

Formation of Alcohols from Alkenes with $\text{TiCl}_4\text{-NaBH}_4$

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Summary The reaction of alkenes with $\text{TiCl}_4\text{-NaBH}_4$ in 1,2-dimethoxyethane afforded alcohols, the hydroxy group of which was introduced in an anti-Markovnikov direction.

TABLE Reaction of olefins with $\text{TiCl}_4\text{-NaBH}_4$

| Olefin (1) | Product (2) (Yield %) |
|---|---|
| a $\text{Me}[\text{CH}_2]_7\text{CH}=\text{CH}_2$ | a $\text{Me}[\text{CH}_2]_8\text{CH}_2\text{OH}$ (93%) |
| b $\text{PhC}(\text{Me})=\text{CH}_2$ | b $\text{PhCH}(\text{Me})\text{CH}_2\text{OH}$ (90%) |
| c | c ^a $\text{PhCH}(\text{OH})\text{CH}_2\text{Ph}$ (73%) |
| d | d ^b |
| e | e (88%) |
| f | f ^c (89%) |
| g | g (71%) |
| h | h (85%) |
| i | i (70%) |

^a 1,2-Diphenylethane (5%) was formed as a by-product ^b TiCl_4 (3.5 equiv) and NaBH_4 (7.0 equiv) was used ^c *cis*- (22%) and *trans*-isomers (67%) were separated by column chromatography on silica gel ^d Phenylcyclohexane (ca 10%) was formed as a by-product

† This species is effective for the reduction of some groups S Kano Y Tanaka E Sugino and S Hibino submitted to *Synthesis*

‡ When $\text{TiCl}_4\text{-NaBH}_4$ was used a few minutes after mixing TiCl_4 with NaBH_4 the alcohols were obtained in a lower yield (50–70%) accompanied by the formation of the corresponding reduced alkanes (20–25%) Formation of alkanes could be avoided by using the reagent 1 h after preparation Furthermore the yields of alcohols varied with the molar ratios of substrate $\text{TiCl}_4\text{-NaBH}_4$ When the ratio is 1:1:1:1 neither alcohols nor alkanes were obtained However when it is 1:1:1:5 and 1:2:1:4:2, alcohols were obtained in < 50% yield The yields of alcohols were improved when the reactants were in the ratio 1:1:2

§ All compounds were identified by direct comparison of physical data with those of authentic samples

¶ The alcohols may have been formed by air oxidation and/or by hydrolysis of the hydrotitanated intermediates via a radical mechanism The mechanism remains unsolved but hydroboration-oxidation can be excluded as the reactivity of $\text{TiCl}_4\text{-NaBH}_4$ is considerably different from that of diborane For instance the reaction of diphenylacetylene with $\text{TiCl}_4\text{-NaBH}_4$ gave *trans* stilbene (30%) without formation of the *cis* isomer The reaction using diborane gave predominantly *cis* stilbene

** These reactions were re examined under a stream of air In all cases the yields of alcohols were not improved They were also carried out using anhydrous oxygen free solvents under nitrogen or argon These gave low yields of alcohols and the expected reduced alkanes were not obtained except in the case of (1e) where acenaphthene was obtained in 77% yield

¹ S-K Chung *J Org Chem*, 1979 **44**, 1014 and references cited therein

² F Sato S Sato and M Sato *J Organomet Chem*, 1976 **122**, C25

³ T Mukaiyama M Hayashi and K Narasaka *Chem Lett*, 1975, 291, T Mukaiyama and A Ishida, *ibid* p 1201, T Mukaiyama, M Shiono K Watanabe and M Onaka, *ibid* p 711

⁴ J E McMurry and M P Fleming *J Am Chem Soc* 1978, **96**, 4708

⁵ H C Brown and B C Subba Rao, *J Amer Chem Soc*, 1956, **78**, 2586, B C Subba Rao, *Curr Sci*, 1961, **30**, 218 B C Subba Rao and C P Thaker, *J Sci Ind Res*, 1961, **20B**, 318

⁶ G Zweifel and H C Brown, *J Am Chem Soc*, 1964, **86**, 393

⁷ A P Acharya, H C Brown, A Suzuki, S Nozawa, and M Itoh, *J Org Chem*, 1969, **34**, 3415

RECENTLY, reducing agents formed by a combination of transition metal [e.g., Co^{II} (ref 1) or Zr^{IV} (ref 2)] halide and NaBH_4 , have been used for the reduction of various functional groups and these reaction sequences have attracted increasing attention in organic synthesis The low-valent titanium reagent prepared from Ti^{IV} and LiAlH_4 ³ [or $\text{Ti}^{\text{III}}\text{-LiAlH}_4$]⁴ has been widely used in organic synthesis We have investigated the reductive effects of $\text{TiCl}_4\text{-NaBH}_4$ ⁵† on the assumption that coupling of TiCl_4 with NaBH_4 would lead to an active low-valent titanium-borane complex During these investigations we found that alkenes were easily converted into alcohols upon reaction with $\text{TiCl}_4\text{-NaBH}_4$

$\text{TiCl}_4\text{-NaBH}_4$, prepared by mixing TiCl_4 (1 equiv) with NaBH_4 (2 equiv) in 1,2-dimethoxyethane (DME) at room temperature for 1 h,‡ was treated with dec-1-ene (1a) at room temperature for 14 h and the mixture was decomposed with H_2O to give n-decyl alcohol (2a) § The same reaction of α -methylstyrene (1b), *trans*-stilbene (1c), 2-hydroxy-*trans*-stilbene (1d) and acenaphthylene (1e) yielded the corresponding alcohols¶ (see the Table) The hydroxy group of the alcohols was introduced in an anti-Markovnikov direction In the reaction of 1-phenylcyclohexene (1f) with $\text{TiCl}_4\text{-NaBH}_4$, 2-phenylcyclohexanol (2f) was obtained as a mixture of *cis*- and *trans*- isomers We also examined the same reaction using some sterically hindered olefins Treatment of (\pm)- α -pinene (1g) with $\text{TiCl}_4\text{-NaBH}_4$ gave (\pm)-isopinocampheol (2g)⁶ without formation of other stereoisomers (\pm)- β -Pinene (1h) gave (\pm)-*cis*-myrtilol (2h)⁶ while (\pm)-thujyl alcohol (2i)⁷ was obtained from (\pm)- α -thujene (1i) In these cases, the hydroxy group was introduced with stereoselectivity Compounds containing trisubstituted endocyclic double bonds as well as terminal methylene groups were converted into the corresponding alcohols by the use of this reagent The foregoing condition gave the best results for formation of alcohols from alkenes **

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