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STEREOCHEMISTRY OF ELECTROPHILIC SUBSTITUTION OF TRISUBSTITUTED VINYLSILANES. A GENERAL METHOD OF STEREOSELECTIVE SYNTHESIS OF TRISUBSTITUTED ALKENES

T.H. Chan*, P.W.K. Lau and W. Mychajlowskij,

Department of Chemistry,
McGill University,
Montreal, Quebec, Canada

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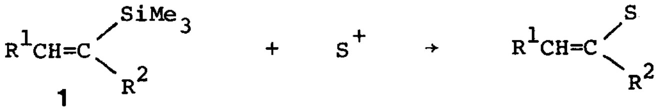
Recently, we[1] and others[2] have reported on the stereoselective synthesis of trisubstituted vinylsilanes[3]. In our opinion, these vinylsilanes can serve as useful precursors for the stereoselective synthesis of trisubstituted alkenes[4,5] which are of particular interest because of the widespread occurrence of this structure in nature. We report here the conversion of these vinylsilanes to variously trisubstituted alkenes by electrophilic substitution (equation 1) and the stereochemistry thereof.



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(1)

a $R^1 = c\text{-}C_6H_{11}$; $R^2 = C_2H_5$
b $R^1 = i\text{-}Pr$; $R^2 = n\text{-}C_5H_{11}$
c $R^1 = n\text{-}C_{10}H_{21}$; $R^2 = n\text{-}C_5H_{11}$

2 S = Br
3 S = I
4 S = $CH_3\text{-}C\overset{O}{\leqslant}$
5 S = $H\text{-}C\overset{O}{\leqslant}$

Bromodesilylation: The reactions of bromine with disubstituted vinylsilanes have been reported.[6-9] The results appeared to be mainly retention of configuration[6,8] in the case of β-silylstyrenes and mainly inversion of configuration in the case of alkenylsilanes.[7,9] The reactions of bromine with the trisubstituted vinylsilanes 1 are somewhat complicated. The E isomers of 1 reacted rapidly with bromine in CH_2Cl_2 at -78°. The reaction mixture was worked up and the product was purified by TLC on silica gel with hexane as eluent to give cleanly the Z-isomers of 2. (Yield: 65-87%. Physical data: ir: 1655 cm^{-1}; nmr: $\delta=5.4(d)$). The inversion of stereochemistry observed is presumably due to anti-addition of bromine across the double bond to give the dibromide adduct followed by anti-elimination of bromosilane as suggested originally by Jarvie.[9] The intermediate dibromide was detected in the case of 1c. On the other hand, reactions of the Z-isomers of 1 with bromine gave a complicated mixture of products, among which the dibromide adducts constituted 10-65%.[10] Stirring the crude product mixture in acetonitrile at room temperature resulted in the debromosilylation of the dibromide adducts to give the E-isomers of vinylbromides 2. (Yield: 10-56%, Physical data: ir: 1640 cm^{-1}; nmr: δ = 5.6(d)).

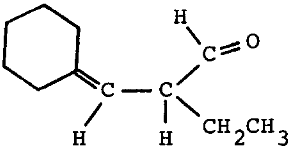
Fortunately, a convenient method for preparing E-2 was discovered when we found that reaction of E-1 with cyanogen bromide in the presence of aluminum chloride in methylene chloride at 0° proceeded cleanly to give the desired E-2 with retention of stereochemistry (isolated yield: 53-73%). Thus with appropriate reagents, it is possible to obtain either isomer of vinylbromide 2 starting from the same vinylsilane E-1. The difference in stereochemical results suggests strongly that a different mechanism is operative in the bromodesilylation reaction with cyanogen bromide.

Iododesilylation[7]: In contrast, the reactions of iodine with the trisubstituted vinylsilanes 1 were straightforward and gave the corresponding vinyliodides 3 with high stereospecificity and retention of configuration. For example, a solution of iodine (1 mmole) in 5 ml methylene chloride was added to a solution of vinylsilane 1 (1 mmole) in 5 ml methylene chloride at room temperature. The mixture was stirred for one hour and worked up to give the product which was purified by TLC (silica gel) with benzene:hexane (5:1) as eluent to give the vinyliodide 3. Yield 60-81%. Physical data: E-3 ir: 1625 cm^{-1}; nmr: δ = 6.0(d); Z-3 ir: 1640 cm^{-1}; nmr: δ = 5.2(d). Since vinylbromides and vinyliodides can be converted easily to other trisubstituted alkenes either via lithiation[11] or by reaction with organocopper compounds,[12] the vinylsilane route to these vinylhalides represents a reaction of considerable synthetic utility.

Friedel-Crafts Acylation[13]: Reactions of 1 with acetyl chloride and aluminum chloride in methylene chloride at 0° for twenty minutes gave the corresponding α,β-unsaturated ketones 4 in good yields with high stereospecificty and retention of stereochemistry (isolated yield by TLC 58-70%). The stereochemistries of the isomeric ketones 4 were evident from the carbonyl absorptions in the infrared spectra (E-4: 1665 cm^{-1}; Z-4: 1690 cm^{-1}) and the chemical shifts as well as allylic coupling of the vinyl protons in the pmr spectra (E-4: δ = 6.2(d); Z-4: δ = 5.2(t,d)). Chemical correlation of stereochemistries has also been demonstrated (see Scheme 1). Friedel-Crafts acylation of vinylsilanes represents therefore one of the few methods for the direct stereoselective synthesis of α,β-unsaturated ketones.

Friedel-Crafts Formylation[14]: Formylation of the vinylsilanes 1-a with dichloromethyl methyl ether and aluminum chloride in methylene chloride at 0° gave the conjugated aldehyde E-5a in good yield irrespective of the stereochemistry of the precursor vinylsilanes. E-5a has ir: 2700, 1690, 1640 cm^{-1} and nmr at δ = 6.1(d), 9.2(s). Lowering the reaction temperature to -45° and shorter reaction time revealed that in the case of Z-1a, a mixture of products E-5a, Z-5a as well as the deconjugated isomer 6 were formed in a ratio of

1:2:1. Upon warming or on longer reaction time the mixture eventually transformed into E-5a only. It is likely therefore that the formylation proceeds with retention of stereochemistry but under the reaction conditions, the less stable Z-5a is catalytically isomerised to the more stable E isomer via 6. (Z-5a: ir: 2700, 1690, 1610 cm^{-1}; nmr: δ = 5.7(d), 10.1(s); 6: ir: 1725 cm^{-1}; nmr: δ = 5.5(d), 9.4(d)). Unfortunately, it was not possible to arrest the isomerization even when the reaction was carried out at -100°.



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The stereochemistries of compounds 1-5a have been correlated by chemical transformations according to the Scheme 1. Lithiation of the vinylhalides are known to proceed with retention of configurations[11]. The other chemical transformations are standard operations and do not involve the stereochemistry of the double bond. Scheme 1 serves also to emphasize the versatility of vinylsilanes as synthetic precursors.

Finally, a few comments can be made about the mechanism of electrophilic substitution of vinylsilanes. The model put forth by Koenig and Weber[15] for the protodesilylation can be suitably modified to account for the stereochemical observations. Retention of stereochemistry results whenever the counter ion of the electrophile is either complexed or sterically too bulky so that addition to the incipient carbonium ion is kinetically not competitive with the elimination of the trimethylsilyl moiety. If an adduct is formed as in the case of bromination, the stereochemical outcome depends then on the mode of addition.

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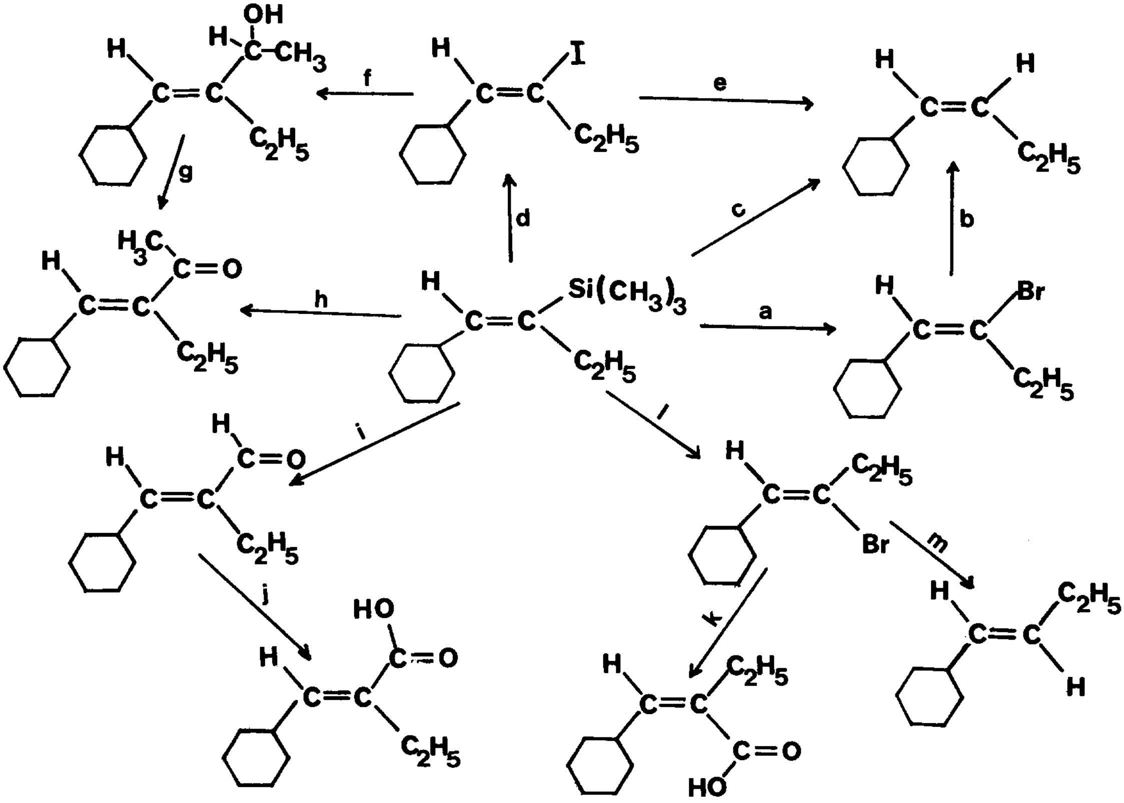

SCHEME 1: Chemical Correlation of Stereochemistries of Some Trisubstituted Alkenes. a) $BrCN/AlCl_3$; b) t-BuLi, H_2O; c) HI; d) I_2; e) t-BuLi, H_2O, f) t-BuLi, CH_3CHO; g) MnO_2 h) $CH_3COCl/AlCl_3$; i) $Cl_2CHOCH_3/AlCl_3$; j) $HCrO_4$ k) Mg, CO_2; l) Br_2; m) t-BuLi, H_2O.