Allyl Sulphide Synthesis by Phenylthio Migration: Relationship between Stereochemistry of Starting Materials and Regioselectivity of Double Bond Formation

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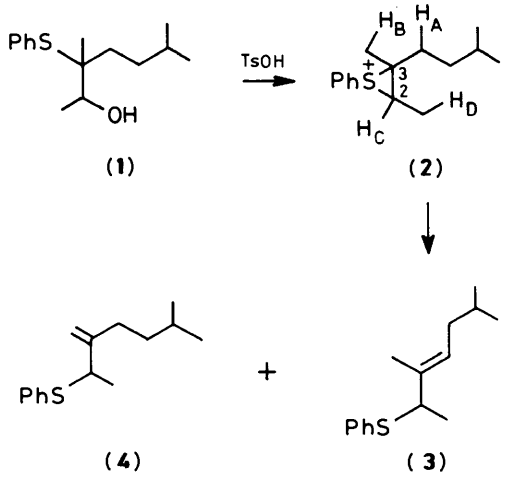
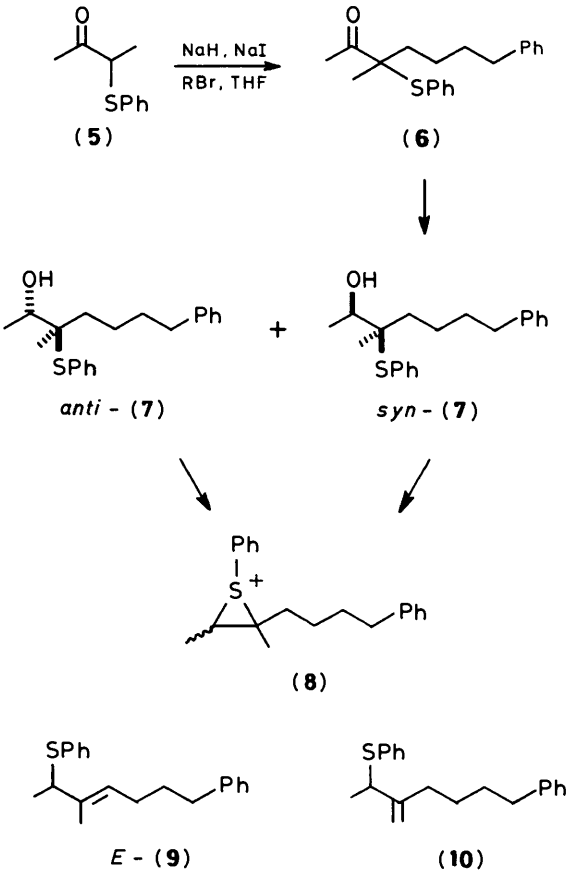
Phenylthio migration to an alkyl migration terminus can be controlled to give mostly an allyl sulphide with a trisubstituted double bond and good *E*:*Z* selectivity but migration to a benzylic migration terminus is affected by stereochemistry: each diastereoisomer of the starting material preferentially forms one of two regioisomeric allylic sulphides.

Rearrangement[1,2] of β-phenylthio alcohols, *e.g.* (**1**), under dehydrating conditions gives allyl sulphides, (**3**) and (**4**), and not vinyl sulphides as the bond between H_C and C-2 cannot become anti-parallel to a C–S^+ bond in the intermediate (**2**). Only rearranged allyl sulphides, (**3**) and (**4**), are formed by phenylthio (PhS) migration as only the weaker C–S^+ bond in (**2**), to the tertiary centre C-3, is broken and H_D is not lost. Either of the remaining two sets of protons ($H_{A,B}$) can be lost [in MeCN a mixture of *E*- and *Z*-(**3**) and (**4**) is formed] but under the right conditions [toluene-*p*-sulphonic acid (TsOH) in benzene for 10 min] the reaction is remarkably selective, giving in this case a 98% yield of a 10:1 mixture of *E*- and *Z*-(**3**).



Although our explanation[2] of these results ignored the stereochemistry of the alcohol (**1**) [the sample of (**1**) giving 98% of (**3**) was a 5:4 mixture of diastereoisomers], we now report that there is in fact a relationship between the diastereoisomeric structure of the starting materials for these rearrangements and the composition of the products. In particular, the position of the double bond in the products, *e.g.* the tri-substituted double bond in (**3**) [by loss of H_A from (**2**)] or the *exo*-methylene compound (**4**) (by loss of H_B), may depend on the stereochemistry at C-2 in the intermediate (**2**).

We have studied three β-phenylthio alcohols (**7**), (**15**), and (**19**), synthesized by straightforward methods [Scheme 1 for (**7**) and Scheme 2 for (**15**) and (**19**)]. In each case reduction of an α-phenylthio ketone (**6**), (**14**; R = H), or (**14**; R = Me) favours the *syn*† isomer of the alcohol (Table 1) by the usual[3] Felkin-Anh[4] stereoselectivity. The diastereoisomeric alcohols were separated by h.p.l.c. to give pure samples of *syn*- and *anti*-(**7**) and (**15**) but only enriched samples of (**19**): a 2.26:1 *anti*:*syn* mixture and a nearly pure sample (32:1) of *syn*-(**19**).



Scheme 1.

Rearrangement of *syn*- and *anti*-(**7**) (Scheme 1) revealed that the product composition depended on the reaction time and amount of TsOH. Short times and low TsOH concentration produced a *ca.* 70:30 mixture of *E*-(**9**) and (**10**). Longer reaction times or higher TsOH concentrations produced almost exclusively the tri-substituted isomer (**9**) but with poorer stereoselectivity (Table 2). We suggest that the initial (kinetic) product is *ca.* 70:30 *E*-(**9**):(**10**) but that *both* products equilibrate by reversion to the intermediate (**8**) to give the final (thermodynamic) product, mostly (**9**). The transition state from

† The carbon chain is drawn in its most extended form: the compound is *syn* if PhS and OH are on the same side, and *anti* if they are on opposite sides. This is the convention introduced by Masamune. S. Masamune, T. Kaiho, and D. S. Garvey, *J. Am. Chem. Soc.*, 1982, **104**, 5521.

Table 1. Stereoselectivities of reduction of α-phenylthio ketones

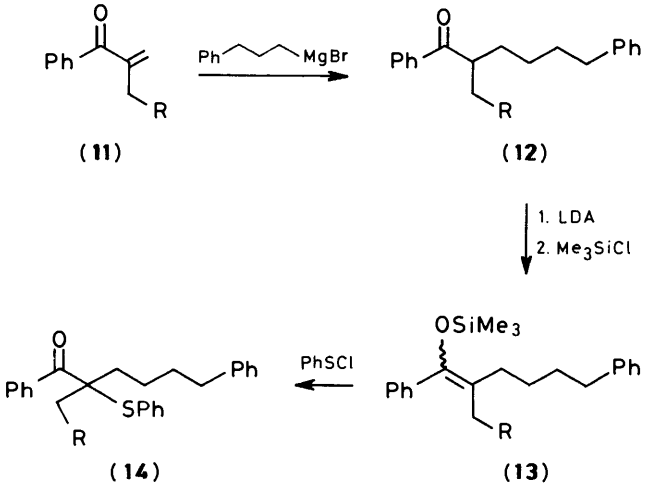
Ketone	Reducing agent	Temp. (°C)	Product	Yield (%)	Ratio *syn*:*anti*
(**6**)	$NaBH_4$, EtOH	Room	(**7**)	92	1.5 1
(**6**)	L-Selectride	−78	(**7**)	35	2.6 1
(**6**)	$LiAlH_4$, Et_2O	−78	(**7**)	98	2.0 1
(**6**)	$NaBH_4$, $CeCl_3$	−78	(**7**)	96	1.9 1
(**14**; R = H)	$NaBH_4$, EtOH	Room	(**15**)	94	2.0 1
(**14**; R = Me)	$NaBH_4$, EtOH	Room	(**19**)	90	1.0 1
(**14**; R = Me)	$LiAlH_4$, Et_2O	−78	(**19**)	95	1.1 1
(**14**; R = Me)	DIBAL	−23	(**19**)	93	1.2 1
(**14**; R = Me)	L-Selectride	−78	*a*	*a*	*a* *a*

[a] Product was 54% (**12**; R = Me).

Table 2. Rearrangement of the alcohol (**7**)

Isomer	Mol % TsOH	Mol equiv. TsOH	Reflux time (min)	Yield (%) (**9**)	*E*:*Z*	(**10**)
syn-(**7**)	5	0.09	2.5	24[a]	—	9[a]
	10	0.18	2.5	80	*b*	20
	25	0.46	2.5	89	*b*	11
	50	0.91	2.5	99	91:9	1
syn-(**7**)	5	0.09	10	82	88:12	18
	10	0.18	10	90	83:17	10
anti-(**7**)	10	0.18	2.5	83	91:9	17
	20	0.46	2.5	97	89:11	3

[a] With 67% starting material *syn*-(**7**). [b] > 15:1 *E*:*Z*; *Z* not detected by n.m.r.



Scheme 2.

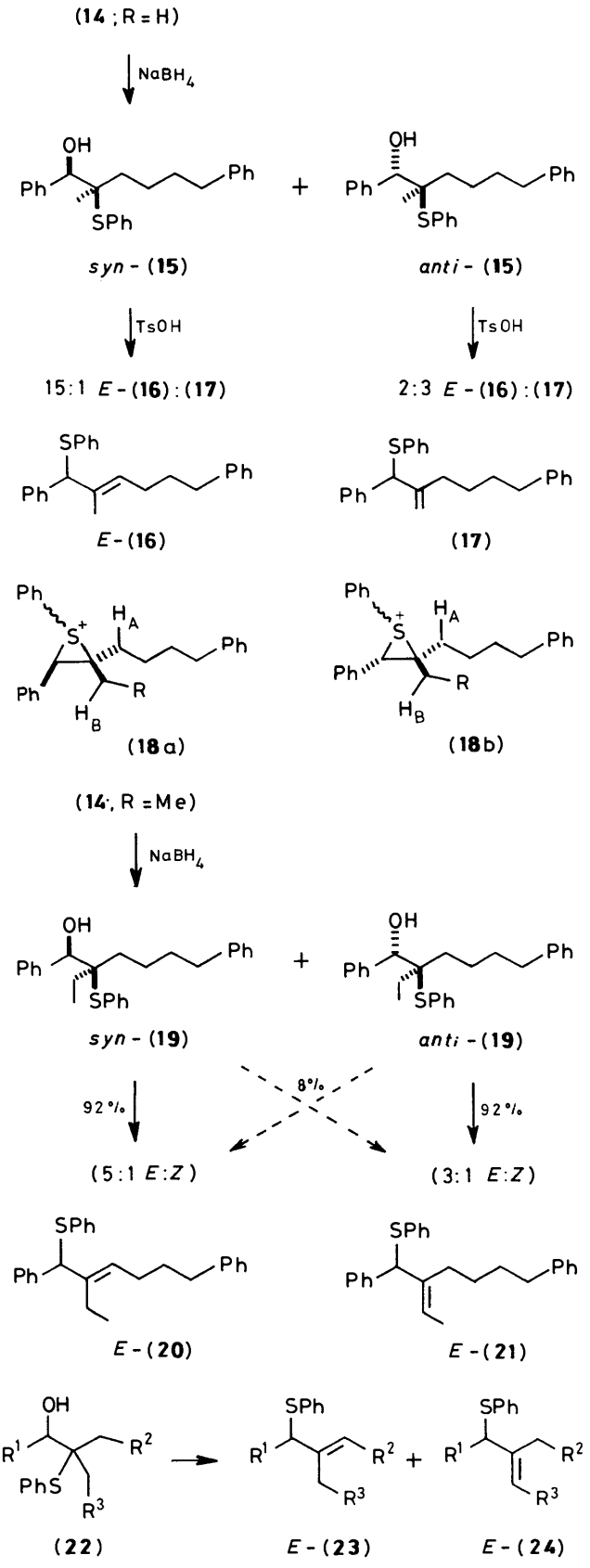
(**8**) to (**9**) is more sensitive to steric effects than (**9**) itself which is therefore initially formed as pure *E* isomer but equilibrates to a thermodynamic *ca.* 90:10 *E*:*Z* mixture. These equilibration processes mask the dependence (if any) on the stereochemistry of the starting material in accordance with our earlier results[2] on (**1**).

Rearrangement of the two benzylic alcohols (**15**) and (**19**) revealed a marked dependence on stereochemistry. The alcohol *syn*-(**15**) gave almost exclusively the allyl sulphide with the tri-substituted double bond [15:1 *E*-(**16**):(**17**)] while *anti*-(**15**) gave a mixture slightly richer in the *exo*-methylene compound [2:3 *E*-(**16**):(**17**)]. Our samples of (**19**) gave results which suggest that *syn*-(**19**) gives a 92:8 mixture of (**20**):(**21**) while *anti*-(**19**) gives an 8:92 mixture of (**20**):(**21**). Both these allyl sulphides have tri-substituted double bonds: (**20**) is formed as a 5:1 *E*:*Z* and (**21**) as a 3:1 *E*:*Z* mixture.

The stereochemical dependence is simply explained if the episulphonium ion intermediates (**18**) prefer to lose a proton from the face of the three-membered ring opposite the C-phenyl group, *i.e.* (**18a**), formed stereospecifically from *syn*-(**15**) or *syn*-(**19**) with inversion at C-1, prefers to lose protons H_A while (**18b**), formed from *anti*-(**15**) or *anti*-(**19**), prefers to lose protons H_B. If one product has a tri-substituted double bond while the other is an *exo*-methylene compound [*e.g.* (**16**) and (**17**)] the stereochemical preference competes with an electronic preference for the former. If the two substituents at the migration origin are more similar, *i.e.* $MeCH_2$ and $Ph(CH_2)_4$ in (**19**), the stereochemical preference dominates.

This similarity at the migration origin was also evident in the poor stereoselectivity of the reduction of the α-phenylthio ketone (**14**; R = Me) and the difficulty of separation of *syn*- and *anti*-(**19**). It is again evident in the formation of both (**20**) (5:1 *E*:*Z*) and (**21**) (3:1 *E*:*Z*) as mixtures. By contrast, the *E*-isomer of (**16**) is alone formed by rearrangement of *syn*- or *anti*-(**15**), just as *E*-(**9**) is the kinetic product from (**7**). Equilibration of products is not observed during the rearrangement of either (**15**) or (**19**), but prolonged refluxing leads to an acid catalysed [1,3] PhS shift.[5]

Conclusions.—Compounds with an aryl group at the migration terminus (**22**; R′ = Ar) show a stereochemical dependence of product ratio (**23**):(**24**) on stereochemistry: the proton is preferentially lost from whichever side-chain (R^2CH_2 or R^3CH_2) is *anti* to R^1 in the episulphonium ion intermediate. Compounds with an alkyl group at the migration terminus and one methyl group at the migration origin (**22**; R^1 = Alkyl, R^3 = H) can be rearranged under conditions (*ca.* half a molar



equivalent of TsOH, 2.5 *min* reflux in benzene) which favour the product (**23**; R^3 = H) with the trisubstituted double bond regardless of the stereochemistry of the starting material. We have used these conclusions in recent work.[6]

Experimental

2-Benzoylprop-1-ene (**11**; R = H).—Bromine (21.62 g, 0.14 mol) was added dropwise over 30 min to a stirred solution of isobutyrophenone (20.0 g, 0.14 mol) and a catalytic quantity of aluminium trichloride (0.5 g, 3.7 mmol) in dry ether (150 ml) at 0 °C. The ether and dissolved hydrogen bromide were removed simultaneously under reduced pressure with a slight current of air. The product was dissolved in ether (200 ml), shaken with brine (50 ml), dried ($MgSO_4$), and evaporated under reduced pressure to give the bromo ketone (30.25 g, 99%); $R_F(CH_2Cl_2)$ 0.67; $\delta_H(CDCl_3)$ 8.00 (2 H, dd, *J* 2 and 8 Hz, ArH *o* to CO), 7.32 (3 H, m, Ph), and 1.98 (6 H, s, CMe_2). Anhydrous LiBr (45 g, 0.52 mol) and Li_2CO_3 (40 g, 0.54 mol) was added to a solution of the bromo ketone (15 g, 66 mmol) in dry DMF (400 ml). The mixture was stirred with a mechanical stirrer for 4 h at 100 °C, poured into water, and extracted with light petroleum (b.p. 40—60 °C) (4 × 100 ml). The combined petroleum extracts were washed with dilute hydrochloric acid (50 ml), aqueous sodium hydrogen carbonate (50 ml), water (30 ml), and brine (30 ml), dried (Na_2SO_4), evaporated under reduced pressure, and distilled to give the pale yellow enone (8.62 g, 92%), b.p. 58—60 °C/0.5 mmHg (lit.,[7] b.p. 60 °C/3 mmHg); $\nu_{max.}$(film) 1 660 (C=O) and 1 640 cm^{-1} (C=C); $R_F(CH_2Cl_2)$ 0.43; $\delta_H(CDCl_3)$ 7.85 (2 H, dd, *J* 2 and 8 Hz, ArH *o* to CO), 7.55 (3 H, m, Ph), 5.95 (1 H, s, =CH *trans* to Me), 5.67 (1 H, s, =CH *cis* to Me), and 2.09 (3 H, s, CMe).

2-Methyl-1,6-diphenylhexan-1-one (**12**; R = H).—3-Bromo-1-phenylpropane (17.8 g, 0.89 mmol) was added to Mg turnings (2.5 g, 104 mmol) and dry ether (100 ml) in a 500 ml, 3-necked flask fitted with reflux condenser under nitrogen at 0 °C. The Grignard reaction was initiated using an ultrasonic bath for 30 s at 0 °C and the mixture stirred for 1 h at room temperature before being subjected to a final 30 s of ultrasonication. The Grignard reagent was cooled to −23 °C and the enone (**11**; R = H) (5.0 g, 34 mmol) in dry ether (25 ml) was added dropwise over 20 min from a dropping funnel; the mixture was then stirred for 1 h before being allowed to warm to room temperature. It was quenched with saturated aqueous ammonium chloride (250 ml) and extracted with ether (4 × 100 ml). The combined ether extracts were washed with water (50 ml), evaporated under reduced pressure, and distilled to give the *ketone* (6.56 g, 72%), b.p. 144—148 °C/0.05 mmHg; $R_F(CH_2Cl_2)$ 0.60; $\nu_{max.}$(film) 1 680 cm^{-1} (C=O); $\delta_H(CDCl_3)$ 8.0 (2 H, dd, *J* 2 and 8 Hz, ArH *o* to CO), 7.60—7.12 (8 H, m, Ph), 3.45 (1 H, sextuplet, *J* 7 Hz, C*H*Me), 2.58 (2 H, t, *J* 8 Hz, CH_2Ph), 1.90—1.33 [6 H, m, $PhCH_2(CH_2)_3$], and 1.19 (3 H, d, *J* 7 Hz) (Found: M^+, 266.1655. $C_{19}H_{22}O$ requires *M*, 266.1665); *m/z* 266 (12%, M^+), 134 (42, $PhCOCH_2Me$), and 105 (100, PhCO).

2-Methyl-1,6-diphenyl-1-trimethylsilyloxyhex-1-ene (**13**; R = H).—The ketone (**12**; R = H) (2.42 g, 9.1 mmol) in THF (5 ml) was added dropwise over 10 min to a solution of lithium di-isopropylamide (LDA) (10 mmol) under nitrogen at −78 °C for 45 min and then 20 min at −23 °C. The red enolate was quenched with trimethylsilyl chloride (2.17 g, 20 mmol) at −78 °C and the solution allowed to warm to room temperature over 1 h. THF was evaporated under reduced pressure and the product was taken up in pentane and the solution filtered. Purification by column chromatography on flash silica, eluting with light petroleum (b.p. 30—40 °C)–ether (95:5) gave the silyl enol ether (1.26 g, 40%) as an oil, R_F[ether–hexane (15:85)] 0.63, $\delta_H(CDCl_3)$ 7.62—7.25 (10 H, m, Ph), 2.92—0.91 [8 H, m, $Ph(CH_2)_4$], 1.82 (3 H, s, C=CMe), and 0.15 (9 H, s, $SiMe_3$).

2-Methyl-1,6-diphenyl-2-phenylthiohexan-1-one (**14**; R = H).—Phenylsulphenyl chloride (1M solution in dichloromethane; 6 ml) was added dropwise to a stirred solution of the

silyl enol ether (**13**; R = H) (2 g, 6 mmol) in dry CH_2Cl_2 (5 ml) at −78 °C under argon. After 20 min the mixture was allowed to warm to room temperature, concentrated under reduced pressure, and the residue purified by column chromatography on silica gel eluting with CH_2Cl_2–hexane (2:3) to give the *ketone* (1.05 g, 61%) as a yellow oil, R_F[CH_2Cl_2–hexane, (3:2)] 0.64; $\nu_{max.}$(film) 1 680 cm^{-1} (C=O); δ_H($CDCl_3$) 8.21 (2 H, dd, *J* 2 and 8 Hz, ArH *o* to CO), 7.55—7.05 (13 H, m, Ph), 2.46 (2 H, t, *J* 7 Hz, PhCH_2), 2.13—1.05 [6 H, m, PhCH_2(CH_2)$_3$], and 1.43 (3 H, s, CMe) (Found: M^+ − PhCO, 269.1359. $C_{18}H_{21}S$ requires *M* − C_7H_5O, 269.1364); *m*/*z* 269 (85%, M^+ − PhCO) and 105 (100, PhCO).

2-*Methyl*-1,6-*diphenyl*-2-*phenylthiohexan*-1-*ol* (**15**).—Sodium borohydride (52 mg, 1.4 mmol) in sodium hydroxide solution (1% solution; 5 ml) was added dropwise to the ketone (**14**; R = H) (1.155 g, 3.09 mmol) in ethanol (50 ml) and the mixture stirred for 36 h. After neutralization with dilute sulphuric acid (5 ml), ethanol was evaporated under reduced pressure and the alcohol was extracted with dichloromethane (2 × 20 ml). The combined extracts were dried ($MgSO_4$) and evaporated to give a 2:1 ratio of the diastereoisomeric *alcohols* (1.088 g, 94%), R_F (CH_2Cl_2) 0.44, 0.48. The diastereoisomers were separated by h.p.l.c. on a Zorbax Sil column using CH_2Cl_2–light petroleum (b.p. 30—40 °C) (65:35) as eluant. The major *alcohol syn*-(**15**) had $\nu_{max.}$(film) 3 450 cm^{-1} (OH); δ_H($CDCl_3$) 7.51—7.13 (15 H, m, Ph), 4.51 (1 H, s, PhC*H*OH), 3.77 (1 H, s, PhCHO*H*), 2.61 (2 H, t, *J* 7 Hz, PhCH_2), 1.97—1.11 [6 H, m, PhCH_2(CH_2)$_3$], and 1.07 (3 H, s, CMe) (Found: M^+ − PhCHOH, 269.1381. $C_{18}H_{21}S$ requires *M* − C_7H_7O, 269.1365); *m*/*z* 269 (65%, *M* − PhCHOH), 159 (35), 117 (68), 110 (60, PhSH), 105 (40), and 91 (100). The minor *alcohol anti*-(**15**) had $\nu_{max.}$(film) 3 470 cm^{-1} (OH); δ_H($CDCl_3$) 7.55—7.19 (15 H, m, Ph), 4.36 (1 H, s, PhC*H*OH), 3.94 (1 H, s, PhCHO*H*), 2.63 (2 H, t, *J* 7 Hz, PhCH_2), 1.97—1.10 [6 H, m, PhCH_2(CH_2)$_3$], and 1.18 (3 H, s, CMe) (Found: M^+ − PhCHOH, 269.1365. $C_{18}H_{21}S$ requires *M* − C_7H_7O, 269.1365); *m*/*z* 269 (100%, *M* − C_7H_7O), 159 (32), 117 (54), 110 (32, PhSH), 105 (35), and 91 (61).

Dehydration of the Alcohol syn-(**15**).—The alcohol *syn*-(**15**) (48 mg, 0.13 mmol) was refluxed in dry benzene (5 ml) in a foil-wrapped flask with TsOH (8 mg). Refluxing was continued for 4 min, the mixture was cooled, passed through a short silica column using dichloromethane as eluant, and the solvents were removed under reduced pressure to give the *olefins* (**16**) and (**17**) (44 mg, 96%) as a colourless oil, which was found by n.m.r. to be a 15:1 ratio of (**16**):(**17**).

(E)-2-*Methyl*-1,6-*diphenyl*-1-*phenylthiohex*-2-*ene* (**16**) had R_F (CH_2Cl_2) 0.8; $\nu_{max.}$(film) 1 580 cm^{-1} (SPh); δ_H($CDCl_3$) 7.48—7.15 (15 H, m, Ph), 5.58 (1 H, t, *J* 8 Hz, C=CH), 4.93 [1 H, s, Ph(PhS)C*H*], 2.70—1.33 [8 H, m, Ph(CH_2)$_4$], and 1.69 (3 H, s, CMe). 2-(1-*Phenyl*-1-*phenylthiomethyl*)-6-*phenyl*-*hex*-1-*ene* (**17**) had R_F(CH_2Cl_2) 0.8; δ_H($CDCl_3$) 7.48—7.15 (15 H, m, Ph), 5.31 (1 H, s, *H*HC=C), 5.08 (1 H, s, H*H*C=C), 4.88 [1 H, s, Ph(PhS)C*H*], and 2.70—1.33 [8 H, m, Ph(CH_2)$_4$] (Found: M^+, 356.1608. $C_{25}H_{24}S$ requires *M*, 356.1599); *m*/*z* 356 (1%, M^+), 247 (90, *M* − SPh), 131 (85), and 110 (100, PhSH).

Dehydration of the Alcohol anti-(**15**).—In the same way, the alcohol *anti*-(**15**) produced a 2:3 ratio of (**16**):(**17**) in quantitative yield.

3-*Dimethylamino*-2-*ethylpropiophenone Methyl Iodide*.—Butyrophenone (5 g, 33.8 mmol), paraformaldehyde (1.35 g, 45 mmol), dimethylammonium chloride (3.58 g, 44 mmol), 95% ethanol (6 ml), and 5 drops of concentrated hydrochloric acid were refluxed for 16 h. The mixture was allowed to cool and ethanol evaporated under reduced pressure. The residue was diluted with 5% aqueous sodium hydroxide (150 ml) and extracted with ether (3 × 50 ml). The combined organic layers were dried ($MgSO_4$) and evaporated under reduced pressure. The crude material and methyl iodide (9.5 g, 66.9 mmol) were refluxed in dry ethanol under argon for 2 h as described by Whiting.[8] Ethanol was evaporated under reduced pressure and crystallization of the residue from methanol gave the amine salt (7.88 g, 70%) as prisms, m.p. 187—188 °C (lit.,[9] m.p. 188.8—189.8 °C).

2-*Benzoylbut*-1-*ene* (**11**; R = Me).—The above amine salt (7.8 g, 21.3 mmol) and lithium carbonate (7.22 g, 98 mmol) were refluxed in dry DMF (20 ml) under argon for 16 h as described by Whiting.[8] Lithium carbonate was filtered off and the filtrate was poured into water (150 ml) and extracted with ether (3 × 50 ml). The combined ether extracts were washed with dilute hydrochloric acid (25 ml), water (25 ml), and brine (25 ml), dried ($MgSO_4$), and evaporated under reduced pressure. Purification of the residue by column chromatography with ethyl acetate–hexane (1:9) as eluant gave the enone [3.14 g, 92% (65% based on butyrophenone)] as an oil, R_F[ethyl acetate–hexane 1:1)] 0.56; $\nu_{max.}$(film) 1 710 (C=O) and 1 660 cm^{-1} (C=C) (lit.,[10] 1 710 and 1 655 cm^{-1}); δ_H($CDCl_3$) 7.75 (2 H, m, PhH *o* to CO), 7.56—7.31 (3 H, m, Ph), 5.81 (1 H, dd, *J* 1.5 and 2.2 Hz, C=CH^1H^2), 5.56 (1 H, d, *J* 0.9 Hz, C=CH^1H^2), 2.47 (2 H, m, CH_2Me), and 1.11 (3 H, t, *J* 7.4 Hz) (Found: M^+, 160.0881. $C_{11}H_{12}O$ requires *M*, 160.0888); *m*/*z* 160 (18%, M^+), 145 (25, *M* − Me), 125 (30), 110 (58), 105 (91, PhCO), and 77 (100, Ph).

2-*Ethyl*-1,6-*diphenylhexan*-2-*one* (**12**; R = Me).—The above enone (4.17 g, 26 mol) was added at −78 °C to an ethereal solution of the Grignard formed from 3-bromo-1-phenylpropane (8.3 g, 41.6 mmol) and magnesium turnings (1.25 g, 52 mmol) as above. The crude material was purified by column chromatography using ethyl acetate–hexane (1:9) as eluant to give the *ketone* (6.5 g, 89%) as an oil, R_F[ethyl acetate–hexane (1:3)] 0.56; $\nu_{max.}$(film) 1 690 cm^{-1} (C=O); δ_H($CDCl_3$) 7.95 (2 H, dd, *J* 2 and 8 Hz, ArH *o* to CO), 7.60—7.11 (8 H, m, Ph), 3.36 (1 H, sym m, PhCOCH), 2.56 (2 H, t, *J* 8.1 Hz, PhCH_2), 1.86—1.25 [8 H, m, PhCH_2(CH_2)$_3$ and MeCH_2], and 0.87 (3 H, t, *J* 7.4 Hz, *Me*CH_2); δ_C($CDCl_3$) 204.35, 142.45, 137.78, 132.69, 128.27, 128.16, 128.08, 125.55, 47.54, 35.66, 31.66, 31.60, 27.18, 25.38, and 11.80 (Found: M^+, 280.1831. $C_{20}H_{24}O$ requires *M*, 280.1828); *m*/*z* 280 (7%, M^+), 148 (39, PhCOPr), and 105 (100, PhCO).

2-*Ethyl*-1,6-*diphenyl*-2-*phenylthiohexan*-1-*one* (**14**; R = Me).—The silyl enol ether (**13**; R = Me) was prepared as above to give, after Kugelrohr distillation, the silyl enol ether (1.28 g, 51%) as an oil, b.p. 195—200 °C/0.1 mmHg. Quenching the silyl enol ether (1.23 g, 3.5 mmol) with benzenesulphenyl chloride by the method used above gave the *ketone* (0.65 g, 48%) as an oil, R_F(CH_2Cl_2) 0.67; $\nu_{max.}$(film) 1 690 cm^{-1} (C=O); δ_H($CDCl_3$) 8.20 (2 H, dd, *J* 1.5 and 7.8 Hz, ArH *o* to CO), 7.51—7.07 (13 H, m, Ph), 2.48 (2 H, m, PhCH_2), 1.93—1.11 [8 H, m, PhCH_2(CH_2)$_3$ and MeCH_2], and 0.86 (3 H, t, *J* 7.4 Hz, CH$_2$*Me*) (Found: M^+ − PhCO, 283.1521. $C_{19}H_{23}S$ requires *M* − C_7H_5O, 283.1521); *m*/*z* 283 (70%, M^+ − PhCO), 173 (10), 117 (65), 110 (32, PhSH), 105 (100, PhCO), 91 (85, PhCH_2), and 77 (64, Ph).

2-*Ethyl*-1,6-*diphenyl*-2-*phenylthiohexan*-1-*ol* (**19**).—The ketone (**14**; R = Me) (100 mg, 0.26 mmol) in dry ether (1 ml) was added to a suspension of lithium aluminium hydride (12 mg, 0.31 mmol) in dry ether (10 ml) at −78 °C under argon. After 1 h, the reaction was quenched with aqueous sodium hydroxide (5 ml) at −78 °C and the mixture allowed to warm to room temperature; it was then diluted with water (50 ml) and extracted with ether (3 × 20 ml). The combined ether extracts

were washed with saturated aqueous ammonium chloride (10 ml) and brine (10 ml), dried ($MgSO_4$), evaporated under reduced pressure, and passed through a short silica column, eluting wth CH_2Cl_2 to give a 1.1:1 mixture of diastereoisomeric alcohols (96 mg, 95%) (by ^1H n.m.r. and h.p.l.c.). H.p.l.c. separation, eluting with ethyl acetate–hexane (1:50) on a Zorbax Sil column with a flow rate of 14 ml/min gave one fraction enriched (32:1) in the (1SS,2RR) *alcohol syn-*(**19**), R_F [ethyl acetate–hexane (1:50)] 21.4 min; $\nu_{max.}$(film) 3 425 cm^{-1} (OH); $\delta_H(CDCl_3)$ 7.51—7.14 (15 H, m, Ph), 4.45 (1 H, s, *H*COH), 2.56 (2 H, sym, m, PhCH_2), 1.79—1.26 [8 H, m, $PhCH_2(CH_2)_3$ and CH_2Me], and 1.00 (3 H, t, *J* 7.5 Hz, CH_2*Me*) (Found: M^+ − PhCHOH, 283.1523. $C_{19}H_{23}OS$ requires *M* − C_7H_7O, 283.1521); *m/z* 283 (55%, M^+ − PhCHOH), 173 (18), 117 (70), 110 (68, PhSH), 105 (70, PhCO), and 91 (100, $PhCH_2$); and one fraction enriched (2.26:1) in the (1SR,2RS) *alcohol anti-*(**19**), R_F[ethyl acetate–hexane (1:50)] 21.9 min; $\nu_{max.}$(film) 3 425 cm^{-1} (OH); $\delta_H(CDCl_3)$ 7.63—7.16 (15 H, m, Ph), 4.42 (1 H, s, C*H*OH), 2.61 (2 H, m, PhCH_2), 1.79—1.26 [8 H, m, $PhCH_2(CH_2)_3$ and CH_2Me], and 1.00 (3 H, t, *J*, 7.4 Hz, CH_2*Me*) (Found: M^+ − PhCHOH, 283.1521. $C_{19}H_{23}OS$ requires *M* − C_7H_7O, 283.1521); *m/z* 283 (55%, M^+ − PhCHOH), 173 (18), 117 (70), 110 (68, PhSH), 105 (70, PhCO), and 91 (100, $PhCH_2$).

Rearrangement of 2-*Ethyl*-1,6-*diphenyl*-2-*phenylthiohexan*-1-*ol* (**19**).—The 32:1 mixture of diastereoisomeric alcohols (55 mg, 0.14 mmol) enriched in the (1*SS*,2*RR*) isomer *syn-*(**19**) was refluxed in benzene (2 ml) and a solution of TsOH in refluxing benzene (0.05M; 0.5 ml) was added. After 5 min the reaction was cooled in ice and passed through a short silica column eluting with CH_2Cl_2. The solvents were evaporated under reduced pressure to give an 8.3:1 mixture of (**20**):(**21**) (52 mg, 99%) as an oil. 2-*Ethyl*-1,6-*diphenyl*-1-*phenylthiohex*-2-*ene* (**20**) was a 5:1 mixture of *E*:*Z* isomers and had $R_F(CH_2Cl_2)$ 0.77; $\nu_{max.}$(film), 1 580 cm^{-1} (SPh); $\delta_H(CDCl_3)$ 7.52—7.07 (15 H, m, Ph), 5.58(*E*) and 5.30(*Z*) (1 H, t, *J* 7.4 Hz, C*H*=C), 5.45(*Z*) and 4.90(*E*) (1 H, s, PhC*H*SPh), 2.67—1.10 [8 H, m, $Ph(CH_2)_3$ and CH_2Me], and 0.93(*Z*) and 0.89(*E*) (3 H, t, *J* 7.4 Hz, CH_2Me) (Found: M^+, 372.1897. $C_{26}H_{28}S$ requires *M*, 372.1912); *m/z* (2%, M^+), 263 (100, *M* − SPh), 143 (97), 131 (91), 129 (81), 117 (64), and 110 (48, SPh).

By the same method, the 2.26:1 mixture of diastereoisomeric alcohols (82 mg, 0.21 mmol), enriched in the (1*SR*,2*RS*) isomer *anti-*(**19**) gave a 1.9:1 mixture of (**21**):(**20**) (76 mg, 98%) as an oil. 3-(1-*Phenyl*-1-*phenylthiomethyl*)-7-*phenylhept*-2-*ene* (**21**) was a 3:1 mixture of *E*:*Z* isomers and had $R_F(CH_2Cl_2)$ 0.77; $\nu_{max.}$(film) 1 580 cm^{-1} (SPh); $\delta_H(CDCl_3)$ 7.53—7.05 (15 H, m, Ph), 5.63(*E*) and 5.37(*Z*) (1 H, q, *J* 6.7 Hz, MeC*H*=C), 5.50(*Z*) and 4.82(*E*) (1 H, s, PhC*H*SPh), and 2.67—1.23 [11 H, m, $Ph(CH_2)_4$ and *Me*CH=C] (Found: M^+, 372.1897. $C_{26}H_{28}S$ requires *M*, 372.1912); *m/z* 372 (2%, M^+), 263 (100, *M* − SPh), 143 (97), 131 (91), 129 (81), 117 (64), and 110 (48, PhSH).

2-*Methyl*-7-*phenyl*-2-*phenylthioheptan*-2-*one* (**6**).—2-Phenylthiobutanone (**5**) (1.64 g, 9.1 mmol) in THF (5 ml) was added dropwise to a slurry of sodium hydride (0.24 g, 10 mmol) in THF (30 ml) under argon and heated for 30 min. 1-Bromo-4-phenylbutane (2.14 g, 10 mmol) and sodium iodide (1.53 g, 11 mmol) in THF (5 ml) was added to the red enolate and refluxed for 2 days. The reaction mixture was cooled, quenched with aqueous sodium thiosulphate (100 ml) and saturated aqueous ammonium chloride (100 ml), and extracted with CH_2Cl_2 (3 × 50 ml). The organic fractions were combined, dried (Na_2SO_4), and evaporated under reduced pressure. Purification by column chromatography on flash silica eluting with ethyl acetate–hexane (1:9) gave the *ketone* (2.15 g, 76%) as an oil, R_F [ethyl acetate–hexane (1:3)] 0.56; $\nu_{max.}$(film) 1 700 cm^{-1} (C=O); $\delta_H(CDCl_3)$ 7.35—7.15 (10 H, m, Ph), 2.61 (3 H, t, *J* 7.7 Hz, CH_2Ph), 2.37 (3 H, s, *Me*CO), 1.81—1.61 [6 H, m, $PhCH_2(CH_2)_3$], and 1.31 (3 H, s, *Me*CSPh) (Found: M^+, 312. 1571. $C_{20}H_{24}OS$ requires *M*, 312. 1542); *m/z* 312 (3%, M^+), 269 (100, *M* − MeCO), 117 (65), 110 (50, PhSH), and 91 (100, $PhCH_2$).

2-*Methyl*-7-*phenyl*-2-*phenylthioheptan*-2-*ol* (**7**).—$LiAlH_4$ was added to a solution of the above ketone (0.529 g, 1.7 mmol) in dry ether (10 ml) at −78 °C under nitrogen. Stirring was continued for 2 h at −78 °C and then aqueous sodium hydroxide (5 ml) was cautiously added. The mixture was allowed to warm to room temperature, diluted with water (50 ml) and extracted with ether (2 × 40 ml). The combined ether extracts were dried (Na_2SO_4) and evaporated under reduced pressure. The residue was passed through a short alumina column and gave the *alcohols* (**7**) (0.531 g, 99%) as a 2:1 mixture of diastereoisomers, $R_F(CH_2Cl_2)$ 0.40, 0.44. H.p.l.c. separation, eluting with ethyl acetate–hexane (1:20) on a Zorbax Sil column with a flow rate of 14 ml/min gave the (2RS,3SR) *alcohol syn-*(**7**) as an oil, R_F 20.0 min; $\nu_{max.}$(film) 3 420 cm^{-1} (OH); $\delta_H(CDCl_3)$ 7.45—7.18 (10 H, m, Ph), 3.53 (1 H, q, *J* 6.3 Hz, C*H*OH), 3.12 (1 H, br s, OH), 2.67 (2 H, m, PhCH_2), 1.65—1.20 [6 H, m, $PhCH_2(CH_2)_3$], 1.16 (3 H, d, *J* 6.3 Hz, *Me*CH), and 1.15 (3 H, s, *Me*CSPh) (Found: M^+, 314.1703. $C_{20}H_{26}OS$ requires *M*, 314.1698); *m/z* 314 (2%, M^+), 269 (30, *M* − MeCHOH), 117 (45), 110 (60, PhSH), and 91 (100, $PhCH_2$) and the (2RR,3SS)-*alcohol anti-*(**7**) as an oil R_F 22 min; $\nu_{max.}$(film) 3 420 cm^{-1} (OH); $\delta_H(CDCl_3)$ 7.54—7.17 (10 H, m, Ph), 3.59 (1 H, q, *J* 6.4 Hz, C*H*OH), 3.00 (1 H, br s, OH), 2.68 (2 H, t, *J* 7.3 Hz, PhCH_2), 1.76—1.54 [6 H, m, $PhCH_2(CH_2)_3$], 1.18 (3 H, d, *J* 6.4 Hz, *Me*CH), and 1.11 (3 H, s, *Me*CSPh) (Found: M^+, 314.1708. $C_{20}H_{26}OS$ requires *M*, 314.1698); *m/z* 314 (2%, M^+), 269 (35, *M* − MeCHOH), 117 (48), 110 (72, PhSH), and 91 (100, $PhCH_2$).

Rearrangement of the Alcohol (**7**).—Rearrangement was carried out as above with the alcohol *syn-*(**7**) (50 mg, 0.16 mmol) and TsOH (5 mg, 0.029 mmol) with a reflux time of 2.5 min to give a 4:1 ratio of (**9**):(**10**) (46 mg, 97%) as an oil. The allyl sulphides were inseparable and (E)-3-*Methyl*-7-*phenyl*-2-*phenylthiohept*-3-*ene* (**9**) had $R_F(CH_2Cl_2)$ 0.8; $\nu_{max.}$(film) 1 580 cm^{-1} (SPh); $\delta_H(CDCl_3)$ 7.53—7.03 (10 H, m, Ph), 5.15 (1 H, t, *J* 7 Hz, C=CH), 3.79 (1 H, q, *J* 6.9 Hz, C*H*SPh), 2.7—0.7 [6 H, m, $Ph(CH_2)_3$], 1.66 (3 H, s, MeC=C), and 1.38 (3 H, d, *J* 6.9 Hz, *Me*CHSPh) (Found: M^+, 296.1608. $C_{20}H_{24}OS$ requires *M*, 296.1593); *m/z* 296 (0.5%, M^+), 187 (1.5, *M* − SPh), 131 (22), 117 (56), 110 (68, PhSH), and 91 (100, $PhCH_2$). 6-*Phenyl*-2-(1-*phenyl*-1-*phenylthiomethylhex*-1-*ene* (**10**) had $R_F(CH_2Cl_2)$ 0.8; $\nu_{max.}$(film) 1 580 cm^{-1} (SPh); $\delta_H(CDCl_3)$ 7.53—7.09 (10 H, m, Ph), 4.82 (1 H, br s, C=CH^1H^2), 4.79 (1 H, t, *J* 1.3 Hz, C=CH^1H^2), 3.76 (1 H, q, *J* 7.1 Hz, MeC*H*SPh), 2.64 (2 H, t, *J* 7.3 Hz, CH_2Ph), 2.00—1.36 [6 H, m, $PhCH_2(CH_2)_3$], and 1.41 (3 H, d, *J* 7.0 Hz, *Me*CHSPh) (Found: M^+, 296.1608. $C_{20}H_{24}OS$ requires *M*, 296.1593); *m/z* 296 (0.5%, M^+), 187 (1.5, *M* − SPh), 131 (22), 117 (56), 110 (68, PhSH), and 91 (100, $PhCH_2$).

Rearrangement of *syn-*(**7**) (50 mg, 0.16 mmol) with TsOH (28 mg, 0.15 mmol) and refluxing for 2.5 min gave almost pure (**9**) which was a 91:9 mixture of *E*:*Z* isomers.

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