Bacterial Carotenoids. XLVIII.* Total Syntheses of Carotenes of the 1,2-Dihydro Series

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The total syntheses of 1,2,7,8,1',2',7',8'-octahydro-\(\gamma,\gamma\)-carotene (1), 1,2,7,8-tetrahydro-\(\gamma,\gamma\)-carotene (2), 1,2,1',2'-tetrahydro-\(\gamma,\gamma\)-carotene (3), 1,2-dihydro-\(\gamma,\gamma\)-carotene (4), 1,2-dihydro-3,4-didehydro-\(\gamma,\gamma\)-carotene (5), and 1,2,1',2'-tetrahydro-3,4,3',4'-tetrahydro-\(\gamma,\gamma\)-carotene (6) are described. The properties of products and intermediates, including the three new apocarotenals 1,2,7,8-tetrahydro-12'-apo-\(\gamma,\gamma\)-caroten-12'-al (20), 1,2-dihydro-3'-apo-\(\gamma,\gamma\)-caroten-8'-al (25), and 1,2-dihydro-3,4-didehydro-8'-apo-\(\gamma,\gamma\)-caroten-8'-al (32), are reported.

A fragment ion at M−68 on electron impact appears to be characteristic for carotenoids with a 1,2,7,8-tetrahydro end-group.

A photosynthetic bacterium isolated by Eimhjellen and subsequently named \textit{Rhodopseudomonas viridis} was initially considered to contain common aliphatic carotenoids, mainly neurosporene. However, Malothra et al., demonstrated that common aliphatic carotenoids were only minor constituents, the major carotenes were of a novel 1,2-dihydro (1,2,1',2'-tetrahydro) aliphatic series, both in normal cells and cells grown in the presence of diphenylamine.

Due to the restricted quantities available some of these carotenoids were identified on the basis of their visible light absorptions and fragmentation patterns on electron impact alone. Total synthesis have now been performed in order to allow full physical characterization.

The synthesis of the lycopene derivatives 3 and 4 has previously been reported in a priority note. We now describe in full the preparations of the series 1−6.

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RESULTS AND DISCUSSION

The synthesis of 1,2,7,8,1',2',7',8'-octahydro-\(\gamma,\gamma\)-carotene (1) and 1,2,7,8-tetrahydro-\(\gamma,\gamma\)-carotene (2) is summarized in Scheme 1.

Methylheptenone (7) was hydrogenated in the presence of palladium catalyst to give the saturated ketone 8. Reaction of 8 with vinyl magnesium bromide gave the tertiary allylic alcohol 9 which was converted to the primary allylic bromide 10 with phosphorus tribromide. Condensation of 10 with acetooacetic ester gave 11 which was hydrolyzed and decarboxylated directly to give dihydrogeranylacetate (12). Horner condensation of 12 with ethyl diethylphosphonoacetate gave the conjugated ester 13 which was reduced to the allylic alcohol 14 with LiAlH₄ and subsequently converted to the phosphonium salt 15 with triphenylphosphonium bromide.

Similarly pseudoionone (16) was converted to the phosphonium salt 18 via the tertiary alcohol 17.

Wittig condensation of the ylid of 15 with the \(\text{C}_{18}\)-dialdehyde 19 gave a mixture of 1,2,7,8,1',2',7',8'-octahydro-\(\gamma,\gamma\)-carotene (1, with heptaene chromophore) and the \(\text{C}_{20}\)-aldehyde 20 which were separated by chromatography. The \(\text{C}_{20}\)-aldehyde 20 was subsequently condensed with the ylid of the phosphonium salt 18 in a second Wittig reaction to 1,2,7,8-tetrahydro-\(\gamma,\gamma\)-carotene (2, with nonaene chromophore).

1,2,1',2'-Tetrahydro-\(\gamma,\gamma\)-carotene (3) and 1,2-dihydro-\(\gamma,\gamma\)-carotene (4) were synthesized as depicted in Scheme 2:
Scheme 1.

The saturated ketone 8 was condensed with ethyl diethylphosphonoacetate in a Horner reaction to give the unsaturated ester 21 which was reduced with LiAlH₄ to dihydrogeraniol (22), in turn converted to the phosphonium salt 23 with triphenylphosphonium bromide. Wittig condensation of the ylid of 23 with crocetindial (24) gave a mixture of 1,2,1',2'-tetrahydro-\(\beta\),\(\gamma\)-carotene (3, with undecaene chromophore) and the \(C_{20}\)-carotenal 25 which were separated by chromatography. A second Wittig condensation of 25 with geranyltropolynaphosphonium bromide (26) provided the lycoene derivative 1,2-dihydro-\(\beta\),\(\psi\)-carotene (4). The physical properties of 3, 4, and 25 are compiled in Tables 1–3. The preparation of 1,2-dihydro-3,4-didehydro-\(\beta\),\(\psi\)-carotene (5, with dodecaene chromophore) and 1,2,1',2'-tetrahydro-3,4,3',4'-tetradehydro-\(\beta\),\(\psi\)-carotene (6, with tridecaene chromophore) was accomplished as depicted in Scheme 3:

Horner condensation of isovaleraldehyde (27) and the phosphonate 28 gave the conjugated ester 29 which gave the allylic alcohol 30 on reduction with LiAlH₄. Treatment of 30 with triphenylphosphonium bromide resulted in the phosphonium salt 31, the ylid of which was condensed with crocetindial (24) in a Wittig reaction to give a mixture of 6 and the apo-carotenal 32. Separation of these products by chromatography and subsequent Wittig condensation of 32 with the ylid of geranyltri-
Scheme 2.

Scheme 3.

phenylphosphonium bromide (26) gave 5.

The IR spectra of the hydrocarbons 1–6, as well as of the apo-carotenals 20, 25 and 32 were not informative and only normal carotenoid CH absorptions as well as carbonyl frequencies for the apo-carotenals were observed.

The visible light properties were all consistent with those observed for the analogues of the common aliphatic series. Certain deviations in extinction coefficients and spectral fine-structure may be due to the purity of the samples.

In the $^1$H NMR spectra the only characteristic feature is a six proton doublet at ca. δ 0.88 caused by the isopropyl end group coupled to the C-1 methine proton. All other signals were in close agreement with those observed for the common analogues.

The mass spectra (Table 1) all showed fragments derived by in-chain eliminations (Table

**Table 1.** Fragmentations induced by electron impact of carotenoids of the 1,2-dihydro series.

### A. In-chain eliminations.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Molecular ion m/e (rel.int.)</th>
<th>Relative intensity of fragments</th>
<th>Base peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>544 (100)</td>
<td>15.3  -</td>
<td>544</td>
</tr>
<tr>
<td>2</td>
<td>540 (100)</td>
<td>12.2  0.4</td>
<td>540</td>
</tr>
<tr>
<td>3</td>
<td>540 (57)</td>
<td>-</td>
<td>43</td>
</tr>
<tr>
<td>4</td>
<td>538 (100)</td>
<td>-</td>
<td>538</td>
</tr>
<tr>
<td>5</td>
<td>536 (25)</td>
<td>-</td>
<td>91</td>
</tr>
<tr>
<td>6</td>
<td>536 (55.5)</td>
<td>-</td>
<td>69</td>
</tr>
<tr>
<td>20</td>
<td>354 (100)</td>
<td>21</td>
<td>354</td>
</tr>
<tr>
<td>25</td>
<td>418 (100)</td>
<td>0.8</td>
<td>418</td>
</tr>
<tr>
<td>32</td>
<td>416 (34.5)</td>
<td>-</td>
<td>91</td>
</tr>
</tbody>
</table>

### B. In-chain cleavages.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Losses from the molecular ion [x, (rel. int.)] derived by cleavage of bond</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>139(5.1)  207(0.9)</td>
</tr>
<tr>
<td>2</td>
<td>139(1.8)  207(0.5)</td>
</tr>
<tr>
<td>3</td>
<td>139(1.0)  205(1.5)</td>
</tr>
<tr>
<td>4</td>
<td>139(0.7)  205(1.3)</td>
</tr>
<tr>
<td>5</td>
<td>137(9.8)  -</td>
</tr>
<tr>
<td>6</td>
<td>139(82)   207(24.6)</td>
</tr>
<tr>
<td>20</td>
<td>139(1.3)  205(2.6)</td>
</tr>
<tr>
<td>25</td>
<td>139(1.3)  205(2.6)</td>
</tr>
<tr>
<td>32</td>
<td>139(1.3)  205(2.6)</td>
</tr>
</tbody>
</table>

### C. Other losses.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Expelled fragments [M – x, (rel. int.)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>M – 80(0.5)</td>
</tr>
<tr>
<td>6</td>
<td>M – 24(1.2), M – 26(0.4), M – 40(1.8), M – 66(1.9), M – 68(0.9), M – 132(0.8), M – 175(2.9)</td>
</tr>
<tr>
<td>20</td>
<td>M – 15(0.6), M – 29(0.5), M – 83(1.0), M – 85(0.7), M – 113(2.0), M – 126(12.3)</td>
</tr>
<tr>
<td>25</td>
<td>M – 16(0.7), M – 28(0.4), M – 29(0.4), M – 83(0.7), M – 85(0.7), M – 113(0.7), M – 121(0.7), M – 135(1.0), M – 137(0.8)</td>
</tr>
<tr>
<td>32</td>
<td>M – 40(0.7), M – 54(0.9), M – 66(1.4), M – 120(1.2)</td>
</tr>
</tbody>
</table>
For I only the loss of 92 (toluene) mass units (m.u.) was observed in agreement with its structure and the accepted mechanism for these fragmentations. The other C₉⁻compounds all exhibited losses of 79 (methylcyclopentadienyl), 92 (toluene), 106 (xylene), and 158 (dimethylcyclooctaene) m.u. except for 6 which only exhibited losses of 92 and 106 m.u. The C₉⁻carotenals 25 and 32 exhibited losses of 92 and 106 m.u. but no loss of 158 m.u. was observed.

Diagnostic important fragments derived by in-chain cleavages of the 3,4; 7,8; 11,12; 15,16'; 11',12'; 7,8' and 3',4' bonds were also observed (Table 1 B). For compounds 1-4, 20, and 25 these fragments are observed at 2 m.u. higher than the corresponding fragments of the common aliphatic (1,2-ene) analogues.

For the carotenones 1 and 2 and the apocarotenal 20 a relatively strong fragment ion M-68 (Table 1), previously not encountered in carotenoid mass spectra, was observed. This fragmentation, supported by a metastable peak, seems restricted to the 1,2,7,8-tetrahydro end group, since it has not been observed for carotenoids with the 1,2- or 7,8-dihydro end groups alone. The fragmentation may be explained by an in-chain elimination of methylcyclobutene (Scheme 4). This thermally forbidden rearrangement could take place under electron impact. When a 1,2-double bond is present, this type of reaction appears to be suppressed by the favoured simple cleavage of the 3,4-bond (M-69). Malhotra et al. reported no M-68 fragment for their natural 1,2,7,8-tetrahydrocarotenoids, possibly due to different recording conditions (200-240°C, 70 eV vs. 150-200°C, 70 eV in our work).

A number of other fragments were also observed, but have no obvious diagnostic value (Table 1C).

In view of the very similar adsorptive and visible light properties of the carotenoids of this 1,2-dihydro series with those of the common (1,2-ene) series it is imperative that full spectral characterization, including MS and preferably ¹H NMR, be employed even for the identification of carotenones.

So far the occurrence of these 1,2-dihydrocarotenones is restricted to Rhsp. viridis. However, this restricted occurrence is not considered definite, since misidentification with common carotenones is possible.

**EXPERIMENTAL**

Materials and methods were as normally employed in our laboratory and are summarized elsewhere. If of satisfactory purity, as judged by ¹H NMR spectrometry or other criteria, crude intermediates were used directly without further purifications. Otherwise purifications by distillation or chromatography on columns or thin layer plates were resorted to.

6-Methylheptan-2-one (8). Methylheptanone (7, 12.6 g) in methanol (100 ml) was hydrogenated in the presence of palladium (10% on BaSO₄) catalyst (0.5 g) until hydrogen uptake had ceased, ca. 30 h. Filtration and removal of the solvent afforded 12.1 g (95%) crude 8; n̄D₁₁₂=1.4283; λmax (lit) 3000-2820 (CH), 1720 (C=O), 1670 (CH₆), 1390, 1370 (CH₃), 1172, 793, 767 and 683 cm⁻¹; δ (CDCl₃) 0.86 (d, 6 H, J 5 Hz, isopropyl CH₃), 1.0-1.9 (m, 5 H, 2×CH₂CH₃), 2.00 (s, 3 H, methyl ketone), 2.36 (t, 2 H, J 7 Hz, CH₂). 3,7-Dimethyl-1-ene-3-0l (dihydrolinalool, 9). Vinylvagnesium bromide, prepared from magnesium (5.6 g) and vinyl bromide (25 g) in dry ether (20 ml), was reacted with 8 (15 g) in dry ether (20 ml) at room temperature for 3 h. The reaction mixture was decomposed with saturated aqueous NH₄Cl and the reaction products extracted into ether. The extract was washed with water, dried over MgSO₄ and evaporated to give 13 g (70%) crude 9; δ (CDCl₃) 0.88 (d, 6 H, J 6 Hz, isopropyl CH₃), 1.25 (s, 3 H, CH₃ at C-3), 1.15-1.6 (m, ~7 H, 3×CH₂CH₃ + H), 2.19 (1 H, OH), 5.00 (dd, 1 H, J₃,₁₂ 10.5 Hz, J₃,₁′ 2 Hz, H-1, cis), 5.14 (dd, 1 H, J₃,₁′ 17.5 Hz, J₁,₁′ 2 Hz, H-1, trans), 5.94 (dd, 1 H, J₃,₁′ 10.5 Hz, J₁,₁′ 17.5 Hz, H-2).

3,7-Dimethyl-2-enyl bromide (dihydrogeranyl bromide, 10). Dihydrolinalool (9, 13 g) in petroleum ether (25 ml) and pyridine (2.5 ml) were cooled to -10°C and phosphorus tribromide (10.5 g) in petroleum ether (15 ml) was added dropwise. The reaction mixture was stirred at -10°C for a further 20 min and then decomposed with ice and water. The reaction
products were extracted into petroleum ether, the extract washed with water, NaHCO₃ solution and dried over MgSO₄. Evaporation of the solvent afforded 14 g (71 %) crude 10; δ (CDCl₃) 0.89 (d, 6 H, J 6 Hz, isopropyl CH₃), 1.1-1.7 (5 H, 2 × CH₂-CH=H), 1.71 (s, 3 H, CH₃ at C-3), 2.02 (t, 2 H, J 6 Hz, H-4), 3.99 (d, 3 H, J 6 Hz, H-1).

6,10-Dimethylundeca-5-one-2-one [dihydrogeranyl acetone, 15]. Acetoacetic ester (11.5 g) and J0 (14 g) were cooled to -15°C and sodium ethoxide solution (prepared from sodium (4.5 g) and ethanol (100 ml), 35 ml) was added dropwise while the temperature was kept at ca. -10°C. The reaction was continued at room temperature overnight. The solution was heated to 80°C and 10 % aqueous sodium hydroxide (110 ml) was added with vigorous stirring and the reaction mixture kept at 80°C for 4 h. The mixture was cooled, the products extracted into petroleum ether, the extract washed with water and dried over MgSO₄. Evaporation of the solvent and distillation of the residue gave 10 g (85 %) of b.p. 152°C/15 Torr; δ (CDCl₃) 0.88 (d, 6 H, J 6 Hz, isopropyl CH₃), 1.1-1.7 (5 H, 2 × CH₂-CH=H), 1.81 (s, 3 H, CH₃ at C-6), 1.75-2.3 (2 × 2 H, allylic, CH₂), 3.10 (s, 3 H, CH₃-1), 3.30 (t, 2 H, J 5 Hz, CH=), 5.08 (t, 1 H, J 6.5 Hz, H-5).

Ethyl 3,7,11-trimethylundeca-2,6-dienoate [ethyl dihydrogeranylacetonylidenediacetate, 13]. Ethyl diethylphosphonooacetaet (60 g) was added to a suspension of sodium hydride (50 % in mineral oil, 1.35 g, washed repeatedly with petroleum ether before use) and the mixture stirred until hydrogen evolution had ceased (ca. 1 h). 12 (4.1 g) was added and the mixture was reacted overnight and then decomposed with water. The products were extracted into ether, the extract washed with water and evaporated over Na₂SO₄. Evaporation of the solvent gave 4.54 g (81 %) crude 13; νmax (liq) 2960-2870 (CH), 1720 (C=O), 1650 (C=C), 1455 (CH), 1385, 1369 (CH₃, isopropyl), 1220, 1157, 1142, 1055, and 862 cm⁻¹; δ (CDCl₃) 0.87 (d, 6 H, J 6 Hz, isopropyl CH₃), 1.26 (t, 3 H, J 7 Hz, ethyl CH₃), 1.60 (s, 3 H, CH₃ at C-7), 1.89 and 2.16 (d + d, 3 H, J 1 Hz, CH₂ at C-3, cis-trans), 4.14 (q, 2 H, J 7 Hz, ethyl CH₂), 5.10 (m, 1 H, H-6), 5.65 (brad s, 1 H, H-2).

3,7,11-Trimethylundeca-2,6-dien-1-ol [dihydrogeranylacetonylidenediol ethanol, 14]. 13 (4.07 g) in dry ether (25 ml) was reduced with LiAlH₄, (1 g) at 0°C for 4 h. Saturated aqueous NH₄Cl solution was added, the mixture filtered and the filtrate extracted with ether and dried over Na₂SO₄. Evaporation of the solvent gave 3.3 g (97.5 %) crude 14; νmax (liq) 3320 (OH), 2950-2865 (CH), 1470 (CH), 1385, 1367 (CH₃, isopropyl) and 1005 cm⁻¹; δ (CDCl₃) 0.86 (d, 6 H, J 6 Hz, CH₃) isopropyl CH₃, 1.51 (s, 3 H, CH₃ at C-7), 1.68 (s, 3 H, CH₃ at C-3), 4.10 and 4.14 (d + d, 2 H, J 7 Hz, CH₂=CH₂, cis-trans), 5.10 (m, 1 H, H-6), 5.39 and 5.42 (t + t, 1 H, J 7 Hz, H at C-7, cis-trans).

(3,7,11-Trimethylundeca-2,6-dienyl)triphenylphosphonium bromide (15). 14 (2.78 g) in dry CHCl₃ (70 ml) was reacted with triphenylphosphonium bromide (4.43 g) at room temperature for 60 h. Crystallization from ethyl acetate/ether gave 2.71 g (40 %) colourless crystals of 15, m.p. 151°C; νmax (KBr) 3045-2780 (CH), 1637 (C=C), 1435 (CH), 1383, 1366 (CH₃, isopropyl). 1112, 996, 887, 856, 745, 725, and 692 cm⁻¹; δ (CDCl₃) 0.87 (d, 6 H, J 6 Hz, isopropyl CH₃), 1.33 and 1.41 (s + s, 3 H, CH₃ at C-3), 1.52 (s, 3 H, CH₃ at C-7), 4.2-5.3 (m, 4 H, CH₂ at C-1 and olefinic H), 7.73 (s, ca. 15 H, phenyl-H).

3,7,11-Trimethylundeca-1,4,6,10-tetraene-3-ol (17). The Grignard reagent, prepared by treating vinyl bromide (8.25 g) in tetrahydrofuran (100 ml) with magnesium (1.9 g), was cooled to 0°C and v-ionone (16, 2.5 g) in tetrahydrofuran (50 ml) was added dropwise. The mixture was stirred for another 30 min at 20°C followed by addition of saturated aqueous ammonium chloride (ca. 50 ml). The organic phase was extracted with ether, the extracts washed several times with water and dried over Na₂SO₄ and K₂CO₃. Evaporation of the solvent and distillation (78°C, 0.1 Torr) gave 2.46 g (85 %) of the alcohol 17 as a colourless oil; νmax (methanol) 2343 cm⁻¹ (21 600); δ (max) (liq) 3370 (OH), 3082-2930 (CH), 1450 (CH), 1377, 1105, 1090, 970, 920, 830, and 690 cm⁻¹; δ (CDCl₃) 1.28 (s, 3 H, CH₃ at C-3), 1.52 and 1.58 (s + s, 6 H, 2 CH₂ at C-1), 1.67 (s, 3 H, CH₃ at C-7), 2.0-2.2 (m, 4 H, 2 CH₂ allylic), 4.5-6.7 (7 H, olefinic H).

3,7,11-Trimethylundeca-2,4,6,10-tetraene-1-yl)triphenylphosphonium bromide (18). 17 (1.98 g) in abs. methanol (45 ml) was reacted with triphenylphosphonium bromide (3.16 g) at room temperature for 24 h. The solvent was evaporated, the residue dissolved in hot ethyl acetate and the resulting solid precipitate recrystallized in ethyl acetate giving 380 mg colourless crystals of 18, m.p. 146°C (decomp.); νmax (methanol) 2955.5 nm (s), 1610-2730 (CH), 1587 (C=C), 1437 (CH), 1112, 985, 955, 745, 725, and 694 cm⁻¹; δ (CDCl₃) 1.60 and 1.66 (s + s, 2 CH₂ at C-11), 1.77 (s, CH₃ at C-3 and C-7), 2.0-2.3 (m, CH₂-8 and -9), 4.5-6.3 (m, CH₃-1 and olefinic H), 7.72 (s, phenyl-H). The combined mother liquors after evaporation of the solvent provided further 4.36 g 18 as a viscous oil.

1,2,3,5-Tetrahydro-12'-apo-v-carotene-12'-al (29). Butylene oxide (4 ml), CHCl₃ (4 ml), Cu₂dial (19, 482 mg) and I₈ (801 mg) were reacted in a sealed tube under N₂-atmosphere at 90°C for 1 h. The reaction mixture was cooled and suspended in benzene/ether, washed several times with water and dried over Na₂SO₄. Chromatography on alumina grade 2 using benzene and collection of the main fraction gave 304 mg 20 (58.5 %) as an oil; νmax (acetone) 2955.5 nm (s), 1610-2700 (OH), 1414 (liq) 3035 (olefinic CH), 2950-2800 (CH), 2705 (-CHO), 1673.
Synthesis of 1,2-Dihydro-carotenes

(C=O), 1610, 1560 (C=O), 1470—1430 (CH), 1405, 1380, 1355 (CH_2), 1255, 1235, 1185, 1008, 990, 960 (trans = CH=CH—), 883, 835 (C—CH—) and 690 cm⁻¹; δ (CDCl_3) 0.87 (d, 6 H, 6 J 6 Hz, isopropyl CH_3), 1.1—1.4 (m, 4 H, CH_2-2 and -3), 1.60 (s, 3 H, CH_3 at C-5, C-6, 1.54 (d, 1 H, J 6 Hz, tert. H), 1.84 (s, 6 H, CH_3 at C-9 and C-13), 2.00 (s, 3 H, CH_3 at C-5), 1.8—2.3 (m, 6 H, CH_2=4,7,8), 4.95—5.3 (H at C-6), 5.7—7.2 (m, 7 H, olefinic), 9.42 (1 H, aldehyde); m/e (Table 1).

1,2,7,8,12,13,17,18-Octahydro-β-carotene (1,12, 1',2'-tetrahydro-β-carotene, 1). Butyline oxide (1 ml), CaO-diathyl (19, 20 mg) and 15 (200 mg) were reacted in a sealed tube under N_2 at 90°C for 30 min. The reaction mixture was cooled and suspended in benzene. Triphenylphosphine oxide was removed by filtration and the product purified by TLC on silica gel using petroleum ether as developer; yield 20 mg (50%) as an oil; λ<sub>max</sub> (light petroleum) 378, 5, 487, 434 nm; δ III/II = 10; ν<sub>max</sub> (lq) 3040—2820 (CH), 1740, 1635 (C=O), 1480—1440 (CH_2), 1390, 1370 (CH_3), 970 (trans = CH—CH—), 890 and 790 cm⁻¹; δ (CDCl_3) 0.87 (d, 12 H, J 6 Hz, 4 × CH_3 at C-1,1'), 1.60 (s, 6 H, CH_3 at C-5,5'), 1.81 (s, 6 H, CH_3 at C-9,9'), 1.34 (s, 6 H, CH_3 at C-13,13'), 5.12 (m, 2 H, H-6,6'), 5.7—6.8 (10 H, olefinic); m/e (Table 1).

1,2,7,8-Tetrahydro-β-carotene (1,12-dihydro-neurosporinen, 2). 15 (2 g) and 20 (334 mg) in 12 ml butylene oxide/CHCl_3 (1:1) were reacted in a sealed tube under N_2 atmosphere at 90°C for 1 h. The reaction mixture was cooled, suspended in benzene/ether, washed with water and dried over Na_2SO_4. The residue was chromatographed twice on alumina (Woelm, grade 3) gradually eluted with increasing amounts of ether (5—10%) in hexane for the second column, separating the main fraction into two zones. From the more polar zone 2 (108 mg) was isolated as a cis-trans mixture. The less polar zone gave 79 mg mainly all-trans-2 (total yield 37%). Further purification of the all-trans product by TLC on silica using 3% acetone in hexane and crystallization from acetone/methanol gave 14.4 mg crystalline all-trans-2, m.p. 98°C; λ<sub>max</sub> (hexane) 468.5, 439 (e 138 200) and 415 nm; δ III/II = 102; ν<sub>max</sub> (KBr) 3040 (olefinic CH), 2950—2860 (CH), 1627 (C=C), 1480—1420 (CH_2), 1383, 1367 (CH_3), 960 (trans = CH=CH—), 885, and 825 cm⁻¹; δ (CDCl_3) 0.89 (d, 6 H, J 6 Hz, CH_3 isopropyl), 1.1—1.4 (m, CH_2=2,3), 1.61 (s, 6 H, CH_3 at C-5 and C-1, 1.70 (s, 3 H, CH_3 at C-1), 1.83 (s, 6 H, CH_3 at C-6 and 9), 1.97 (s, 9 H, CH_3 at C-13, 13' and 9'), 1.8—2.3 (m, CH_2=4,7,8), 5.0—5.35 (m, 2 H at C-6 and C-2'), 5.7—6.9 (13 H olefinic); m/e (Table 1).

Ethyl 3,7-dimethyl-2-enoate (21). To sodium hydride (50%) in mineral oil, 3.12 g in dry dimethyoxetane (40 ml) was added ethyl diethylphosphonoacetate (11.5 g). The mixture was stirred until hydrogen evolution had ceased (ca. 1 h). 8 (6.4 g) in dry dimethoxyethane (50 ml) was added and the mixture stirred at room temperature for 24 h. Water (1.5 l) was added and the product extracted with ether. The combined ether extracts were washed with water until neutral and dried over calcium chloride. Evaporation of the solvent afforded 9.5 g (100%) crude 21; n<sub>D</sub> = 50.0; ν<sub>max</sub> (lq) 3000—2820 (CH), 1720 (C=O), 1650 (C—C), 1465 (CH), 1388, 1360 (CH_2, isopropyl), 1237, 1151 (C—O—) and 1050 cm⁻¹; δ (CDCl_3) 6.14 and 6.60 (q, q, 1 H, J ca. 1 H, cis + trans α-H), 4.10 (q, 2 H, J 7 Hz, CH_2=CH_2), 2.13 d and 1.88 (d + d, 3 H, J 1 Hz, trans + cis β-CH_3), 1.25 (t, 3 H, J 7 Hz, CH_2CH_3), 2.1—1.0 (m, 7 H, 3 × CH_2+tert. H), and 0.90 (d, 6 H, J 5 Hz, isopropyl CH_3).

3,7-Dimethyl-2-eno-1-ol (22). 21 (5.9 g) in dry ether (30 ml) was added to a cooled (0°C) suspension of lithium ammonium hydride (0.7 g) in dry ether (20 ml) and the mixture was stirred at room temperature for 5 h. Ammonium chloride (0.9 g) in water (3 ml) was added and stirring continued for 1 h. The mixture was filtered, the filter washed with ether and the combined filtrates evaporated to dryness; yield 3.9 g (99%) crude 22; ν<sub>max</sub> (lq) 3600—3100 (bndded OH), 3000—2820 (CH), 1740 (CH), 1388, 1370 (CH_2, isopropyl), 1010 (OH), and 762 cm⁻¹; δ (CDCl_3) 5.83 and 5.42 (t, 1 H, J 7 Hz, cis + trans α-H), 4.13 (d, 2 H, J 7 Hz, CH_2O), 3.05 (s, 1 H, OH), ca. 2.0 (m, allylic CH_3), 1.69 (s, 3 H, β-CH_3), 2.0—1.0 (m, 5 H, 2 × CH_2+tert. H), 0.90 (d, 6 H, J 6 Hz, isopropyl CH_3).

3,7-Dimethyl-2-enyl)triphenylphosphinum bromide (23). 22 (3.12 g) and triphenylphosphonium bromide (7.2 g) in methanol (50 ml) were stirred under nitrogen at room temperature for 24 h and finally refluxed for 4 h. The reaction mixture was poured into water and extracted with chloroform. The combined extracts were dried over anhydrous sodium sulfate, the solvent evaporated and the resultant oil triturated with ethyl acetate. Filtration and recrystallization from chloroform-ethyl acetate afforded 4.94 g (55.7%) of m.p. 185—170°C; δ (CDCl_3) ca. 7.8 (m, 15 H, aromatic), 5.13 (s, 1 H, J 7 Hz, α-H), 4.57 (dd, 2 H, Jα—β = 15 Hz, Jα—H = 7 Hz, CH_2P), ca. 1.9 (m, 2 H, allylic CH_3), 1.40 and 1.34 (a+s, 3 H, CH_3), 1.5—1.0 (m, 5 H, 2 × CH_2+tert. H), and 0.80 (d, 6 H, isopropyl CH_3).

1,2',7',8'-Tetrahydro-β,γ-carotene (3) and 1,2-dihydro-8'-apo-β-caroten-8'-al (25). To a suspension of 23 (100 mg) in dry ether (50 ml) was added 0.6 N butyl lithium (8 ml) and the resultant deep red solution stirred for ca. 5 min. Crocetindial (24, 600 mg) in methylene chloride (30 ml) was added and the mixture refluxed under nitrogen for 70 min. The reaction mixture was poured into water and the products extracted with ether. The combined extracts were washed with water and evaporated with benzene to dryness.

The individual pigments were separated by chromatography on alumina grade 2.10. Rechromatography afforded the homogeneous pigments. Crocetindial (24, 323 mg) was recovered. 1,2-Dihydro-8'-apo-β-carotene (25, 232 mg) was eluted with 10 % ether in petroleum ether from alumina grade 2. Crystallization from acetone-methanol afforded crystalline 25 (69.4 mg) of m.p. 128 - 130 °C; λmax (acetone) 467 (ε = 107 000) and (490) nm: rmax (KBr) 3040 (olefinic CH), 3000 - 2800 (CH), 2720 (-CH=O), 1682 (C=O), 1630, 1625 (con.). C=C, 1590, 1560, 1520 (C=C), 1470 - 1440 (CH), 1405, 1388, 1370, 1360 (CH3), 1320, 1280, 1185, 1160, 1050, 1005, 900, 900 (trans - CH=CH=CH-), 888, 835 (>C=CH-), 740, 696, and 660 cm⁻¹; δ (CDCl3) 9.50 (s, 1 H, aldehydic), 7.0 - 5.75 (m, 13 H, olefinic), 2.3 - 2.0 (m, 2 H, allylic CH2), 2.00 (s, 3 x 3 H, in-chain CH3); 1.91 (s, 3 H, α-CH3), 1.83 (s, 3 H, end-of-chain CH3) 1.8 - 1.0 (5 H, 2 x CH2 + tert. H), 0.96 (d, 6 H, 6 Hz, isopropyl CH3); m/e (Table 1).

1,2,1',2'-Tetrahydro-β,β-carotene (3, 104 mg) was eluted with 15 - 25 % ether in petroleum ether from alumina grade 1.13. Crystallization from methylene chloride-methanol afforded crystalline 3 (59.4 mg) of m.p. 150 - 155 °C; λmax (petroleum ether) 442, 468.5 (ε = 171 000), and 499 nm; % III/II = 67; rmax (KBr) 3040 (olefinic CH), 3000 - 2820 (CH), 1630, 1550 (C=C), 1470 - 1430 (CH3), 1386, 1369 (CH3), 961 (trans - CH=CH=CH-) and 828 (>C=CH-) cm⁻¹; δ (CDCl3) 6.90 - 5.80 (16 H, olefinic), 3.03 (2 x 2 H, allylic CH2), 1.87 (s, 4 x 3 H, in-chain CH2), 1.82 (s, 2 x 3 H, end-of-chain CH2), 1.7 - 1.1 (6 H, 2 x CH2 + 2 tert. H), and 0.87 (d, 4 x 3 H, J 6 Hz, isopropyl CH3); m/e (Table 1).

1,2-Dihydro-β,β-carotene (4). To a suspension of geranyltriphenylphosphonium bromide (26, 240 mg) in dry ether (10 ml) was added 0.6 N butyl lithium (2 ml) and the resultant dark red solution stirred for ca. 1 min, a 1,2-Dihydro-apo-8'-lycopenal (25, 104 mg) in dry ether (40 ml) was added and the mixture refluxed under nitrogen for 90 min. Geranyltriphenylphosphonium bromide (26, 240 mg) was treated with 0.6 N butyl lithium (2 ml) and this was added to the solution. The reaction was stopped after a further 15 min by the addition of water. The products were extracted with ether and the combined extracts washed with water, evaporated with benzene to dryness and the pigments were purified by chromatography twice on alumina grade 2. 4 (83.5 mg) was eluted with 5 % ether in petroleum ether. Crystallization from acetone-methanol afforded crystalline 4 (18 mg) of m.p. 162 - 165 °C; λmax (light petroleum) 443, 469 (ε = 164 000) and 499.5 nm % III/II = 63; rmax (KBr) 3040 (olefinic CH), 3000 - 2820 (CH), 1720, 1675, 1630 - 1550 (C=C), 1470 - 1430 (CH3), 1385, 1370, (CH3), 961 (trans - CH=CH=CH-), 888 and 828 (>C=CH-) cm⁻¹; δ (CDCl3) 7.0 - 5.8 (16 H, olefinic), 5.15 (m, 1 H, H-2'), 2.22 (3 x 2 H, allylic CH3), 1.98 (s, 4 x 3 H, in-chain CH3), 1.83 (s, 2 x 3 H, end-of-chain CH3), 1.72 s and 1.63 (s + s, 3 + 3 H, isopropenyl CH3), 1.6 - 1.0 (m, 3 H, non-allylic CH3 + tert. H), and 0.88 (d, 2 x 3 H, J 6 Hz, isopropyl CH3); m/e (Table 1).

Methyl 3,7-dimethylocta-2,4-dienoate (29). To a suspension of sodium hydride (50 % in mineral oil, 3.1 g) washed repeatedly with petroleum ether) was added methyl 3-methyl-4-diethylphosphonocrotonate (30, 16 g) in dry ether (20 ml) and the mixture stirred until H2 evolution had ceased. Isovaleraldehyde (27, 7.9 g) was added and the reaction run overnight with stirring. The reaction mixture was poured into water, the products extracted into ether, the extract washed with water, dried over MgSO4 and evaporated to give 8.4 g (92 %) crude 29; rmax (liq) 3040 (olefinic CH), 3000 - 2820 (CH), 1720 (>C=CH), 1640, 1610, 1430 - 1470 (CH3), 1385, 1370 (CH3), 1240, 1150, 1040, 960 - 980, 850 cm⁻¹; δ (CDCl3) 0.92 (d, 6 H, J 6 Hz, CH3 isopropyl), 1.5 - 2.0 (m, H-6), 2.0 and 2.3 (d + d, 3 H, J 1 Hz, CH2 vinylic trans and cis), 3.70 (s, 3 H, CH3, olefinic cis and trans), 0.87 (d, 4 x 3 H, J 6 Hz, isopropyl CH3); m/e (Table 1).

3,7-Dimethylocta-2,4-diene-1-ol (30). 29 (4.6 g) in dry ether (30 ml) was added to a cooled (0 °C) suspension of LiAlH4 (1 g) in dry ether (30 ml) and the reaction continued at room temperature for 1 h. Excess LiAlH4 was destroyed by addition of ethyl acetate, the reaction mixture was poured into ice - 1 N H2SO4, and the products extracted into ether. The ether extract was washed with water and dried over MgSO4. Evaporation of the solvent gave 2 9 g (52 %) crude 30; rmax (liq) 3600 - 3100 (OH), 3000 - 2820 (CH), 1640, 1610, 1470 - 1430 (CH3), 1370 (CH3), 1240, 1150, 1040, and 980 cm⁻¹; δ (CDCl3) 0.91 (d, 6 H, J 6 Hz, CH3 isopropyl), 1.5 - 2.0 (m, H-6), 1.76 and 1.83 (d + d, 3 H, J 1 Hz, CH2 vinylic trans and cis), 1.7 - 2.2 (m, CH3), 3.92 (s, 1 H, OH), 4.22 (d, 2 H, J 7 Hz, CH=O-), 5.3 - 6.6 (m, 3 H, olefinic cis and trans).

(3,7-Dimethyl-6,8-dienyl)triphenylphosphonium bromide (31). Triphenylphosphonium bromide (4.5 g) and 30 (2 g) in dry methanol (25 ml) were stirred at room temperature for 56 h. Removal of the solvent gave an oil which was triturated with ether. The resultant viscous oily product was dried in high vacuum and gave a colourless semi-solid (2 g, 44 %) which was used without further purification.

1,2-Dihydro-3,4-diethyl-8'-apo-β-caroten-8'-al (32). To 31 (250 mg) and crocetindial (24, 100 mg) in dimethylformamide (30 ml) was added 1.1 N NaOCH3 (0.5 ml) dropwise with stirring, the reaction mixture being stirred at room temperature for 1.5 h and then poured into water. The pigments were extracted into benzene, the extract washed with water, dried over Na2SO4 and evaporated to dryness. The products were chromatographed on alumina.
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grade 2.18 32 was eluted with benzene. Evaporation of the solvent and crystallization twice from petroleum ether gave 50 mg (36%) of m.p. 110-112°C; \( \lambda_{\text{max}} \) (acetone) 473 (\( \varepsilon = 99,800 \)) nm; \( \nu_{\text{max}} \) (KBr) 3000-2820 (CH), 1750, 1675 (C=O), 1610 (C=C), 1470 -1440 (CH), 1385, 1369 (CH), 961 (trans = CH = CH -) cm\(^{-1}\); \( \delta \) (CDCl\(_3\)), 0.87 (d, 6 H, J 7 Hz, isopropyl CH\(_3\)), 1.82 (s, 6 H, CH\(_3\) at C-5 and C-9), 1.97 (s, 9 H, CH\(_3\) at C-9,13 and 15), 5.8-7.0 (15 H, olefinic), 9.50 (s, 1 H, aldehydic); \( m/e \) (Table 1).

1,2,1',2'-Tetrahydro-3,4,3',4'-tetradehydro-\( \alpha \),\( \beta \)-carotene (6). To a suspension of 31 (250 mg) in dry ether (25 ml) was added 1 N butyl lithium (0.55 ml) and the mixture stirred until a solid of sodium carbonate had dissolved. Methylene chloride (3 ml) followed by cyclohexanone (24, 140 mg) in methylene chloride (25 ml) were added. The reaction mixture was refluxed under \( N_2 \) for 2 h, cooled and poured into water. The reaction mixture was filtered with ether, the ether washed with water, dried over MgSO\(_4\), evaporated and the residue chromatographed on alumina grade 2. \( \delta \) was eluted with 10% ether in petroleum ether. The solvent was evaporated and the residue redisolved in petroleum ether, isomerized with iodine in light and rechromatographed. Evaporation of the solvent and crystallization from acetone-methanol afforded 60 mg (25%) \( \delta \) of m.p. 197-199°C; \( \lambda_{\text{max}} \) (pet. ether) 460, 488 (\( \varepsilon = 168,100 \)) and 520 nm; \% III/II = 43; \( \nu_{\text{max}} \) (KBr) 3040-2800 (CH), 1470-1440 (CH), 1373, 1368 (CH\(_3\)), 970 (trans = CH = CH -) and 830 (\( \geq C=CH - \)) cm\(^{-1}\); \( \delta \) (CDCl\(_3\)) 0.87 (d, 12 H, J 6 Hz, isopropyl CH\(_3\)), 1.91 (s, 6 H, CH\(_3\) at C-5,5'), 1.96 (s, 12 H, CH\(_3\) at C-9,13,15 and 9'), 5.8-7.0 (20 H, olefinic); \( m/e \) (Table 1).

1,2-Dihydro-3,4-didehydro-\( \alpha \),\( \beta \)-carotene (6). To a suspension of geranyltriphenylphosphonium bromide (26, 100 mg) in ether (20 ml) was added 1 N butyl lithium in ether (0.25 ml) and the resultant deep red ylid solution stirred until all phosphonium salt had gone into solution. Methylene chloride (3 ml) followed by 32 (40 mg) in methylene chloride (10 ml) were added and the reaction mixture refluxed for 1 h. Another portion of ylid, prepared from 26 (50 mg) and butyl lithium (0.12 ml), was added and the reaction continued for another 30 min. The reaction mixture was poured into water and the pigments extracted into ether. The extract was washed with water, dried over MgSO\(_4\), and evaporated. The crude product was chromatographed on alumina, grade 2, and eluted with 10% ether in light petroleum. The pigment was isomerized with iodine in light and rechromatographed. Evaporation of the solvent and crystallization from acetone-methanol afforded 13 mg (25%) \( \delta \) of m.p. 180-185°C; \( \nu_{\text{max}} \) (light petroleum) 453, 480 (\( \varepsilon = 163,400 \)) and 513 nm; \% III/II = 64; \( \nu_{\text{max}} \) (KBr) 3040 (= CH -), 3000-2820 (CH), 1570, 1640 (C=C), 1470-1440 (CH\(_3\)), 1378, 1369 (CH\(_3\)), 960 (\( \geq C=CH - \)) cm\(^{-1}\); \( \delta \) (CDCl\(_3\)) 0.87 (d, 6 H, J 6 Hz, isopropyl CH\(_3\)).

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