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CYANOTRIMETHYLSILANE AS A VERSATILE REAGENT FOR INTRODUCING CYANIDE FUNCTIONALITY

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Abstract—Cyanotrimethylsilane adds to some α,β-unsaturated ketones in conjugate manner under the catalytic action of Lewis acids such as triethylaluminium, aluminium chloride, and $SnCl_2$. Hydrolysis of the products gives β-cyano ketones which are identical to the hydrocyanated products of the starting enones. The title silicon reagent reacts with acetals and orthoesters under the catalytic action of $SnCl_2$ or $BF_3{\cdot}OEt_2$ affording 2-alkoxy- and 2,2-dialkoxyalkanenitriles. Application of the reaction to O-protected β-D-ribofuranoses gives selectively β-D-ribofuranosyl cyanide in excellent yield.

Organosilicon reagents have found important roles in organic syntheses.[1] One of these is cyanotrimethylsilane (1) which can be easily prepared from potassium or sodium cyanide and chlorotrimethylsilane[2] and is considered as stabilized hydrogen cyanide. Typically 1 is used in preparation of synthetically useful nitriles: (1) addition to hetero double bonds such as C=O[3] and C=N[4] giving NC–C–$OSiMe_3$ and NC–C–$NSiMe_3$ moieties which serve as protected carbonyl or as precursors of hydroxyamines and amino acids; (2) substitution of active halogen producing RCOCN,[5] N–CN,[6] P–CN,[7] and S–CN[8] compounds, respectively; (3) addition to oxiranes affording 3-trimethylsilyloxyalkanenitriles;[9] (4) homologation of ketones being achieved via the adducts of 1 to carbonyl group;[10] (5) reaction with S_N1 active chlorides to form nitriles.[10c] This article describes two further synthetic applications of 1, first, conjugate addition to some enones or a new technique of hydrocyanation and second, direct cyano-substitution of one of the alkoxyl groups of acetals and orthoesters under the catalysis of Lewis acids. Some applications of the procedures are discussed.

Conjugate addition of cyanotrimethylsilane (1). Besides the reported 1,2-addition of 1 to conjugate enones,[3] 1,4-addition to some enones has been disclosed.[11] General scheme of the transformation is shown.

Hydrolysis of the adduct 3 afforded β-cyano ketone 4.[11]Reaction with 6 - methylbicyclo[4.4.0]dec - 1 - en - 3 - one (5) is studied in detail with respect to the relation between the reaction conditions and product distributions. Heating of a THF solution containing 5, 2.2 equiv of 1, and 2 equiv of triethylaluminium at reflux for 20 hr (condition A) gave quantitatively a mixture of 1,4-adducts which contained predominantly the *cis*-isomer (*cis*/*trans* = 6/7 = 95/5). Shortening the reaction period to 3 hr gave less stereoselective mixture of 1,4-adducts (6/7 = 55/45) in quantitative yield. This indicates the *cis*-adduct 6 is the thermodynamically stable isomer. The reaction seems to be kinetically controlled in a toluene solution at room temperature. A mixture of 5, 2.2 equiv of 1, and 2 equiv of Et_3Al dissolved in toluene was stirred at room temperature for 20 hr (condition B). Workup gave a mixture of 1,4-adducts containing the *trans*-isomer predominantly (6/7 = 31/69) in a quantitative yield.

1,2-Adduct 8 is exclusively obtained upon treatment with 2,2 equiv of 1 and 0.2 equiv of Et_3Al at room temperature for 3 hr. GLC and NMR analyses indicate the homogeneity of the product but the stereochemistry is still an open question. The 1,2-adduct 8 is transformed to 1,4-adducts by the further application of the condition A (reflux for 3 hr, 6/7 = 67/33) or condition B (6/7 = 46/54). In the absence of an additional amount of cyanotrimethylsilane the isomerization of 8 gave a complex mixture. The formation of 1,4-adducts is explained as shown in the figure (next page).

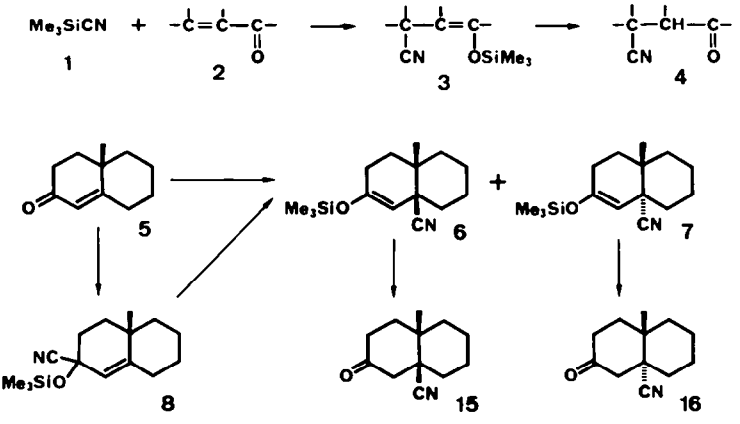


Table 1. Conjugate addition of 1 to 5 under condition C

Catalyst	Conditions		1,4-Adduct Yield (%)	6/7
$AlCl_3$	70-80°C	7 h	75[a]	44/56
$AlCl_3$	room temp.	2 h	—[b]	
$BF_3 \cdot OEt_2$	70-80°C	7 h	93	37/63
Pr_3B	70-80°C	7 h	100	40/60
Me_3SiOTf	70-80°C	7 h	100	40/60
ZnI_2	room temp.	48 h	95	41/59
$SnCl_2$	room temp.	48 h	95	33/67

[a]1,2-Adduct was obtained in 10% yield. [b]Exclusive formation of 1,2-adduct in 71% yield.

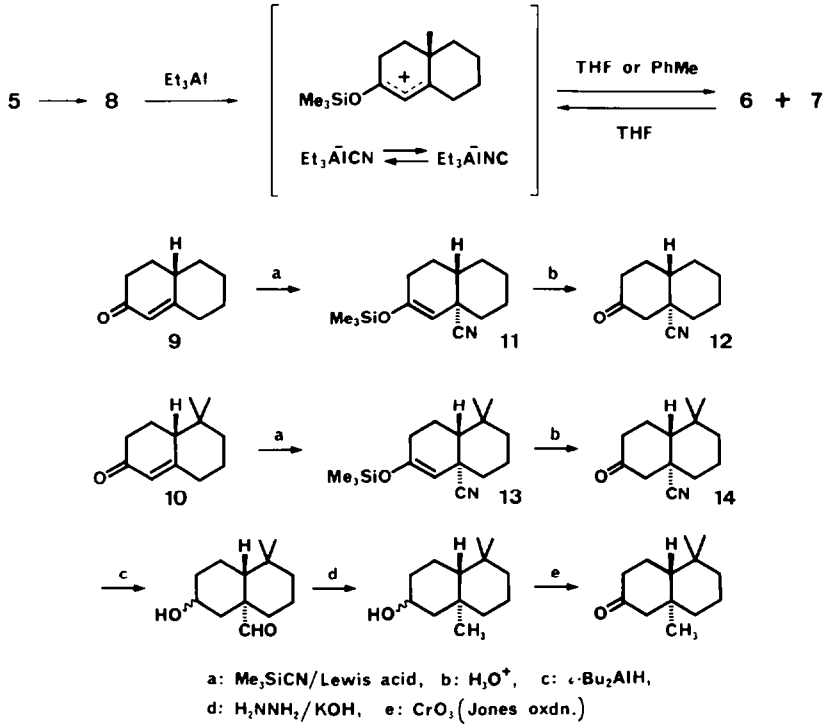
Formation of 1,4-adducts **6** and **7** was observed also in the reaction of **5** with 3 equiv of **1** under catalysis of Lewis acids (<0.1 equiv) without any additional solvent (condition C). The results are summarized in Table 1. The fact that the catalysts did not affect the isomer ratio practically indicates the reaction being kinetically controlled.

The angular Me group of **5** did control the stereochemical course of the reaction, as it turned out. In contrast to **5**, bicyclic enone **9** and **10** stereoselectively gave *trans* - 1,4 - adducts, **11** and **13**, respectively, under all three conditions A, B and C. Stereochemistry of **11** was determined by the comparison of GLC as well as NMR spectra of the hydrolyzed product **12** with those of the authentic sample.[12] Structure **13** was assigned by the transformation to *trans* - 1,7,7 - trimethylbicyclo[4.4.0]decan - 3 - one.[13]

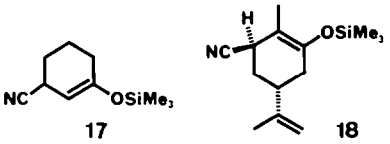
Hydrolysis of the 1,4-adducts **6**, **7**, **11** and **13** affords quantitatively β-cyano ketones **15**, **16**, **12** and **14**, respectively, which are identical to the hydrocyanated products of the starting enones.[14]

The present method is a modification of Nagata's wellknown hydrocyanation technique.[14] The manipulation is much simpler and the reagents are commercially available.

Some conjugated enones give 1,4-adducts under condition A, B or C. 4 - Methyl - 3 - penten - 2 - one affords 2,2 - dimethyl - 4 - trimethylsilyloxy - 3 - pentenenitrile

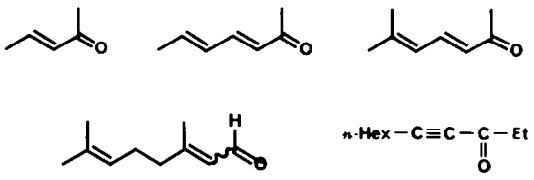


(quantitative yield under condition C, 87% under A), while 2 - cyclohexen - 1 - one and carvone quantitatively give **17** and **18**, respectively.[15]



17 **18**

In contrast to the above described results, the following unsaturated carbonyl compounds produced exclusively 1,2-adducts under all conditions A, B or C.[3]

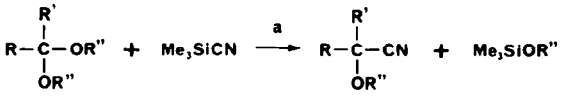


The above described procedures allow the 1,4-addition of cyanotrimethylsilane to enones with certain limitations.

One example of 1,6-addition of **1** is added. Dienone **19** gave a 1,6-adduct **20** in quantitative yield under condition C ($BF_3 \cdot OEt_2$). Yield diminished to 71% under condition A, and 35% of **20** and 12% of the 1,2-adduct were obtained under condition B.

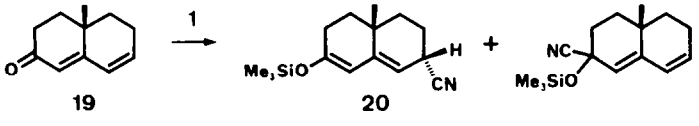
Exchange of one of the alkoxyl groups of acetals and orthoesters with cyano group. Reaction of cyanotrimethylsilane with acetals and orthoesters under catalytic action of $SnCl_2$ or $BF_3 \cdot OEt_2$ has been found to give 2-alkoxy- or 2,2-dialkoxyalkanenitriles, respectively, in excellent yields. Introduction of cyano group was previously carried out by acyl cyanides,[16] and was accompanied by considerable amounts of side reaction products.[17] The procedure described here utilizes catalytic amounts of Lewis acid and no solvent. Products are obtained in excellent yield and in pure state.[18]

An equimolar mixture of 1,1-dimethoxyheptane and cyanotrimethylsilane (**1**) was added with catalyst (1-10 mol%) and stirred for 2 hr at 0°. GLC as well as NMR analyses indicated the completion of the reaction affording 2-methoxyoctanenitrile (**21**, R = H, R' = n-C_6H_{13},



1 **21**

a: $SnCl_2$ or $BF_3 \cdot OEt_2$ without any solvent



19 **20**

Table 2. 2-Alkoxy- and 2,2-dialkoxyalkanenitriles (**21**)

Entry	R	R'	R"	Catalyst	Yield (%)[a]	Bp. °C (mmHg)
1	H	H	Me	$SnCl_2$[b]	64	90-110
2	Me	H	Me	$BF_3 \cdot OEt_2$[c]	73	114-117
3	Me	H	Et	$BF_3 \cdot OEt_2$[b]	97	50-55 (10)
4	n-C_6H_{13}	H	Me	$SnCl_2$	83	82-87 (10)
5	$PhCH_2$	H	Me	$BF_3 \cdot OEt_2$	83	100 (5)
6	Ph	H	Me	$SnCl_2$[c]	94	103-106 (9)
7	$ClCH_2$	H	Me	$SnCl_2$	80[d]	80-85 (30)
8	$H_2C{=}CH$	H	Me	$SnCl_2$	72	136-137
9	n-$C_6H_{13}C{\equiv}C$	H	Me	$BF_3 \cdot OEt_2$	94	107-110 (5)
10	H	OMe	Me	$BF_3 \cdot OEt_2$[c]	80	115-121
11	H	OEt	Et	$BF_3 \cdot OEt_2$	84	160-168
12	Me	OMe	Me	$BF_3 \cdot OEt_2$	70	134-138
13	OMe	OMe	Me	$SnCl_2$[b]	83[d]	135-140

[a]Isolated yields are shown. GLC yields are quantitative. [b]Reaction was carried out at room temperature for 2-5 h. [c]Exothermic reaction was observed upon simultaneous addition of all reagents. [d]Reaction catalyzed by $BF_3 \cdot OEt_2$ gave unsatisfactory result.

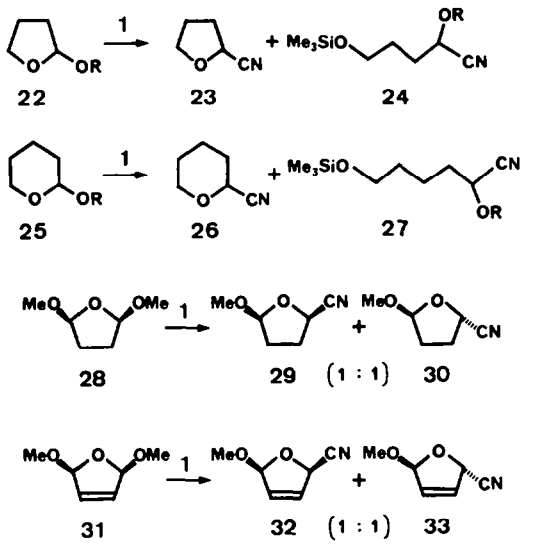
R″ = Me) and methoxytrimethylsilane in quantitative yield. Workup of the reaction mixture gave the product in 83% isolated yield after distillation (entry 4). Application of $BF_3 \cdot OEt_2$ in place of $SnCl_2$ gave satisfactory results with some exceptions. As shown in entry 7 and 13,2 - chloro - 1,1 - dimethoxyethane and tetramethyl orthocarbonate afforded the products in almost quantitative yields when $SnCl_2$ was employed as catalyst. Although the preparation of **21** has been reported,[17,19] the present procedure is much simpler and gives higher yields. The resulting 2-alkoxyalkanenitriles are O-protected cyanohydrins of aldehydes and ketones, while 2,2-dialkoxyalkanenitriles acyl cyanide acetals, all of which serve as useful intermediates of organic synthesis.[16,20]

The lithio derivative of O-protected cyanohydrin of aldehyde has been used in the preparation of ketones in the sense of umpolung. Some lithiated 2-alkoxyalkanenitriles provide masked acyl anions,[20] while lithio derivative of 2,2-dimethoxyacetonitrile serves as an equivalent of "methyl lithioformate".[18]

Direct introduction of cyano group into carbohydrates. Applications of the above described novel cyanation to cyclic acetals and carbohydrates have been explored.[21] Reaction of **1** with 2-methoxytetrahydrofuran (**22**, R = Me) in CH_2Cl_2 gave a mixture of 2-cyanotetrahydrofuran (**23**, 39%)[22] and 2 - methoxy - 5 - trimethylsilyloxypentanenitrile (**24**, R = Me, 44%). The reaction of 2-t-butoxytetrahydrofuran favored the cleavage of the endocyclic ether linkage affording 2 - t - butoxy - 5 - trimethylsilyloxypentanenitrile (**24**, R = t-Bu) in 98% yield. Analogous reaction of 2-methoxytetrahydropyran (**25**, R = Me) gave 2-cyanotetrahydropyran (**26**)[23] in 20% and 2 - methoxy - 6 - trimethylsilyloxypentanenitrile (**27**, R = Me) in 80% yield.

On the other hand 2-acetoxytetrahydrofuran (**22**, R = Ac) and 2-acetoxytetrahydropyran (**25**, R = Ac) selectively produced 2-cyanotetrahydrofuran (**23**) and 2-cyanotetrahydropyran (**26**), respectively. These results suggest the applicability of the reaction to carbohydrate synthesis.

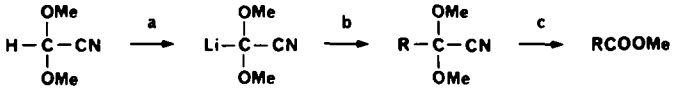
About 1:1 mixture of *cis*/*trans*-isomers of 2-cyano-5-methoxytetrahydrofuran (**29** and **30**) was obtained in



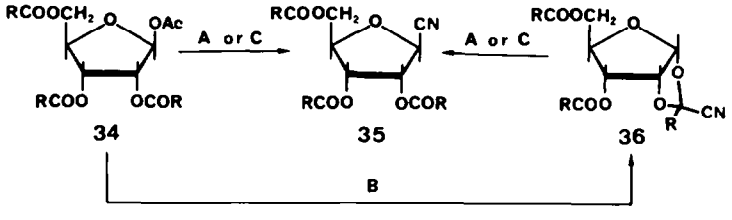
84% yield by this reaction in CH_2Cl_2 solution starting from either *cis* - 2,5 - dimethoxytetrahydrofuran (**28**) or *cis*/*trans*-mixture. *cis* - 2,5 - Dimethoxy - 2,5 - dihydrofuran (**31**) also gave a *cis*/*trans*-mixture of 2 - cyano - 5 - methoxy - 2,5 - dihydrofuran in 90% yield (**32**:**33** = 1:1). These results suggest an S_N1 type mechanism of the reaction involving planar carbocation intermediates.

Transformation of D-ribofuranose into β - D - ribofuranosyl cyanide was successful under the above reaction conditions. The resulting product is an important intermediate of C-nucleoside synthesis.[24,25]

A mixture of 1 - O - acetyl - 2,3,5 - tri - O - benzoyl - β - D - ribofuranose (**34**, R = Ph), cyanotrimethylsilane (**1**, 4.5 equiv), and a catalytic amount of $SnCl_2$ was heated at 70° for 2 hr afforded stereoselectively 2,3,5 - tri - O - benzyl - β - D - ribofuranosyl cyanide (**35**, R = Ph)[8,26] in 85% yield. When the above mixture was stirred for 2 hr at room temperature, 3,5 - di - O - benzoyl - 1,2 - O - (1 - cyanobenzylidene) - β - ribofuranose (**36**, R = Ph) was obtained as a sole product with some recovery of the starting material. The product **36** (R = Ph) was converted



a: LDA, b: RX, c: H^+/acetone - H_2O

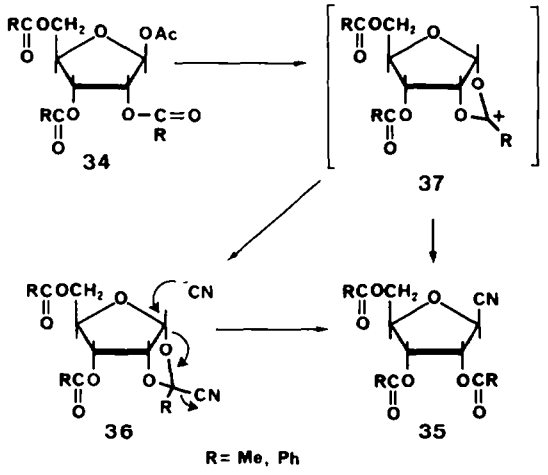


A :	Me_3SiCN	$SnCl_2$	70°C	(R = Ph)
B :	Me_3SiCN	$SnCl_2$	r.t.	(R = Ph, Me)
C :	Me_3SiCN	BF_3OEt_2	r.t.	(R = Ph, Me)

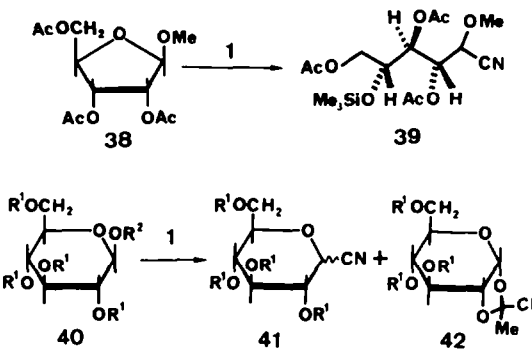
into the cyanide **35** (R = Ph) in excellent yield by the treatment with cyanotrimethylsilane (**1**) at 70° in the presence of $SnCl_2$. The action of $BF_3{\cdot}OEt_2$, in place of $SnCl_2$, gave the same cyanide **35** (R = Ph) in 85% yield from **34** (R = Ph) after stirring at room temperature for 2 hr and also gave **35** in 85% yield from **36** under the same reaction conditions.

The reaction of O-acetylated ribofuranose (**34**, R = Me) with **1** under the catalytic action of $BF_3{\cdot}OEt_2$ at room temperature provided acetylated cyanide (**35**, R = Me) in 64% yield in addition to **36** (R = Me) in 29% yield. The reaction catalyzed by $SnCl_2$ at room temperature gave **36** (R = Me) in 96% yield and further transformation into ribofuranosyl cyanide **35** (R = Me) was accomplished by treatment with cyanotrimethylsilane (**1**) and $BF_3{\cdot}OEt_2$ at room temperature. Tin(II) chloride was ineffective to the latter transformation. The same cyanide **35** (R = Me) was obtained stereoselectively from 1,2,3,5 - tetra - O - acetyl - α - D - ribofuranose which was a 1 - α - epimer of **34** (R = Me).

These results suggest the mechanism of the above described stereoselective cyanation, namely double inversion at C-1 by the formation of carbocation **37** or cyanobenzylidene compound **36** and successive attack of cyanide at C-1 stereospecifically.



In contrast to 1 - O - acetyl ribofuranose **34**, 2,3,5 - tri - O - acetyl - 1 - O - methyl - β - D - ribofuranose (**38**) gave acyclic product **39** in 71% yield by treatment with cyanotrimethylsilane (**1**) under the catalytic action of $BF_3{\cdot}OEt_2$ and the yield was decreased to 34% with $SnCl_2$ as catalyst.



Results of the application of the procedure to glucopyranose are shown in Table 3.

The cyclic acetal **42** was recovered unchanged after treatment with **1** together with Lewis acids for prolonged reaction time.

EXPERIMENTAL

GLC was performed on a Shimadzu GC-4BPT with 3 mm × 3 m glass column packed with 20% PEG-20M and 20% HVSG on Chromosorb W-AW (80–100 mesh). IR spectra were obtained on a Shimadzu IR-27G spectrometer. ^{1}H-NMR were measured on a Varian EM-390 with Me_4Si as internal standard and CCl_4 or $CDCl_3$ as solvent and ^{13}C-NMR on a Varian CFT-20 with Me_4Si as internal standard and $CDCl_3$ as solvent. Mass spectra were obtained on either Hitachi RMU-6L or Hitachi M-80 spectrometer. Elemental analyses were performed by Elemental Analyses Center of Kyoto University. All the reactions were carried out under an atmosphere of dry argon.

General procedures of conjugate addition of cyanotrimethylsilane (**1**)

Condition A. An unsaturated ketone (1 mmol) was added to a soln containing 2.2 mmol of **1** and Et_3Al (2.0 mmol, 2.2 ml of 15% hexane soln), and 4 ml THF at room temp. The mixture was stirred at reflux for 20 hr, cooled, worked up with NH_4Cl aq, and extracted with benzene, hexane, or ether. The combined organic layers were washed with NH_4Cl aq, sat $NaHCO_3$ aq, and brine, dried ($MgSO_4$), and concentrated. Distillation or chromatography of the concentrate gave the pure product.

Condition B. Toluene (4 ml) was used in place of THF in the above described procedure and the mixture was stirred at room temp for 20 hr.

Condition C. Lewis acid (0.05–0.1 equiv) such as $AlCl_3$, $BF_3{\cdot}OEt_2$ and $SnCl_2$ (shown in Table 1) was added to a mixture of the enone and 3 equiv of **1** at room temp. The mixture was stirred at an adequate temp and suitable period (Table 1).

A mixture of **6** *and* **7** *from* **5**

A mixture of **6** and **7** (Calc. for $C_{15}H_{25}NOSi$: C, 68.39; H,

Table 3. Reaction of **1** with glucopyranose **40**

Starting Material 40	R^1	R^2	Temp. °C	Time h	Product (%)[a] 41	42
a	Me	Me	60	40	--	--[b]
b	Me	Ac	60	9	87[c,d]	--
c	Ac	Ac	60	9	<1	64[e]

[a] $SnCl_2$ (0.0–0.2 equiv.) was used as catalyst. [b] Recovery of **40a**. [c] Isomer ratio was α:β = 1.5:1. [d] Ref. 27. [e] Ref. 29.

9.56%. Found C, 68.54; H, 9.65) was obtained under condition A, B and C. Clear separation of the isomers was unsuccessful under applied GLC conditions. The isomer ratio was determined by NMR: among other proton signals, δ 1.18 (s, 3H) and 4.58 (broad s, 1H) were assigned to **6** and 0.94 (s, 3H) and 4.50 (broad s, 1H) to **7**. Ratio of the integrated signals corresponded to the ratio of **6** and **7**.

β-Cyanoketones **15** *and* **16**

To a mixture of **6** and **7** (205 mg, 0.78 mmol) in 10 ml of THF was added 0.1 ml of 1 N HCl and stirred for 0.5 hr at room temp. The mixture was worked up with ice-water and extracted with ether. Washing (sat. $NaHCO_3$ aq, brine), drying (Na_2SO_4) and concentration gave a mixture of **15** and **16** (150 mg, 96% yield).

Conjugate addition of **1** *to bicyclo*[4.4.0]*dec - 1 - en - 3 - one* (**9**)

Reaction of **9** (150 mg, 1.0 mmol) with **1** under condition B afforded 200 mg (0.80 mmol, 80% yield) of **11**. IR (neat), 2225, 1660, 1200, 840 cm^{-1}; Mass spectrum, P^+, *m/z* 249.1582 (Calc. for $C_{14}H_{23}NOSi$: 249.1548).

β-Cyanoketone **12**. Adduct **11** (160 mg, 0.64 mmol) gave 90 mg (80%) of **12** by the above described procedure of hydrolysis.

Conjugate addition of **1** *to* **10**

Starting from 9.1 g (51 mmol) of **10**, 12 g (43 mmol, 84% yield) of **13** were obtained under condition A. B.p. 102–115°/3 mmHg; IR (neat) 2230, 1660, 1255, 840 cm^{-1}; ^{1}H-NMR (CCl_4), δ 0.24 (9H, s), 0.93 (3H, s), 1.07 (3H, s), 1.10–2.27 (11H, m); Mass spectrum, P^+, *m/z* 277.1838 (Calc. for $C_{16}H_{27}NOSi$: 277.1860). Analogous results were obtained under condition B and C.

β-Cyanoketone **14**. Hydrolysis of **13** (10 g, 36 mmol) with dil HCl in THF as described above gave **14** quantitatively. IR (neat) 2240, 1730 cm^{-1}; ^{1}H-NMR (CCl_4), δ 1.03 (3H, s), 1.09 (3H, s), 1.20–2.67 (13H, m); Mass spectrum, P^+, *m/z* 205.1469 (Calc. for $C_{13}H_{19}NO$: 205.1466).

trans - 1,7,7 - Trimethylbicyclo[4.4.0]*decan - 3 - one*

Toluene soln of DIBAH (8.8 mmol in 5 ml soln) was added to a soln of 0.45 g (2.2 mmol) of **14** in 10 ml benzene under ice-cooling. The mixture was stirred for 0.5 hr at 0° and 1 hr at room temp. The mixture was worked up with ice-cooled 1 N-HCl and extracted with ether. Ethereal soln was washed with brine and dried (Na_2SO_4). Concentration gave 0.37 g (1.8 mmol) of hydroxy aldehyde [IR (neat), 3400, 1720, 1050 cm^{-1}], which was used without purification. The crude product (0.37 g) was dissolved in 23 ml diethylene glycol and 1.2 g KOH and 3.4 ml hydrazine hydrate was added to the soln. The mixture was heated to 100° for 1 hr and 200° for 1.5 hr. The mixture was diluted with ether, washed with 1 N-HCl and brine, and dried (Na_2SO_4). Evaporation gave 0.43 g of a oil (IR showed the disappearance of the CO group), which was oxidized with Jones reagent. Usual workup of the mixture gave 0.18 g of *trans - 1,7,7 - trimethylbicyclo*[4.4.0]decan - 3 - one (overall yield from **14** was 42%). ^{1}H-NMR was identical to the reported one.[13]

Conjugate addition of **19**

Dienone **19** (151 mg, 0.93 mmol) gave 1,6-adduct **20** [quantitative; purification by chromatography gave 244 mg (93%)] under condition C. IR (neat) 2250, 1650, 1255, 1200, 860, 845 cm^{-1}; ^{1}H-NMR (CCl_4) δ 0.21 (9H, s), 1.00 (3H, s), 1.44–1.68 (4H, m), 1.82–2.17 (4H, m), 3.3 (1H, m), 5.03 (1H, d, J = 5 Hz), 5.21 (1H, broad s); double irradiation at 5.03 changed multiplet at 3.3 to a double doublet (J = 4, 6 Hz); Mass spectrum, P^+, *m/z* 261.1571 (Calc. for $C_{15}H_{23}NOSi$: 261.1548).

General procedure for the preparation of **21**

Lewis acid ($BF_3 \cdot OEt_2$ or $SnCl_2$, 0.05–0.1 equiv) was gradually added to a mixture of one equiv each of acetal and **1** at 0°, and the whole was stirred for 2 hr at 0°. The mixture was worked up with $NaHCO_3$ aq and extracted with ether. Drying (Na_2SO_4) and distillation gave the product **21**. Orthoesters reacted analogously.

Reaction of **22** *and* **25** *with* **1**. Reaction of **22** with **1** in CH_2Cl_2 at 0° was catalyzed by 0.1 equiv of $SnCl_2$ affording **23** and **24**. Analogously **25** gave **26** and **27** at room temp.

Reaction of cis - 2,5 - *dimethoxytetrahydrofuran* (**28**) *with* **1**. To a soln of **28** (1.1 g, 8.2 mmol) in 15 ml CH_2Cl_2 was successively added $SnCl_2$ (150 mg, 0.8 mmol) and **1** (1.25 ml) at 0°. The whole mixture was stirred at 0° for 1 hr and worked up with sat $NaHCO_3$ aq, and extracted with ether. The ethereal soln was washed with cold brine and dried over Na_2SO_4. Distillation of the concentrate gave a mixture of **29** and **30** (1 : 1). B.p. 60°/10 mmHg; ^{1}H-NMR (CCl_4) δ 1.6–2.5 (4H, m), 4.5–4.7 (1H, m), 4.9–5.1 (1H, m), 3.28 (s, OMe of one isomer), 3.35 (s, OMe of another isomer); IR (neat), 2255, 1035 cm^{-1}; Mass spectrum, P^+, *m/z* 127.0590 (Calc. for $C_6H_9NO_2$: 127.0649).

cis - 2,5 - Dimethoxy - 2,5 - dihydrofuran (**31**) analogously gave a 1 : 1 mixture of **32** and **33**. B.p. 49–50°/7 mmHg; IR (neat), 2240, 1630, 1040 cm^{-1}; ^{1}H-NMR (CCl_4) δ 5.1–6.2 (4H, m), 3.35 (s, OMe of one isomer), 3.40 (s, OMe of another); Mass spectrum, P^+, *m/z* 125.0410 (Calc. for $C_6H_7NO_2$: 125.0475).

Reaction of **1** *with carbohydrates*

General procedures. (D). A mixture of carbohydrate (1 equiv), **1** (4.5 equiv) and $SnCl_2$ (0.1–0.2 equiv) was stirred at 70° for 2 hr. The mixture was worked up with $NaHCO_3$ aq and extracted with ether. Ethereal soln was washed with brine, dried over Na_2SO_4, and concentrated. Purification by column chromatography gave a pure product.

(E). Reaction was carried out at room temp in the presence of $SnCl_2$.

(F). In place of $SnCl_2$, $BF_3 \cdot OEt_2$ (0.1 equiv) was used and the mixture was stirred at room temp for 2 hr.

2,3,5 - *Tri* - O - *benzoyl* - *β* - D - *ribofuranosyl cyanide* (**35**, R = Ph). Starting from 1.09 g (2.16 mmol) of **34** (R = Ph), 860 mg (85% yield) of **35** (R = Ph) was obtained under procedure D. Procedure E gave **36** (R = Ph) in 45% yield (96% of the consumed **34**) along with 53% of the recovered **34**. **36** (R = Ph): IR (neat), 2250, 1730 cm^{-1}; ^{1}H-NMR ($CDCl_3$) δ 4.4–4.8 (3H, m), 5.10–5.45 (2H, m), 6.27 (1H, d, J = 4 Hz), 7.6–8.2 (15H, m); ^{13}C-NMR, δ 62.4, 72.6, 76.8, 78.8, 102.8, 105.6, 116.4, 165.3, 165.9 and aromatic carbons between 125 and 134.

Procedure F afforded **35** (R = Ph, 480 mg, 85%) from 600 mg (1.2 mmol) of **34** (R = Ph).

Transformation of **36** (R = Ph) *to* **35**. Compound **36** (R = Ph, 500 mg, 1.06 mmol) gave **35** (420 mg, 84% yield) by the application of procedure F. Procedure D gave the product **35** (51 mg, 85% yield) from 60 mg of **36**.

Reaction of 1,2,3,5 - *tetra* - O - *acetyl* - *β* - D - *ribofuranose* (**34**, R = Me) *with* **1**. Under condition F, 250 mg (64%) of **35** (R = Me) and 115 mg (29%) of **36** was obtained from 440 mg (1.38 mmol) of **34** (R = Me). **35** (R = Me): IR (neat) 2250, 1755 cm^{-1}; ^{1}H-NMR ($CDCl_3$) δ 2.07 (3H, s), 2.13 (3H, s), 2.15 (3H, s), 4.0–4.4 (3H, m), 4.65 (1H, d, J = 4.5 Hz), 5.35 (1H, m), 5.53 (1H, t, J = 4.5 Hz); ^{13}C-NMR δ 20.4, 20.8, 62.5, 69.2, 71.3, 73.9, 81.0, 115.9, 169.2, 169.5, 170.4; Mass spectrum, $(P+H)^+$, *m/z* 286.0920 (Calc. for $C_{12}H_{16}NO_7$: 286.0925). **36** (R = Me): viscous oil. IR (neat) 2250, 1750 cm^{-1}; ^{1}H-NMR (CCl_4) δ 1.78 (s, H_3C–C–CN of one isomer), 1.86 (s, H_3C–C–CN of another isomer), 2.10 (3H, s), 2.17 (3H, s), 4.0–5.15 (5H, m), 6.05 (two doublets, J = 3.3, 3.4 Hz); ^{13}C-NMR showed the product was a mixture of two stereoisomers on H_3C–C–CN, δ 20.3, 20.6, 24.6, 27.4, 61.7, 71.5, 76.1, 78.1, 100.9, 105.0, 116.7, 117.7, 169.7, 170.4; 20.6 and 24.6 were assigned to H_3C–C–CN and 116.7 and 117.7 to CN; Mass spectrum, $(P+H)^+$, *m/z* 286.0944 (Calc. for $C_{12}H_{16}NO_7$: 286.0925).

Starting from 1.12 g (3.52 mmol) of **34** (R = Me), 960 mg (3.37 mmol) of **36** (R = Me) was obtained under procedure E.

Transformation of **36** (R = Me) *into* **35** (R = Me). Application of procedure F to 452 mg (1.59 mmol) of **36** (R = Me) afforded **35** (R = Me, 312 mg, 69% yield or 85% yield based on consumed **36**) and unchanged **36**.

Reaction of 1,2,3,5 - *tetra* - O - *acetyl* - *α* - D - *ribofuranose with* **1**. Treatment of 358 mg (1.13 mmol) of the tetra-acetate with **1** according to the procedure F gave 240 mg (0.84 mmol, 74% yield) of **35** (R = Me) and 58 mg (0.2 mmol, 18% yield) of **36** (R = Me).

Reaction of **38** *with* **1**. Procedure F gave **39** in 71% yield; Mass spectrum, $(P+H)^+$, *m/z* 390.1583 (Calc. for $C_{16}H_{28}NO_8Si$: 390.1583); (Found: C, 49.29; H, 6.90%. Calc. for $C_{16}H_{27}NO_8Si$, C, 49.34; H, 6.99%).

Reaction of glucopyranose (**40**) *with* **1**. Starting from 724 mg (2.37 mmol) of **40c**, 540 mg (1.51 mmol, 64% yield) of **42** (R^1 = Me) was obtained by procedure D.

Treatment of 690 mg (2.7 mmol) of **40b** with **1** by procedure D gave 570 mg (87% yield) of **41**. Chromatographic separation gave pure α - D - isomer, $[\alpha]_D^{20}$ + 119° (*c* = 3.3, $CHCl_3$, lit.[27] 120°), and β - D - isomer, $[\alpha]_D^{20}$ + 38.1° (*c* = 4.2, $CHCl_3$, lit.[27] 36.2°).

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