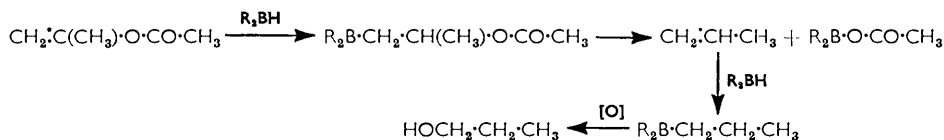### 736. *The Reaction of Enol Acetates with Bis-*(1,2-*dimethyl-propyl*)*borane*

By D. B. BIGLEY and D. W. PAYLING

The reaction of bis-(1,2-dimethylpropyl)borane with enol acetates derived from aldehydes having two α-hydrogen atoms involves a slow anti-Markownikoff hydroboration, followed by rapid elimination and rehydroboration reactions. Enol acetates derived from ketones do not generally react.

THE reaction of diborane with enol acetates has been investigated by Cagliotti *et al.* who have developed therefrom a convenient route for the conversion of enol acetates into olefins.[1] Bis-(1,2-dimethylpropyl)borane is a more selective reagent than diborane, on account of both its greater bulk and its lower Lewis acidity;[2] it seemed that its use in place of diborane might lead to a more selective olefin synthesis.

At the inception of this work two cases of the reaction of bis-(1,2-dimethylpropyl)-borane with enol acetates were known to us. An isolated report in the literature states that cyclohexenyl acetate reacts with an excess of the reagent to give, after oxidation, a mixture of cyclohexanol and cyclohexanediol,[3] and we have observed[4] that isopropenyl acetate reacts similarly to give a good yield of n-propanol. Both observations were interpreted in terms of the following scheme:

$$CH_2{:}C(CH_3){\cdot}O{\cdot}CO{\cdot}CH_3 \xrightarrow{\;R_2BH\;} R_2B{\cdot}CH_2{\cdot}CH(CH_3){\cdot}O{\cdot}CO{\cdot}CH_3 \longrightarrow CH_2{:}CH{\cdot}CH_3 + R_2B{\cdot}O{\cdot}CO{\cdot}CH_3$$

$$\Big\downarrow R_2BH$$

$$HOCH_2{\cdot}CH_2{\cdot}CH_3 \xleftarrow{\;[O]\;} R_2B{\cdot}CH_2{\cdot}CH_2{\cdot}CH_3$$

We have now investigated the reaction in more detail.

RESULTS AND DISCUSSION

Scope of the Reaction.—The reaction of an approximately four-fold excess of bis-(1,2-dimethylpropyl)borane in tetrahydrofuran solution at 0° with a series of enol acetates is reported in Table 1. It is clear that the reactions fall largely into two types. Enol acetates derived from ketones react very slowly, giving rise to undetectable amounts of alcohol, whereas the enol acetates derived from aldehydes having an α-methylene group react to give good yields of alcohols. In the latter case, one molecule of enol acetate reacts with two of the borane. The eliminated dialkylborane acetate has been shown not to react with bis-(1,2-dimethylpropyl)borane.[5]

The difference in behaviour between ketone and aldehyde enol acetates is best accounted

[1] L. Cagliotti and G. Cainelli, *Atti Accad. naz. Lincei, Rend. Classe Sci. fis. met. nat.*, 1961, 8, **30**, 225.

[2] H. C. Brown in " Hydroboration," W. A. Benjamin, New York, 1962.

[3] A. Hassner and B. H. Braun, *Univ. Colorado Studies, Ser. Chem. Pharm.*, 1962, **4**, 48.

[4] H. C. Brown and D. B. Bigley, unpublished work.

[5] H. C. Brown and D. B. Bigley, *J. Amer. Chem. Soc.*, 1961, **83**, 486.

for on steric grounds. Bis-(1,2-dimethylpropyl)borane readily hydroborates *cis*-disubstituted olefins and more slowly *trans*-disubstituted olefins; it is unreactive towards trisubstituted olefins.[2] In the present work we have chosen enol acetates of symmetrical ketones as substrates in order that isomerism is limited to *cis–trans* isomerism only. Such enol acetates have a trisubstituted double bond and will be expected to hydroborate very slowly. The case of isopropenyl acetate is unique in that, although derived from a ketone, it contains only a 1,1-disubstituted double bond. It should therefore hydroborate readily. The enol acetates derived from normal aldehydes contain 1,2-disubstituted double bonds and hydroborate readily. In contrast, when the aldehyde group is attached to a secondary alkyl group, as in isobutyraldehyde, the resulting enol acetate contains a trisubstituted double bond and is unreactive.

In our hands cyclohexenyl acetate did not react significantly with bis-(1,2-dimethylpropyl)borane during 48 hr. at 0°, whereas Hassner and Braun report over 60% reaction.[3] We believe that this difference is due to the fact that these authors report that their reaction temperature rose to 60°. At 25°, bis-(1,2-dimethylpropyl)borane reacts almost completely with 2-methylbut-2-ene in 24 hr.;[6] further, at 60° in tetrahydrofuran solution, it slowly isomerises to a less hindered borane which gives 3-methylbutan-1-ol on oxidation. Either of these factors would account for the difference between our results and those of Hassner and Braun.

The yields of alcohol, approaching 80%, suggest that bis-(1,2-dimethylpropyl)borane is adding to the double bond very largely in the anti-Markownikoff sense (Pasto[7] recently obtained a 77% overall yield in the hydroboration of 1-ethoxycyclohexene, where no Markownikoff addition was detected). Addition in the Markownikoff sense should give rise, after oxidation, to a 1,1-diol, which would lose water to regenerate the parent aldehyde. We have not been able to detect significant quantities of aldehyde in the reaction products. In experiments on enol acetates derived from ketones the small amount of ketone detected undoubtedly derives from hydrolysis of part of the residual enol acetate. The hydrobor-

TABLE 1

Reaction of enol acetates with an excess of bis-(1,2-dimethylpropyl)borane in tetrahydrofuran solution at 0° (24 hr.)

Enol ester derived from	Initial enol ester (mmoles)	Initial R_2BH (mmoles)	Residual enol ester (mmoles)	Residual R_2BH (mmoles)	Alcohol (mmoles)
n-Butyraldehyde	11·5	45·5	0·0	20·5	7·9
n-Hexaldehyde	10·9	45·0	0·0	23·0	7·3
n-Octaldehyde	9·3	42·8	0·0	17·7	5·5
Isobutyraldehyde	7·6	29·8	6·3	25·7	—
Acetone	11·2	37·2	0·0	15·0	8·4
3-Pentanone	10·9	42·8	9·8	38·0	0·0
4-Heptanone	11·5	38·2	9·8	31·9	0·0
Cyclohexanone	9·5	38·1	9·1	33·8	0·0

ation of allyl acetate occurs with 35% of the boron adding to the 2-position; such addition may be explained in terms of polarisation of the double bond by the inductive withdrawal of the ester group.[8] In the case of enol esters it appears that inductive withdrawal is outweighed by the mesomeric donation of a lone pair from the ethereal oxygen atom, an effect operating in the opposite direction. A similar explanation has been offered in the case of enol ethers.[7]

Attempted Separation of the Two Steps of Reaction.—We attempted to separate the initial hydroboration from the subsequent elimination and rehydroboration reactions by reacting the enol acetate and bis-(1,2-dimethylpropyl)borane in equimolar amounts. Samples were withdrawn during the reaction, the bis-(1,2-dimethylpropyl)borane was

[6] H. C. Brown and G. Zweifel, *J. Amer. Chem. Soc.*, 1961, **83**, 1241.
[7] D. J. Pasto and C. C. Cumbo, *J. Amer. Chem. Soc.*, 1964, **86**, 4343.
[8] H. C. Brown and O. J. Cope, *J. Amer. Chem. Soc.*, 1964, **86**, 1801.

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TABLE 2

Reaction of enol acetates with equimolar quantities of bis-(1,2-dimethylpropyl)borane
in tetrahydrofuran solution at 0° (24 hr.)

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Enol ester derived from	Initial enol ester (mmoles)	Initial R_2BH (mmoles)	Residual enol ester (mmoles)	Residual R_2BH (mmoles)
n-Butyraldehyde ...	45·0	45·0	22·9	0·0
n-Hexaldehyde	38·5	42·0	15·1	0·0
n-Octaldehyde	34·4	34·7	19·0	0·0
Acetone	24·9	23·0	13·1	0·0

quenched by the addition of an excess of hex-1-ene, and the residual enol ester was estimated by vapour-phase chromatography (v.p.c.). Similar samples were taken to estimate active hydrogen loss. In all cases the enol-ester and active-hydrogen loss followed a smooth curve, with a stoicheiometry of two moles of organoborane reacting with one mole of enol ester. The overall stoicheiometries at the end of reaction are presented in Table 2. It is evident that the initial hydroboration is considerably slower than the subsequent two stages. Similar rapid β-eliminations have recently been discussed.[7,8]

Selectivity.—Bis-(1,2-dimethylpropyl)borane has been used to remove the more reactive *cis*-isomer from a mixture of *cis*- and *trans*-olefins. By reacting a mixture of aldehyde enol acetates with a deficiency of the same reagent in a competition experiment we have obtained the following figures: n-butenyl acetate, $k_{cis}/k_{trans} = 1·3$; n-hexenyl acetate, $k_{cis}/k_{trans} = 1·3$; n-octenyl acetate, $k_{cis}/k_{trans} = 1·2$. Reported values[9] for the hydroboration of olefins are: but-2-ene, $k_{cis}/k_{trans} = 6$; hex-3-ene, $k_{cis}/k_{trans} = 9·5$. In order to establish that the small selectivity was not due to isomerisation of the enol acetates by any of the boron species present, each of the isomers was obtained pure by preparative v.p.c. and subjected to the reaction conditions. No isomerisation resulted. These isomers do not appear to have been separated previously, and their physical constants are recorded in the Experimental section. The reaction of bis-(1,2-dimethylpropyl)borane with aldehyde enol acetates is thus considerably less selective than its reaction with olefins of similar structure, reflecting the smaller size of the ethereal oxygen of the ester compared with the alkyl group of the hydrocarbon. Reaction between hexenyl acetate and the very hindered di-isopinocampheylborane resulted in an increase of selectivity ($k_{cis}/k_{trans} = 1·6$); however, reaction of the same reagent with the corresponding olefin shows such selectivity that the *trans*-olefin reacts by a displacement reaction.[10] These observations indicate that the acetoxy-group is exerting very little steric effect on the course of addition. On steric grounds, therefore, the organoborane might be expected to add its boron to the acetoxy-end of the double bond. The fact that addition is in the opposite sense appears to confirm the electronic nature of the control of addition discussed above.

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EXPERIMENTAL

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Isopropenyl acetate was supplied by Eastman Organic Chemicals. The ketone enol acetates were prepared by the method of House and Kramar;[11] the aldehyde enol acetates were prepared after Bedoukian.[12] All were fractionated until at least 97% pure by v.p.c. Since they were mixtures of isomers, physical constants are not quoted. The pairs of isomers of Table 3 were separated by v.p.c. using a 10 ft. × ⅜ in. column of 30% Carbowax 20-M on Chromosorb P. The i.r. and n.m.r. spectra were in accord with expectation. Only the relevant portions serving to differentiate the *cis*- from the *trans*-isomers are listed in the Table. The C–H out-of-plane deformation frequency of the *cis*-acetates (746—749 cm.$^{-1}$) is slightly higher than the corresponding absorption (733 cm.$^{-1}$) reported for *cis*-but-1-enyl butyl ether.[13] The same absorption of the *trans*-acetate correlates exactly with the rather low frequency (933 cm.$^{-1}$) reported for the

[9] H. C. Brown and A. W. Moerikofer, *J. Amer. Chem. Soc.*, 1961, **83**, 3417.
[10] H. C. Brown, N. R. Ayyangar, and G. Zweifel, *J. Amer. Chem. Soc.*, 1964, **86**, 1071.
[11] H. O. House and V. Kramar, *J. Org. Chem.*, 1963, **28**, 3362.
[12] P. Z. Bedoukian, *J. Amer. Chem. Soc.*, 1944, **66**, 1325.
[13] R. H. Hall, A. R. Philpotts, E. S. Stern, and W. Thain, *J.*, 1951, 3341.

TABLE 3

Spectral data of enol acetates

Compound	n_D^{21}		Spectral data (i.r. in CS_2; n.m.r. in CCl_4)
cis-1-Acetoxy-but-1-ene	1·4170	I.r.	3101w*, 3057w*, 1671m, 1044s, 750m
		N.m.r.	C_1–H: Doublet ($J = 6\cdot5$ c./sec.) at 2·93τ; partially resolved triplet structure, $J \sim 1$ c./sec. C_2–H: Two superimposed triplets giving four lines at 5·11τ; $J = 7$ c./sec.
trans-1-Acetoxy-but-1-ene	1·4193	I.r.	3081w*, 3027w*, 1675m, 1104s, 930m
		N.m.r.	C_1–H: Doublet ($J = 12\cdot5$ c./sec.) at 2·80τ; partially resolved triplet structure, $J \sim 1$ c./sec. C_2–H: Two superimposed triplets giving five lines at 4·58τ; $J = 12\cdot5$ and 7 c./sec.
cis-1-Acetoxy-hex-1-ene	1·4269	I.r.	3103w*, 3059w*, 1672m, 1044s, 750m
		N.m.r.	C_1–H: Doublet ($J = 7$ c./sec.) at 2·92τ; partially resolved triplet structure, $J \sim 1$ c./sec. C_2–H: Two superimposed triplets giving four lines at 5·16τ; $J = 7$ c./sec.
trans-1-Acetoxy-hex-1-ene	1·4292	I.r.	3084w*, 3030w*, 1675m, 1104s, 934m
		N.m.r.	C_1–H: Doublet ($J = 12\cdot5$ c./sec.) at 2·82τ; partially resolved triplet structure, $J \sim 1$ c./sec. C_2–H: Two superimposed triplets giving five lines at 4·60τ; $J = 12\cdot5$ and 7 c./sec.
cis-1-Acetoxy-oct-1-ene	1·4342	I.r.	3100w*, 3056w*, 1671m, 1060s, 749m
		N.m.r.	C_1–H: Doublet ($J = 6\cdot5$ c./sec.) at 2·92τ; partially resolved triplet structure, $J \sim 1$ c./sec. C_2–H: Two superimposed triplets giving four lines at 5·16τ; $J = 7$ c./sec.
trans-1-Acetoxy-oct-1-ene	1·4370	I.r.	3080w*, 3024w*, 1674m, 1102s, 931m
		N.m.r.	C_1–H: Doublet ($J = 13$ c./sec.) at 2·85τ; partially resolved triplet structure, $J \sim 1$ c./sec. C_2–H: Two superimposed triplets giving five lines at 4·61τ; $J = 12\cdot5$ and 7 c./sec.

* Liquid-film spectrum.

trans-ether. These figures, together with the J values of Table 3 and the consistently shorter retention times of the *cis*-acetates, leave no doubt as to the correct identification of each isomer.

Diborane was generated externally, and was stored at $-8°$ in tetrahydrofuran solution.[14] Bis-(1,2-dimethylpropyl)borane was prepared [9] for each experiment, and was estimated by the hydrolysis of an aliquot portion under a gas burette. Typical experiments were as follows.

Reaction of 1-*Acetoxyhex*-1-*ene with an Excess of Bis-*(1,2-*dimethylpropyl*)*borane.*—A solution of bis-(1,2-dimethylpropyl)borane in tetrahydrofuran (33·0 ml., 45·0 mmoles) at 0° was introduced by means of a dried all-glass syringe into a 50 ml. flask *via* a wired Suba-Seal rubber cap. The flask was equipped with a magnetic stirrer and a thermometer well, and a small static head of dry nitrogen was maintained over the solution. The flask was cooled to $-10°$, and 1-acetoxy-hex-1-ene (mixed isomers; 1·54 g., 10·9 mmoles) and chlorobenzene (0·39 g.; internal standard) were injected from syringes. The temperature of the solution was allowed to rise to 0°, and samples (2·0 ml.) were withdrawn at intervals, during 24 hr., by means of a syringe. Half the sample was hydrolysed under a gas burette to estimate residual bis-(1,2-dimethylpropyl)-borane and the remainder was quenched with dec-1-ene (0·40 ml.). 1-Acetoxyhex-1-ene in the latter was estimated by v.p.c. [poly(ethylene glycol succinate) on firebrick]. After 24 hr. the reaction mixture was hydrolysed with water (2·0 ml.), the volume of hydrogen evolved being corrected for material taken as samples. The hydrolysed reaction mixture was oxidised at 0° with a mixture of aqueous sodium hydroxide (3N, 20·2 ml.) and hydrogen peroxide (100 vol., 30%, 20·2 ml.). Glycerol (2·0 ml.) was then added, and the whole was saturated with sodium chloride. The organic layer was separated, dried over freshly dried magnesium sulphate, and the hexan-1-ol was estimated by v.p.c. [poly(ethylene glycol) on Teflon].

Reaction of 1-*Acetoxyhex*-1-*ene with an Equivalent Amount of Di-isopinocampheylborane.*— To a stirred solution of sodium borohydride in diethylene glycol dimethyl ether (1·0M, 10 ml.) and α-pinene (4·25 ml., 26·8 mmoles) at 0° was added boron trifluoride etherate (1·68 ml., 13·4 mmoles) during 5 min., and the mixture was maintained at 0—5° for 4 hr. At the end of this period a mixture of 1-acetoxyhex-1-ene (1·92 g., 13·5 mmoles) and chlorobenzene (0·42 g.;

[14] H. C. Brown and B. C. Subba Rao, *J. Amer. Chem. Soc.*, 1959, **81**, 6428.

internal standard) was added by syringe. Samples (1·0 ml.) were withdrawn at intervals, quenched with dec-1-ene (0·40 ml.), and estimated for residual enol ester by v.p.c. Since the reaction mixture was heterogeneous, the residual active hydrogen of the samples could not be estimated. After 24 hr., hydrolysis of the mixture gave 0·25 mmole of hydrogen. At the time of injection the enol ester mixture consisted of *cis*, 6·2 mmoles and *trans*, 7·3 mmoles. After 24 hr. the values were *cis*, 2·7 mmoles and *trans*, 5·2 mmoles.

Isomerisation of Bis-(1,2-dimethylpropyl)borane.—A solution of bis-(1,2-dimethylpropyl)-borane (17·3 mmoles) in tetrahydrofuran (15·0 ml.) was refluxed under an atmosphere of dry oxygen-free nitrogen. Samples (5·0 ml.) were withdrawn at the times shown and oxidised with an excess of hydrogen peroxide and 3N-sodium hydroxide. V.p.c. analysis of the salted-out tetrahydrofuran layer gave the following results.

Time (hr.)	0	3	6
3-Methylbutan-2-ol/3-Methylbutan-1-ol	100/0	83·7/16·3	77·0/23·0