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AROMATIC ANNULATION WITH BISPHENYLTHIONIUM IONS

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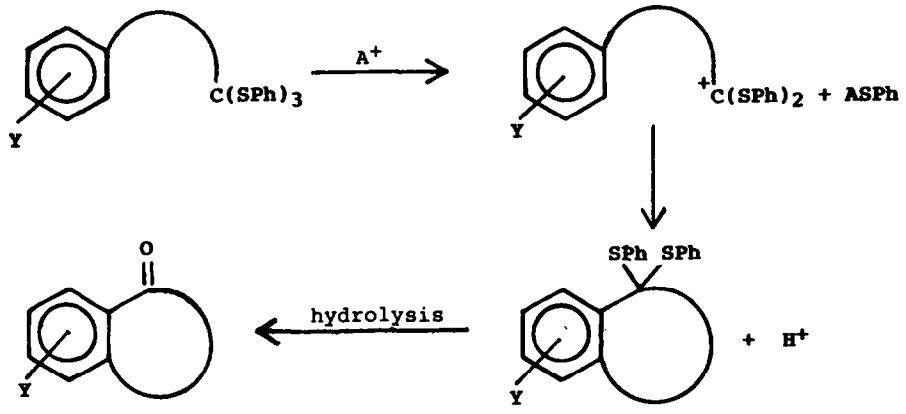
Abstract - The chemospecific production and intramolecular aromatic electrophilic substitution (annulation) of bis(phenylthio)carbocations (bisphenylthionium ions) has been studied using appropriate model compounds. The annulation reaction is very sensitive to the Lewis acid initiator and also the solvent. The best reaction conditions were found to be a suspension of silver trifluoromethanesulfonate in dichloromethane. Annulation of six-membered rings onto alkylbenzenes and five- and seven-membered rings onto activated benzenes have been achieved.

Synthetic procedures which result in the annulation of carbocyclic derivatives incorporating latent functionality have considerable potential for use in the synthesis of complex organic compounds.[1-5] Chemospecific methods for annulation are also attractive, as this allows synthetic operations using unprotected, otherwise reactive groups in the reactant molecule. Thionium ions[1,6,7], α-aryl(or alkyl)thio carbocations, and bisthionium ions[8] have been proposed previously as alternatives to carbonyl groups in certain synthetic procedures ("super carbonyl" equivalents[1,9]). Production of these cationic intermediates has been achieved by the addition of electrophiles (proton[2,10], sulfur[4,5], selenium[3]) to appropriate substrates. Chemospecificity in the production of thionium ions has been achieved by reacting soft, thiophilic, Lewis acids with bis(alkylthio)- acetals[1,6,7]. We have previously reported[8] that the bisphenylthionium methyl cation can be similarly created by observing that reaction of tris(phenylthio)methane **1** with dimethyl(methylthio)sulfonium fluoroborate (DMTSF)[11] in the presence of activated aromatic compounds gave aryl bis(phenylthio)acetals **2**.

$$\underset{\mathbf{1}}{(PhS)_3CH} + DMTSF \longrightarrow [(PhS)_3CH]^+ \xrightarrow{ArH} \underset{\mathbf{2}}{ArCH(SPh)_2} + H^+$$

The objective of this study was to examine the annulation reaction of bisphenylthionium ions derived from tris(phenylthio)alkyl derivatives by reaction of Lewis acids (A^+) with suitable cyclization precursors:



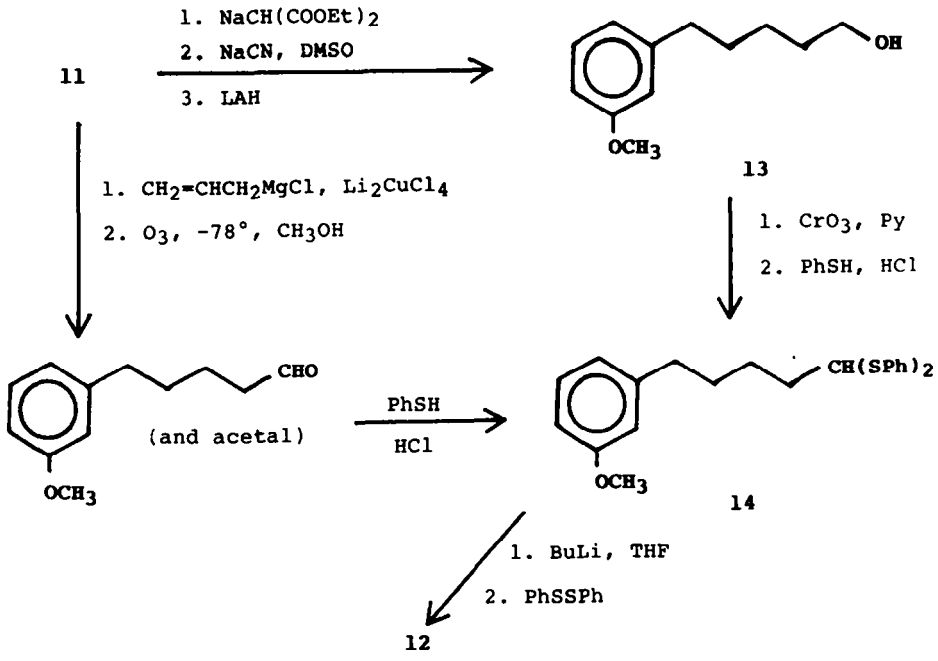
The potential advantages of this system are the chemoselective formation of the carbocation using appropriate Lewis acids and the facile hydrolysis[12] of the bis(phenylthio)acetal cyclization product to a ketone. Previous intermolecular formylation studies[8] required an activated aromatic ring for successful carbon-carbon bond formation, so suitable cyclization precursors for the initial portion of the investigation were prepared containing a strategically positioned methoxyl group.

Preparation of Cyclization Precursors

The basic component for preparation of the desired compounds was a series of 3-aryl-1-propanols **3**, **4**, **5** available by LAH reduction[13] of the corresponding cinnamic acids. Oxidation of **3** to **6** followed by thioacetalization to **7** was achieved by standard procedures. Deprotonation of bis(phenylthio)acetals such as **7** is generally achieved with BuLi[15] although considerable variation in reactivity with different alkyl substituents has been observed[14]. Fortunately, **7** was satisfactorily deprotonated with BuLi(THF, 0°) and phenylsulfenation (PhSSPh) gave **8** (74%). Formation of **9** required overall replacement of the -OH in **3** by a tris(phenylthio)methyl group. Tris(phenylthio)methyl lithium **10** did not give any useful product on reaction with the tosylate derived from **3**. However, reaction of **10** with the related iodide **11**, particularly in the presence of HMPT, gave **9** (62%).

The homologue of **9**, i.e, **12** was prepared from **11** by malonic ester anion alkylation (57%) followed by decarbethoxylation (59%) and reduction (75%) to **13**. Oxidation of **13** (80%) followed by thioacetalization gave the bis(phenylthio)acetal **14**, which was deprotonated and phenylsulfenated to produce the desired precursor **12** (89%) (Scheme). An alternative shorter route to **12**, which allows for future preparation of other homologues, used the copper-catalysed[16] cross coupling of **11** with allylmagnesium chloride followed by low temperature ozonolysis in CH_3OH to give a mixture of aldehyde and dimethylacetal. Direct phenylthioacetalization of this mixture produced **14** in 29% overall yield from **11** (Scheme).

The 4-aryl-1,1,1-tris(phenylthio)butanes **15** and **16** were prepared by alkylation of **10** with the appropriate iodides **17** and **18** in 42% and 46% yield respectively.



SCHEME

Cyclization Reaction Studies

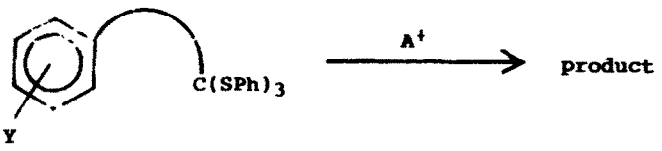
The cyclization reactions were investigated either by reacting the precursor with 1 equivalent of Lewis acid (A^+) followed by hydrolysis[12] or by using 3 equivalents of A^+ initially followed by hydrolytic workup. This experimental protocol allowed ready determination of the reaction products as stable, isolable compounds. The results of these studies are presented in the Table.

6-Methoxy-1-tetralone **19** was obtained in good yield from reaction of **9** with 1 equivalent of either DMTSF(CH_2Cl_2), silver trifluoromethanesulfonate (AgOTf, CH_2Cl_2) or $Cu(CH_3CN)_4BF_4$ (C_6H_6)[17] followed by hydrolysis or alternatively from reaction of **9** with 3 equivalents of AgOTf(CH_2Cl_2). In contrast, reaction of **9** with AgOTf or $Cu(CH_3CN)_4BF_4$ in CH_3CN gave a complex reaction product mixture containing no detectable amounts of **19** but probably significant amounts of the ketene bis(phenylthio)acetal **20**. Evidence for the production of **20**, the result of the β-elimination of PhSH, is based on the observation of an NMR triplet resonance at δ 6.33 (vide infra).

A more rigorous test of the efficiency of the cyclization reaction was provided by **8**. Reaction of **8** with 3 equivalents of AgOTf(CH_2Cl_2) in slow formation of the cyclized ketone **21** in moderate yield. Alteration of the Lewis acid to $Cu(CH_3CN)_4BF_4$ gave no **21**, instead the uncyclized thiolester **22** was obtained virtually exclusively. The structural formulation for **22** was confirmed by alternative synthesis[12] from **8** and presumably results from hydrolysis of the intermediate cation. Reaction of **8** with varying amounts of $Cu(CH_3CN)_4BF_4$ (CH_2Cl_2) under strictly anhydrous conditions for various times consistently gave high yields of **22** without any trace of **21** being detected. In contrast, reaction of **8** with $Cu(CH_3CN)_4BF_4$ in C_6H_6 gave the elimination product **23**. The structure for **23** followed from elemental analysis and NMR, which showed a diagnostic triplet resonance at δ 6.43. Reaction of AgOTf(C_6H_6) with **8** also gave **23** but in lesser amounts. Reaction of **8** with DMTSF gave very complex product mixtures.

TABLE

Reaction of ω-Aryl-1,1,1-tris(phenylthio)alkanes with Lewis Acids



Precursor	A⁺, solvent	Reaction time[a]/hr	Product	Isolated Yield/%
9	DMTSF, CH_2Cl_2[b]	0.25	**19**	78
9	AgOTf, CH_2Cl_2[b]	0.50	**19**	85
9	$Cu(CH_3CN)_4BF_4$, C_6H_6[b]	1.0[c]	**19**	96
9	AgOTf, CH_2Cl_2[d]	1.0	**19**	91
8	AgOTf, CH_2Cl_2[d]	20	**21**	59
8	$Cu(CH_3CN)_4BF_4$, CH_2Cl_2	20	**22**	90
8	$Cu(CH_3CN)_4BF_4$, C_6H_6	0.5[c]	**23**	59
12	AgOTf, CH_2Cl_2[d]	17	**24**	59
15	AgOTf, CH_2Cl_2[d]	20	**25**	92
15	$Cu(CH_3CN)_4BF_4$, C_6H_6	1.0[c]	**26**	30
16	AgOTf, CH_2Cl_2[d]	15	**27** and **28**	54 and 25

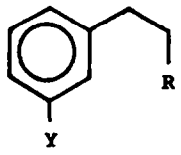
[a] reaction run at room temperature unless otherwise stated
[b] 1 equivalent followed by hydrolysis[12] (AgOTf, CH_3CN, H_2O)
[c] reaction at 70°
[d] 3 equivalents

From these results it was clear that the most efficient cyclization protocol involved AgOTf with CH_2Cl_2 solvent. It was therefore not surprising to find that only AgOTf(CH_2Cl_2) was able to effect cyclization of **12**, albeit relatively slowly, to create the seven-membered ring ketone **24** in encouraging yield.

Cyclization reactions with **15** and **16** were examined in order to estimate the amount of aryl activation necessary for six-membered ring formation. Reaction of **15** with AgOTf(CH_2Cl_2) gave **25** in good yield indicating that oxygen activation of the aryl ring was not essential. As observed previously, elimination to the ketene bis(phenylthio)acetal **26**, occurred when $Cu(CH_3CN)_4BF_4$ (C_6H_6) was used as reaction initiator. The less activated aryl ring in **16** was also amenable to cyclization using AgOTf(CH_2Cl_2) although the yield of the cyclized product **27** was significantly lower. A small amount of the thiol ester **28** was also isolated from this reaction. Reaction of **16** with $Cu(CH_3CN)_4BF_4$ (C_6H_6) again gave a complex mixture.

Conclusion

Formation and cyclization of bisphenylthionium alkyl cations can be achieved, especially with AgOTf in CH_2Cl_2. As in the formylation study[9], high regioselectivity for the para position with respect to the activating group is observed. The nature of the Lewis acid and the solvent play important roles in the success of this type of reaction. In noncoordinating CH_2Cl_2 the cations appear to be most reactive towards cyclization, particularly in preference to elimination to alkenes. AgOTf is relatively insoluble in CH_2Cl_2 and the most effective cyclization conditions involve replacement of the fine, white AgOTf suspension by a dense, yellow AgSPh precipitate. It is therefore attractive to postulate that the reaction conditions provide a low, but persistent, concentration of relatively unsolvated Ag^+ ions which continually create a reactive carbocation under conditions which do not favour elimination or hydrolysis. The nature of the reactive species involved in these reactions is currently under investigation.



3 Y = OCH_3, R = CH_2OH

4 Y = CH_3, R = CH_2OH

5 Y = H, R = CH_2OH

6 Y = OCH_3, R = CHO

7 Y = OCH_3, R = $CH(SPh)_2$

8 Y = OCH_3, R = $C(SPh)_3$

9 Y = OCH_3, R = $CH_2C(SPh)_3$

11 Y = OCH_3, R = CH_2I

12 Y = OCH_3, R = $CH_2CH_2C(SPh)_3$

15 Y = CH_3, R = $CH_2C(SPh)_3$

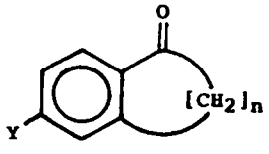
16 Y = H, R = $CH_2C(SPh)_3$

17 Y = CH_3, R = CH_2I

18 Y = H, R = CH_2I

22 Y = OCH_3, R = CO(SPh)

28 Y = H, R = CO(SPh)



19 Y = OCH_3, n = 3

21 Y = OCH_3, n = 2

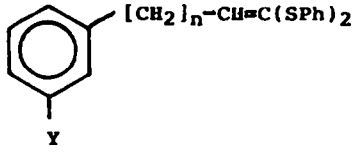
24 Y = OCH_3, n = 4

25 Y = CH_3, n = 3

27 Y = H, n = 3

$(PhS)_3CLi$

10



20 Y = OCH_3, n = 2

23 Y = OCH_3, n = 1

26 Y = CH_3, n = 2

EXPERIMENTAL

Melting points were determined on a Kofler hot-stage. They are expressed in degress Celsius and are uncorrected. Infrared spectra were obtained on Perkin Elmer model 357 and 137 spectrophotometers. Solid samples were examined in Nujol mulls and liquid samples as liquid films. Values are given in wave numbers (cm^{-1}).

^1H nuclear magnetic resonance (NMR) spectra were recorded on Varian T-60, EM-360, EM-390 and VXR-300 spectrometers. Samples were examined as dilute solutions in $CDCl_3$ using $(CH_3)_4Si$ as an internal standard. The chemical shifts (δ) are quoted in ppm downfield from $(CH_3)_4Si$. Spectra are reported according to the convention: chemical shift (multiplicity, observed coupling constant (Hz), number of protons, assignment). Multiplicities are reported as: s, singlet; d, doublet; t, triplet; q, quartet; m, multiplet.

Analytical thin layer chromatographs (tlc) were obtained using Merck tlc aluminium roll silica gel $^{60}F_{254}$ strips with a layer thickness of 0.20 mm. Preparative layer chromatograms (plc) were carried out on glass plates (20 cm x 20 cm or 20 cm x 50 cm) coated with Merck silica gel $PF_{254+366}$ with a layer thickness of 1.25 mm. Flash column chromatography[18] was performed using Merck silica gel 60 (Type 9385). E = ether, H = hexane.

Microanalyses were carried out by Professor A.D. Campbell and associates at this department. Reactions involving organometallic reagents were performed under an atmosphere of dry, oxygen-free N_2 in Schlenck tubes dried by heating to 110° and cooling under N_2 or alternatively by heating with a flame under vacuum then cooling in a stream of N_2, equipped with septum stoppers.

Na-dried diethyl ether was refluxed with lithium aluminium hydride (LAH) under N_2 for 1-2 hr and distilled immediately before use. Tetrahydrofuran (THF) was refluxed with Na under N_2 in the presence of small quantities of benzophenone until a blue colour appeared, and distilled immediately before use. CH_2Cl_2 was distilled from $CaCl_2$ and stored over 4A molecular sieves. CH_3CN was distilled and stored over 13X molecular sieves. C_6H_6 was stored over Na wire. Pyridine was distilled from and stored over solid KOH. Hexamethylphosphoric triamide (HMPT) was distilled from Na under vacuum and stored over 4A molecular sieves. Dimethyl sulfoxide (DMSO) was distilled from powdered CaH_2 under reduced pressure immediately before use.

Butyl lithium (BuLi) was obtained as a hexane solution (Aldrich) and analysed directly before use by the Gilman double titration method[19]. $Cu(CH_3CH)_4BF_4$[17] and dimethyl(methylthio)sulfonium fluoroborate[20] were prepared by published procedures. Silver trifluoromethanesulfonate (AgOTf) was purchased (Aldrich) or prepared from silver oxide[21], recrystallized from E and stored under vacuum away from light.

"Work up as usual" implies dilution of the final reaction mixture with an equal volume of H_2O then E extraction (2x). The combined organic extract is washed with H_2O (2x), dried over $MgSO_4$ and the solvents removed by rotatory evaporation.

3-(m-Methoxyphenyl)-1-propanol **3**

m-Methoxycinnamic acid[22] (3.56 g, 20 mmol) and LAH (1.52 g, 40 mmol) in dry THF (100 ml) was refluxed for 5 hr. Dilute HCl was added and the mixture was extracted with E (2 x 50 ml). The combined extracts were washed with 2M NaOH, H_2O and dried ($MgSO_4$). Evaporation of the solvents and distillation of the crude product gave **3** (3.0 g, 90%); b.p. 135° at 1 mm (Lit.[23] b.p. 135-140° at 3.5 mm); NMR δ 1.65-2.0 (m, 2H, $-CH_2-$), 2.45(broad s, 1H, -OH), 2.65(t, J = 8 Hz, 2H, $ArCH_2-$), 3.60(t, J = 8 Hz, 2H, $-CH_2O-$), 3.78(s, 3H, $-OCH_3$), 6.6-7.2(m, 4H, aromatic).

3-(m-Methoxyphenyl)propanal **6**

Dry chromium trioxide (12.0 g, 120 mmol) was added to a stirred solution of pyridine (19.0 g, 240 mmol) in dry CH_2Cl_2 (300 ml) under N_2. The solution was stirred for 15 min at room temperature after which a soluiton of **3** (3.32 g, 20 mmol) in CH_2Cl_2 (10 ml) was added in one portion. After stirring an additional 15 min at room temperature, the organic solution was decanted from the residue. The solution was evaporated *in vacuo* then stirred with E (100 ml). The ethereal suspension was filtered and the filtrate washed with 5% NaOH then saturated NaCl solution and dried ($MgSO_4$). Evaporation of the solvent gave pure **6** (2.1 g, 64%). Evaporative bulb-to-bulb distillation gave a boiling point of 80° at 0.1 mm in contrast to the literature[24] report of b.p. 110° at 0.01 mm; ν_{max}(film) 1725(C=O); NMR δ 2.30-2.95(m, 4H, $-CH_2-CH_2-$), 3.72(s, 3H, $-OCH_3$), 6.60-7.20(m, 4H, aromatic), 9.73(t, J = 1 Hz, 1H, -CH=O).

3-(m-Methoxyphenyl)-1,1-bis(phenylthio)propane **7**

Dry HCl gas was bubbled through a stirred solution of **6** (2.2 g, 13.4 mmol) and PhSH (2.9 ml, 28 mmol) in $CHCl_3$ (5 ml) for 5 hr. The mixture was then dissolved in E (80 ml) washed successively with H_2O (50 ml), 10% KOH until alkaline and H_2O (50 ml) then dried ($MgSO_4$). Evaporation of the solvent afforded a crude product (1.7 g) which was purified by column chromatography. Elution with 1:4 CH_2Cl_2/H gave **7** as an oil (1.63 g, 33%); NMR δ 2.0-2.3(m, 2H, $-CH_2-$), 2.90(t, J = 7 Hz, 2H, $ArCH_2-$), 3.66(s, 3H, $-OCH_3$), 4.33(t, J = 6 Hz, 1H, -CH-S), 6.60-7.50(m, 14H, aromatic). (Found: C, 72.3; H, 6.0; S, 17.8. $C_{22}H_{22}OS_2$ requires C, 72.1; H, 6.1; S, 17.5).

3-(m-Methoxyphenyl)-1,1,1-tris(phenylthio)propane **8**

A solution of BuLi (2.72 mmol) in H (1.6 ml) was added to a stirred solution of **7** (1.02 g, 2.67 mmol) in dry THF (20 ml) at 0° under N_2. The resulting brownish yellow solution was stirred for 15 min then a solution of PhSSPh (0.582 g, 2.67 mmol) in dry THF (5 ml) was added in one aliquot and stirring was continued for 30 min. Work up as usual gave a crude product which recrystallized from EtOH to give **8** (0.94 g, 74%); m.p. 93-94°; NMR δ 1.96-2.16(m, 2H, $-CH_2-$), 2.90-3.10(m, 2H, $ArCH_2-$), 3.66(s, 3H, $-OCH_3$), 6.30-7.80(m, 19H, aromatic). (Found: C, 70.8; H, 5.7; S, 20.5. $C_{28}H_{26}OS_3$ requires C, 70.8; H, 5.5; S, 20.3).

1-Iodo-3-(m-methoxyphenyl)propane **11**

A mixture of **3** (5.44 g, 32.8 mmol), purified red phosphorus (0.34 g, 10.9 mmol) and resublimed iodine (4.2 g, 32.8 mmol) was stirred and heated at 145-150° for 5 hr. The reaction mixture was cooled and the crude product dissolved in E (100 ml). The ethereal solution was washed with H_2O (50 ml), 5% NaOH (25 ml), H_2O (50 ml), then dried ($CaCl_2$) and evaporated. The crude product (4.9 g) was stirred with 2M NaOH (30 ml, 60 mmol) and dimethylsulfate (8 ml, 60 mmol) overnight. Work up as usual followed by distillation gave **11** (4.0 g, 44%); b.p. 120-125° at 1.0 mm (Lit[25] b.p. 155-160° at 11 mm); NMR δ 1.90-2.25(m, 2H, $-CH_2-$), 2.7(t, J = 7 Hz, $ArCH_2-$), 3.13(t, J = 7 Hz, 2H, $-CH_2I$), 3.80(s, 3H, $-OCH_3$), 6.6-7.2(m, 4H, aromatic).

4-(m-Methoxyphenyl)-1,1,1-tris(phenylthio)butane **9**

A solution of BuLi (8.64 mmol) in H (3.9 ml) was added to a stirred solution of $(PhS)_3CH$ **1**[26] (2.93 g, 8.64 mmol) in THF (30 ml) at 0° under N_2. After stirring for 30 min, a solution of **11** (2.38 g, 8.64 mmol) in THF (10 ml) was added followed by HMPT (1.5 ml). The mixture was stirred for further 3 hr at 0° and then at room temperature for 2 hr. Work up as usual gave a crude product which was chromatographed on a column. Elution with 1:1 CH_2Cl_2/H gave **9** (2.63 g, 62%) which recrystallized from EtOH m.p. 75-76°; NMR δ 1.6-2.5(m, 6H, $-CH_2-$), 3.80(s, 3H, $-OCH_3$), 6.5-7.7(m, 19H, aromatic). (Found: C, 71.0; H, 5.8; S, 19.4. $C_{29}H_{28}OS_3$ requires C, 71.3; H, 5.8; S, 19.7).

Ethyl 5-(m-methoxyphenyl)pentanoate

Diethyl malonate (3.2 g, 20 mmol) was added to a solution of Na (0.46 g, 20 mmol) in dry EtOH (15 ml) and the mixture was stirred for 10 min. Compound **11** (5.52 g, 20 mmol) in dry EtOH (5 ml) was then added and the mixture was refluxed for 2 hr. The EtOH was removed *in vacuo* and the residue was taken up in E (100 ml), washed with H_2O (2 x 50 ml) then dried ($MgSO_4$) and the solvents were evaporated. Evaporative bulb-to-bulb distillation of the crude product gave diethyl 3-(m-methoxyphenyl)propyl- malonate (3.5 g); b.p. 200° at 0.5 mm; ν_{max} 1730 (O-C=O); NMR δ 1.23(t, J = 7 Hz, 6H, $-CH_3$), 1.50-2.10(m, 4H, $-CH_2-CH_2-$), 2.60(t, J = 6 Hz, 2H, $ArCH_2-$), 3.33(t, J = 6 Hz, 1H, -CH), 3.73(s, 3H, $-OCH_3$), 4.15(q, J = 7 Hz, 4H, $-OCH_2-$), 6.55-7.20(m, 4H, aromatic).

Diethyl 3-(m-methoxyphenyl)propylmalonate (3.08 g, 10 mmol) and NaCN (0.98 g, 20 mmol) in DMSO (20 ml) was heated at 160° for 5 hr. After the mixture had cooled, H_2O was added and the mixture was extracted with pentane (2 x 50 ml) and the organic solution was dried ($MgSO_4$) then evaporated. Evaporative bulb-to-bulb distillation gave the product (1.4 g, 59%); b.p. 160° at 0.3 mm; ν_{max} 1730(O-C=O); δ 1.23(t, J = 7 Hz, 3H, $-CH_3$), 1.5-1.8(m, 4H, $-CH_2-$), 2.20-2.70 (m, 4H, $-CH_2-$), 3.80(s, 3H, $-OCH_3$), 4.08(q, J = 7 Hz, 2H, $-OCH_2-$), 6.60-7.20 (m, 4H, aromatic). (Found: C, 71.5; H, 8.7. $C_{14}H_{20}O_3$ requires C, 71.2; H, 8.5).

5-(m-Methoxyphenyl)-1-pentanol **13**

Ethyl 5-(m-methoxyphenyl)pentanoate (1.3 g, 5.5 mmol) and LAH (0.2 g, 5.5 mmol) in dry THF (60 ml) were refluxed for 1 hr. Dilute HCl was added and the mixture was extracted with E (2 x 30 ml). The combined extracts were washed with H_2O, dried ($MgSO_4$) and evaporated. The crude product (1.2 g) was distilled to give **13** (0.8 g, 75%); b.p. 170° at 0.5 mm; ν_{max} 3350(-OH); NMR δ 1.2-2.0(m, 6H, $-CH_2-$), 2.58(t, J = 6 Hz, 2H, $ArCH_2-$), 3.60(t, J = 6 Hz, 2H, $-CH_2O-$), 3.80(s, 3H, $-OCH_3$), 6.6-7.3(m, 4H, aromatic). (Found: C, 74.0; H, 9.5. $C_{12}H_{18}O_2$ requires C, 74.2; H, 9.5).

5-(m-Methoxyphenyl)pentanal

5-(m-Methoxyphenyl)-1-pentanol **13** (1 g, 5.15 mmol) was oxidized using chromium trioxide-pyridine complex, to 5-(m-methoxyphenyl)pentanal (0.8 g, 80%) as previously described for **6**; b.p. 130° at 0.3 mm; ν_{max} 1730(C=O); NMR δ 1.55-1.7(m, 4H, $-CH_2-$), 2.3-2.7(m, 4H, $-CH_2-$), 3.80(s, 3H, $-OCH_3$), 6.6-7.3(m, 4H, aromatic), 9.72(t, J = 1 Hz, 1H, -CHO). (Found: C, 74.9; H, 8.7. $C_{12}H_{16}O_2$ requires C, 75.0; H, 8.4).

6-(m-Methoxyphenyl)-1-hexene

A solution of allylmagnesium chloride (prepared from allyl chloride (20 mmol) and magnesium (20 mmol) in THF (20 ml)) was added to a stirred solution of **11** (2.8 g, 10.14 mmol) and dilithium tetrachlorocuprate[16] (0.3 ml, 1 M) in THF (20 ml) at 0° under N_2. Work up as usual after 2 hr gave a product (1.9 g) whose NMR showed only 6-(m-methoxyphenyl)-1-hexene. Plc (1:19 E/H) of a sample was followed by distillation; b.p. 100° at 0.4 mm; NMR δ 1.20-2.20(m, 6H, $-CH_2-$), 2.56(t, J = 7 Hz, 2H, $ArCH_2-$), 3.78(s, 3H, $-OCH_3$), 4.80-5.20 (m, 2H, $=CH_2$), 5.56-6.00(m, 1H, =CH-), 6.6-7.2(m, 4H, aromatic). (Found: C, 81.8; H, 9.7. $C_{13}H_{18}O$ requires C, 82.1; H, 9.5).

5-(m-Methoxyphenyl)-1,1-bis(phenylthio)pentane **14**

(a) Dry HCl gas was bubbled into a stirred solution of 5-(m-methoxyphenyl)pentanal (0.8 g, 4.17 mmol) and PhSH (0.9 ml, 8.1 mmol) in $CHCl_3$ (5 ml) at room temperature for 4 hr. The mixture was dissolved in E (60 ml) and the solution washed with 10% KOH, H_2O, then dried ($MgSO_4$) and evaporated to give a crude product. Chromatography on a column and elution with 20 and 40% CH_2Cl_2/H gave **14** (1.0 g, 60%); NMR δ 1.40-2.40(m, 6H, $-CH_2-$), 2.50(t, J = 7 Hz, 2H, $ArCH_2-$), 3.78(s, 3H, $-OCH_3$), 4.33(t, J = 6 Hz, 1H, -CH-S), 6.60-7.50(m, 14H, aromatic). (Found: C, 73.4; H, 6.6; S, 16.5. $C_{24}H_{26}OS_2$ requires C, 73.1; H, 6.6; S, 16.2).

(b) Ozonized oxygen was bubbled into a stirred solution of 6-(m-methoxy phenyl)-1-hexene (1 g, 5.26 mmol) in dry CH_3OH (40 ml) at -78° until a light blue solution was obtained (20 min). The cooling bath was removed and CH_3SCH_3 (0.6 ml, 8.17 mmol) was added and the mixture was stirred for 2 hr. H_2O (30 ml) was then added and the mixture was extracted with E (3 x 50 ml). The combined extracts were washed with 10% HCl, then dried ($MgSO_4$) and evaporated to give a crude product (0.8 g); NMR δ 1.3-1.9(m, 6H), 2.60(t, J = 6Hz, 2H), 3.46(s, 6H), 3.80(s, 6H), 4.72(t, J = 6 Hz, 1H), 6.6-7.3(m, 4H aromatic). The total crude product was dissolved in $CHCl_3$ (5 ml) and PhSH (1 ml) was then added. Dry HCl gas was bubbled into the solution while stirring for 2 hr at room temperature. Work up as in (a) above gave pure **14** (0.6 g, 29%).

5-(m-Methoxyphenyl)-1,1,1-tris(phenylthio)pentane **12**

BuLi (1.5 mmol) in dry H (1 ml) was added to a stirred solution of **14** (0.58 g, 1.47 mmol) in dry THF (15 ml) at 0° under N_2. The solution was stirred for 15 min at 0° and PhSSPh (0.33 g, 1.5 mmol) in THF (5 ml) was then added. Tlc showed all starting materials had reacted after 30 min. The mixture was worked up as usual and the crude product was column chromatographed. Elution with 1:1 CH_2Cl_2/H gave **12** (0.66 g, 89%) which recrystallized from EtOH, m.p. 69°; δ 1.50-2.00(m, 6H, $-CH_2-$), 2.46(t, J = 6 Hz, 2H, $ArCH_2-$), 3.73(s, 3H, $-OCH_3$), 6.60-7.70(m, 19H, aromatic). (Found: C, 71.7; H, 6.2; S, 18.9. $C_{35}H_{34}OS_3$ requires C, 71.7; H, 6.0; S, 19.1).

1-Iodo-3-(m-methylphenyl)propane **17**

3-(m-Methylphenyl)-1-propanol[27] (2.0 g, 13.7 mmol), red phosphorus (0.14 g, 4.6 mmol) and iodine (1.84 g, 14.5 mmol) were heated at 145-150° for 5 hr under reflux. Work up as for **11** gave **17** (2.0 g, 56%); b.p. 100-105° at 0.1 mm; NMR δ 1.80-2.06(m, 2H, $-CH_2-$), 2.26(s, 3H, $-CH_3$), 4.33(t, J = 6 Hz, 2H, $ArCH_2-$), 3.13(t, J = 6 Hz, 2H, $-CH_2I$), 6.83-7.10(m, 4H, aromatic). (Found: C, 46.2; H, 5.4; I, 48.8. $C_{11}H_{13}I$ requires C, 46.2; H, 5.1; I, 48.8).

4-(m-Methylphenyl)-1,1,1-tris(phenylthio)butane **15**

BuLi (10.5 mmol) in dry H (7.9 ml) was added to a stirred solution of **1** (3.58 g, 10.5 mmol) in THF (30 ml) at 0°. After stirring for 30 min, a solution of **17** (2.74 g, 10.5 mmol) in THF (10 ml) was added to the mixture followed by HMPT (1.5 ml). After stirring at 0° for 30 min and at room temperature for 2 hr the mixture was worked up as usual to give a crude product (5.2 g) which was column chromatographed. Elution with 1:1 CH_2Cl_2/H gave **15** (2.1 g, 42%) which recrystallized from EtOH; m.p. 101-102°; NMR δ 1.6-2.4(m, 6H, $-CH_2-$), 2.27(s, 3H, $-CH_3$), 6.68-7.80(m, 19H, aromatic). (Found: C, 73.6; H, 5.8; S, 20.4. $C_{35}H_{34}S_3$ requires C, 73.7; H, 6.0; S, 20.4).

4-Phenyl-1,1,1-tris(phenylthio)butane **16**

BuLi (11.8 mmol) in dry H (11.8 ml) was added to a solution of **1** (4.01 g, 11.8 mmol) in THF (40 ml) at 0°. The mixture was stirred for 15 min at 0° and *3-iodo-1-phenylpropane*[28] **18** (2.9 g, 11.8 mmol) in THF (10 ml) was then added followed by HMPT (1.5 ml). After stirring 5 hr at room temperature, work up as usual gave a crude product (6.4 g) which recrystallized from EtOH to give **16**, (2.5 g, 46%); m.p. 98°; NMR δ 1.6-2.4(m, 6H, $-CH_2-$), 6.95-7.55(m, 20H, aromatic). (Found: C, 73.3; H, 5.8; S, 20.7. $C_{34}H_{32}S_3$ requires C, 73.3; H, 5.7; S, 21.0).

Reaction of ω-Aryl-1,1,1-tris(phenylthio)alkanes with Lewis Acids

(a) *4-(m-Methoxyphenyl)-1,1,1-tris(phenylthio)butane* **9**

(i) DMTSF (0.126 g, 0.63 mmol) was added to a solution of **9** (0.283 g, 0.58 mmol) in CH_2Cl_2 (15 ml) at room temperature resulting in an immediate red solution. Tlc examination showed that the starting material had been consumed after 15 min so the mixture was worked up as usual. A solution of AgOTf (0.29 g, 1.16 mmol) in CH_3CN (5 ml) was then added to the solution of the crude product in CH_3CN (10 ml) and H_2O (1 ml) resulting in an immediate yellow precipitate. After stirring for 15 min at room temperature the mixture was filtered and the filtrate was diluted with E (30 ml), washed with H_2O (2 x 30 ml), dried ($MgSO_4$) and evaporated. Plc (1:1 E/H) of the crude product gave *6-methoxy-1-tetralone* **19** (0.080 g, 78%); m.p. 78-79°; identical with an authentic sample (Aldrich).

(ii) To a stirred mixture of **9** (0.100 g, 0.20 mmol) in dry CH_2Cl_2 (20 ml) was added AgOTf (0.051 g, 0.20 mmol) resulting in a red-orange coloured mixture, which after ~1 min produced a yellow precipitate. Tlc after 30 min indicated that all **9** had reacted. The mixture was then filtered, the precipitate washed with CH_2Cl_2 and the combined filtrate evaporated to give a yellow oil. Hydrolysis and purification as for (a,i) gave **19** (0.030 g, 85%).

(iii) To a solution of **9** (0.098 g, 0.20 mmol) in C_6H_6 (10 ml) was added $Cu(CH_3CN)_4BF_4$ (0.063 g, 0.2 mmol). The resulting suspension was stirred and heated to 70° for 1 hr by which time tlc indicated all starting materials had reacted. The solution was then filtered and the filtrate evaporated. The residue was dissolved in CH_3CN (10 ml) and a solution of AgOTf (0.1 g, 0.4 mmol) in CH_3CN (2 ml) and H_2O (0.2 ml) was added to the mixture resulting in an immediate yellow precipitate. Work up after 15 min and purification as for (a,i) gave **19** (0.034 g, 96%).

(iv) A mixture of **9** (0.100 g, 0.2 mmol) and AgOTf (0.15 g, 0.6 mmol) in dry CH_2Cl_2 (20 ml) was stirred for 1 hr at room temperature by which time tlc indicated all starting material had reacted. The yellow suspension was filtered and the filtrate was worked up as usual to give a crude product which after plc (1:1 E/H) gave **19** (0.033 g, 91%).

(v) Repetition of the reaction using AgOTf (1 or 3 eq) or $Cu(CH_3CN)_4BF_4$ (1 or 3 eq) in CH_3CN after 24 hr gave a crude mixture whose NMR showed no evidence for **19**. A significant component of the mixture was probably **20**, a product resulting from β-elimination of PhSH; NMR δ 2.6-2.9(m, 4H, $-CH_2-$), 3.75(s, 3H, $-OCH_3$), 6.33(t, J = 8 Hz, 1H, =CH-), 6.7-7.4(m, 14H, aromatic).

(b) *3-(m-Methoxyphenyl)-1,1,1-tris(phenylthio)propane* **8**

(i) AgOTf (0.16 g, 0.63 mmol) was added to a solution of **8** (0.10 g, 0.21 mmol) in dry CH_2Cl_2 (20 ml). A pale yellow suspension resulted which slowly precipitated a bright yellow solid. The mixture was stirred for 20 hr at room temperature by which time tlc showed all starting material had reacted. The precipitate was filtered and the filtrate was washed with H_2O then dried ($MgSO_4$) and evaporated. Plc (1:1 E/H) of the crude product gave *5-methoxy-1-indanone* **21** (0.020 g, 59%) identical with an authentic sample (Aldrich).

(ii) Repetition of (b,i) using $Cu(CH_3CN)_4BF_4$ (1 or 3 eq) in CH_2Cl_2 gave *phenyl 3-(m-methoxyphenyl)thiopropanoate* **22** (>90%). ν_{max} 1710(-S-C=O); NMR δ 2.99(s, 4H, $-CH_2CH_2-$), 3.80(s, 3H, $-OCH_3$), 6.6-7.7(m, 9H, aromatic). (Found: C, 71.0; H, 6.1; S, 12.0. $C_{16}H_{16}O_2S$ requires C, 70.6; H, 5.9; S, 11.8).

(iii) AgOTf (0.13 g, 0.51 mmol) was added to a solution of **8** (0.08 g, 0.17 mmol) in 10% aqueous THF (10 ml). A white precipitate was immediately formed. After stirring for 15 min at room temperature the solution was filtered and worked up as usual to give a product whose NMR and IR were identical to **22** obtained in (b,ii).

(iv) $Cu(CH_3CN)_4BF_4$ (0.5 g, 1.56 mmol) was added to a solution of **8** (0.37 g, 0.78 mmol) in C_6H_6 (20 ml). The suspension was stirred at 70° for 30 min by which time tlc showed all starting material had been consumed. The solution was filtered and the filtrate was extracted with E (2 x 15 ml), washed with H_2O then dried ($MgSO_4$) and evaporated to give a crude product (0.26 g). Plc (1:9 E/H) gave *3-(m-methoxyphenyl)-1,1-bis(phenylthio)-1- propene* **23** (0.15 g, 59%); NMR δ 3.68(s, 3H, $-OCH_3$), 3.75(d, J = 6 Hz, 2H, $ArCH_2-$), 6.43(t, J = 6 Hz, 1H, =CH-), 6.6-7.2(m, 14H, aromatic). (Found: C, 72.6; H, 5.9; S, 17.2. $C_{22}H_{20}OS_2$ requires C, 72.5; H, 5.5; S, 17.6).

(c) *5-(m-Methoxyphenyl)-1,1,1-tris(phenylthio)pentane* **12**

AgOTf (0.27 g, 1.06 mmol) was added to a solution of **12** (0.18 g, 0.36 mmol) in CH_2Cl_2 (30 ml). The mixture was stirred for 17 hr at room temperature by which time tlc showed that all starting materials had reacted. Work up as for (b,i) gave *7-methoxy-1-suberone* **24** (0.04 g, 59%) as a liquid which distilled at 130° at 0.4 mm (Lit[29] b.p. 90° at 0.16 mm); NMR identical with an authentic spectrum[30]. (Found: C, 75.5; H, 7.5. $C_{13}H_{16}O_2$ requires C, 75.8; H, 7.4). The derived 2,4-dinitrophenylhydrazone had m.p. 172-173° (Lit[31] m.p. 175-176°).

(d) *4-(m-Methylphenyl)-1,1,1-tris(phenylthio)butane* **15**

(i) A mixture of **15** (0.08 g, 0.17 mmol) and AgOTf (0.13 g, 0.51 mmol) in CH_2Cl_2 (30 ml) was stirred at room temperature for 20 hr when tlc showed all starting materials had reacted. Work up as in (b,i) gave, after plc (1:1 E/H), *6-methyl-1-tetralone* **25** (0.025 g, 92%), NMR consistent with literature[32] values; 2,4-dinitrophenylhydrazone m.p. 248° (Lit[33] m.p. 249°).

(ii) A mixture of **15** (0.24 g, 0.5 mmol) and $Cu(CH_3CN)_4BF_4$ (0.314 g, 1 mmol) in C_6H_6 (15 ml) was stirred at 70° for 1 hr. Work up as in (b,iv) gave, after plc (1:4 E/H), *4-(m-methylphenyl)-1,1-bis(phenylthio)-1-butene* **26** (0.054 g, 30%); NMR δ 2.26(s, 3H, $-CH_3$), 2.60-2.86 (m, 4H, $-CH_2-$), 6.30(t, J = 7 Hz, 1H, =CH-), 6.8-7.3(m, 14H, aromatic). (Found: C, 76.0; H, 6.4; S, 18.0. $C_{23}H_{22}S_2$ requires C, 76.2; H, 6.1; S, 17.7).

(e) *4-Phenyl-1,1,1-tris(phenylthio)butane* **16**

(i) A mixture of **16** (0.2 g, 0.44 mmol) and AgOTf (0.34 g, 1.32 mmol) in CH_2Cl_2 (30 ml) was stirred at room temperature for 15 hr. Work up as for (b,i) gave, after plc (1:1 E/H), α-*tetralone* **27** (0.035 g, 54%), NMR identical with an authentic spectrum[30]. Also obtained was *phenyl 4-phenylthiobutanoate* **28** (0.028 g, 25%); ν_{max} 1710 (-S-C=O); NMR δ 1.8-2.4(m, 4H, $-CH_2-$), 2.66(t, J = 6 Hz, 2H, $ArCH_2-$), 7.1-7.5(m, 10H, aromatic). (Found: C, 75.2; H, 6.3; S, 12.2. $C_{16}H_{16}OS$ requires C, 75.0; H, 6.3; S, 12.5).

(ii) Reaction using $Cu(CH_3CN)_4BF_4$ (0.1 g, 0.3 mmol) and **16** (0.1 g, 0.2 mmol) in C_6H_6 (10 ml) at 70° as in (b,iv) gave a mixture of products whose NMR showed no evidence for **27** but indicated elimination; δ 2.5-2.9(m, 4H, $-CH_2-$), 6.26(t, J = 7 Hz, 1H, =CH-), 7.0-7.4(m, 15H, aromatic).

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