The Chemistry of Organoborates. Part 6.[1] Alkylation of Alkynylborates with some Complex Alkylating Agents

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The reactions of α-bromo-ketones, ethyl α-bromoacetate, iodoacetonitrile, and prop-2-ynyl bromide with alkynyltrialkylborates are regio- and stereo-specific. Oxidation of the intermediate vinylboranes gives 1,4-diketones and γ-oxo-esters, -nitriles, and -alkynes. Hydrolysis of the intermediates is a stereospecific route to trisubstituted olefins of defined configuration bearing various functional groups suitable for further elaboration.

In the preceding paper [1] we showed that alkylation of alkynyltrialkylborates is a versatile route to substituted ketones and olefins. It was decided to explore direct routes to bifunctional intermediates of synthetic significance by extending the reaction as in Scheme 1. (It was found that in the case X = Y = halogen the reaction took a different course,[2] and this case has therefore been excluded from the results presented here.)

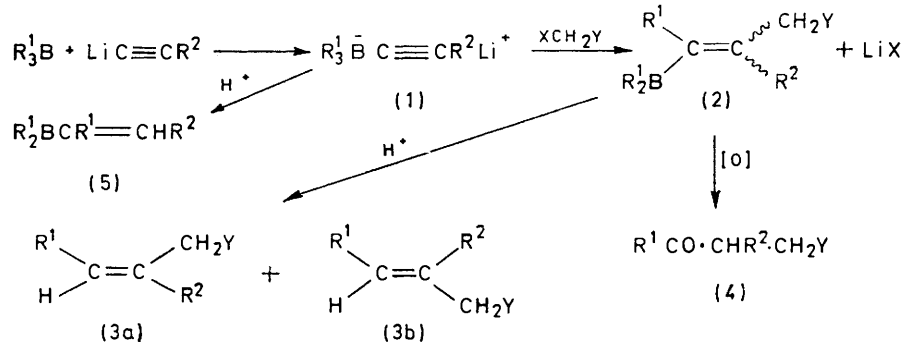
The reaction of chloroacetone with lithium tri-n-hexyloctynylborate was studied first. However the required β-attack was slow and oxidative work-up gave a plethora of products. Reaction with bromoacetone was more promising, the 1,4-diketone being formed in reasonable yield. However owing to variable quantities of protic acid being present in the starting material or possibly produced during the reaction, products derived from the vinylborane (5) were always present. For this reason, great care must be taken in every case to rid the

[1] Part 5, A. Pelter, T. W. Bentley, C. R. Harrison, R. J. Laub, and C. Subrahmanyam, preceding paper.

[2] A. Pelter and C. R. Harrison, *J.C.S. Chem. Comm.*, 1974, 828.

reagents of traces of protic acid immediately before use. The procedure used was adapted so that the functional groups of the various substrates should survive intact.

Table 1 shows that oxidative work-up of the reactions gives good yields of 1,4-diketones and γ-oxo-esters, -nitriles, and -alkynes. The overall process is a flexible, direct, and novel route to these important intermediates in heterocyclic and carbocyclic synthesis.



X = Br, Y = C≡CH, COMe, COPh, or CO_2Et
X = I, Y = C≡N

SCHEME 1

TABLE 1

Synthesis of substituted ketones ($R^1CO{\cdot}CHR^2{\cdot}CH_2Y$) and olefins ($R^1CH{=}CR^2{\cdot}CH_2Y$)

R^1	R^2	Y	Reaction time (h); temp. (°C)	% Yield of ketone [a]	% Yield of olefin [a]
n-Hexyl	n-Hexyl	CO_2Et	4; 40	78 [b]	69
Cyclopentyl	n-Butyl	CO_2Et	6; 55	74 [b]	67
n-Hexyl	n-Hexyl	COMe	6; 55 (20; 25)	75 [c]	75
Cyclopentyl	n-Butyl	COMe	5; 40	74 [c]	70
n-Hexyl	n-Hexyl	COPh	12; 25	74 [c]	74
n-Hexyl	n-Hexyl	C≡CH	6; 25	80 [b]	74
n-Octyl	n-Butyl	C≡CH	6; 25	76 [b]	75
Cyclopentyl	n-Butyl	C≡CH	3.5; 40	75 [b]	77
Cyclopentyl	n-Hexyl	CN	2.5; 25	51 [b] 62 [d]	64
n-Hexyl	n-Hexyl	CN	1.5; 25	69 [b] 71 [d]	72
n-Octyl	n-Butyl	CN	1.5; 25	66 [b] 70 [d]	68

[a] Yields are of purified, characterised product. [b] Oxidation with 50% H_2O_2 buffered with 5M-NaOAc at 25 °C for 15 h. [c] Oxidation with 50% H_2O_2–NaOH at 25 °C for 15 h. [d] Oxidation with 4 equiv. of anhydrous Me_3NO at 50 °C for 4 h.

Hydrolytic work-up of the alkylation product (2) was first attempted by warming with ethanol. This gentle method worked well for those vinylboranes (2) derived from tri(primary alkyl)boranes, but the reaction was slow and gave a poor yield when secondary groups were present. All the yields given of olefins (Table 1) are based on hydrolysis at room temperature with either acetic or isobutyric acids, and in no case did either of these procedures lead to complications. Initially all the reactions were carried out in diglyme (2,5,8-trioxanonane) and the yields given are for this solvent. However glyme (2.5-dioxahexane) is also efficient and tetrahydrofuran (THF) only slightly less so, in terms of yield. When using diglyme we noted that in every case the olefinic product ran as one peak on efficient Apiezon N columns which had easily separated the mixture of *E*- and *Z*-trisubstituted olefins previously obtained using simple alkylating agents.[1] The products of the present reactions had longer retention times than the simple olefins and it seemed likely that if two isomers had been present then they would have been separated. The ^1H n.m.r. spectra of all the products reinforced the idea that the reaction was stereospecific as well as regiospecific. Thus the signals of the methylene groups situated between the carbonyl and olefinic groups of the products from alkylation with α-bromocarbonyl compounds showed in each case as a sharp singlet, clear of all other peaks. Expansion of the peak and decouplings showed that at most the observed allylic coupling constant was 0.1—0.2 Hz, indicating that the products would be represented as structure (3a). If this were so then a valuable stereospecific new route to trisubstituted olefins bearing various functional groups was to hand.

Only when using ethyl bromoacetate was any variation from stereospecificity to stereoselectivity noted. Our first experiments with diglyme as solvent throughout gave one product showing an α-methylene singlet at τ 6.98. However if warm glyme was used then the product showed another peak at τ 7.05 (d, *J* 0.8 Hz) corresponding to *ca.* 12% of a second product. The mass

spectra of the two products were identical and the overall yields of the two reactions very similar. If the temperature of the reaction in glyme was lowered to 20 °C and the reaction allowed to proceed for 20 h, once more the yield was similar but the ratio of the two isomers became 94 : 6. As various experiments showed that the results of this reaction was not accurately predictable (low temperatures however always favouring higher stereospecificity) the alkylation of di-n-hexyloctynyl(thexyl)-borate * was studied. Ethyl bromoacetate reacted with this salt over 72 h at room temperature to give a 75% yield of hydrolysis product consisting of at least 98% of the isomer with the methylene signal at τ 6.98 ($CDCl_3$). Hence the use of a thexylborate salt [1] is recommended when small quantities of isomeric olefin cannot be tolerated.

The possibility that only one isomer was produced when prop-2-ynyl bromide was used was particularly surprising, as allyl bromide always gave mixtures of *E*- and *Z*-isomers. However the prop-2-ynyl products ran as one component in each case on g.l.c. columns that readily separated the allylation products. The same phenomenon was seen when the products were examined by high pressure liquid chromatography on 8% silver nitrate and 17% ethylene glycol on Merckosorb S.J. 60, a system that also separated the allyl isomers.

In order to see whether the reactions were stereospecific, and if so in what sense, it was decided to correlate as many compounds as possible with each other and with simple trisubstituted olefins of stereochemistry that we had previously established unequivocally.[1] Lithium tri-n-hexyloctynylborate was used as the starting material, our assumption being that the results would be general if no particular constrictions were imposed. The reactions carried out are shown in Scheme 2.

Selective reduction of the product (6) was successful with dicyclohexylborane at 0 °C. The crude product from hydrolysis followed by oxidation before column chromatography consisted of cyclohexanol and a hydrocarbon identical with the major product (7) produced by direct allylation,[1] as shown by the retention time on an Apiezon column and by co-injection with a 60 : 40 mixture of the *Z*- and *E*- allylation products. The reduction product was >99% the *Z*-isomer, showing that the reaction with prop-2-ynyl bromide is stereospecific for all practical purposes. Moreover the production of the *Z*-isomer (7) proves that prop-2-ynylation has proceeded so that the alkylating agent and the migrating group finish on the same side of the double bond. The situation is the same as for the major isomers produced in simple alkylations.[1]

The prop-2-ynyl product (6) was converted directly into the enone (8) with mercury(II) oxide and sulphuric acid. The ketonic product was identical with the compound obtained by the action of bromoacetone on the alkynylborate salt. In particular the α-methylene signal appeared at τ 6.91 ($CDCl_3$) and the retention times (co-injection) were identical in a variety of g.l.c. systems. Hence it seemed likely that the reaction with bromoacetone was stereospecific to give (8) only. However the yield of purified (8) derived from (6) was only 49% and therefore another sequence was used to check the result. The ketone (8) was readily converted into the dithioacetal (9), which with Raney nickel gave the product (10) (at least 98% one compound), identical with the *E*-isomer (10) previously characterised from the direct propylation.[1] Both sequences prove that alkylation with bromoacetone is both regio- and stereo-specific.

Interestingly enough the direct reduction of (8) [derived from (6) or from the alkynylborate] to (10) with sodium cyanoborohydride gave the required olefin, but as a mixture of (10) and its *Z*-isomer in the ratio 90 : 10, whilst an extended reaction gave an 81 : 19 mixture. Hence this recently introduced [3] and convenient method for the reduction of ketone to methylene groups may lead to equilibration and must be used with care.

To characterise the ester the previously mentioned 88 : 12 mixture of the *Z*-product (11) and its *E*-isomer was used. It was convenient to have both isomers present, when possible, as this served to check both the analytical methods and the course of the reactions used. Reduction with lithium aluminium hydride gave a high yield of two isomeric alcohols shown to be in the same proportions as starting material by g.l.c. The crude alcohol mixture was converted into the tosylates which were quantitatively reduced by $LiAlH_4$ to (14) and its *Z*-isomer, the ratio of the two being almost exactly 88 : 12. Thus the major isomer in the mixture used was (11), and as explained previously, by judicious choice of reaction and conditions this can be made the sole product of the alkylation with ethyl bromoacetate. The stereochemistry of the alkylation is therefore the same as with previous alkylation agents.

Saponification of an 80 : 20 mixture of (11) and its *E*-isomer gave a mixture of two isomeric acids in the same proportions. The major isomer had an α-methylene peak at τ 6.97 (s) and the minor isomer a peak at τ 7.03br s. Re-esterification of the acid (*Z* : *E* 78 : 22) with ethanol–concentrated sulphuric acid at reflux for 18 h gave a high yield of the *Z*- and *E*-esters but in the ratio 72 : 28. Hence in this re-esterification some equilibration must be allowed for.

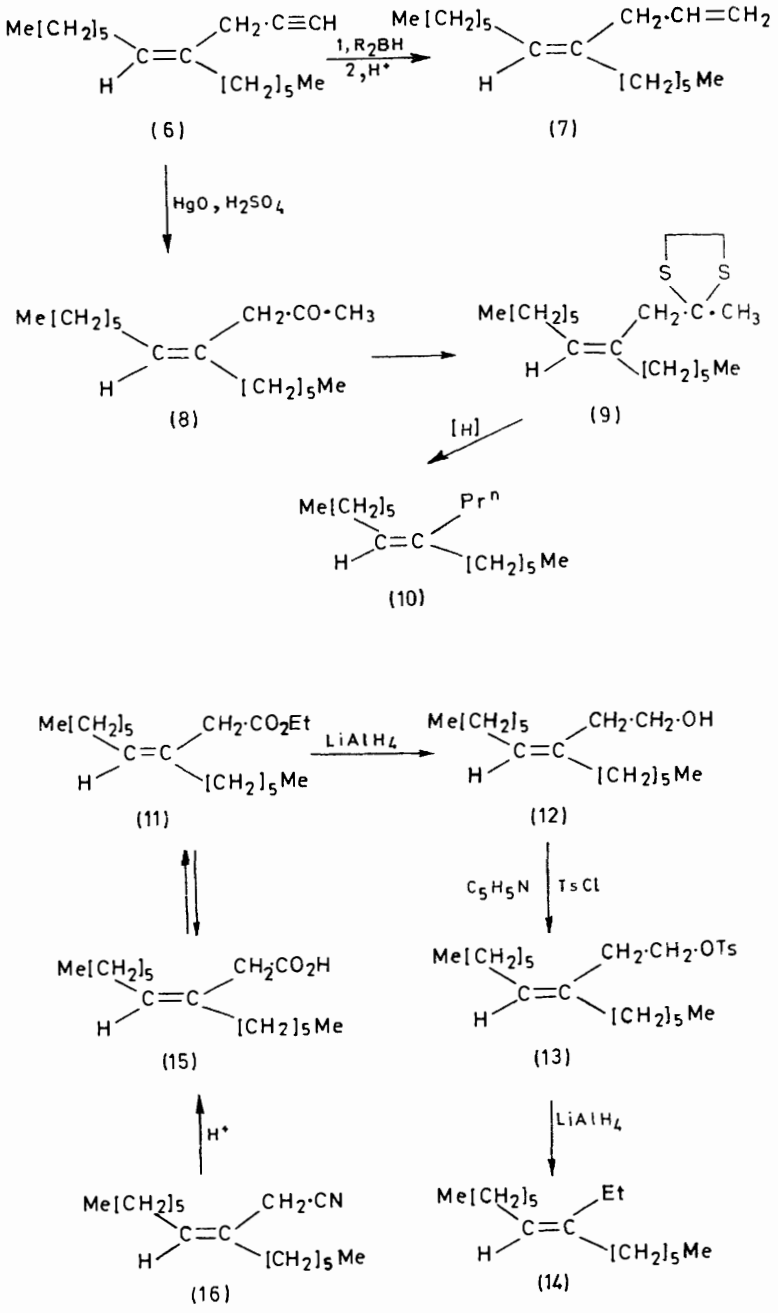
Hydrolysis of the nitrile (16), which ran as one isomer in several g.l.c. systems, with base was not successful, as the double bond moved into conjugation. Vigorous acidic hydrolysis gave the carboxylic acid, however in high yield. The product had the expected i.r. spectrum and showed a single ^1H n.m.r. peak for the α-methylene group at τ 6.93, corresponding to (15). However the 'noisy' base line would allow up to 8% of the other isomer to be present unobserved, though a discrete peak at τ 7.03 could not be seen. Re-esterification gave a similar result, but as this reaction had been shown to lead to some isomerisation it was felt that, in fact, the

* Thexyl = 1,1,2-trimethylpropyl.

[3] R. O. Hutchins, C. A. Milewski, and B. E. Maryanoff, *J. Amer. Chem. Soc.*, 1973, **95**, 3663.

acid was one isomer, hence the reaction with iodoacetonitrile is also stereospecific.

As yet we have not been able to correlate directly the product from alkylation with phenacyl bromide with at 190 °C on a 2% PEGA (polyethylene glycol adipate) column. It therefore seems certain that it is indeed one compound, and in view of the almost imperceptible allylic coupling of the benzylic methylene



SCHEME 2

any known olefin. The benzylic methylene group of the product gives an n.m.r. signal at τ 6.36 as a sharp singlet which is not further sharpened by irradiation at the frequency of the vinyl proton signal [τ 4.66br (t)]. A reciprocal irradiation was also without effect. The product ran as one peak on isothermal runs at 220 °C on a 5% FFAP (free fatty acid phase) column and group it is assigned structure (3a; Y = COPh), in line with our other results.

The alkylation–hydrolysis procedures described constitute valuable new methods for the synthesis of trisubstituted olefins of known configuration bearing various functional groups suitable for further elaboration.

EXPERIMENTAL

Ether solvents were distilled under dry, oxygen-free nitrogen from CaH_2 or $LiAlH_4$ prior to use. Other solvents were purified by standard procedures.[4] Diborane was kept as a boron trifluoride-free solution in THF and standardised prior to use.[5] AnalaR $CaCO_3$ was dried by heating to 110 °C *in vacuo* and added hot when used. Ethyl bromoacetate was purified by distillation and stored over alumina. Bromoacetone was stored over anhydrous $CaCO_3$ and purified immediately before use by distillation at 25 mmHg from fresh anhydrous $CaCO_3$. Phenacyl bromide was recrystallised twice from methanol and prop-2-ynyl bromide was carefully distilled up a Vigreux column then passed down a short alumina column immediately before reaction. Iodoacetonitrile was passed down a short column of alumina (type H) to remove iodine and acids. Commercially available n-butyl-lithium in hexane was standardised and used directly.

Hydroborations were carried out according to published procedures [1,5] and all manipulations prior to work-up were performed in dry glassware under nitrogen, dry syringes being used for the transfer of liquids. The reaction vessels used were as previously described,[1,6] as were the spectroscopic and g.l.c. instruments. All n.m.r. spectra were measured for solutions in $CDCl_3$.

General Procedures.—Alkylations. All the reactions described were carried out in diglyme, but glyme was also a satisfactory solvent.

A solution of the trialkylborane (5 mmol) in either THF or diglyme (5 ml) was prepared in the dropping funnel.[1,5] In the reaction flask a suspension of the alkynyl-lithium in hexane was prepared by treating the alkyne (5 mmol) in hexane at 0 °C with a solution of n-butyl-lithium (5 mmol) in hexane. The suspension was allowed to warm to 25 °C for 10 min and then re-cooled to 0 °C. The trialkylborane solution was added slowly to the stirred suspension of the alkynyl-lithium, followed by a further 1 ml of solvent as washing. The mixture was stirred at 25 °C for 45 min and then the volatile materials were removed at the pump, dry nitrogen being admitted *via* a nitrogen line. The syrupy borate was dissolved in diglyme (or other solvent) (5 ml) and cooled to −78 °C, and the alkylating agent (5.25—5.5 mmol) was added by syringe. The mixture was allowed to warm to room temperature and stirred for the appropriate time and temperature (Table 1). The reaction may be conveniently followed by the disappearance of the i.r. band at *ca.* 2 150 cm^{-1}. *Note.* When α-bromo-ketones were used it was slightly advantageous (yields raised by *ca.* 5%) to have anhydrous $CaCO_3$ (200 mg) suspended in the borate solution in diglyme prior to addition of the alkylating agent.

Oxidative work-up. Aqueous NaOAc (5M; 20 ml) was added to the reaction mixture at 0 °C followed dropwise by 50% H_2O_2 (3 ml). The mixture was stirred overnight at room temperature and the organic product taken into ether. The extract was washed with water, dried ($MgSO_4$), filtered, and evaporated. The crude product was placed on a dry silica column (for more difficult separations a column made up in light petroleum may be used). Elution was carried out with light petroleum, light petroleum–dichloromethane (1 : 1), dichloromethane, ether, and finally methanol, if required. The simple ketones or olefins produced from the vinylborane (5) were eluted with either light petroleum or 1 : 1 light petroleum–dichloromethane. The pure dichloromethane eluate contained the desired products, sometimes contaminated with a little alcohol, which was removed at the pump. *Note.* (*a*) Use of $NaOH–H_2O_2$ was advantageous for the oxidation of the products of alkylation with α-bromoacetone, as very little hydrolysis product was obtained. (*b*) When iodoacetonitrile was used neither $NaOH–H_2O_2$ nor *m*-chloroperbenzoic acid was an effective oxidant. Buffered oxidation with $NaOAc–H_2O_2$ was successful but some iodine was formed. Treatment with anhydrous trimethylamine oxide [7] (4 equiv) at 50 °C for 4 h, followed by hydrolysis for 30 min with 5M-NaOAc gave the best yield of pure product.

Hydrolytic work-up. Degassed acetic acid (1 ml) was added to the reaction mixture and the solution stirred under nitrogen for 15 h at 25 °C. Alternatively, degassed isobutyric acid (1 ml) was added and the mixture stirred under nitrogen for 3 h at 25 °C. The mixture was then oxidised as usual with NaOAc–50% H_2O_2 so that all the boron was converted into boric acid. Extraction into ether was followed by washing with $NaHCO_3$ solution and water, drying ($MgSO_4$), filtration, and evaporation to give a viscous product which was subjected to chromatography on silica. *Note.* (*a*) The required products from alkylation with prop-2-ynyl bromide were eluted with light petroleum. They always followed any simple olefins (<5%) produced from (5). (*b*) With all other alkylating agents the product was eluted with the 1 : 1 mixture of light petroleum–dichloromethane. (*c*) Further oxidation after hydrolysis is not always necessary, the column frequently being sufficient to separate the product from any boronic or borinic acids present. However when long chain dialkylborinic acids are likely to be produced by the hydrolysis, then the oxidation makes isolation of pure product simpler.

Determination of Stereochemistry of the Alkylation Products.—Reduction of (Z)-7-*prop*-2-*ynyltetradec*-7-*ene* (6) *to* (Z)-7-*allyltetradec*-7-*ene* (7). The alkyne (6) (140 mg, 0.6 mmol) in THF (3 ml) was added to a stirred suspension of dicyclohexylborane [5] (1 mmol) at 0 °C. The mixture was stirred for 90 min at 0 °C and then isobutyric acid (0.5 ml) was added, and stirring continued for 2 h at 25 °C. The mixture was cooled to 0 °C, 5M-NaOH (5 ml) was added, followed by 50% H_2O_2 (2 ml), and the mixture was stirred at room temperature for 18 h. Extraction as usual gave a crude product which by quantitative g.l.c. contained *ca.* 98% of the required product (7). [When equimolar amounts of (6) and dicyclohexylborane were used conversion was only 80%.]

So that there should be no possibility of isomerisation the crude product, before column chromatography on silica, was analysed directly on a 12 ft 10% Apiezon N column * at 250 °C. There was one main hydrocarbon product, retention time (t_R) 17.2 min comprising at least 99% of the product (base line noise allowing non-detection of 1% of the other isomer). Co-injection with a 60 : 40 mixture of (7) and its *E*-isomer produced by direct allylation [1] showed that the reduction product coincided completely with the *Z*-isomer (7), the *E*-isomer running at 16.4 min.

* In further experiments ' analysis on an Apiezon column ' will refer to this column.

[4] D. D. Perrin, W. L. F. Armarego, and D. W. Perrin, ' Purification of Laboratory Chemicals,' Pergamon, London, 1966.

[5] H. C. Brown, ' Organic Syntheses *via* Boranes,' Wiley–Interscience, New York, 1975.

[6] A. Pelter, K. Smith, M. G. Hutchings, and K. Rowe, *J.C.S. Perkin I*, 1975, 129.

[7] R. Köster and Y. Morita, *Angew. Chem. Internat. Edn.*, 1966, **5**, 580.

The product was then isolated in the usual way, the mass spectrum and n.m.r. spectrum confirming the overall structure (7).

Hydration of the alkyne (6) *to* (Z)-**4**-*hexylundec*-**4**-*en*-**2**-*one* [8] (8).—Red mercury(II) oxide (50 mg) in concentrated H_2SO_4 (5 drops) was warmed to 60 °C for 15 min and then diluted with water (3 ml). The resulting suspension was added to the alkyne (6) (524 mg) and the mixture warmed at 60 °C for 3.25 h. The emulsion that resulted was extracted with ether and the ether layer was washed with saturated aqueous NaCl, dried ($MgSO_4$), filtered, and evaporated. The pale yellow liquid that resulted had $\nu_{max.}$ 1 718 cm^{-1} and ran as one peak (t_R 11 min) on a 6 ft 4% PEGA column. The product was purified on a dry silica column (1.5 × 30 cm). The light petroleum fraction contained only a trace of oil but the methylene chloride fraction (150 ml) contained the product (8) (275 mg, 49%), identical (g.l.c. and i.r.) with the product derived from direct alkylation with bromoacetone. The n.m.r. spectrum showed a single peak at τ 6.91 [slightly sharpened by irradiation at the frequency of the vinyl proton (τ 4.68)]. The mass spectrum showed the expected peaks at *m/e* 252, 237, 209, and 194.

Reduction of the enone (8) *to* (E)-**7**-*propyltetradec*-**7**-*ene* (10). (*a*) (i) The ketone (8) (100 mg) was dissolved in ethanedithiol (0.5 ml) at 0 °C and treated with redistilled BF_3,Et_2O (3 drops); the mixture was then left at 0 °C for 30 min. Ice-cold methanol was added and the supernatant decanted; the process was repeated and the oily product was pumped for 2 h at 10^{-2} mmHg.

The product contained no starting ketone and ran as one peak on a 3 ft 4% PEGA column (t_R 20 min; programmed run 50—190° at 12° min^{-1}). A sample gave no molecular ion but peaks at *m/e* 267 and 119 (base peak) confirmed that the required product (9) had been formed.

(ii) The thioacetal product was refluxed in anhydrous

[8] G. W. Stacey and R. A. Mikulec, *Org. Synth.*, Coll. Vol. IV, 1963, p. 13.

TABLE 2

Characterisation of ketones ($R^1CO{\cdot}CHR^2{\cdot}CH_2Y$)

R^1	R^2	Y	B.p. (°C) [mmHg]	Refr. index	Found %C, H; M^+	Formula	Reqd. %C, H; M
n-Hexyl	n-Hexyl	CO_2Et	115—117 [1]	n_D^{18} 1.4470	72.4, 11.25; 298.2508	$C_{18}H_{34}O_3$	72.45, 11.5; 298.25078
Cyclopentyl	n-Butyl	CO_2Et	102—104 [1]	n_D^{18} 1.4646	70.8, 10.1; 254.1882	$C_{15}H_{26}O_3$	70.85, 10.3; 254.18818
n-Hexyl	n-Hexyl	COMe	90—93 [0.3]	n_D^{17} 1.4628	76.3, 11.9; 268.2402	$C_{17}H_{32}O_2$	76.05, 12.0; 268.2402
Cyclopentyl	n-Butyl	COMe	110—112 [1]	n_D^{18} 1.4688	74.95, 10.8; 224.1766	$C_{14}H_{24}O_2$	75.0, 10.9; 224.177 62
n-Hexyl	n-Hexyl	COPh	196—199 [0.6]	n_D^{19} 1.5048	80.0, 10.5; 330.2559	$C_{22}H_{34}O_2$	79.95, 10.35; 330.255 87
n-Hexyl	n-Hexyl	C≡CH	100—103 [1.5]	n_D^{18} 1.4568	81.55, 11.85; 250.2297	$C_{17}H_{30}O$	81.55, 12.1; 250.229 63
n-Octyl	n-Butyl	C≡CH	97—99 [1]	n_D^{19} 1.4520	81.4, 12.2; 250.2296	$C_{17}H_{30}O$	81.55, 12.1; 250.229 63
Cyclopentyl	n-Butyl	C≡CH	85—88 [1]	n_D^{19} 1.4802	81.7, 10.8; 206.1671	$C_{14}H_{22}O$	81.5, 10.75; 206.167 06
Cyclopentyl	n-Hexyl	C≡N	97—100 [0.9]	n_D^{20} 1.4899	76.3, 10.7; 235.1936	$C_{15}H_{25}NO$	76.55, 10.7; 235.193 60
n-Hexyl	n-Hexyl	C≡N	105—109 [0.8]	n_D^{18} 1.4685	76.3, 11.3; 251.2249	$C_{16}H_{29}NO$	76.45, 11.65; 251.224 90
n-Octyl	n-Butyl	C≡N	102—105 [0.9]	n_D^{19} 1.4581	76.2, 11.75; 251.2249	$C_{16}H_{29}NO$	76.45, 11.65; 251.224 90

TABLE 3

Characterisation of olefins ($R^1CH{:}CR^2{\cdot}CH_2Y$)

R^1	R^2	Y	B.p. (°C) [mmHg]	Refr. index	Found %C, H; M^+	Formula	Reqd. %C, H; M
n-Hexyl	n-Hexyl	CO_2Et	97—99 [1]	n_D^{18} 1.4463	76.3, 12.1; 282.2559	$C_{18}H_{34}O_2$	76.55, 12.15; 282.255 87
Cyclopentyl	n-Butyl	CO_2Et	90—92 [1.5]	n_D^{18} 1.4649	75.6, 11.0; 238.1933	$C_{15}H_{26}O_2$	75.6, 11.0; 238.193 27
n-Hexyl	n-Hexyl	COMe	100—102 [1.5]	n_D^{18} 1.4480	80.7, 13.0; 252.2453	$C_{17}H_{32}O$	80.9, 12.8; 252.245 30
Cyclopentyl	n-Butyl	COMe	94—95 [1.2]	n_D^{18} 1.4650	80.7, 11.7; 208.1827	$C_{14}H_{24}O$	80.7, 11.6; 208.182 71
n-Hexyl	n-Hexyl	COPh	110 [0.2]	n_D^{19} 1.5079	84.2, 11.0; 314.2609	$C_{22}H_{34}O$	84.0, 10.9; 314.260 95
n-Hexyl	n-Hexyl	C≡CH	87—90 [0.8]	n_D^{20} 1.4795	87.2, 12.8; 234.2347	$C_{17}H_{30}$	87.1, 12.9; 234.234 70
n-Octyl	n-Butyl	C≡CH	100—101 [2]	n_D^{19} 1.4776	86.9, 13.05; 234.2347	$C_{17}H_{30}$	87.1, 12.9; 234.234 70
Cyclopentyl	n-Butyl	C≡CH	75—76 [2]	n_D^{19} 1 4876	88.3, 11.45; 190.1721	$C_{14}H_{22}$	88.35, 11.65; 190.172 14
Cyclopentyl	n-Hexyl	C≡N	78—80 [1]	n_D^{19} 1.4865	82.05, 11.65; 219.1987	$C_{15}H_{25}N$	82.15, 11.5; 219.198 69
n-Hexyl	n-Hexyl	C≡N	90—93 [1]	n_D^{19} 1 4680	81.4, 12.2; 235.2300	$C_{16}H_{29}N$	81.65, 12.4; 235.229 99
n-Octyl	n-Butyl	C≡N	88—90 [1]	n_D^{19} 1.4719	81.4, 12.4; 235.2300	$C_{16}H_{29}N$	81.65, 12.4; 235.229 99

EtOH (5 ml) for 18 h in the presence of freshly prepared Raney nickel (0.5 g). After this time no thioacetal remained but a programmed run on a 3 ft 4% PEGA column showed one peak, t_R 7 min, corresponding to (10). Analysis of the product on an Apiezon column at 200 °C showed that it was 98% (*E*)-7-propyltetradec-7-ene (10), t_R 41.2 min, the *Z*-isomer running at 38.5 min. Co-injection with a 70 : 30 mixture of the *E*- and *Z*-isomers from direct propylation confirmed this analysis, the product of reduction and the *E*-isomer being completely coincident. The overall yield (g.l.c.) was 98%.

(*b*) *Direct reduction.*[3] (i) *p*-Tolylsulphonylhydrazine (140 mg) was dissolved in 1 : 1 dimethylformamide–tetramethylene sulphone (3 ml). To this solution were added the ketone (8) (147 mg) dissolved in cyclohexane (3 ml) and toluene-*p*-sulphonic acid (15 mg). Sodium cyanoborohydride (150 mg) was added as a solid to the mixture at 100—105 °C, and after 2.5 h g.l.c. analysis showed no starting material in the cyclohexane layer. Saturated aqueous NaCl was added and the hydrocarbon isolated as usual to give the product (120 mg). Analysis on Apiezon N showed that this was a 90 : 10 mixture of (1) and its *Z*-isomer.

(ii) A repeat of the same experiment was carried out, but the reaction was allowed to proceed for 20 h at 105 °C. Work-up as before gave an 81 : 19 mixture of (10) and its *Z*-isomer.

Preparation of (Z)-*ethyl* 3-*hexyldec*-3-*enoate* (11). To thexyl borane (5 mmol) [5] was added hex-1-ene (10 mmol) and the mixture was set aside for 2 h at 0 °C. The borane was converted into the 'ate' complex with octynyl-lithium as usual [1] and taken into glyme (5 ml). To the solution at −78 °C was added ethyl bromoacetate (1 ml; 40% excess); the mixture was allowed to warm slowly to room temperature and stirred for a total of 72 h. Isobutyric acid (2 ml) was added and hydrolysis allowed to proceed for 18 h. Saturated NaOAc solution (10 ml) and 50% H_2O_2 (3 ml) were added, and the mixture was set aside for 12 h then worked up as usual. The CH_2Cl_2 eluate contained almost pure (*Z*)-ester (11) (1.06 g, 75%) plus a trace of an unknown hydrocarbon. The n.m.r. spectrum showed the product to be >98% *Z*-isomer (11).

Reduction of the ester (11) *to* (Z)-3-*hexyldec*-3-*en*-1-*ol* (12). A mixture of the ester (11) and its *E*-isomer (88 : 12; 400 mg) in ether (3 ml) was added dropwise to a suspension of $LiAlH_4$ (50 mg) in ether (2 ml) at 0 °C. After the initial exothermic reaction had subsided, any adhering ester was washed into the mixture with ether (2 ml) and the mixture was refluxed for 5 min. It was left for a further 45 min at room temperature, then cooled to 0 °C, and 3M-NaOH (3 ml) was added. The resulting suspension was stirred for 30 min and more ether (5 ml) was added. After filtration the organic product was isolated as an oil (290 mg, 86%). The mass spectrum corresponded with that expected for the alcohol (12) and the product separated into two components, t_R 17 and 20 min, in the ratio 12 : 88 on a 3 ft 15% Carbowax 20M column at 160 °C. Thus no isomerisation had occurred.

A sample was purified by chromatography on silica. Elution with methylene dichloride gave only the major *component* (t_R 20 min), τ 8.23br (1 H, exchangeable with D_2O), 8.04br (t), 7.72 (t, *J* 7 Hz), 6.43 (t, *J* 7 Hz), and 4.75 (1 H, *J* 7 Hz), *m/e* 240, 196, 165, 151, 137, 123, 119, 111, and 110 (Found: M^+, 240.2453. $C_{16}H_{32}O$ requires *M*, 240.245 30). The ether fraction from the column had almost identical physical characteristics but was a *ca.* 70 : 30 mixture of (12) and its *E*-isomer.

Reduction of the alcohol (12) *to* (E)-7-*ethyltetradec*-7-*ene* (14). The crude alcohol mixture (550 mg) was dissolved in pyridine (10 ml) and cooled to 0 °C. Purified toluene-*p*-sulphonyl chloride (1.0 g) was added and the stoppered flask shaken to dissolve the chloride. The mixture was left at 0 °C for 16 h, poured into iced water (50 ml), and extracted with ether (2 × 30 ml). The neutral product was isolated in the normal fashion as an oil (774 mg, 89%). This showed an AA'BB' system (4 H) at τ 2.28 and 2.74 in its n.m.r. spectrum and was clearly a mixture of two isomers [CH_2·O τ 6.06 (*J* 7 Hz) and 6.04 (*J* 7 Hz)]. It was not possible to assess accurately the proportions of isomers by either g.l.c. or n.m.r., and the mass spectrum showed no molecular ion. However large peaks at *m/e* 239.2375 ($C_{16}H_{31}O$), 173.0272 ($C_7H_9SO_3$), and 155.0167 ($C_7H_7SO_2$) confirmed the n.m.r. evidence that the required toluene-*p*-sulphonate mixture was in hand, and the product was not purified further.

The crude product (400 mg) in THF (3 ml) was added to a suspension of $LiAlH_4$ (60 mg) in THF (3 ml) at 0 °C. After the initial reaction had subsided the mixture was heated at reflux for 3 h. Aqueous 3M-NaOH (20 ml) was added dropwise at 0 °C and the mixture was stirred for 30 min at 25 °C and extracted with light petroleum (2 × 25 ml). The extract was washed with water, dried ($MgSO_4$), filtered, and evaporated to yield an oil (240 mg, 100%). The mass spectrum showed the absence of starting material, and confirmed that the product was solely 7-ethyltetradec-7-ene, a result justified also by its retention time (5 min) on the usual programmed run on a 3 ft 4% PEGA column. On an Apiezon column at 200 °C the product showed two peaks, t_R 27.5 and 29.5 min, in the ratio 12 : 88. Co-injection with an authentic sample of a mixture of (14) and its *Z*-isomer gave complete co-incidence of both peaks, the major isomer from the reduction corresponding to (14).

Hydrolysis of the ester (11). The ester (11) (300 mg) together with its *E*-isomer (80 : 20) was heated under reflux for 2 h in methanolic M-KOH. Dilution with water, acidification, extraction with ether, and work-up as usual gave the *acid* (15) as an oil (235 mg, 87%) containing no starting material, $\nu_{max.}$ 1 715 and 2 500—3 500 cm^{-1} (OH), τ 2.5br (exchangeable with D_2O), 4.64 (t, *J* 7 Hz, vinylic), and 6.97 and 7.30br (s) (each 1 H, s, allylic) (80 : 20), *m/e* 254 and 194 (base) (Found: M^+, 254.2246. $C_{16}H_{30}O_2$ requires *M*, 254.224 57).

Re-esterification of a sample (*Z* : *E* 78 : 22) with EtOH–H_2SO_4 for 18 h at reflux gave back the ester quantitatively, but the *Z* : *E* ratio had changed to 72 : 28.

Hydrolysis of (Z)-3-*hexyldec*-3-*enonitrile* (16). The nitrile (16) (100 mg) in 75% H_2SO_4 (1 ml) containing NaCl (50 mg) was stirred under reflux at 170 °C for 1 h. The resulting solution was diluted with saturated aqueous NaCl, and extracted for carboxylic acid in the usual way. The product was a pale yellow oil (70 mg), $\nu_{max.}$ 1 714br and 2 500—3 500 cm^{-1} (OH), mass spectrum identical with that of the authentic acid (15). The methylene groups α to the cyano-group showed as a singlet in the ^1H n.m.r. spectrum. Esterification as before gave the ester (11) containing some *E*-isomer (8%).

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