compounds measured for the neat materials). Racemic but-3-en-2-ol has a methyl doublet at  $\delta_H$  1.28, *J* 7 Hz; in the presence of 0.12 molar proportion of tris[trifluoroacetyl-(+)-camphorato]-europium(III) two equal intensity doublets appear at 2.59 and 2.61. (*S*)-(+)-But-3-en-2-ol treated similarly gave only one doublet at  $\delta_H$  2.61; the *R*-isomer likewise gave only one methyl doublet.

The reaction of (*R*)-(-)-but-3-en-2-ol with 2-methylcyclohexanone methyl enol ether yielded (*R*)-(+)-2-(*trans*-but-2-enyl)-2-methylcyclohexanone (**10**),  $[\alpha]_D^{21} + 52.6^\circ$  (ether, *c* 0.3),  $[\alpha]_D^{21} + 52.1^\circ$  (chloroform, *c* 1.0). The 2,4-dinitrophenylhydrazone had m.p. 144 °C (Found: C, 58.85; H, 6.0; N, 16.05. C<sub>17</sub>H<sub>22</sub>N<sub>4</sub>O<sub>4</sub> requires C, 58.94; H, 6.40; N, 16.18%). The *semicarbazone* had m.p. 204 °C (from ethanol). (*S*)-(+)-But-3-en-2-ol reacted with 2-methylcyclohexanone methyl enol ether to give (*S*)-(-)-2-(*trans*-but-2-enyl)-2-methylcyclohexanone (**14a**),  $[\alpha]_D^{25} - 53.1^\circ$  (ether, *c* 0.4),  $[\alpha]_D^{25} - 52.5^\circ$  (chloroform, *c* 0.9). The 2,4-dinitrophenylhydrazone had m.p. 143 °C.

*Wacker Oxidation of* 2-(*trans*-But-2-enyl)-2-methylcyclohexanone.—Palladium chloride (0.354 g), copper(II) chloride (0.340 g), deionised water (1 ml), and dimethylformamide (5 ml) were mixed in a three-necked flask equipped with a magnetic stirrer, gas inlet tube, injection septum, and reflux condenser. The flask was maintained at 70 °C and a steady stream of oxygen was passed through the mixture while the keto-olefin (3.32 g) was added in 200  $\mu$ l quantities over 150 min. After a further hour the mixture was cooled, water added, and the product extracted into ether. G.c. (10% OV-1, 170 °C) established the presence of starting material (37%) and two new products (57 and 6%). After addition of water (25 ml) the mixture was extracted with petroleum (2  $\times$  100 ml) and then ether (2  $\times$  100 ml) Evaporation left a brown oil which was chromatographed on silica gel (300 g, 0–25% ether–petroleum) to give 2-methyl-2-(3-oxobutyl)cyclohexanone (0.15 g, 4%), identical with previously obtained material, and 2-methyl-2-(2-oxobutyl)cyclohexanone (**12**) (1.86 g, 51%) (73% if based on recovered keto-olefin); *m/z* 182 (*M*<sup>+</sup>), 88, 86, and 84; *v*<sub>max</sub> (film) 1 705, 1 410, 1 288, 1 128, and 920 cm<sup>-1</sup>;  $\delta_H$  0.98 (3 H, t, *J* 8 Hz, CH<sub>2</sub>CH<sub>3</sub>), 1.11 (3 H, s, quaternary methyl), 1.5–2.2 (6 H), m.p. 2.22–3.0 (6 H). The 2,4-dinitrophenylhydrazone had m.p. 202 °C (from ethyl acetate) (Found: C, 50.7; H, 4.8; N, 20.45. C<sub>23</sub>H<sub>26</sub>N<sub>8</sub>O<sub>8</sub> requires C, 50.92; H, 4.83; N, 20.66%). The compound was cyclised as for the 3-oxo-isomer and gave 1,3a-dimethyl-3,3a,4,5,6,7-hexahydroinden-2-one (**13**) (87%); *m/z* 165 (*M*<sup>+</sup> + 1), 164 (*M*<sup>+</sup>), 149, 121, and 93; *v*<sub>max</sub> (film) 1 698, 1 648, 1 440, and 1 410 cm<sup>-1</sup>;  $\delta_H$  1.22 (3 H, s, 3a-Me), and 1.3–2.7 (10 H containing  $\delta$  1.64, s, 1-Me). The 2,4-dinitrophenylhydrazone had m.p. 203 °C (Found: C, 59.3; H, 5.9; N, 16.3. C<sub>17</sub>H<sub>20</sub>N<sub>4</sub>O<sub>4</sub> requires C, 59.29; H, 5.85; N, 16.27%). Wacker oxidation of (*R*)-(+)-2-(*trans*-but-2-enyl)-2-methylcyclohexanone (**10**) was conducted as for the racemate and produced (*R*)-(-)-4a-methyl-4,4a,5,6,7,8-hexahydro-3H-naphthalene-2-one (**7**),  $[\alpha]_D^{25} - 188^\circ$  (ethanol, *c* 0.4) and (*R*)-(-)-1,3a-dimethyl-3,3a,4,5,6,7-hexahydroinden-2-one (**13**),  $[\alpha]_D^{25} - 12^\circ$  (ethanol, *c* 0.3).

(*S*)-2-(*trans*-But-2-enyl)-2-methylcyclohexanols (**14b**).—(*S*)-2-(*trans*-But-2-enyl)-2-methylcyclohexanone (**14a**) (10 g) in methanol (180 ml) was added during 20 min to a stirred solution

of sodium borohydride (2.4 g) and sodium hydroxide (2 g) in water (150 ml) and methanol (150 ml) at 10 °C. After 3 h, water (300 ml) was added and the solution extracted with petroleum (8 × 100 ml). Drying and evaporation of the extract yielded (9.6 g, 94%) a dextrorotatory mixture of alcohols, a sample of which was purified by prep. g.c. (10% OV-17, 148 °C, single peak) (Found: C, 78.7; H, 12.25. C<sub>11</sub>H<sub>20</sub>O requires C, 78.51; H, 11.98%; *m/z* 168 (*M*<sup>+</sup>), 150, 113, 112, and 95; *v*<sub>max</sub> (film) 3 400, 1 060, 1 040, and 970 cm<sup>-1</sup>; *δ*<sub>H</sub> 0.87 and 0.93 (3 H, quaternary methyls), 0.95–2.06 (14 H), 3.36 (1 H, m, CHO), and 5.47 (2 H, m, CH=CH).

The *methoxymethyl ethers* were prepared from the alcohols (1 mol), *N*-ethyl-di-isopropylamine (3 mol), and chloromethyl methyl ether (5.5 mol) (88%) (Found: C, 73.7; H, 11.75. C<sub>13</sub>H<sub>24</sub>O<sub>2</sub> requires C, 73.53; H, 11.39%).

The *methyl ethers* were prepared from the alcohols (1 mol), sodium methylsulphinyl methanide (6.5 mol) in dimethyl sulphoxide, and methyl iodide (5 mol) (94%) (Found: C, 79.4; H, 12.45. C<sub>12</sub>H<sub>22</sub>O requires C, 79.10; H, 12.22%).

The *acetates* of the alcohols were prepared in the usual way (Found: C, 74.3; H, 10.55. C<sub>13</sub>H<sub>22</sub>O<sub>2</sub> requires C, 74.24; H, 10.54%).

(*S*)-2-(*trans*-But-2-enyl)-2-methylcyclohexyl adamantane-1-carboxylates (**14d**) were prepared by adding adamantane-1-carbonyl chloride (1.36 g) to a stirred solution of the alcohols (1 g) in methylene dichloride (30 ml) and pyridine (3 ml) at 20 °C. After 16 h 2M hydrochloric acid was added and the product extracted into petroleum. Work-up gave an oil which was stirred with 40% aqueous methanolic potassium hydroxide for 2 h. Addition of water and extraction into petroleum gave the esters (1.39 g, 71%). A portion was chromatographed (silica gel, 0–20% ether–petroleum) (Found: C, 79.9; H, 10.6. C<sub>22</sub>H<sub>34</sub>O<sub>2</sub> requires C, 79.95; H, 10.37%; *m/z* 330 (*M*<sup>+</sup>) 316, 276, 181, 163, and 151; *v*<sub>max</sub> (film) 1 722, 1 340, 1 320, 1 265, and 1 235 cm<sup>-1</sup>; *δ*<sub>H</sub> 0.87 and 0.915 (3 H, both s, quaternary methyls), 1.1–2.1 (28 H), 4.58 (1 H, m, CHO–), and 5.39 (2 H, m, CH=CH).

(*S*)-2-(*trans*-But-2-enyl)-2-methylcyclohexyl 2,4,6-Trimethylbenzoate (**14c**).—The reaction between 2,4,6-trimethylbenzoyl chloride and the alcohols in methylene dichloride–pyridine produced a mixture of compounds one of which was 2,4,6-trimethylbenzoic anhydride, m.p. 106 °C. The following method was eminently more satisfactory. A solution of the alcohols (10 g) in petroleum (100 ml) and ether (50 ml) was added to a stirred solution of freshly prepared 2,4,6-trimethylbenzoyl chloride (12.90 g) in ether (150 ml) and petroleum (50 ml) under dry nitrogen (20 °C) during 15 min. After 4 h, the solvent was expelled by a stream of nitrogen, and after a further 4 h the oily product was treated with 40% potassium hydroxide in methanol–water (1:1), and the mixture stirred for 16 h. Addition of water and extraction with petroleum gave an oil (17.72 g, 95%). A portion was chromatographed (silica gel, 0–20% ether–petroleum) (Found: C, 80.15; H, 9.8. C<sub>21</sub>H<sub>30</sub>O<sub>2</sub> requires C, 80.21; H, 9.62%; *m/z* 314 (*M*<sup>+</sup>), 167, 151, 148, 135, 121, and 108; *v*<sub>max</sub> (film) 1 720, 1 610, 1 260, 1 170, 1 120, and 980 cm<sup>-1</sup>; *δ*<sub>H</sub> 0.92, 0.95 (3 H, singlets, quaternary methyls) 1.05–2.40 (22 H), 4.92 (1 H, m, CHO), 5.41 (2 H, m, CH=CH), and 6.84 (2 H, s, aromatic protons).

(*S*)-2-(2,3-Dibromobutyl)-2-methylcyclohexyl 2,4,6-Trimethylbenzoate (**17**).—A stirred solution of the above compounds (15.02 g) in carbon tetrachloride (350 ml) was treated dropwise at 0 °C under nitrogen with a 10% solution of bromine in carbon tetrachloride. Uptake ceased at 1 mol. Ethylene was bubbled through the solution for 1 min. Evaporation gave the dibromo compound (22.60 g, 100%). A sample was purified by rapid chromatography on silica gel, 0–40% benzene–petroleum.

(Found: C, 52.8; H, 6.45. C<sub>21</sub>H<sub>30</sub>Br<sub>2</sub>O<sub>2</sub> requires C, 53.18; H, 6.40%; *v*<sub>max</sub> (film) 1 715, 1 610, 1 260, and 1 170 cm<sup>-1</sup>; *δ*<sub>H</sub> 1.0–2.17 (13 H, containing at *δ* 1.04, 1.12, and 1.25 quaternary methyl singlets), 2.25–2.46 (12 H, 4 × CH<sub>3</sub>), 4.14 (2 H, m, CHBrCHBr), 4.89 (1 H, m, CHO), and 6.83 (2 H, s, aromatic protons).

(*S*)-2-(3-Bromobut-2-enyl)-2-methylcyclohex-1-yl 2,4,6-Trimethylbenzoates (**18**).—The dibromo adduct (20 g) in *t*-butyl alcohol (200 ml) was treated dropwise at 10 °C under nitrogen to a vigorously stirred solution of potassium *t*-butoxide (30 g) in *t*-butyl alcohol (300 ml). The mixture became viscous; after 10 h water (400 ml) was added and the mixture rotary-evaporated (15 mmHg) to remove *t*-butyl alcohol. The residue was extracted with petroleum and the extract dried and evaporated to give the product as a viscous liquid (13.93 g, 84%) which turned purple at room temperature. A sample was chromatographed rapidly (silica gel, 0–30% ether–petroleum) (Found: C, 64.8; H, 7.55. C<sub>21</sub>H<sub>29</sub>BrO<sub>2</sub> requires C, 64.12; H, 7.43%; *m/z* 394, 392 (both *M*<sup>+</sup>), 313, 312, 311, 164, and 149; *v*<sub>max</sub> (film) 1 720, 1 610, 1 270, 1 170, 1 080, 980, and 850 cm<sup>-1</sup>; *δ*<sub>H</sub> 0.95–2.37 (27 H containing 0.96, 0.99, 1.27, and 1.29 quaternary methyls), 2.23 (3 H, br s, CH<sub>3</sub>CBr=), 2.29 (9 H, br s, aromatic methyls), 4.93 (1 H, m, CHO), and 5.88 (1 H, m, CH=).

(*S*)-2-(*But*-3-ynyl)-2-methylcyclohexanols (**19a**).—To soda-mide, prepared from sodium (7.2 g) was added a solution of the bromobutenyl esters (12 g) in petroleum (60 ml). The petroleum was then evaporated in a slow stream of nitrogen and the mixture gently heated until reaction ensued (*ca.* 130 °C). On cooling butan-2-ol containing *ca.* 10% of water was added to destroy the excess of sodamide. After addition of water the mixture was extracted with petroleum (6 × 100 ml), and the combined extracts, were dried and evaporated. G.c. (10% OV-17, 145 °C) of the residue indicated two components, which were separately collected by Kugelrohr distillation. The one was mesitylene, identified by comparison with an authentic specimen, the other the title compounds, b.p. 115–117 °C/0.15 mmHg (3.36 g, 67%) (Found: C, 79.5; H, 11.0. C<sub>11</sub>H<sub>18</sub>O requires C, 79.46; H, 10.92%; *m/z* 166 (*M*<sup>+</sup>), 152, 133, 113, and 112; *v*<sub>max</sub> (film) 3 400, 3 280, 2 110, 1 065, and 1 050 cm<sup>-1</sup>; *δ*<sub>H</sub> 0.878, 0.944 (3 H, singlets, quaternary methyls), 1.02–2.2 (14 H), and 3.41 (1 H, m, CHO).

(*S*)-2-(*But*-3-ynyl)-2-methylcyclohexanone (**19b**).—To a three-necked flask fitted with a septum and a nitrogen inlet was added a solution of oxalyl chloride (2.40 g) in methylene dichloride (50 ml). The magnetically stirred solution was cooled to –67 °C and treated in 400 μl quantities with a solution of dimethyl sulphoxide (2.90 g) in methylene dichloride (10 ml). The alcohols (2.82 g) in methylene dichloride (5 ml) were then injected during 3 min. After 20 min triethylamine (18 ml) was added and the mixture allowed to warm to room temperature. Water was added and the mixture extracted with petroleum. The extracts were dried and evaporated; Kugelrohr distillation of the residue then gave the acetylenic ketone, b.p. 99 °C/0.02 mmHg (2.61 g, 94%). The compound gave a single peak on g.c. (2% OV-17, 150 °C); [*α*]<sub>D</sub><sup>20</sup> –64.1° (chloroform, *c* 1.0) Marshall and Flynn<sup>20</sup> give [*α*]<sub>D</sub><sup>20</sup> –37.3° for an optically impure specimen of this compound (Found: C, 80.1; H, 9.95. C<sub>11</sub>H<sub>16</sub>O requires C, 80.44; H, 9.83%; *m/z* 164 (*M*<sup>+</sup>), 113, 112, 105, and 97; *v*<sub>max</sub> (film) 3 280, 2 115, 1 704, 1 380, 1 312, and 1 122 cm<sup>-1</sup>; *δ*<sub>H</sub> 1.077 (3 H, s, quaternary methyl), 1.15–2.6 (13 H, containing t, *δ* 1.95, *J* 2.7 Hz, CH<sub>2</sub>C≡CH).

The 2,4-dinitrophenylhydrazone had m.p. 112–113 °C (from ethanol) (Found: C, 59.15; H, 6.0; N, 16.1. C<sub>17</sub>H<sub>20</sub>N<sub>4</sub>O<sub>4</sub> requires C, 59.29; H, 5.85; N, 16.27%). With tris[3-trifluoroacetyl-(+)-camphorato]europium(III) in deuteriochloroform the

quaternary methyl signal of the ketone remained a singlet; the racemic compound gave two peaks of equal intensity.

(*S*)-9-Methyl-1,2,6,7,8,9-hexahydronaphthalene-3(5*H*)-one (**20**) was prepared from the above ketone as for the racemate. The compound had  $[\alpha]_D^{20} + 198^\circ$  (ethanol, *c* 0.8).

(*R*)-2-Butyl-2-methylcyclohexanone.—The (*S*)-ketone above (0.5 g) in ethanol (3 ml) was added to 5% palladium charcoal (0.03 g) in ethanol (3 ml) under hydrogen. On gentle shaking uptake of gas was rapid (10 min) and was virtually quantitative. The product was purified by prep. g.c. (10% OV-17, 155 °C),  $[\alpha]_D^{20} - 73.2^\circ$  (chloroform, *c* 1.4). Marshall and Flynn<sup>20</sup> give  $-20.9^\circ$  for an impure specimen of this compound (Found: C, 78.65; H, 12.15. C<sub>11</sub>H<sub>20</sub>O requires C, 78.51; H, 11.98%); *m/z* 169 (*M*<sup>+</sup> + 1), 168 (*M*<sup>+</sup>), 125, 113, 112, 97, and 95;  $\nu_{\max}$  (film) 1 708, 1 420, 1 310, 1 125, 985, and 900 cm<sup>-1</sup>;  $\delta_H$  0.89 (3 H, t, *J* 6.5 Hz, CH<sub>3</sub>CH<sub>2</sub>) 1.03 (3 H, s, quaternary methyl), 1.10–1.95 (12 H), 2.25–2.45 (2 H, m, CH<sub>2</sub>CO). The 2,4-dinitrophenylhydrazone had m.p. 128 °C (from ethanol). The 2,4-dinitrophenylhydrazone of the racemate had m.p. 148 °C (from ethanol) (Found: C, 58.35; H, 7.1; N, 16.0. C<sub>17</sub>H<sub>24</sub>N<sub>4</sub>O<sub>4</sub> requires C, 58.60; H, 6.94; N, 16.09%).

(*S*)-2-(*But-2-ynyl*)-2-methylcyclohexyl 2,4,6-Trimethylbenzoates (**21a**).—The dibromotrimethylbenzoates (**17**) (2.5 g) in anhydrous dimethylformamide (25 ml) were added during 15 min to a stirred solution of potassium *t*-butoxide (4 g) in dimethylformamide (60 ml) under nitrogen at 15 °C. After 3 h, water (100 ml) was added and the mixture thoroughly extracted with petroleum. The extract was dried and evaporated to give the acetylenic esters (1.43 g, 87%). Chromatography of a portion (silica gel, 0–40% benzene–petroleum) gave pure material (Found: C, 80.35; H, 9.3. C<sub>21</sub>H<sub>28</sub>O<sub>2</sub> requires C, 80.73; H, 9.03%); *m/z* 312 (*M*<sup>+</sup>), 297, 165, 148, 133, and 119;  $\nu_{\max}$  (film) 1 720, 1 610, 1 260, 1 165, 980, and 850 cm<sup>-1</sup>;  $\delta_H$  0.98, 1.10 (3 H, singlets, quaternary methyls), 1.11–2.50 (22 H), 5.04 (1 H, m, CHO–), and 6.83 (2 H, s, aromatic protons);  $\delta_C$  (62.896 MHz) 78.10, 77.55, 75.81, and 75.51 (C≡C × 2).

(*S*)-2-(*But-2-ynyl*)-2-methylcyclohexanols (**21b**).—(a). Sodium hydride dispersion in oil was treated with petroleum under nitrogen in a glove box to leave after decanting and drying 0.95 g of material which was dissolved in dimethyl sulphoxide (25 ml). To the magnetically stirred solution (*S*)-2-(3-bromobut-2-enyl)-2-methylcyclohexyl 2,4,6-trimethylbenzoates (**18**) (1.5 g) in the minimum quantity of petroleum was added. After 14 h, ice was added and the product isolated by extraction into petroleum, which was dried and evaporated to yield the title compound (0.41 g, 64%). A portion was purified by g.c. (10% OV-17, 145 °C) (Found: C, 79.1; H, 11.0. C<sub>11</sub>H<sub>18</sub>O requires C, 79.46; H, 10.92%); *m/z* 166 (*M*<sup>+</sup>), 148, 133, 113, 112, and 95  $\nu_{\max}$  (film) 3 400, 1 135, 1 055, 1 035, and 985 cm<sup>-1</sup>;  $\delta$  0.94, 1.05 (3 H, singlets, quaternary methyls), 1.1–2.2 (14 H), and 3.51 (1 H, m, CHO–);  $\delta_C$  78.07, 77, 56, 76.91, and 76.72 (C≡C × 2).

(b). (*S*)-2-(*But-2-ynyl*)-2-methylcyclohexyl 2,4,6-trimethylbenzoates (**21a**) (1 mol) were treated with sodium methylsulphinyl methanide (8 mol) in dimethyl sulphoxide as above and gave (84%) the alcohols (**21b**). Similarly compounds (**17**), (**14c**), and (**14d**) were converted into (*S*)-2-(but-2-enyl)-2-methylcyclohexanols (**14b**) in yields of 77, 88, and 92% respectively.

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