Structures of α- and β-Turmerone

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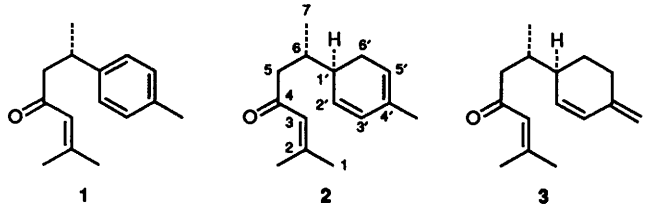
Procedures are described for isolating turmerones from *Curcuma longa* rhizomes and for chromatographically separating α- from β-turmerone. Using a combination of spectroscopic techniques (especially high field ^{1}H NMR spectroscopy and chiroptical methods) these compounds are shown to be (1′*R*,6*S*)-2-methyl-6-(4-methylcyclohexa-2,4-dienyl)hept-2-en-4-one **2** (α-turmerone) and (1′*R*,6*S*)-2-methyl-6-(4-methylenecyclohex-2-enyl)hept-2-en-4-one **3** (β-turmerone).

The dried, ground rhizomes of the plant *Curcuma longa* Linn., called turmeric in England, haldi in India, and ukon in Japan, have been known since the second millenium BC. The first written account of the use of turmeric is an Assyrian herbal dated *ca.* 600 BC.[1] The uses of turmeric include its application for cosmetic, culinary, medicinal and ritual purposes, and as a dye.[2] During the Victorian age many chemists studied turmeric and early in the 19th century the colouring matter curcumin had already been isolated.[3] Michael Faraday confirmed the ability of boric acid to redden turmeric.[4] This is a property of curcumin, which was eventually shown to be 1,7-bis(4-hydroxy-3-methoxyphenyl)hepta-1*E*,6*E*-diene-3,5-dione, a chelating molecule.[5] However, it was not until 1934 that Rupe *et al.* showed that oil of turmeric, which can be obtained simply by extracting turmeric with light petroleum, contained a sesquiterpene named *ar*-turmerone. This was shown to be a bisabolane terpenoid with the constitutional structure corresponding to **1**,[6] the absolute configuration of which was



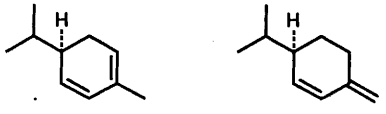
1 **2** **3**

subsequently assigned as (*S*).[7] Rupe *et al.*[6] also obtained a further sesquiterpene ($C_{15}H_{22}O$) from turmeric oil, which was called turmerone, and for which five alternative constitutional structures, including that corresponding to **2**, were proposed.[6] Mima[8] isolated turmerone as a thiourea adduct and by UV spectroscopy determined the presence of a *transoid* diene. He proposed two additional constitutional structures to those of Rupe *et al.*[6] of which a structure corresponding to **3** was one.[8] Other structural proposals are considered later in this paper, when we will show that turmeric oil contains two principal turmerones, named α- and β-turmerone, and that these compounds are (1′*R*,6*S*)-2-methyl-6-(4-methylcyclohexa-2,4-dienyl)hept-2-en-4-one **2** (α-turmerone) and (1′*R*,6*S*)-2-methyl-6-(4-methylenecyclohex-2-enyl)hept-2-en-4-one **3** (β-turmerone). A preliminary communication on part of this work has appeared.[9]

Results and Discussion

Constituents of Turmeric Oil: Isolation of the Main Components (α- **2** *and β-Turmerone* **3**).—The essential oil of turmeric constitutes 3–6% of the dry weight of the rhizomes. Its composition varies with the cultivars,[2] conditions and time of storage of the rhizomes, and the method of extraction. We found that when dry turmeric rhizomes (Allepey fingers) were freshly ground with solid carbon dioxide and extracted immediately with cold hexane, the oil contained three main components. When subjected to GC–MS analysis with single ion monitoring, two of these components presented *m/z* 218, and the other had *m/z* 216. Preparative gas chromatography was not successful for isolating the substances of *m/z* 218, only the compound with *m/z* 216 being sufficiently stable to be obtained by this technique. This was shown to be *ar*-turmerone **1** by its spectroscopic properties. The other two compounds, which together composed *ca.* half of the fresh essential oil, could be separated by column chromatography followed by HPLC, when it was essential to add 1% triethylamine to the eluent to inhibit acid-catalysed degradation.

Previous Spectroscopic Analyses of Turmerones **2** *and* **3**.—High resolution mass spectrometry indicated that both compounds possess the molecular formula $C_{15}H_{22}O$. The 400 MHz ^{1}H NMR spectra of the compounds showed the connectivity of the carbon skeleton. From this and other data, the structures **2** and **3** were assigned.[9] Compounds **2** and **3** were named α- and β-turmerone by analogy with α- **4** and β-phellandrene **5**, the



4 **5**

corresponding monoterpenoids. The configuration at C-6 of both α- and β-turmerone was assigned as *S*, on the grounds that turmerone was oxidised by lead tetraacetate to the known (*S*)-*ar*-turmerone[7] (this assumes that Honwad and Rao[7] used turmerone containing both isomers and that they are both oxidised by this reagent).

Kiso *et al.*, in a paper[10] submitted 3 months after our communication[9] had appeared, claimed to have isolated a 'novel' sesquiterpene from the Japanese drug 'ukon' (*Curcuma longa*, Linn. = turmeric). The structure of this sesquiterpene (called curlone) was identical with that which we had postulated for β-turmerone, with the additional feature of an assignment of stereochemistry at C-1′ as *S*. Their argument is based on the observation of an intramolecular NOE between the 7-Me and 2′-H, and the assumption that 1′-H and 6-H adopt the 'thermodynamically most stable *anti*-arrangement'. Their argument is not convincing for the reasons presented after analysis of our NMR spectral data. In our preliminary communication[9] we overlooked a paper[11] published in the same year, describing the isolation of turmerone from *C. longa*

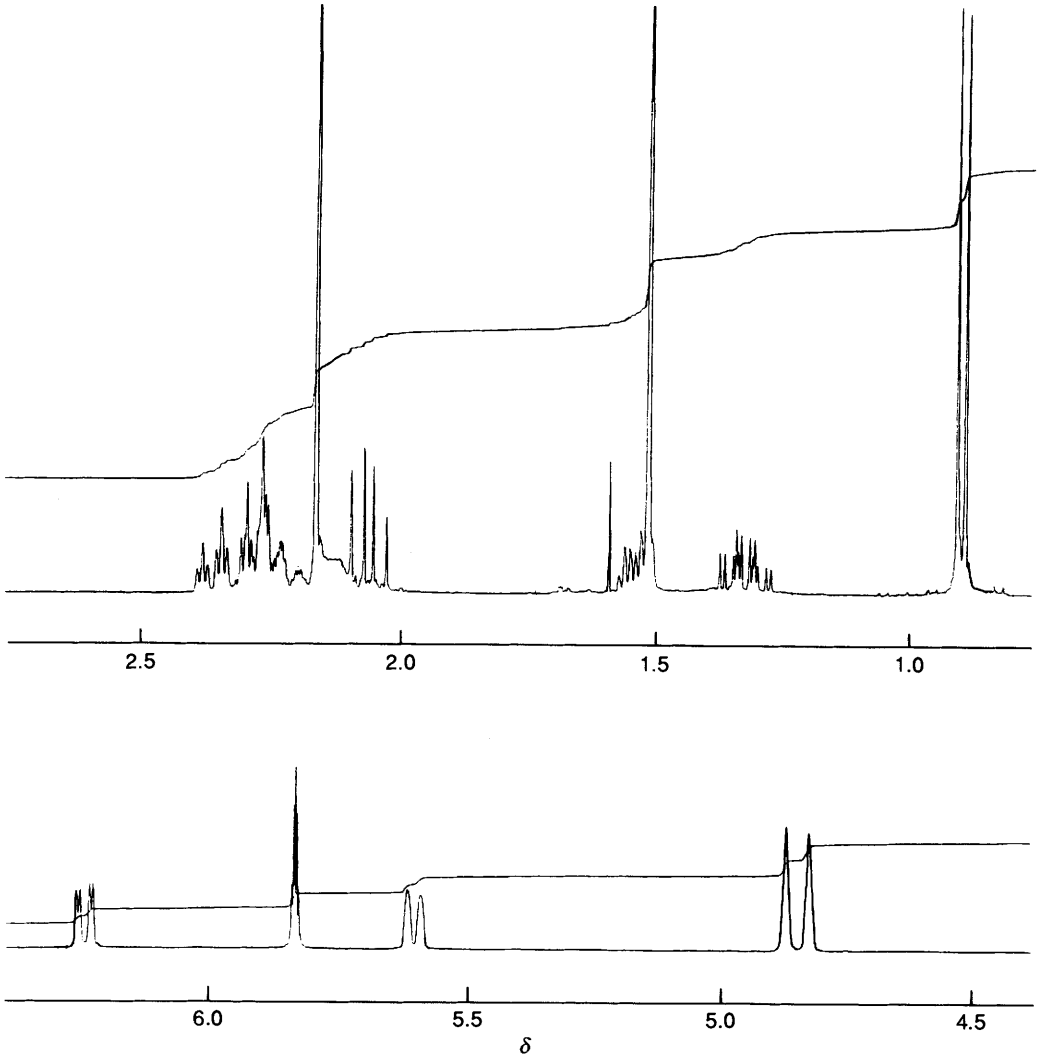


Fig. 1 ^{1}H NMR (in C_6D_6) of β-turmerone **3**

by Soxhlet extraction and HPLC of the extract. The 1,4-diene structure [2-methyl-6-(4-methylcyclohexa-1,4-dienyl)hept-2-en-4-one] postulated by Rupe *et al.*[6] was assigned to this material, which was shown to act as an insect repellent (against *Tribolium castaneum* and other species). However, the low resolution NMR spectral data presented are not convincing for this structure.

Analysis of NMR Spectral Data for β-*Turmerone* (*with Ingmar Sethson*).—The 400 MHz ^{1}H NMR spectrum of β-turmerone in $CDCl_3$ was complex because of the coincidence of many resonances in the range δ 2–2.5. By using C_6D_6 as solvent some resonances were shifted, and it was easier to interpret the spectrum with the help of double resonance experiments.

The 400 MHz ^{1}H NMR spectrum of β-turmerone in C_6D_6 is shown in Fig. 1. The 1 H septet (*J* 1.2 Hz) at δ 5.83 (3-H) is coupled to two 3 H signals at δ 2.16 (2-Me) and 1.51 (1-Me). The broad 1 H singlets at δ 4.87 and 4.82 (4′-methylene protons), together with the double multiplets at 6.24 (3′-H) and 5.61 (2′-H) indicate that the ring is as shown **3**.

In a double resonance experiment, irradiation at δ 4.84 removed the small long-range couplings from these double multiplets for 2′-H and 3′-H; that at δ 6.24 was simplified to a double doublet, *J* 10 and 2 Hz; that at δ 5.61 showed a coupling of 10 Hz and three small (<1 Hz) couplings. Two small, but significant changes were also observed in the high-field region during the double irradiation involving the 4′-methylene protons: a simplification of the multiplet at δ 2.23, and the removal of some couplings from the absorption at 2.13, which made the latter appear as a complex double multiplet, rather than as a broad, featureless absorption. This indicates that the resonances at δ 2.23 and 2.13 correspond to pseudo-axial protons ($5'_{ax}$-H and 1′-H, respectively).

Irradiation of the signal at δ 1.37 caused substantial sharpening of the resonance corresponding to 1′-H (δ 2.13), the signal for $5'_{ax}$-H (δ 2.23) was simplified, and the double triplet at δ 2.36 collapsed to a double doublet (*J* 8 and 2 Hz); the signal at δ 1.55 became a broad singlet. This shows that the proton resonating at δ 1.37 is in a *trans*-diaxial relationship to 1′-H, and $5'_{ax}$-H, and must therefore correspond to $6'_{ax}$-H, whilst the signal at δ 2.36 is due to $5'_{eq}$-H.

These assignments were confirmed by the observation of complementary changes in the spectrum upon irradiation at δ 1.55; only a very small coupling was removed from 1′-H, whilst a 2 Hz coupling was removed from $5'_{eq}$-H (δ 2.36) and the multiplets corresponding to $5'_{ax}$-H (δ 2.23) were sharpened up, due to the loss of a small coupling. The signal at δ 1.55 is therefore due to $6'_{eq}$-H. Irradiation at δ 0.86 (7-Me), caused simplification of the region δ 2.25–2.3, but does not permit detailed analysis of this region, which is due to the strongly coupled signals of one of the 5-H protons and 6-H. The double doublet at δ 2.06 is due to the other 5-H, and presents coupling constants of 9 and 5 Hz. These are the geminal

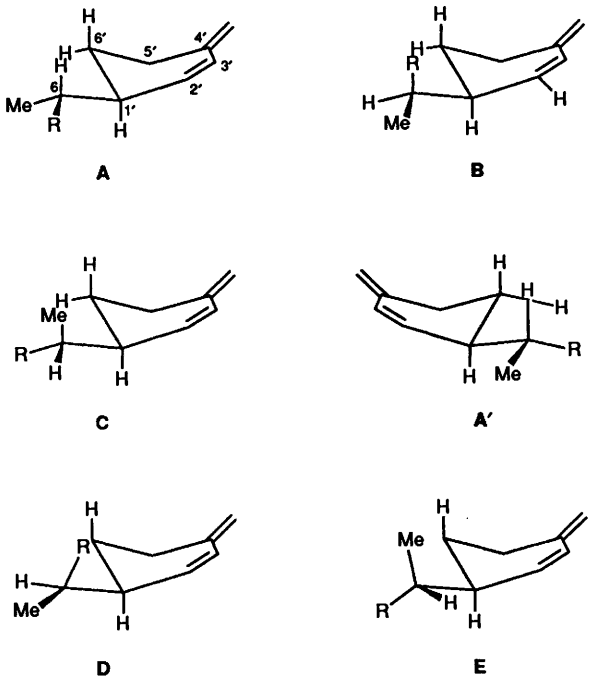


Fig. 2 Projection formulae for conformations of β-turmerone **3** about its C-6–C-1′ bond (R = $Me_2C{=}CHCOCH_2$)

coupling constant to the 5-H partner, and the vicinal coupling to 6-H.

The conformation of the ring of compound **3** that satisfies the assignments made so far is a half-chair, with the side chain in a pseudo-equatorial position (as in Fig. 2).

To strengthen the conclusions thus far, a series of two dimensional NMR experiments (^1H at 300 MHz) were performed for β-turmerone in C_6D_6. A ^{13}C–^1H shift correlation enabled the complete assignment of the ^{13}C NMR spectrum and supported the 1′-H assignment in the ^1H NMR spectrum. *J* Resolved ^1H spectra were examined in an attempt to confirm that 1′-H is essentially a broad doublet [because of *J* (1′-H, $6'_{ax}$-H) ~10 Hz], but were inconclusive. The COSY spectrum for ^1H coupling was in agreement with the assignments from double resonance experiments. T_1 Measurements gave no exceptional results.

The ^1H NMR spectrum of β-turmerone in $CDCl_3$ shows signals for $6'_{ax}$-H (δ 1.36) and $6'_{eq}$-H (δ 1.71) the multiplicities and coupling constants of which are identical with those for the corresponding resonances for β-turmerone in C_6D_6. This indicates that the ring conformation is identical in $CDCl_3$ to that in C_6D_6 (*cf.* Fig. 2). Difference NOE experiments for **3** in $CDCl_3$ gave an enhancement at δ 5.68 (2′-H) when 7-Me was irradiated (as observed by Kiso *et al.*[10]). For β-turmerone in C_6D_6, when the 7-Me was irradiated, enhancements of signal intensity were observed for both 5-H, 2′-H and to a small extent $6'_{ax}$-H. To explain these enhancements, 7-Me must be in proximity to 2′-H and $6'_{ax}$-H. 2D Correlation of NOE with ^1H shift (NOESY) showed significant effects for 3-H/1-Me, 3-H/2′-H, 2′-H/3′-H and some smaller effects including 2′-H/7-Me. Finally, for β-turmerone in [$^2H_6$]acetone irradiation of 2′-H (δ 5.73) caused NOE enhancement at δ 6.20 (3′-H), 2.52 (5-H) and 0.88 (7-Me), whilst irradiation at δ 0.88 caused enhancements at 1.39 ($6'_{ax}$-H) and 5.73 (2′-H).

Kiso *et al.*[10] claimed that the dihedral angle between 1′-H and 6-H is near 180° (*anti*-arrangement). If that were so, the coupling constant between these protons should be of the order of 10 Hz. However, irradiating at $6'_{ax}$-H (δ 1.37) caused 1′-H (δ 2.13) to appear as a broad singlet. Although this singlet is not fully resolved from the methyl signal at δ 2.16, a coupling of 10 Hz should have been observable; the coupling of 1′-H to 6-H must, therefore, be small (<2 Hz). Accordingly, the dihedral angle between these protons is much nearer to 90 than 180°. Decisive evidence for a small coupling between 1′-H and 6-H was obtained by a series of experiments in which increasing amounts of $Eu(fod)_3$ were added to a solution of β-turmerone in C_6D_6. The protons most affected by the addition of $Eu(fod)_3$ were 3-H, 2-Me, 6-H and both 5-H protons. Gratifyingly, 1′-H was revealed as a broad doublet (*J* ~8 Hz), which became a broad singlet in a double irradiation experiment at $6'_{ax}$-H. Irradiation at 6-H (concealed under 2-Me) caused the collapse of 7-Me to a singlet, *but there was no alteration* in the shape of 1′-H. Irradiation of $6'_{eq}$-H caused narrowing of the 1′-H resonance by the removal of a 2 Hz coupling (see Fig. 3).

Conformational Analysis of Turmerone.—In an analysis of the relationship between electronic structure and the optical activity of chiral 1,3-dienes,[12] the preferred conformation of β-phellandrene was taken to be pseudo-equatorial. This has been confirmed by AM1 calculations,[13] which show that the lowest energy conformation of β-phellandrene is a half-chair (approximately as shown by Fig. 2, conformation **B**, R = Me) in which the isopropyl group is pseudo-equatorial, and the dihedral angle defined by 1′-H/C-1′/C-6/6-H is −75.2°. This conformation is preferred by 0.46 kJ mol^{-1} over the next best conformation (half-chair with pseudo-equatorial isopropyl and the dihedral angle for 1′-H/C-1′/C-6/6-H = 164.5°). For (*R*)-(−)-β-phellandrene the lowest energy conformation presents a positive diene helicity (torsion angle 174°), for which a positive Cotton effect would be expected[14–17] (see below) and is found.[18]

These findings accord with the pseudo-equatorial conformation deduced above for β-turmerone from analysis of its ^1H NMR data. The possible staggered conformations **A**–**C** about the C-(1′)–C(6) bond are shown in Fig. 2 for (1′*R*,6*S*)-β-turmerone. Conformation **A**′ [leading to the assignment of (1′*S*,6*S*) configuration] was assumed by Kiso *et al.*,[10] but suffers from interactions between the alkyl substituents (Me and side-chain R) at C-6, and 2′-H and $6'_{eq}$-H, as is also the case for conformation **A**. In conformation **B** there is one such interaction (Me/2′-H), as well as a pseudo 1,3-diaxial interaction between R and $6'_{ax}$-H. By slight clockwise rotation about the C-(6)–C(1′) bond (leading from conformation **B** to **D**) the interaction of the methyl group at C-6 with 2′-H and R with $6'_{ax}$-H, can be diminished. Conformation **C** has interactions between 7-Me and $6'_{ax}$-H, and the R group and $6'_{eq}$-H. Slight anticlockwise rotation about the C-(6)–C(1′) bond alleviates both of these interactions (conformation **E**). The ^1H NMR data presented above suggests that β-turmerone exists predominantly in conformations **D** and **E**. This accounts for the observed NOE effects and for the very small 1′-H/6-H coupling. However, a firm conclusion about the absolute configuration at C-1′ cannot be reached from the NMR data alone because for (1′*S*,6*S*)-turmerone analogous conformations to **D** and **E** would also fit the observed data.

The circular dichroism (CD) spectrum of β-turmerone in chloroform, cyclohexane and methanol shows a strong, positive maximum (λ_{max} 240.5 nm, Δε 2.39 dm^3 mol^{-1} cm^{-1} in methanol). On reduction of the methanolic solution *in situ* with sodium borohydride (to remove the enone functionality) the ellipticity maximum remains positive, but suffers a bathochromic shift of 6.5 nm. The methanol was removed and the residue was taken up in cyclohexane to give, after filtration, a solution exhibiting a CD spectrum with λ_{max} 233.5 nm. This is very similar to the CD spectrum of (*R*)-(−)-β-phellandrene in cyclohexane (λ_{max} 232.5 nm, Δε 7.2 dm^3 mol^{-1} cm^{-1}).[18] The positive sign of both Cotton effects may relate either to the diene helicity[14,15] or to perturbation of the electronic structure

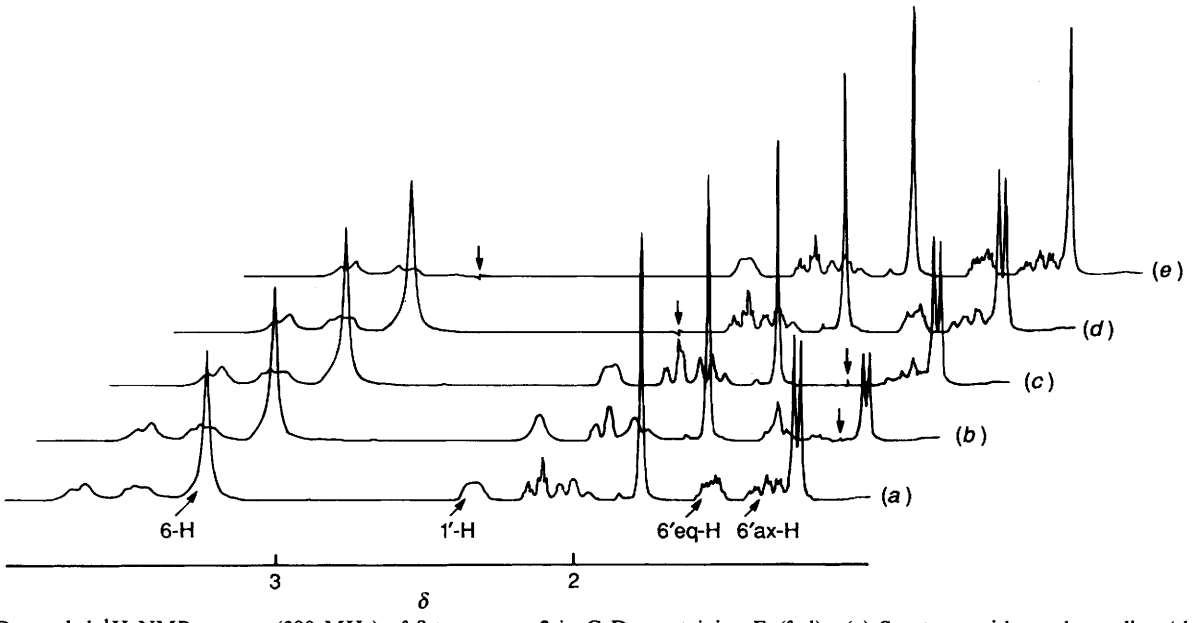


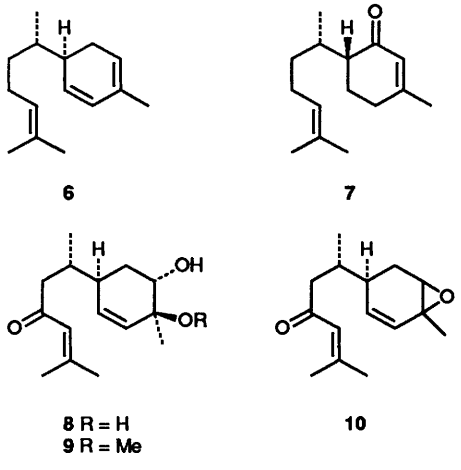
Fig. 3 Decoupled ^1H NMR spectra (300 MHz) of β-turmerone **3** in C_6D_6 containing $Eu(fod)_3$: (*a*) Spectrum with no decoupling (showing substantial shifts for several resonances). (*b*) Decoupling of $6'_{ax}$-H. (*c*) Decoupling of $6'_{eq}$-H. (*d*) Decoupling of 1'-H. (*e*) Decoupling of 6-H.

of the non-planar diene by asymmetric substituents,[16,17] and strongly indicates configuration *R* at C-1' of β-turmerone. Furthermore, Dummer and Kreiser[19] have synthesised the enantiomer of structure **3**. Comparison of ^{13}C NMR data and optical rotations support the enantiomeric relationship between β-turmerone and the synthetic enantiomer of structure **3**.*

Structure and Absolute Configuration of α-Turmerone.—The ^1H NMR spectrum of α-turmerone in C_6D_6 can be straightforwardly assigned (see Experimental section) with the help of the published spectrum of α-phellandrene.[20] The CD of α-turmerone in chloroform is strongly positive (λ_{max} 243 nm, $\Delta\varepsilon$ 2.73 $dm^3\ mol^{-1}\ cm^{-1}$) like that of β-turmerone and also indicates *R* stereochemistry at C-1'. As it is unlikely that α- and β-turmerone would differ in absolute stereochemistry because of their co-occurrence and thus presumed common biosynthetic origin (concerning the biosynthesis of bisabolane terpenoids see ref. 21), the stereochemistry of α-turmerone is also assigned as (1'*R*,6*S*). Since α-turmerone is an oxozingiberene this assignment agrees with the absolute configuration of zingiberene **6**,[22] *i.e.* the same chirality as α-turmerone (*cf.* **2**). It is therefore likely that *C. longa* has an enzyme system that oxidises zingiberene (which has been found in *C. longa*[23]) to α-turmerone. Bohlmann and co-workers have described bisabolones (*e.g.* **7**) and related molecules from plants, that correlate stereochemically with the turmerones, and only deviate biosynthetically by their different oxidation patterns.[23]

Rupe *et al.*[6] reported that turmerone reacts with maleic anhydride and this observation is now accounted for by the presence of α-turmerone. We found that the mixture of α- and β-turmerone obtained by chromatography of turmeric oil on silica (see Experimental section) shows selective consumption of α-turmerone on reaction with maleic anhydride (monitoring of a reaction in [$^2H_6$]acetone by NMR).

Concluding Comments.—Recently, studies of *C. longa* and *C. xanthorrhiza* have reported the isolation of new sesquiterpenes, some of which are structurally related to the turmerones.[24–26]



The absolute configuration assigned by Kiso *et al.*[10] was used by Uehara *et al.*[24] to assign absolute configurations to several of these new sesquiterpenes. However, Itokawa[27] has subsequently revised the structure of one of these compounds as **8**, corresponding to the absolute configuration deduced for β-turmerone in the present paper.

Curiously, Kiso *et al.*[10] only reported the isolation of β-turmerone from *C. longa*, whilst Ohshiro *et al.*[25] only mentioned α-turmerone. The isolation procedure of ref. 10 involved chromatography on silica with chloroform as the eluent and it may be that α-turmerone was destroyed by adventitious acid in the chloroform (*N.B.* Snatzke *et al.* described α-phellandrene as very oxygen-sensitive, detectable *p*-cymene being formed within 1 day at room temp.[28]). We have found that α-turmerone is much less stable to manipulation than β-turmerone. Some of the structures claimed by Ohshiro *et al.*[25] appear to be artefacts of the isolation procedure. They used both methanol and chloroform for initial extractions of *C. longa* rhizomes. Their compounds assigned structures **8** and **9** (with corrected stereochemistry[27]) could have been derived from the putative epoxide **10** of α-turmerone by acid-catalysed ring-opening with either water or methanol.

With the elucidation of the structures of the turmerones **2** and **3**, the way is now clear to the rational synthesis of these molecules.[29]

* We thank Prof. Dr. W. Kreiser for data (*cf.* ref. 19) for the synthetic enantiomer of β-turmerone.

Experimental

Spectroscopy.—CD spectra (λ, $\Delta\varepsilon$) were measured with a Jobin Yvon CD-6 instrument; IR spectra (ν/cm^{-1}) with a Bruker IFS-66 FTIR; ^{1}H and ^{13}C NMR (δ/ppm, J/Hz) with a Bruker WM-300, WH-360 or WH-400 instrument; electron impact mass spectra (70 eV, m/z, % of base peak) with a Kratos MS90 or Varian MAT 212. Specific optical rotations are given in units of 10^{-1} deg cm^2 g^{-1}.

Solvents.—Solvents for chromatography and spectroscopy were either HPLC grade (from Rathburn Chemicals Ltd., Walkerburn, Scotland) or were carefully purified (*e.g.* both light petroleum and triethylamine were refluxed over calcium hydride and fractionally distilled). Chloroform and deuteriochloroform were pre-treated with basic alumina, redistilled and stored at 0 °C under nitrogen in darkness.

Isolation of Turmerones.—Method 1: *C. longa* rhizomes (Allepey fingers, 300 g) were soaked in nitrogen-flushed water for 14 days at room temperature. The roots were dried with tissue paper, minced, and extracted by stirring with light petroleum (b.p. 40–60 °C) for 4 h. The suspension was filtered and the filtrate was concentrated. The solid material from the filtration was extracted twice more with light petroleum and the concentrated filtrates were combined. ^{1}H NMR analysis of the crude oil showed it to contain *ar*, α- and β-turmerone in ratio 1.13:1.7:1. Commercial turmeric powders were also extracted, but yielded relatively more *ar*-turmerone, and in some cases, no α-turmerone.

Method 2: *C. longa* rhizomes (100 g, commercially available material) were mixed with solid carbon dioxide (200 g) and the mixture was ground finely with a Waring blender. The ground mixture was added to light petroleum (b.p. 40–60 °C; 500 cm^3) and stirred for 4 h. The suspension was filtered and the filtrate concentrated. The remaining solid was extracted twice more with light petroleum (2 × 100 cm^3), and the concentrated filtrates were combined.

Method 3: *C. longa* Allepey fingers were ground with a cutter grinder (Condux CS-150) at 1420 rpm to a particle size of 0.01–0.5 mm. The resulting fine yellow powder (300 g) was suspended in hexane (1.5 dm^3) under an argon atmosphere and vigorously stirred for 15 min. The suspension was filtered and the filtrate was concentrated to give a bright yellow oil (7.9 g). Further extractions with hexane (3 × 1.5 dm^3) gave more of the oil (total 9.37 g, 3.1%).

The crude turmeric oil (*e.g.* 5 g from method 3 was further purified by medium pressure chromatography on Merck silica gel 60 [500 g, 230–400 mesh, Wiener column,* elution with 1:4:95 triethylamine–diethyl ether–light petroleum (b.p. 40–60 °C; 30 cm^3 fractions). This gave (fractions 57–66) an α-/β-turmerone mixture (0.78 g) free of *ar*-turmerone. Fractions 67–78 contained α-, β- and *ar*-turmerone (1.45 g) and this mixture was chromatographed in the manner just described to afford an α-/β-turmerone mixture (0.22 g, total α-/β-turmerone mixture 1.00 g, 0.33% yield from rhizomes, 20% from turmeric oil). Fractions 80–100 contained pure *ar*-turmerone (0.62 g).

HPLC fractionation of the α-/β-turmerone mixture was performed using analytical and preparative silica columns (Hichrom S5W-2546 and S5W-5003, with elution by hexane or heptane containing 1% triethylamine). Optimal flow rates were 1 cm^3 min^{-1} for an analytical column (25 cm × 4.9 mm) or 4 cm^3 min^{-1} for a preparative column (50 cm × 8 mm). Typical resolution parameters on an analytical column were as follows: α (relative retention with respect to *ar*-turmerone) for *ar*-turmerone 1.00 and α-turmerone 1.40, for α- and β-turmerone 1.11; R_S (column resolution) = 0.13 s mm^{-1} (*ar*- and β-turmerone), 0.05 s mm^{-1} (α- and β-turmerone). Pure α- and β-turmerone (yields of a few mg each) were only obtained after recycling partially separated fractions.

(6*S*)-2-*Methyl*-6-(p-*tolyl*)*hept*-2-*en*-4-*one* (**1**, ar-*turmerone*). $[\alpha]_D^{20}$ +76 (*c* 0.6 in MeOH) [lit.,[7] +64 (neat)]; CD (MeOH) λ_{max}/nm 238.5 (3.02), 228 (sh, 2.48), 216 (−0.35) and 211 (0.22).

(1′*R*,6*S*)-2-*Methyl*-6-(4-*methylcyclohexa*-2,4-*dienyl*)*hept*-2-*en*-4-*one* (**2**, α-*turmerone*). δ_H(400 MHz, $CDCl_3$) 0.87 (3 H, d, *J* 6.1, Me-7), 1.69 (3 H, ddd, *J* 2, 2 and 2, Me-4′), 1.89 (3 H, d, *J* 1.3, Me-1), 2.0–2.3 (5 H, m, 1′-H, 1 × 5-H, 6-H and 2 × 6′-H), 2.14 (3 H, d, *J* 1.3, Me-2), 2.50 [1 H, dd, *J* 4 (6-H) and 15 (5-H), 5-H], 5.42 (1 H, br s, Σ *J* 16, 5′-H), 5.63 [1 H, dd, *J* 3 (1′-H) and 10 (3′-H), 2′-H], 5.79 [1 H, ddd, *J* 2, 2 (5′-H) and 10 (2′-H), 3′-H] and 6.05 (1 H, septet, *J ca.* 1.3, 3-H); λ_{max}/nm(EtOH) 238 and 261 (from difference spectrum obtained for solutions before and after addition of sodium borohydride); m/z 218.1668 (M^+, 10%, calculated for $C_{15}H_{22}O$ 218.1669), 119, 105, 91, 83 (100%), 65, 55 and 39; CD ($CHCl_3$) λ_{max}/nm 243 (2.73).

(1′*R*,6*S*)-2-*Methyl*-6-(4-*methylenecyclohex*-2-*enyl*)*hept*-2-*en*-4-*one* (**3**, β-turmerone). δ_H(300 MHz, C_6D_6) 1.01 (3 H, d, *J* 7.0, 7-Me), 1.44 (1 H, m, 6′$_{ax}$-H), 1.63 (3 H, d, *J* 1.3, 1-Me), 1.69 (1 H, m, 6′$_{eq}$-H), 2.18 (1 H, dd, *J* 16.7 and 9.9, 1 × 5-H), 2.27 (1 H, br, 1′-H), 2.28 (3 H, d, *J* 1.2, 2-Me), 2.33–2.52 (4 H, overlapping m, 1 × 5-H, 6-H, 2 × 5′-H), 4.94 (1 H, br d, *J* 0.5, 1 of =CH_2), 4.99 (1 H, br s, 1 of =CH_2), 5.72 (1 H, br d, *J* 10, 2′-H), 5.94 (1 H, m, 3-H) and 6.35 (1 H, dd, *J* 10.0 and 2.6, 3′-H) *N.B.* Me groups assigned from NOESY spectrum (crosspeak observed between Me-1 and 3-H); δ_C(75 MHz, C_6D_6) 17.42 (q, Me-7), 21.21 (q, Me-2), 25.99 (t, C-6′), 27.88 (q, 1-Me), 31.23 (t, C-5′), 34.07 (d, C-6), 41.51 (d, C-1′), 49.38 (t, C-5), 111.28 (t, =CH_2), 125.09 (d, C-3), 131.18 (d, C-3′), 134.67 (d, C-2′), 144.32 (s, C-4′), 154.36 (s, C-2) and 199.69 (s, C-4); ν_{max}/cm^{-1} (film) 3020, 2957, 2933, 2874, 2835, 1686s, 1653w, 1620s, 1598w, 1446, 1419, 1377, 1364, 1036 and 877; λ_{max}/nm (EtOH) 232 and 237 (from difference spectrum obtained for solutions before and after addition of sodium borohydride), m/z 218.1661 (M^+, 3%), 120 (100%), 105, 92, 83, 55 and 39; CD ($CHCl_3$) λ_{max}/nm 245 (3.37), CD (cyclohexane) λ_{max}/nm 238.5 (4.53), CD (MeOH) λ_{max}/nm 240.5 (2.39). To the solution used to record the CD of β-turmerone in methanol was added an excess of sodium borohydride in three portions over 30 min. The resulting solution showed λ_{max}/nm 234.0 (1.72). It was concentrated to dryness and the residue was extracted with cyclohexane. The filtrate was diluted to 2 cm^3 with more cyclohexane and the CD was measured (λ_{max}/nm 233.5).

* A Sandoz-designed column, similar to Merck or Labomatic columns for medium pressure chromatography.

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