# β-Silylcarbonyl Compounds as Masked Enones †

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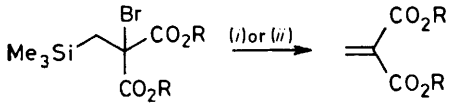
β-Trimethylsilylketones and lactones can be brominated (3)→(4) and desilylbrominated (4)→(5) specifically to place a double bond between the carbonyl group and the β-carbon atom to which the silicon had originally been bound. The silyl group therefore is a base- and acid-stable group masking the α,β-unsaturation of enones. Several α-methylene-ketones and -lactones have been prepared in this way. With ketones, the bromination step seems always to introduce bromine mainly or exclusively at the α-position on that side of the ketone on which the β-silyl group is placed, regardless of whether it is the more or the less substituted α-position.

In 1956 Eberson [1] briefly examined the possibility of generating the double bond of an α,β-unsaturated ester by desilylbromination (Scheme 1) and found that the

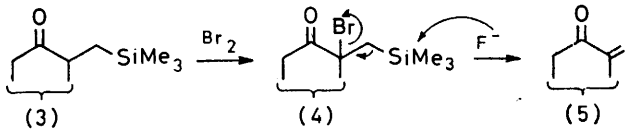



(1a) R = Et (2a) R = Et
(1b) R = Me (2b) R = Me

Scheme 1 (*i*) 190—200 °C; (*ii*) NaF–HMPA, 20 °C

reaction was possible, but not particularly easy. In the intervening years, organosilicon chemistry has advanced to the stage where we could be reasonably confident that Eberson's compound (1a) would be desilylbrominated by treatment with fluoride ion.[2] We find that desilylbromination (1b)→(2b) does indeed take place cleanly with sodium fluoride in hexamethylphosphoramide (HMPA) at room temperature in 3 h.

Now that the reaction was easier, it seemed to us that it had considerable potential in organic synthesis (Scheme 2). A silyl group β to a carbonyl group should



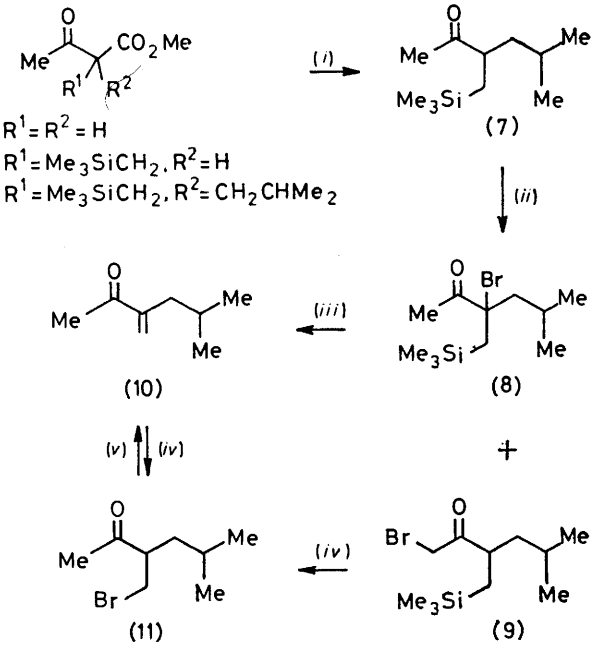

Scheme 2

be stable to redox reactions, and to acid and base, except in fairly vigorous conditions like concentrated sulphuric acid [3] or alkoxide ion in dimethyl sulphoxide.[4] Yet bromination of the carbonyl compound (3)→(4) and desilylbromination (4)→(5) would create a double bond conjugated to the carbonyl group, in a specific position determined by where the silyl group had been placed, and in mild conditions. Thus the silyl group β to the carbonyl group in (3) should survive most of the conditions used in organic synthesis, and still be available at whatever stage the α,β-unsaturation was needed. No other base- and acid-stable group is available to fulfil this function of masking the α,β-unsaturation of α,β-unsaturated carbonyl compounds.

In our preliminary communication,[5] we described one example (Scheme 3) of this reaction, an example which showed that desilylbromination could be used to place the double bond in a predetermined position, regardless of the side of the ketone on which bromination took place. In this paper, we describe this work in more detail, with a number of other examples, including the syntheses of some simple *exo*-methylene-lactones.

## RESULTS AND DISCUSSION

*Syntheses of the β-Silylketones and Lactones.*—Although we have prepared β-silylketones in other ways, those



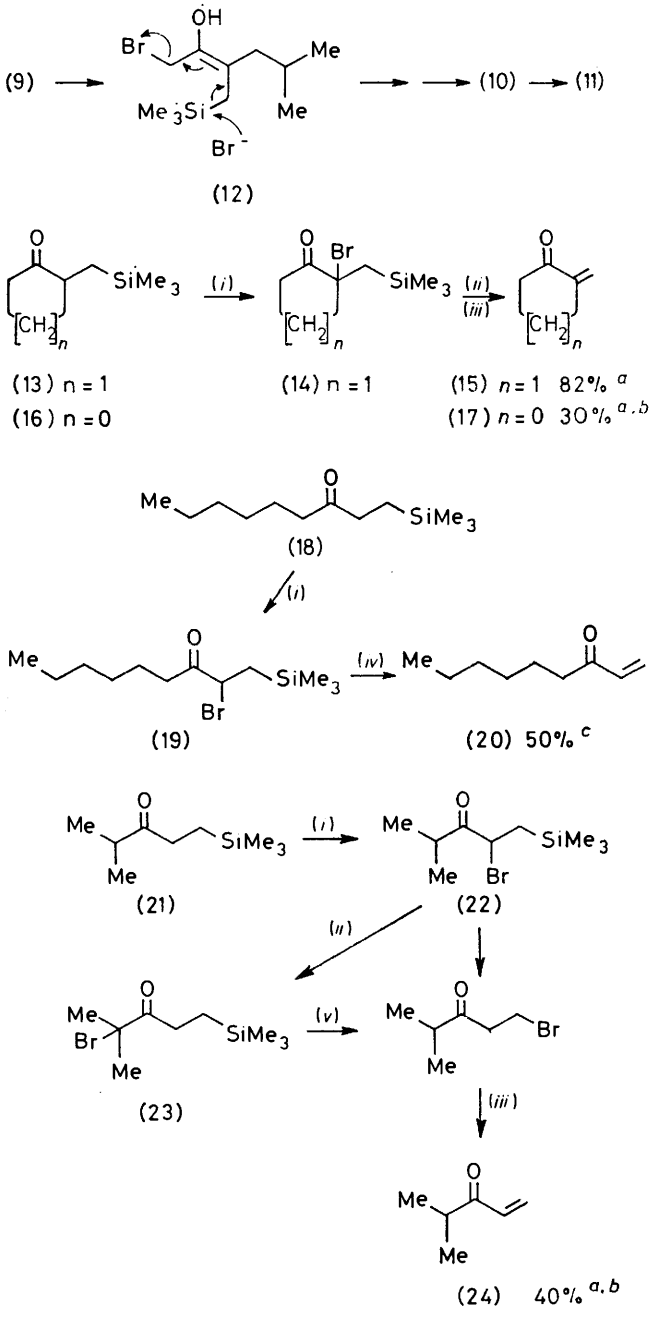

(6a) $R^1 = R^2 = H$
(6b) $R^1 = Me_3SiCH_2$, $R^2 = H$
(6c) $R^1 = Me_3SiCH_2$, $R^2 = CH_2CHMe_2$

Scheme 3 (*i*) NaCN–HMPA, 90 °C; (*ii*) $Br_2$–$CCl_4$, 0 °C; (*iii*) NaF–EtOH; (*iv*) HBr–$CCl_4$, 20 °C; (*v*) $NaHCO_3$–EtOH–$H_2O$, reflux

used in this work were all prepared using the alkylation of an enolate (or its equivalent) with trimethylsilylmethyl iodide.[6] For the alkylation of malonate and acetoacetate (6a), we modified known reactions.[7] Further alkylation with isobutyl bromide was easy, giving, in the case of (6b), the β-keto-ester (6c), hydrolysis and decarboxylation of which gave the ketone (7). The order in which the two alkylations are done is critical: alkylation with trimethylsilylmethyl halides is known to be

† No reprints available.

limited to unsubstituted malonates and acetoacetates,[7] and cannot be used to introduce trimethylsilylmethyl groups into β-keto-esters like methoxycarbonyl cyclopentanone. In this case, we found evidence for *O*-alkylation.



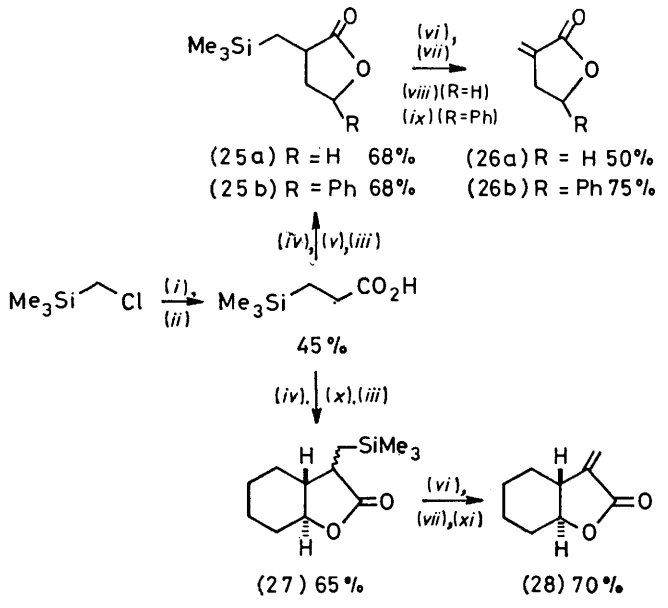

SCHEME 4 (*i*) $Br_2$–$CCl_4$, 0 °C or −20 °C; (*ii*) HBr–$CCl_4$, 20 °C; (*iii*) DBU–$CCl_4$, 20 °C; (*iv*) BTAF–THF, 20 °C; (*v*) HBr–$CCl_4$, 60 °C

[a] Yield measured by n.m.r. [b] Low yield explained in Experimental section. [c] Isolated yield.

An easier and more generally applicable synthesis of simple β-silylketones is to alkylate the lithium salt of the cyclohexylimine derivative of a ketone.[8,9] This was the method we used to prepare the ketones (13), (16), (18), and (21).

We prepared the lactones (25a), (25b), and (27) by the sequences shown in Scheme 5. The first of these could also be obtained by alkylation of the lithium enolate[10] of γ-butyrolactone but yields were low.

*The Bromination and Desilylbromination of β-Silylketones.*—Bromination of (7) (Scheme 3) with 1 equiv. of bromine in carbon tetrachloride at 0 °C gave a mixture of bromides (8) and (9) in 65% and 15% yield, respectively, as judged by n.m.r. spectroscopy. Treatment of




SCHEME 5 (*i*) LDA–MeCN; (*ii*) KOH–$H_2O_2$–$H_2O$; (*iii*) TsOH–toluene, reflux; (*iv*) 2LDA–THF, 0 °C; (*v*) R–$CH_2$–$CH_2$–O, 20 °C; (*vi*) LDA–THF, −78 °C; (*vii*) $Br_2$–$CCl_4$, −78 °C; (*viii*) $Al_2O_3$–$CH_2Cl_2$–reflux; (*ix*) CsF–DMF, 20 °C; (*x*) cyclohexene oxide–THF, reflux; (*xi*) $PhCH_2NMe_3F$–THF, 20 °C

this mixture with fluoride ion in ethanol at room temperature cleanly converted the former, (8), into the known[11] unsaturated ketone (10) [55% by n.m.r., based on (7)]. This unsaturated ketone could be distilled off, leaving a relatively pure sample of the ' wrong ' bromide (9). After some trial and error, we found a remarkable reaction: a stream of hydrogen bromide at room temperature converted the α'-bromo-β-silylketone (9) into the β-bromo-ketone (11). There are two plausible mechanisms for this transformation, related to the two mechanisms of equilibration of α-halogenoketones.[12] One begins with desilylbromination [(12) arrows] of one of the enols of the ketone (9); and the other begins with debromination and re-bromination (9)→(8) catalysed by hydrogen bromide.[13] Since we found that our reaction (9)→(11) was easy only with hydrogen bromide, and that starting material was recovered when other acids such as boron trifluoride–ether and toluene-*p*-sulphonic acid were used, we favour, at least in this case, the latter mechanism. Whatever the mechanisms of the earlier stages, the enone (10) is an intermediate, to which hydrogen bromide adds in the expected way. This was

supported by the observation that the enone (10) did give the β-bromide (11) under the conditions of the reaction. The best overall procedure for desilylbromination is thus to add bromine to the ketone and to treat the mixture of bromides (8) and (9) directly with hydrogen bromide. The β-bromide (11) is then produced from them both, and it can be converted to the enone (10) with mild base, in an overall yield of 75—80%.

A similar sequence was used with the other β-silylketones (13), (16), (18), and (21), which gave the enones (15), (17), (20), and (24), respectively, in the yields shown in Scheme 4.

We should like to draw attention to one curious and unexpected observation: in each of the ketones (7), (13), (18), and (21), bromination took place with a noticeable bias in favour of the side of the ketone on which the silyl group was placed, regardless of the level of substitution at that site. Thus the bromides (8) and (9) were formed in a ratio of 4 : 1, the bromide (14) and the bromide (19) were the only ones detected, and the bromides (22) and (23) were formed in the ratio of 6 : 1.

In each case, the conditions are those in which kinetic control is probable, and in the case of (22) and (23) it is certain, for we find that the first consequence of treatment with hydrogen bromide is that the mixture of bromides (22) and (23) equilibrates to give the bromide (23) as the only detectable isomer. Only after longer treatment does the bromine atom return from C-4 to C-2 and undergo desilylative elimination, (23)→(22)→(24).

Acid-catalysed enolisation of unsymmetrical ketones generally takes place faster towards a methylene group than towards a methyl, and is slowest towards a methine carbon.[14] Steric hindrance, however, as in 4,4-dimethylpentan-2-one, slows down enolisation towards the large group.[14] A π-electron-donating substituent, like a methoxy-group, shows down the acid-catalysed enolisation towards itself, the methyl group of methoxyacetone exchanging its protons for deuterium up to six times faster than the methylene group.[15] Since the trimethylsilylmethyl group is both π-electron-donating and fairly large, it would be expected on both counts to deter enolisation towards itself, yet the opposite is actually the case.

*Bromination and Desilylbromination of β-Silyl-lactones.*—The bromination and desilylbromination of the lactones (25a), (25b), and (27) was less eventful (Scheme 4), and the *exo*-methylene-lactones (26a), (26b), and (28) were all prepared in reasonable yield. These reactions demonstrated that the *exo*-methylene group in this biologically important class of compounds could, for synthetic purposes, be introduced as a β-silylmethyl group, and unmasked when desired.

*Conclusions.*—The syntheses of the methylene-ketones and -lactones described in this work are not the best available, nor were they expected or intended to be. Indeed another method, which we have published,[16] is very much better, and is probably the best route available. What we have shown in the present work is that β-silylcarbonyl compounds are masked α,β-unsaturated carbonyl compounds, and that the unsaturation can be stored safely in this way. It should be useful for many synthetic purposes to have such a device available.

## EXPERIMENTAL

Abbreviations used; THF (tetrahydrofuran); HMPA (hexamethylphosphoramide); DMF (dimethylformamide); LDA (lithium di-isopropylamide); DBU (diazabicyclo-[5.4.0]undec-5-ene); BTAF (benzyl trimethyl ammonium fluoride).

LDA was made by the addition of butyl-lithium (1.6M in hexane) to di-isopropylamine in the quantity of THF stated at the temperature of the subsequent reaction. The amide was ready for use after 5 min at 0 °C or 15 min at −78 °C.

*Trimethylsilylmethyl Iodide.*—Trimethylsilylmethyl chloride (36 g, 294 mmol) and dry sodium iodide (80 g, 530 mmol) in dry acetone (300 ml) were stirred overnight in the dark. Most of the acetone was distilled off at atmospheric pressure; the residue was poured into aqueous sodium thiosulphate and extracted with dichloromethane. The combined organic fractions were washed twice with water, dried ($MgSO_4$), evaporated, and distilled to give the iodide (51.5 g, 82%), b.p. 58 °C at 38 mmHg (lit.,[6] b.p. 139.5 °C at 144 mmHg); δ ($CCl_4$) 0.20 (9 H, s, $SiMe_3$) and 2.00 (2 H, s, $CH_2$).

*Methyl 3-Oxo-2-(trimethylsilylmethyl)butyroate* (6b).—Methyl acetoacetate (19.48 g, 168 mmol) in dry dioxan (50 ml) was added slowly to a stirred suspension of sodium hydride (8.64 g of a 50% dispersion, washed with hexane) in dry HMPA (40 ml) and dry dioxan (60 ml) under reflux. After hydrogen evolution had ceased, the flask was flushed with nitrogen, and trimethylsilylmethyl iodide (25.68 g, 120 mmol) in dry dioxan (50 ml) was added. The reaction was maintained at reflux for 2.5 h, then cooled, poured into brine, and extracted with light petroleum. The combined organic layers were washed repeatedly with brine, dried ($MgSO_4$), and evaporated to give after distillation the *ester* (18.0 g, 76%), b.p. 40—44 °C at 0.1 mmHg; $\nu_{max.}$ (film) 1 247 (SiO) and 1 715 (C=O) $cm^{-1}$; δ ($CCl_4$) 0.06 (9 H, s, $Me_3Si$), 1.09 (2 H, d, *J* 8.5 Hz, $CH_2Si$), 2.16 (3 H, s, MeCO), 3.36 (1 H, t, *J* 8.5 Hz, CH), 3.70 (3 H, s, OMe) (Found: $M^+$, 202.100 6. $C_9H_{18}O_3Si$ requires *M*, 202.102 5); *m/e* 202 (2.5%), 187 (30, *M* − Me), and 73 (100, $SiMe_3^+$).

*3-(Trimethylsilylmethyl)-5-methylhexan-2-one* (7).—The acetoacetate (6b) (16.15 g, 80 mmol) in dry DMF (50 ml) was added slowly to a stirred suspension of sodium hydride (4.6 g of 50% dispersion, washed with hexane) in dry DMF (150 ml) at 90 °C under nitrogen. After hydrogen evolution had ceased, isobutyl iodide (17.65 g, 80 mmol) in dry DMF (50 ml) was added, and the reaction stirred at 90 °C for 3 h. The product was worked up as for (6b) above and distilled to give (6c) (13.36 g, 65%), b.p. 64—68 °C 0.05 mmHg. The alkylated acetoacetate (6c) (10.3 g, 40 mmol) was added to a stirred suspension of dry sodium cyanide (60 mmol, 3 g) in dry HMPA (72 ml) at 90 °C under nitrogen.[17] After 6 h, the reaction was cooled, worked up as in (6b) above, and distilled to give the *ketone* (5.46 g, 68%), b.p. 56—57 °C at 2.3 mmHg (Found: C, 66.2; H, 12.2. $C_{11}H_{24}OSi$ requires C, 66.0; H, 12.0%); $\nu_{max.}$ (film) 1 248 (Si–C) and 1 705 (C=O) $cm^{-1}$; δ ($CCl_4$) 0.02 (9 H, s, $SiMe_3$), 0.06—1.85 (11 H, m), 2.04 (3 H, s, MeCO), and 2.25—2.76 (1 H, m, CH); *m/e* 185 (20%, $M^+$ − Me) and 73 (100%, $SiMe_3^+$).

*2-(Trimethylsilylmethyl)cyclohexanone* (13).—Freshly pre-

pared *N*-cyclohexylidenecyclohexylamine (18.4 g, 100 mmol) in dry THF (20 ml) was added slowly to a stirred solution of LDA (105 mmol) in dry THF (200 ml) at 0 °C under nitrogen. After 30 min at 0 °C, trimethylsilylmethyl iodide (16.3 ml, 105 mmol) was added, and the solution stirred for 45 min. The products were separated between brine and ether, and the organic layer shaken with a buffered acetic acid solution [sodium acetate trihydrate (25 g), acetic acid (50 ml), and water (50 ml)] for 5 min. The organic layer was washed twice with saturated brine, then repeatedly with saturated aqueous sodium hydrogencarbonate, dried ($MgSO_4$), evaporated, and distilled to give the *ketone* (15.06 g, 82%), b.p. 73—75 °C at 4.5 mmHg; $\nu_{max.}$ (film) 1 250 (Si–C) and 1 710 (C=O) $cm^{-1}$; δ ($CCl_4$) 0.03 (9 H, s, $SiMe_3$), 0.37 (1 H, dd, *J* 15 and 6 Hz, CHSi), 1.16 (1 H, dd, *J* 15 and 7 Hz, CHSi), and 1.36—2.2 (9 H, m) (Found: $M^+$, 184.127 8. $C_{10}H_{20}OSi$ requires *M*, 184.127 3); *m/e* 184 (11%, $M^+$), 169 (56, *M* − Me), and 75 (100).

2-(*Trimethylsilylmethyl*)*cyclopentanone* (16).—This compound was prepared from *N*-cyclopentylidenecyclohexylamine as 2-(trimethylsilylmethyl)cyclohexanone, above, with the exception that the reaction was carried out at −78 °C, to give 2-(*trimethylsilylmethyl*)*cyclopentanone* (13.1 g, 77%), b.p. 62—64 °C at 3.5 mmHg; $\nu_{max.}$ (film) 1 735 (C=O) and 1 250 (Si–C) $cm^{-1}$; δ ($CCl_4$) 0.08 (9 H, s, $SiMe_3$), 0.20 (1 H, dd, *J* 15 and 9.5 Hz, CHSi), 1.12 (1 H, dd, *J* 15 and 4 Hz, CHSi), and 1.25—2.45 (7 H, m) (Found: $M^+$, 170.113 2; $C_9H_{18}OSi$ requires *M*, 170.112 7); *m/e* 170 (19%, $M^+$), 169 (13, *M* − H), 155 (40, *M* − Me), 75 (100), and 73 (95, $SiMe_3^+$).

1-*Trimethylsilylnonan*-3-*one* (18).—This compound was prepared from *N*-(2-octylidene)cyclohexylamine as 2-(trimethylsilylmethyl)cyclohexanone, above, to give, after distillation, a 3 : 1 mixture of 1-trimethylsilylnonan-3-one and 3-(trimethylsilylmethyl)octan-2-one (by n.m.r. and g.l.c.( (16.9 g, 79%), b.p. 90—91 °C at 2 mmHg. A pure sample of 1-*trimethylsilylnonan*-3-*one* was obtained after chromatography (silica gel, dichloromethane), $\nu_{max.}$ (film) 1 705 (C=O) and 1 250 (Si–C) $cm^{-1}$; δ ($CCl_4$) 0.02 (9 H, s, $SiMe_3$), 0.74 (2 H, t *J* 8 Hz, $CH_2Si$), 0.7—1.8 (11 H, m), 2.34 (2 H, t *J* 8 Hz, $CH_2$–$CH_2Si$), and 2.38 (2 H, t *J* 6.5 Hz, $CH_2CO$) (Found: $M^+$, 214.174 9. $C_{12}H_{26}OSi$ requires *M*, 214.175 3); *m/e* 214 (0.1%, $M^+$), 199 (48, *M* − Me), and 73 (100, $SiMe_3^+$).

1-*Trimethylsilyl*-4-*methylpentan*-3-*one* (21).—This compound was prepared from *N*-(3-methyl-2-butylidene)cyclohexylamine as 2-(trimethylsilylmethyl)cyclohexanone above, to give after distillation 1-*trimethylsilyl*-4-*methylpentan*-3-*one* (13.60 g, 79%), b.p. 82—83 °C at 18 mmHg; $\nu_{max.}$ (film) 1 705 (C=O) and 1 250 (Si–C) $cm^{-1}$; δ ($CCl_4$) 0.02 (9 H, s, $SiMe_3$), 0.74 (2 H, t *J* 8 Hz, $CH_2Si$), 1.09 (6 H, d *J* 7 Hz, $Me_2CH$), 2.40 (2 H, t *J* 8 Hz, $CH_2CO$), and 2.62 (1 H, septet, *J* 7 Hz, $CHMe_2$) (Found: $M^+$, 157.103 4. $C_8H_{17}OSi$ requires *M*, 157.104 8); *m/e* 172 (3%, $M^+$), 175 (35, *M* − Me), and 75 (100).

3-*Trimethylsilylpropionic acid*.—Acetonitrile (5.2 ml, 100 ml) was added dropwise to a stirred solution of LDA (100 mmol) in dry THF (200 ml) at 0 °C under nitrogen. After a further 30 min, trimethylsilylmethyl chloride (13.8 ml, 100 mmol) was added rapidly and the resultant solution stirred for 20 min. The products, diluted with ether, were washed with brine, dried ($MgSO_4$), evaporated, and distilled, b.p. 66—70 °C at 17 mmHg, to give, after column chromatography (silica–dichloromethane), 3-trimethylsilylpropionitrile (6.3 g, 50%). A suspension of 3-trimethylsilylpropionitrile (30 mmol, 3.81 g) was rapidly stirred in a solution of potassium hydroxide (*ca.* 100 mmol, 6 g) and hydrogen peroxide (*ca.* 50 mmol, 5 ml of 100-vol. solution) in water (25 ml) and heated under reflux overnight. The resultant solution was cooled, washed with chloroform, acidified to pH 1, and extracted with chloroform. The acidic extract was dried ($MgSO_4$), evaporated, and distilled to give the acid (3.95 g, 90%), b.p. 92 °C at 3 mmHg (lit.,[7] b.p. 100 °C at 6 mmHg).

2-(*Trimethylsilylmethyl*)-γ-*butyrolactone* (25a).—3-Trimethylsilylpropionic acid (4.8 ml, 30 mmol) was added dropwise to a solution of LDA (63 mmol) in dry THF (150 ml) at 0 °C under nitrogen. After 5 min the solution was allowed to warm to room temperature, and after a further 30 min, ethylene oxide (30 mmol, 1.5 ml) was added. After 15 h, the products were poured into 3M hydrochloric acid, and extracted with chloroform. The combined organic layers were washed with brine, dried ($MgSO_4$), evaporated, and distilled to give 2-(*trimethylsilylmethyl*)-γ-*butyrolactone* (3.50 g, 68%), b.p. 96—98 °C at 0.6 mmHg, plates, m.p. 27.5—28 °C (Found: C, 55.6; H, 9.55. $C_8H_{16}O_2Si$ requires C, 55.8; H, 9.35%); $\nu_{max.}$ ($CDCl_3$) 1 750 (C=O) and 1 250 (C–Si) $cm^{-1}$; δ ($CCl_4$) 0.11 (9 H, s, $SiMe_3$), 0.64 (1 H, dd *J* 15 and 10 Hz, CHSi), 1.23 (1 H, dd *J* 15 and 4 Hz, CHSi), 1.72—2.15 (1 H, m, CHC=O), 2.25—2.70 (2 H, m, $CH_2CH_2O$), and 4.00—4.46 (2 H, m, $CH_2O$) (Found: $M^+$, 172.092 0. $C_8H_{16}O_2Si$ requires *M*, 172.089 2); *m/e* 172 (19%, $M^+$), 171 (25, *M* − H); 157 (43 (*M* − Me), and 73 (100, $SiMe_3^+$).

2-(*Trimethylsilylmethyl*)-4-*phenyl*-γ-*butyrolactone* (25b).—3-Trimethylsilylpropionic acid (2.43 ml, 15 mmol) was added dropwise to a stirred solution of LDA (30 mmol) in dry THF (50 ml) at 0 °C under nitrogen. After 5 min the mixture was allowed to warm to room temperature, and after a further 30 min, styrene oxide (15 mmol, 1.71 ml) was added. The mixture was stirred for 18 h, then poured into 3M hydrochloric acid, and extracted with chloroform. The combined organic layers were dried ($MgSO_4$) and evaporated. The crude products were lactonised by heating in toluene under reflux with 4A molecular sieve (3 g) for 4 h. The products were filtered and evaporated to give, after chromatography on silica gel ($CH_2Cl_2$), the *lactone* (2.9 g, 68%) as a mixture of diastereoisomers, m.p. 34 °C (Found: C, 68.0; H, 8.22. $C_{14}H_{20}O_2Si$ requires C, 67.7; H, 8.06%); $\nu_{max.}$ ($CCl_4$) 3 040 (C–H) and 1 780 (C=O) $cm^{-1}$; δ ($CCl_4$) 0.10 (9 H, s, $SiMe_3$), 0.70 (1 H, dd ×2, CHSi), 1.15 (1 H, dd ×2, CHSi), 2.2—2.9 (3 H, m) 5.26 (0.5 H, dd *J* 10 and 6 Hz, C*H*Ph, one isomer), 5.48 (0.5 H, dd *J* 7 and 6 Hz, C*H*Ph, other isomer), and 7.31 (5 H, br s, Ph); *m/e* 248 (3%, $M^+$) and 233 (70%, $M^+$ − Me).

2-(*Trimethylsilylmethyl*)-3,4-trans-*tetramethylene*-γ-*butyrolactone* (27).—3-Trimethylsilylpropionic acid (2.43 ml, 15 mmol) was added dropwise to a stirred solution of LDA (30 mmol) in dry THF (50 ml) at 0 °C under nitrogen. After 5 min, the mixture was allowed to warm to room temperature, and after a further 30 min, cyclohexene oxide (1.52 ml, 15 mmol) was added. The mixture was heated under reflux for 18 h, cooled, extracted, cyclised, and purified as for (25b) above to give the *lactone* (27) (2.22 g, 65%) as a mixture of stereoisomers (Found: C, 63.7; H, 9.60. $C_{12}H_{22}O_2Si$ requires C, 63.8; H, 9.75%); $\nu_{max.}$ ($CCl_4$) 1 780 (C=O) $cm^{-1}$; δ ($CCl_4$) 0.13 (9 H, s, $SiMe_3$), 0.56—1.00 (2 H, m, $CH_2Si$), 1.2—2.7 (10 H, m), and 3.6—4.1 (1 H, m, OCH); *m/e* 206 (20%, $M^+$) and 73 (100, $SiMe_3^+$).

5-*Methyl*-3-*methylenehexan*-2-*one* (10).—A standard solution of bromine (1 mmol) in AnalaR carbon tetrachloride

(*ca.* 1.5 ml) was added dropwise to a stirred solution of the ketone (7) (200 mg, 1 mmol) in AnalaR carbon tetrachloride (2 ml) at 0 °C. Hydrogen bromide was blown off by a stream of nitrogen, to give a mixture of the bromides (8) and (9); (8), 65% by n.m.r., characterised in the n.m.r. spectrum by the singlet at δ 2.58 (MeCO); and (9), 15% by n.m.r., characterised in the n.m.r. by the singlet at δ 3.88 ($BrCH_2CO$).

Hydrogen bromide was bubbled through the solution of the bromides in carbon tetrachloride (2 ml) for 20 min, then the residual HBr blown out by a stream of nitrogen. The resultant solution of the β-bromoketone (11) was added to a solution of sodium hydrogencarbonate (200 mg) in ethanol–water (1 : 1; 5 ml) and heated under reflux for 2.5 h. The reaction mixture was cooled, poured into brine, and extracted with carbon tetrachloride, dried ($MgSO_4$), and evaporated to give the product (10), which was not further purified. N.m.r. analysis, using *N*-phenylmaleimide as internal quantitative standard, showed the enone (10) [60%; 75% allowing for recovered ketone (7)]. A larger sample, purified by evaporation (room temperature, 3 mmHg) into a cold trap, had n.m.r. and i.r. spectra indentical to those reported for this compound.[11]

2-*Methylenecyclohexanone* (15).—A standard solution of bromine (2.2 mmol) in AnalaR carbon tetrachloride (*ca.* 3 ml) was added dropwise to a solution of the ketone (13) 368 mg, 2 mmol) in AnalaR carbon tetrachloride (5 ml) at 0 °C. The hydrogen bromide was blown out with a stream of nitrogen, giving as major product the bromoketone (14); δ ($CCl_4$) 0.12 (s, $SiMe_3$), 1.63 and 1.95 (d *J* 14 Hz, $CH_2Si$), and 3.25 (td *J* 14.5 and 6 Hz, axial CHCO). There were no peaks in the region δ 4.3—4.8, where COC*H*Br signals would be expected.[18] A stream of hydrogen bromide was passed through a solution of the bromoketone (14) in carbon tetrachloride (maintained at 2 ml) for 10 min, and the resultant solution was washed with aqueous sodium hydrogencarbonate, dried, and evaporated. A solution of the resultant β-bromoketone in carbon tetrachloride (1 ml) was added to a stirred solution of DBU (304 mg, 2 mmol) in carbon tetrachloride (5 ml). After 5 min the products were filtered and evaporated to give a crude sample of the enone (15) (82% by n.m.r. analysis, using toluene as the quantitative internal standard), which had n.m.r. and i.r. spectra identical with those reported.[19]

2-*Methylenecyclopentanone* (17).—A standard solution of bromine (1.1 mmol) in carbon tetrachloride (*ca.* 1.5 ml) was added dropwise to a solution of the ketone (16) in carbon tetrachloride (2 ml) at −20 °C. The hydrogen bromide was blown out with a stream of nitrogen, giving a mixture of the three α-bromoketones. Treatment with hydrogen bromide at 0 °C gave no reaction, while at room temperature significant amounts of α,β-dibromoketone [δ 3.80 and 4.05 (d, *J* 12 Hz, $CH_2Br$)] and starting ketone were produced. This provides additional evidence for the mechanism of the reaction discussed in the text, in which the intermediate free bromine has added to the enone in competition with the large excess of hydrogen bromide. Treatment of the resulting mixture with a solution of DBU (0.5 mmol, 152 mg) in carbon tetrachloride, followed by filtration and evaporation, gave a mixture containing the enone (17),[20] (30% by n.m.r. analysis using toluene as the quantitative internal standard).

*Non*-1-*en*-3-*one* (20).—A standard solution of bromine (1.1 mmol) in AnalaR carbon tetrachloride (*ca.* 1.2 ml) was added dropwise to a solution of the ketone (18) (1 mmol, 214 mg) in AnalaR carbon tetrachloride (2 ml) at 0 °C. Hydrogen bromide was blown out with nitrogen to give the bromoketone (19) as the major product [δ 0.06 (s, $SiMe_3$), 4.47 (dd, *J* 10 and 6 Hz, CHBr)]. Treatment of the resulting solution with hydrogen bromide from room temperature to 65 °C was ineffective. A similar solution was added to a suspension of excess BTAF, prepared according to Kuwajima,[21] in dry THF (30 ml). After 2 h the products were filtered through Celite, evaporated, and purified by p.l.c. [silica, ether–hexane (3 : 7)] to give the enone (20) (70 mg, 50%), which had n.m.r. and i.r. spectra identical with those reported,[22] except that the α-vinyl H resonates at δ 6.31, not 6.81; presumably this was a typographical error. The value 6.31 is like that of several analogous compounds.[23]

4-*Methylpent*-1-*en*-3-*one* (24).—A standard solution of bromine (3.3 mmol) in AnalaR carbon tetrachloride (*ca.* 4 ml) was added dropwise to a solution of the ketone (21) (516 mg, 3 mmol) in AnalaR carbon tetrachloride (2 ml) at 0 °C. Hydrogen bromide was blown out to give a mixture of the α-bromoketones (22) and (23): (22) [δ 0.06 (s, $SiMe_3$), 1.05 (t *J* 7 Hz, $CH_2Si$), 3.98 (septet, *J* 7 Hz, CHCO), and 4.51 (dd *J* 10 and 6 Hz, CHBr)], and (23) [δ 0.06 (s, $SiMe_3$), 0.84 (t, *J* 7.5 Hz, $CH_2Si$), 1.90 (s, 2 Me), and 2.83 (t *J* 7.5 Hz, $CH_2CO$)] in the ratio 6 : 1.

Hydrogen bromide was bubbled through a solution of the bromides in carbon tetrachloride (6 ml) for 15 min, resulting in the complete isomerisation of (22) to (23). This bromide solution was treated with hydrogen bromide at 65 °C, maintaining solvent volume, for 3 h. The hydrogen bromide was blown out with nitrogen, and the solution washed with sodium hydrogencarbonate, dried ($MgSO_4$), and treated with a solution of DBU (456 mg, 3 mmol) in carbon tetrachloride (2 ml). The products were filtered and evaporated to give a crude sample of the enone [23] (24) (40% by n.m.r. analysis using toluene as quantitative internal standard). Because of the volatility of the product, the low yield was not further investigated.

α-*Methylene*-γ-*butyrolactone* (26a).—A solution of the lactone (25a) (344 mg, 2 mmol) in dry THF (2 ml) was added slowly to a solution of LDA (2 mmol) in dry THF (5 ml) at −78 °C under nitrogen. After stirring at −78 °C for 30 min, a standard solution of bromine (2.1 mmol) in AnalaR carbon tetrachloride (*ca.* 205 ml) was added resulting in immediate decolourization of the bromine. After 5 min, the cold solution was poured into saturated aqueous ammonium chloride containing some sodium thiosulphate; the organic layer was washed additionally with brine, dried ($MgSO_4$), and evaporated.

The crude bromolactone was heated to reflux in dichloromethane (15 ml) containing a suspension of neutral alumina (5 g). After 5 h the products were cooled, filtered, and evaporated to give, after chromatography on alumina ($CH_2Cl_2$), the product (26a) (96 mg, 50%) which had n.m.r. and i.r. spectra identical to those reported.[24]

2-*Methylene*-4-*phenylbutyrolactone* (26b).—The lactone (25b) (496 mg, 200 mmol) was brominated by the procedure given for (25a) above. The crude bromolactone was added to a stirred suspension of caesium fluoride (*ca.* 0.8 g, 5 mmol) in dry DMF (10 ml). After 2 h, the products were poured into ether, washed three times with brine, dried ($MgSO_4$), and evaporated. The crude products were purified by p.l.c. (silica, $CH_2Cl_2$) to give the α-methylene lactone (26b) (263 mg 75%) which had an n.m.r. spectrum identical to that reported.[25]

2-*Methylene*-3,4-trans-*tetramethylenebutyrolactone* (28).—

The lactone (27) (452 mg, 2.0 mmol) was brominated by the procedure given for (25a) above. The crude bromolactone was added to a suspension of excess BTAF [21] in THF (30 ml), stirred for 4.5 h, filtered through Celite, and evaporated. Purification by t.l.c. (silica, $CH_2Cl_2$) gave the α-methylene-lactone (28) (215 mg, 70%), which had an n.m.r. spectrum identical to that reported.[26]

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