References

1. For comprehensive reviews, see: (a) Winterfeldt, E. *Synthsis* **1975**, 617. (b) Bruno, G. *The Use of Aluminum ALkyls in Organic Synthsis*; Ethyl Corp.: Baton Rouge, LA, 1968. (c) Bruno, G. *The Use of Aluminum Alkyls in Organic Synthsis*; 1969-1972 Supplement; Ethyl Corp.: Baton Rouge, LA, 1972. (d) *Speciality Reducing Agents*; Texas Alkyls.
2. Yoon, N. M.; Gyoung, Y. S. *J. Org. Chem.* **1985**, *50*, 2443.
3. Cha, J. S.; Brown, H. C. *J. Org. Chem.* **1993**, *58*, 3974.
4. ^{27}Al NMR of DIBAH itself in toluene showed a broad singlet at δ 78 relative to $Al(H_2O)_6^{3+}$.
5. No escape of dimethyl sulfide from the 1 : 1 complex was detected at least for 24 h *in vacuo* at room temperature.
6. Zakharkin, L. I.; Khorlina, I. M. *Zh. Obshch. Khim.* **1964**, *34*, 1029.
7. (a) Zakharkin, L. I.; Khorlina, I. M. *Dokl. akad. Nauk* SSSR **1959**, *116*, 442. (b) Miller, A. E. G.; Bliss, J. W.; Schwartzman, L. H. *J. Org. Chem.* **1959**, *24*, 627.
8. Brown, H. C.; Kramer, G. W.; Midland, M. M. *Organic Synthesis via Boranes*; Wiley-Interscience: New York, 1975.

Reaction of Sodium Tris(diethylamino)aluminum Hydride with Selected Organic Compounds Containing Representative Functional Groups

Jin Soon Cha*, Min Kyoo Jeoung, Jong Mi Kim, Oh Oun Kwon, Keung Dong Lee, and Eun Ju Kim

Department of Chemistry, Yeungnam University, Kyongsan 712-749, Korea
Received July 13, 1994

The approximate rates and stoichiometry of the reaction of excess sodium tris(diethylamino)aluminum hydride (STDEA) with selected organic compounds containing representative functional groups under standardized conditions (tetrahydrofuran, 0 ℃) were studied in order to characterize the reducing characteristics of the reagent for selective reductions. The reducing ability of STDEA was also compared with those of the parent sodium aluminum hydride (SAH) and lithium tris(diethylamino)aluminum hydride (LTDEA). The reagent appears to be milder than LTDEA. Nevertheless, the reducing action of STDEA is very similar to that observed previously for LTDEA, as is the case of the corresponding parent sodium and lithium aluminum hydrides. STDEA shows a unique reducing characteristics. Thus, benzyl alcohol, phenol and 1-hexanol evolved hydrogen slowly, whereas 3-hexanol and 3-ethyl-3-pentanol, secondary and tertiary alcohols, were essentially inert to STDEA. Primary amine, such as *n*-hexylamine, evolved only 1 equivalent of hydrogen slowly. On the other hand, thiols examined were absolutely stable. STDEA reduced aldehydes and ketones rapidly to the corresponding alcohols. The stereoselectivity in the reduction of cyclic ketones by STDEA was similar to that by LTDEA. Quinones, such as *p*-benzoquinone and anthraquinone, were reduced to the corresponding 1,4-dihydroxycyclohexadienes without evolution of hydrogen. Carboxylic acids and anhydrides were reduced very slowly, whereas acid chlorides were reduced to the corresponding alcohols readily. Esters and epoxides were also reduced readily. Primary carboxamides consumed hydrides for reduction slowly with concurrent hydrogen evolution, but tertiary amides were readily reduced to the corresponding tertiary amines. The rate of reduction of aromatic nitriles was much faster than that of aliphatic nitriles. Nitrogen compounds examined were also reduced slowly. Finally, disulfide, sulfoxide, sulfone, and cyclohexyl tosylate were readily reduced without evolution of hydrogen. In addition to that, the reagent appears to be an excellent partial reducing agent: llike LTDEA, STDEA converted ester and primary carboxamides to the corresponding aldehydes in good yields. Furthermore, the reagent reduced aromatic nitriles to the corresponding aldohydes chemoselectively in the presence of aliphatic nitriles. Consequently, STDEA can replace LTDEA effectively, with a higher selectivity, in most organic reductions.

Introduction

The diethylamino-derivative of lithium aluminum hydride, lithium tris(diethylamino)aluminum hydride (LTDEA), has appeared to be an attractive reducing agent[1]: it converts free carboxylic acids,[2] esters[3,4] and amides[4,5] to the corresponding aldehydes. The reagent also reduces aromatic nitriles to aldehydes chemoselectively in the presence of aliphatic nitriles intact.[4,6] Similarly, the diethylamino-derivative of sodium aluminum hydride, sodium tris(diethylamino)aluminum hydride (STDEA), has also proven to be a promising reducing agent for such transformation.[7-9] STDEA performs the conversion of carboxylic acid derivatives to aldehydes equally well. In the course of these compared experiments, we found that STDEA shows the very similar reaction trends, except for reactivity, in the reduction of organic compounds examined as LTDEA. STDEA[1] seems to be milder and, hence, more selective than LTDEA.

Consequently, in order to compare the reducing characteristics of these two diethylaminoaluminum hydrides and extend its applicability in the field of selective reduction, we undertook a systematic study of the rate and stoichiometry of the reaction of STDEA with the standard list of organic compounds containing representative functional groups under the standardized conditions.

Results and Discussion

Preparation of Standard Solution of Sodium Tris (diethylamino)aluminum Hydride (STDEA). A standard solution of STDEA in THF was prepared by treating sodium aluminum hydride (SAH) with three equivalents or excess diethylamine both at 0 ℃ or room temperature (Eq. 1).

$$NaAlH_4 + 3Et_2NH \xrightarrow[0 \text{ or } 25\ ^\circ C]{THF} \underset{\text{STDEA}}{Na(Et_2N)_3AlH} + 3H_2 \uparrow \quad (1)$$

STDEA is very stable at ambient temperature or below. No sign of disproportionation and hydride loss is observed while the reagent is kept under a static pressure of dry nitrogen. The ^{27}Al NMR spectrum of STDEA in THF showed a broad singlet at δ 116 ppm relative to $[Al(H_2O)_6]^{3+}$.

Procedure for Rate and Stoichiometry Studies. The general procedure used involved preparation of a reaction mixture of STDEA (1.0 M, 1.0 M in hydride) and the compound (0.25 M) in tetrahydrofuran (THF) at 0 ℃. Hydrogen evolution following addition of the compound to the reagent was measured gasometrically. A blank reaction was run under the identical conditions, but without addition of the compounds. Periodically, aliquots were withdrawn from the reaction mixture and analyzed for the remaining hydride by hydrolysis. From the difference in volumes of hydrogen in the two cases, the hydride consumption by the compound for reduction was calculated. In this manner, the number of moles of hydride used by compound for hydrogen evolution and the number of moles of hydride utilized for reduction were determined.

In cases where the compound consumes more than 3 equivalents of hydride, the hydride concentration was maintained constant, but the concentration of compound was reduced to give a higher ratio. In some cases where the reaction did not come to an expected stoichiometry at 0 ℃, the reaction was repeated at room temperature.

Alcohols, Phenols, Amines, and Thiols (Active Hydrogen Compounds). 1-Hexanol and benzyl alcohol evolved hydrogen slowly, however secondary and tertiary alcohols such as 3-hexanol and 3-ethyl-3-pentanol did not react with this reagent at all. Phenol evolved hydrogen very sluggishly and *n*-hexylamine liberated only one equivalent of hydrogen slowly in 6 h. However, both the thiols examined were inert toward STDEA under these reaction condition. These results are summarized in Table 1.

In general, the rate of reaction with STDEA is slower than that with LTDEA.[1] LTDEA reacted with 1-hexanol relatively fast and the reaction with 3-hexanol evolved hydrogen sluggishly. Phenol and *n*-hexylamine reacted with LTDEA relatively fast. However, in the case of the tertiary alcohol and thiols examined LTDEA, like STDEA, did not react at all.

Table 1. Reaction of Sodium Tris(diethylamino)aluminum Hydride with Representative 'Active Hydrogen Compounds' in Tetrahydrofuran at 0 ℃

Compound[a]	Time, h	Hydrogen evolved[b]	Hydride used[b]	Hydride used for reduction[b]
1-Hexanol	0.5	0.49	0.49	0.00
	1.0	0.67	0.67	0.00
	3.0	0.87	0.87	0.00
	6.0	1.01	1.01	0.00
Benzyl alcohol	0.5	0.54	0.54	0.00
	1.0	0.68	0.68	0.00
	3.0	0.84	0.84	0.00
	6.0	1.00	1.00	0.00
3-Hexanol	0.5	0.01	0.01	0.00
	6.0	0.01	0.01	0.00
3-Ethyl-3-pentanol	0.5	0.00	0.00	0.00
	24.0	0.00	0.00	0.00
Phenol	0.5	0.29	0.29	0.00
	12.0	0.58	0.58	0.00
	48.0	0.79	0.79	0.00
	120.0	0.91	0.91	0.00
	168.0	1.00	1.00	0.00
n-Hexylamine	0.5	0.59	0.59	0.00
	1.0	0.70	0.70	0.00
	3.0	0.91	0.91	0.00
	6.0	0.99	0.99	0.00
	12.0	0.99	0.99	0.00
1-Hexanethiol	0.5	0.00	0.00	0.00
	3.0	0.00	0.00	0.00
Benzenthiol	0.5	0.00	0.00	0.00
	3.0	0.00	0.00	0.00

[a] 5.0 Mmol of compound to 20 mmol of STDEA (20 mmol of hydride) in 20.0 m*l* of solution; 0.25 M in compound and 1.0 M in hydride. [b] Mmol/mmol of compound.

The introduction of diethylamino group into SAH[10] diminishes its reactivity to a great extent, as the case of lithium aluminum hydride (LAH).[11] SAH itself reacted with all of the active hydrogen compounds examined to evolve one equivalent of hydrogen immediately at 0 ℃.

Aldehydes and Ketones. All the saturated aldehydes and ketones examined consumed 1 equivalent of hydride readily for reduction to the corresponding alcohols within 1 h at 0 ℃. Therefore, no difference in reactivity toward these carbonyl compounds between LTDEA[1] and STDEA is observed in this study.

In the case of cinnamaldehyde, an α, β-unsaturated aldehyde, STDEA also attacked the double bond, one equivalent of hydride being used relatively fast and the second equivlaent slowly in 48 h at 0 ℃. The reduction with LTDEA involved the double bond readily in 0.5 h. SAH also attacked the double bond rapidly to yield 100% of hydrocinnamyl alcohol.[10] The result are summarized in Table 2.

The stereochemistry of STDEA in the reduction of typical cyclic ketones was also examined, and the results and those of LTDEA for comparison are summarized in Table 3. The

Table 2. Reaction of Sodium Tris(diethylamino)aluminum Hydride with Representative Aldehydes and Ketones in Tetrahydrofuran at 0 ℃

Compound[a]	Time, h	Hydrogen evolved[b]	Hydride used[b]	Hydride used for reduction[b]
Caproaldehyde	0.5	0.00	1.00	1.00
	3.0	0.00	1.00	1.00
Benzaldehyde	0.5	0.00	0.99	0.99
	1.0	0.00	1.01	1.01
	3.0	0.00	1.01	1.01
2-Heptanone	0.5	0.00	1.00	1.00
	1.0	0.00	1.00	1.00
Norcamphor	0.5	0.00	0.72	0.72
	1.0	0.00	1.00	1.00
Acetophenone	0.5	0.00	0.94	0.94
	1.0	0.00	1.00	1.00
Benzophenone	0.5	0.00	0.92	0.92
	1.0	0.00	1.00	1.00
Cinnamaldehyde	0.5	0.00	0.67	0.67
	1.0	0.00	1.10	1.10
	6.0	0.00	1.63	1.63
	24.0	0.00	1.81	1.81
	48.0	0.00	2.00	2.00
	72.0	0.00	2.01	2.01

[a,b] See the corresponding footnotes in Table 1.

Table 3. Stereochemistry in the Reduction of Cyclic Ketones with Sodium and Lithium Tris(diethylamino)aluminum Hydrides in Tetrahydrofuran at 0 ℃

Ketone	Less stable isomer (%)[a,b]		
	$NaAlH_4$	$Na(Et_2N)_3AlH$	$Li(Et_2N)_3AlH$
Cyclohexanone			
2-Methyl-	22	59	51.5
3-Methyl-		27	19
4-Methyl-		28	25
4-*t*-Butyl-		34	43
3,3,5-Trimethyl-		92	86.5
Norcamphor	88	91	96
Camphor		92	93

[a] 100 % excess reagent used. [b] Quantitative yields.

introduction of diethylamino group enhances the stereoselectivity to a large extent. For exampe, the parent SAH[10] reduced 2-methylcyclohexanone to the corresponding less stable isomer (*cis* alcohol) in a ratio of 22% at 0℃, whereas STDEA reduced it in a ratio of 59%. The stereoselectivity of STDEA is quite similar to that of LTDEA.[1]

Quinones. Like LTDEA,[1] STDEA also showed a unique reducing characteristics on the reaction of quinones examined. Thus, the reaction of both benzoquinone and anthraquinone evolved no hydrogen and utilized 2 equivalents of hydride for reduction slowly. This stoichiometry corresponds to the formation of 1,4-dihydroxy moieties. In the case of reaction with SHA,[10] both quinones examined evolved *ca.* 0.8 euqivalent of hydrogen and utilized *ca.* 1.2 equivalent of hydride for reduction readily, indicating the formation of a mixture of the corresponding hydroquinone and 1,4-dihydroxycyclohexadiene moieties. The results are summarized in Table 4.

Table 4. Reaction of Sodium Tris(diethylamino)aluminum Hydride with Representative Quinones in Tetrahydrofuran at 0 ℃

Compound[a]	Time, h	Hydrogen evolved[b]	Hydride used[b]	Hydride used for reduction[b]
p-Benzoquinone[c]	0.5[d]	0.00	1.23	1.23
	1.0	0.00	1.40	1.40
	3.0	0.00	1.62	1.62
	6.0	0.00	1.87	1.87
	12.0	0.00	2.01	2.01
Anthraquinone[c]	0.5[e]	0.00	1.10	1.10
	1.0	0.00	1.51	1.51
	6.0	0.00	1.85	1.85
	12.0	0.00	1.99	1.99

[a,b] See the corresponding footnotes in Table 1. [c] Batch reaction. [d] Turned to be greenish immediately. [e] Turned to be a dark brown solution immediately.

Carboxylic Acids and Acyl Derivatives. The reagent showed exactly the same trends in the reduction of carboxylic acids and their derivatives examined as LTDEA.[1] Thus, carboxylic acids were reduced very slowly to the correponding alcohols with slow evolution of 1 equivalent of hydrogen. Acid anhydrides also consumed 2 equivalents of hydride relatively fast, but the further hydride consumption was very slow. Reduction of acid chlorides was completed readily to alcohols at 0℃. Nevertheless, the rate of reaction with STDEA is slower than that with LTDEA.[1] However, the warming to room temperature accelerated the rate of reaction, showing the complete reduction in 48-72 h. The experimental results are summarized in Table 5.

The parent SAH also showed the similar trends in the reduction of these compounds examined.[10] However, the rate of reaction with SAH itself is much faster than that with the diethylamino-derivative.

Esters and Lactones. Like LTDEA,[1] STDEA reduced all the esters examined readily to the alcohol stages. However, the reagent with a limiting amount transformed esters into aldehydes at −78° in good yields Eq. (2).[7]

$$R\text{-}\overset{O}{\overset{\|}{C}}\text{-}OR' \xrightarrow{STDEA} \xrightarrow{H_3O^+} RCHO \qquad (2)$$

The reductioin of lactones, such as γ-butyrolactone and phthalide, utilized one equivalent of hydride fast, with the second hydride being taken up sluggishly. However, the warming to room temperature accelerated the reduction to be completed in 12-48 h. Isopropenyl acetate utilized 2 equivalents of hydride relatively fast, and a third hydride was consumed very slowly. Apparently the reaction involves the attack on the double bond as LTDEA.[1] The parent SAH also reduced esters and lactones to the corresponding alcohols rapidly.[10] The results are summarized in Table 6.

Epoxides. The reduction of epoxides examined proved

Representative Carboxylic Acids and Acyl Derivatives in Tetrahydrofuran at 0 ℃

Compound[a]	Time, h	Hydrogen evolved[b]	Hydride used[b]	Hydride used for reduction[b]
Caproic acid	0.5	0.26	0.71	0.45
	3.0	0.33	1.06	0.73
	6.0	0.47	1.22	0.75
	24.0	0.85	1.66	0.81
	48.0	0.97	2.29	1.32
	72.0	1.00	2.46	1.46
	120.0	1.00	2.78	1.78
	168.0	1.00	3.00	2.00
	0.5[c]	0.33	1.15	0.82
	1.0[c]	0.39	1.49	1.10
	3.0[c]	0.58	1.74	1.16
	6.0[c]	0.76	2.16	1.40
	24.0[c]	0.89	2.56	1.67
	48.0[c]	1.00	2.82	1.82
	72.0[c]	1.00	2.99	1.99
Benzoic acid	1.0	0.39	0.91	0.52
	6.0	0.57	1.40	0.83
	24.0	0.74	1.83	1.09
	48.0	0.83	2.24	1.41
	72.0	0.89	2.51	1.62
	120.0	0.96	2.80	1.84
	168.0	1.01	3.01	2.00
	0.5[c]	0.50	1.05	0.55
	1.0[c]	0.59	1.26	0.67
	3.0[c]	0.78	1.53	0.75
	6.0[c]	0.95	2.16	1.21
	24.0[c]	0.99	2.46	1.47
	48.0[c]	0.99	2.65	1.66
	72.0[c]	0.99	2.97	1.98
Acetic anhydride[d]	0.5	0.00	0.42	0.42
	1.0	0.00	1.79	1.79
	6.0	0.00	2.91	2.91
	24.0	0.00	3.49	3.49
	48.0	0.00	3.84	3.84
	72.0	0.00	4.00	4.00
	0.5[c]	0.00	1.64	1.64
	1.0[c]	0.00	2.10	2.10
	3.0[c]	0.00	2.81	2.81
	6.0[c]	0.00	3.31	3.31
	12.0[c]	0.00	3.65	3.65
	24.0[c]	0.00	3.88	3.88
	48.0[c]	0.00	4.00	4.00
Succinic anhydride[d]	0.5	0.00	0.63	0.63
	3.0	0.00	1.36	1.36
	6.0	0.00	1.71	1.71
	24.0	0.00	2.41	2.41
	72.0	0.00	3.02	3.02
	120.0	0.00	3.76	3.76
	168.0	.00	3.98	3.98
	0.5[c]	0.00	1.40	1.40
	1.0[c]	0.00	1.74	1.74
	3.0[c]	0.00	2.30	2.30
	6.0[c]	0.00	2.86	2.86
	24.0[c]	0.00	3.69	3.69
	48.0[c]	0.00	4.01	4.01
Phthalic anhydride[d]	1.0	0.00	0.93	0.93
	3.0	0.00	1.18	1.18
	6.0	0.00	1.54	1.54
	24.0	0.00	2.33	2.33
	72.0	0.00	3.12	3.12
	120.0	0.00	3.63	3.63
	168.0	0.00	3.89	3.89
	0.5[c]	0.00	1.41	1.41
	1.0[c]	0.00	2.14	2.14
	6.0[c]	0.00	3.07	3.07
	12.0[c]	0.00	3.95	3.95
	24.0[c]	0.00	3.99	3.99
Caproyl chloride	0.5	0.00	1.55	1.55
	1.0	0.00	1.73	1.73
	3.0	0.00	1.89	189
	6.0	0.00	2.01	2.01
Benzoyl chloride	0.5	0.00	1.38	1.38
	1.0	0.00	1.52	1.52
	3.0	0.00	1.87	1.87
	6.0	0.00	2.00	2.00

[a,b]See the corresponding footnotes in Table 1. [c]At 25 ℃. [d]Ratio of reagent to compound is 6 : 1.

Table 6. Reaction of Sodium Tris(diethylamino)aluminum Hydride with Representative Esters and Lactones in Tetrahydrofuran at 0 ℃

Compound[a]	Time, h	Hydrogen evolved[b]	Hydride used[b]	Hydride used for reduction[b]
Ethyl caproate	0.5	0.00	1.64	1.64
	0.3	0.00	1.83	1.83
	24.0	0.00	1.94	1.94
	48.0	0.00	2.01	2.01
Ethyl benzoate	0.5[c]	0.00	1.84	1.84
	1.0[c]	0.00	1.92	1.92
	3.0[c]	0.00	1.99	1.99
	6.0[c]	0.00	2.01	2.01
Phenyl acetate	0.5	0.00	1.56	1.56
	3.0	0.00	1.66	1.66
	6.0	0.00	1.75	1.75
	24.0	0.00	1.79	1.79
	72.0	0.00	1.88	1.88
	96.0	0.00	1.96	1.96
	120.0	0.00	2.01	2.01
γ-Butyroactone	0.5	0.00	1.04	1.04
	6.0	0.00	1.52	1.52
	24.0	0.00	1.76	1.76
	48.0	0.00	1.88	1.88
	120.0	0.00	2.01	2.01
	0.5[c]	0.00	1.17	1.17
	1.0[c]	0.00	1.47	1.47
	3.0[c]	0.00	1.56	1.56
	6.0[c]	0.00	1.62	1.62

	24.0[c]	0.00	1.84	1.84
	48.0[c]	0.00	2.00	2.00
Phthalide	0.5	0.00	0.87	0.87
	3.0	0.00	1.01	10.1
	24.0	0.00	1.22	1.22
	72.0	0.00	1.49	1.49
	168.0	0.00	1.87	1.87
	0.5[c]	0.00	1.07	1.07
	1.0[c]	0.00	1.65	1.65
	3.0[c]	0.00	1.87	1.87
	6.0[c]	0.00	1.96	1.96
	12.0[c]	0.00	1.99	1.99
Isopropenyl acetate	0.5	0.00	1.32	1.32
	6.0	0.00	1.85	1.85
	24.0	0.00	1.99	1.99
	72.0	0.00	2.34	2.34
	168.0	0.00	3.01	3.01

[a,b] See the corresponding footnotes in Table 1. [c] At 25 ℃.

Table 7. Reaction of Sodium Tris(diethylamino)aluminum Hydride with Representative Epoxides in Tetrahydrofuran at 0 ℃

Compound[a]	Time, h	Hydrogen evolved[b]	Hydride used[b]	Hydride used for reduction[b]
1,2-Butylene oxide[c]	0.5	0.00	1.00	1.00
	3.0	0.00	1.00	1.00
Styrene oxide[d]	0.5	0.00	1.00	1.00
	3.0	0.00	1.00	1.00
Cyclohexene oxide	0.5	0.00	0.98	0.98
	1.0	0.00	1.00	1.00
	3.0	0.00	1.00	1.00
1-Methylcyclo-	0.5	0.00	0.94	0.94
hexene oxide[e]	1.0	0.00	1.01	1.01
	3.0	0.00	1.01	1.01

[a,b] See the corresponding footnotes in Table 1. [c] 98% of 2-butanol and 2% of 1-butanol. [d] 97% of 1-phenylethanol and 3% of 2-phenylethanol. [e] Only 1-methylcyclohexanol was detected.

fast, an uptake of equivalent of hydride per mole of epoxide being realized in 0.5-1 h, at a rate comparable to that of LTDEA. This fast reaction with the diethylamino derivatives is quite surprising. The reaction of SAH with epoxides appeared much slower than those of these derivatives, requiring 6-24 h at 0 ℃ to consume 1 equivalent of hydride. However, the selectivity of STDEA toward the unsymmetrical epoxides appeared to be quite similar to those of LTDEA[1] and SAH,[10] showing the major hydride transfer to the less substituted carbon atom of the epoxy ring. These reults are summarized in Table 7.

Amides and Nitriles. Primary carboxamides, such as caproamide and benzamide, were reduced slowly with concurrent slow evolution of hydrogen in an amount of less than 1 equivalent. On the contrary, tertiary amides were reduced readily to the corresponding tertiary amines within 6 h at 0 ℃. The reaction of aliphatic nitrile, such as capronitrile, was quite slow, whereas aromatic nitrile, such as benzonitrile, was reduced readily to primary amine. These results are summarized in Table 8.

Table 8. Reaction of Sodium Tris(diethylamino)aluminum Hydride with Representative Amides and Nitriles in Tetrahydrofuran at 0 ℃

Compound[a]	Time, h	Hydrogen evolved[b]	Hydride used[b]	Hydride used for reduction[b]
Caproamide	0.5	0.28	0.97	0.69
	1.0	0.33	1.23	0.90
	3.0	0.35	1.36	1.01
	24.0	0.44	1.74	1.30
	168.0	0.60	2.29	1.69
Benzamide	0.5	0.32	1.17	0.85
	1.0	0.38	1.26	0.88
	3.0	0.51	1.50	0.99
	6.0	0.55	1.77	1.22
	24.0	0.72	2.18	1.46
	168.0	0.84	2.62	1.78
N,N-Dimethyl-	0.5	0.00	1.31	1.31
caproamide	1.0	0.00	1.44	1.44
	3.0	0.00	1.68	1.68
	6.0	0.00	2.00	2.00
N-N-Dimethyl-	0.5	0.00	1.51	1.51
benzamide	1.0	0.00	1.68	1.68
	3.0	0.00	1.88	1.88
	6.0	0.00	2.01	2.01
Capronitrile[c]	0.5	0.00	0.83	0.83
	1.0	0.00	0.96	0.96
	3.0	0.00	1.03	1.03
	6.0	0.00	1.17	1.17
	24.0	0.00	1.32	1.32
	72.0	0.00	1.59	1.59
	168.0	0.00	2.01	2.01
Benzonitrile[c]	0.25	0.00	1.30	1.30
	0.5	0.00	1.47	1.47
	1.0	0.00	1.64	1.64
	3.0	0.00	1.84	1.84
	6.0	0.00	1.93	1.93
	12.0	0.00	2.00	2.00
	24.0	0.00	2.00	2.00

[a,b] See the corresponding footnotes in Table 1. [c] Turned to be yellow immediately.

Like the reaction of primary carboxamides with LTDEA,[1,4,5] the reaction with STDEA seems to be feasible for conversion of amides to aldehydes. In fact, the reaction of primary amides with 2 equivalents of STDEA afforded the corresponding aldehydes in good yields at room temperature (Eq. 3).[9] Although tertiary amides consumed 2 equivalents of hydride readily, the controlled reaction with a limiting amount of STDEA provided aldehydes in high yields. The reagent also converted aromatic nitriles into aldehydes in yields of 70-98% (Eq. 4).[8] In addition to that, the reagent achieved up

$$\mathrm{R\text{-}\overset{O}{\overset{\|}{C}}\text{-}NH_2} \xrightarrow{\text{STDEA}} \xrightarrow{H_3O^+} \mathrm{RCHO} \qquad (3)$$

Table 9. Reaction of Sodium Tris(diethylamino)aluminum Hydride with Representative Nitro Compounds and Their Derivatives in Tetrahydrofuran at 0 ℃

Compound[a]	Time, h	Hydrogen evolved[b]	Hydride used[b]	Hydride used for reduction[b]
1-Nitropropane[c]	0.5	0.00	1.19	1.19
	3.0	0.00	1.34	1.34
	6.0	0.00	1.45	1.45
	24.0	0.00	1.61	1.61
	72.0	0.00	1.91	1.91
	96.0	0.00	2.01	2.01
Nitrobenzene[c]	0.25	0.96	1.92	0.96
	0.5	0.96	2.24	1.28
	1.0	0.96	2.44	1.48
	6.0	0.96	2.65	1.69
	24.0	0.96	2.81	1.85
	72.0	0.96	2.97	2.01
Azobenzene	0.5	0.00	0.82	0.82
	3.0	0.00	1.04	1.04
	6.0	0.00	1.24	1.24
	24.0	0.00	1.65	1.65
	72.0	0.00	1.87	1.87
	168.0	0.00	2.01	2.01
Azoxybenzene	0.5	0.00	0.92	0.92
	3.0	0.00	1.39	1.39
	6.0	0.00	1.58	1.58
	24.0	0.00	1.84	1.84
	48.0	0.00	2.01	2.01

[a,b] See the corresponding footnotes in Table 1. [c] Color changed to dark yellow.

$$ArC{\equiv}N \xrightarrow{STDEA} \xrightarrow{H_3O^+} ArCHO \quad (4)$$

to 95-99% conversion of aromatic nitriles into aldehydes in mixtures with aliphatic nitriles, without any reduction of the aliphatic nitriles, with a limiting amount of reagent.[8]

In a similar way, excess SAH reduced readily amides and nitriles to the corresponding amines, whereas a limiting amount of the reagent converted these compounds into aldehydes in good yiels.[10,12]

Nitro Compounds and Their Derivatives. 1-Nitropropane consumed 2 equivalents of hydride slowly without evolution of hydrogen, similar to the case of LTDEA.[1] The reaction of nitrobenzene also utilized slowly 2 equivalents of hydride for reduction with, unexpectedly, rapid evolution of *ca.* 1 equivalent of hydrogen. The reduction of nitro compounds with SAH consumed a total of 6 equivalents of hydride with 3 equivalents of hydride being utilized for reduction and 3 for hydrogen evolution, corresponding to the stiochiometry for reduction to the amine. We believe that nitro compounds undergo the reaction through azo and hydrazo intermediates to the final amines stage.[10] Therefore, the reaction of nitro compounds with STDEA seems to reach the corresponding azo stages under these reaction conditions.

Azobenzene also utilized 1 equivalent of hydride relatively fast to the corresponding hydrazobenzene stage without evolution of hydrogen, and further reduction to the amine stage followed slowy. On the other hand, both LTDEA and SAH reduced azobenzene readily to hydrazobenzene, but no further utilization of hydride was realized. Similarly, the reagent reacted with azoxybenzene with the uptake of 1 equivalent of hydride fast and the second hydride slowly for reduction without evolution of hydrogen. This stoichiometry indicates that azoxybenzene is reduced to hydrazobenzene. The parent SAH reduced azoxybenzene readily to hydrazobenzene with the uptake of 4 equivalents of hydride, 2 equivalents being used for reduction 2 for hydrogen evolution at 0 ℃. The results are summarized in Table 9.

Table 10. Reaction of Sodium Tris(diethylamino)aluminum Hydride with Other Nitrogen Compounds in Tetrahydrofuran at 0 ℃

Compound[a]	Time, h	Hydrogen evolved[b]	Hydride used[b]	Hydride used for reduction[b]
Cyclohexanone	0.5	0.25	0.72	0.47
oxime	1.0	0.33	0.85	0.52
	6.0	0.57	1.71	1.14
	24.0	0.69	2.19	1.50
	72.0	0.85	2.57	1.72
	168.0	1.02	2.84	1.82
Phenyl isocyanate	0.5	0.00	0.82	0.82
	1.0	0.00	1.09	1.09
	3.0	0.00	1.19	1.19
	6.0	0.00	1.25	1.25
	24.0	0.00	1.78	1.78
	48.0	0.00	1.91	1.91
	72.0	0.00	2.00	2.00
Pyridine	0.5	0.00	0.19	0.19
	6.0	0.00	0.22	0.22
	72.0	0.00	0.23	0.23
4-Picoline	0.5	0.00	1.38	1.38
N-oxide	1.0	0.00	1.65	1.65
	3.0	0.00	1.79	1.79
	6.0	0.00	2.01	2.01

[a,b] See the corresponding footnotes in Table 1.

Other Nitrogen Compounds. The reaction of cyclohexanone oxime proceeded to utilize 1 equivaent of hydride at a relatively fast rate, and followed by the sluggish utilization of further equivalent of hydride for reduction with concurrent slow liberation of 1 equivalent of hydrogen. This stoichiometry corresponds to reduction to N-hydroxyamine stage. Phenyl isocyanate was also slowly reduced, utilizing 1 equivalent of hydride at a fast rate and the further utilization slowly, indicating ready reduction to the formanilide stage. The attack to pyridine ring was very sluggish, whereas 4-picoline N-oxide was readily reduced by STDEA. These results are summarized in Table 10.

LTDEA also reduced cyclohexanone oxime to the N-hydroxyamine stage and phenyl isocyanate to the formanilide stage at a much faster rate[1] than that with STDEA. On the other hand, SAH reduced cyclohexanone oxime to cyclohexylamine and phenyl isocyanate to N-methylaniline readily.[1]

Sulfur Derivatives. LTDEA appeared to be an ideal reducing agent for conversion of disulfides to the corres-

Table 11. Reaction of Sodium Tris(diethylamino)aluminum Hydride with Representative Sulfur Derivatives in Tetrahydrofuran at 0 ℃

Compound[a]	Time, h	Hydrogen evolved[b]	Hydride used[b]	Hydride used for reduction[b]
Di-*n*-butyl disulfide	0.5	0.00	0.86	0.86
	1.0	0.00	0.95	0.95
	3.0	0.00	1.00	1.00
	6.0	0.00	1.00	1.00
Diphenyl disulfide	0.5	0.00	0.95	0.95
	1.0	0.00	0.99	0.99
	3.0	0.00	1.00	1.00
	6.0	0.00	1.00	1.00
Dimethyl sulfoxide	0.5	0.00	0.59	0.59
	3.0	0.00	0.69	0.69
	6.0	0.00	0.83	0.83
	12.0	0.00	0.99	0.99
	24.0	0.00	1.01	1.01
Diphenyl sulfone	0.5	0.00	1.10	1.10
	3.0	0.00	1.30	1.30
	24.0	0.00	1.40	1.40
	72.0	0.00	1.53	1.53
	168.0	0.00	1.68	1.68
Methanesulfonic	0.5	0.27	0.27	0.00
acid	1.0	0.41	0.41	0.00
	3.0	0.65	0.65	0.00
	6.0	0.86	0.86	0.00
	12.0	0.99	0.99	0.00
	24.0	1.00	1.00	0.00
p-Tolunesulfonic	0.5	1.28	1.28	0.00
acid monohydrate	1.0	1.48	1.48	0.00
	6.0	1.65	1.65	0.00
	24.0	1.79	1.79	0.00
	72.0	2.29	2.29	0.00
	120.0	2.68	2.68	0.00
	168.0	3.01	3.01	0.00
Cyclohexyl tosylate	0.5	0.00	0.62	0.62
	3.0	0.00	0.84	0.84
	6.0	0.00	0.93	0.93
	12.0	0.00	1.01	1.01

[a,b] See the corresponding footnotes in Table 1.

ponding thiols[1,3]: the reagent reduces disulfides to thiols at an exceedingly fast rate at 0° without evolution of any hydrogen. Similary, STDEA reduced disulfides to thiols at a fast rate, but slower than LTDEA, without evolution of any hydrogen (Eq. 5). Dimethyl sulfoxide was reduced slowly to dimethyl

$$\text{R-S-S-R} \xrightarrow[\text{or STDEA}]{\text{LTDEA}} \longrightarrow 2\ \text{RSH} \qquad (5)$$

sulfide in 12 h at 0°. On the other hand, sulfone such as diphenyl sulfone was reduced by STDEA at a much faster rate than that by LTDEA. Methanesulfonic acid and *p*-toluenesulfonic acid monohydrate liberated hydrogen slowly: the former evolved 1 equivalent of hydrogen within 24 h and the latter evolved 3 equivalents in 168 h at 0 ℃.

Finally cyclohexyl tosylate reacted readily with the uptake of 1 equivalent of hydride for reduction without evolution of hydrogen to give cyclohexane. The result are summarized in Table 11.

The parent SAH reduced disulfides to thiols rapidly with concurrent evolution of hydrogen.[10] Dimethyl sulfoxide was also reduced readily, whereas diphenyl sulfone was essentially stable. Sulfonic acids liberated hydrogen instantly and quantitatively, but no reduction was detected. Unlike the case of STDEA, SAH reacted with cyclohexyl tosylate only very sluggishly, even at room temperature.

Conclusion

This study has clearly revealed the similarities and differences in the reducing actions of lithium and sodium tris(diethylamino)aluminum hydrides (LTDEA and STDEA) toward the selected organic functional compounds. In general, the reducing characteristics of STDEA is very similar to that observed previously for LTDEA. Although STDEA shows a lower reactivity than LTDEA toward most functionalities, the reagent shows exactly the same trends in those reactions examined as LTDEA. Such a relatively lower reactivity, on the other hand, adds an advantage to STDEA to show a possible selective reduction between some organic functional groups. As a consequence, STDEA can replace LTDEA efficiently, with a higher selectivity, in most organic reductions.

Experimental Section

Meterials. All chemicals were commerical products of the highest purity, which were further purified by standard methods before use when necessary. Tetrahydrofuran (THF) was dried over 4 Å molecular sieve and distilled from sodiumbenzophenone ketyl prior to use. Some compounds, such as 1-methyl-1,2-cyclohexene oxide, tertiary carboxamides and tosylate, were synthesized by using standard procedures.

General Methods. All glassware was dried thoroughly in a drying oven at 140 ℃, assembled hot, dried further with a flame and cooled under a stream of nitrogen. All reactions were carried out under a nitrogen atomosphere. Special experimental techniques used in handling air-sensitive material are described in detail elsewhere.[14]

Instruments. GC analyses were carried out on a Hewlett-Packard 5790A FID chromatograph equipped with a Hewlett-Packard 3390A intergrator/plotter, using Carbowax 20 M on 100/120 mesh Supelcoport or 15% THEED on 100/120 mesh Supelcoport (0.125 in.×12 ft. columns). All GC yields were determined with use of suitable internal standards and authentic samples. ^{27}Al NMR spectra were recorded on a Bruker WP 80 SY spectrometer, and chemical shifts reported relative to $[Al(H_2O)_6]^{3+}$.

Preparation of Sodium Aluminum Hydride (SAH) in THF. An oven-dried, 2-*l*, round-bottom flask with a sidearm equipped with a magnetic stirring bar and an adaptor was attached to a mercury bubbler. The flask was flushed with dry nitrogen and then maintained under a static pressure of nitrogen. To this flask were added 27 g of SAH (500 mmol) and 0.2 *l* of THF. The slurry was stirred for

48 h at room temperature and then allowed to stand at 0 ℃ to permit the undissolved materials to settle. The clear solution was transferred to a flask *via* a double-ended needle. A sufficient amount of THF was added to this flask to make a 2 M stock solution.

Preparation of Sodium Tris(diethylamino)aluminum Hydride (STDEA) in THF. To an oven-drided, 500-m*l* flask fitted with a sidearm and reflux condenser leading to a mercury bubbler was added 100 m*l* of 2 M solution of SAH (200 mmol) in THF and the solution was cooled in 0°. To this solution was added 46 g of diethylamine (630 mmol, 5% excess) dropwise with vigorous stirring. And then the mixture was stirred for 6 h at room temperature until the hydrogen evolution was complete. The resulting STDEA solution in THF was standardized by hydrolyzing an aliquot with 2 N H_2SO_4-THF mixture to be 1.50 M, and kept under nitrogen at 0°. The ^{27}Al NMR spectrum of the solution showed a broad singlet at δ 116 ppm.

General Procedure for Determination of Rate and Stoichiometry. To a 100-m*l* flask fitted with a sidearm and capped by a rubber septum connected to a gas meter was added 24 m*l* of a 1.50 M THF solution of STDEA (36 mmol). The flask was immersed into an ice-water bath and the reaction mixture was diluted with 12 m*l* of THF containing 9 mmol of the compound to be examined. This makes the mixture 1 M in hydride and 0.25 M in the compound under investigation. At different time intervals, 4.0 m*l* of sampe aliquots were withdrawn and quenched in a 2 N H_2SO_4 -THF hydrolyzing mixture. The hydrogen evolved was measured volumetrically. The reaction was stopped when two or more analyses indicated that no more hydride was taken up. The hydrogen evolved during the reaction was measured volumetrically by a gas meter attached.

The reaction of caproaldehyde is described to examplity the reaction procedure. In an usual set-up was placed 24 m*l* of 1.50 M STDEA (36 mmol) in THF, and followed by addition of 12 m*l* of THF solution containing 0.90 g (9 mmol) of caproaldehyde at 0 ℃. No hydrogen was evolved throughout the reaction. After 0.5 h, a 4.0 m*l* aliquot of the reaction mixture was withdrawn and hydrolyzed to indicate 3.00 mmol of residual hydride, which means that 1.00 mmol of hydride per mmol of caproaldehyde had been consumed. After 3 h, an aliquot was also analyzed to indicate the same value of residual hydride, which indicated that the reaction was completed within 0.5 h. These results are summarized in Table 2.

Reduction of 1,2-Butylene Oxide. The following experiment illustrates the technique utilized in cases where the reaction mixture was subjected to identification of products.

Using the general procedure described above, the reaction of 1,2-butylene oxide with STDEA was performed for 3 h at 0°. The reaction mixture was then hydrolyzed with 2 N HCl and the aqueous layer was saturated with anhydrous potassium carbonate. The organic layer was dried over anhydrous magnesium sulfate and subjected to GC analysis with 10% Carbowax 20 M column. The mixture of 98% 2-butanol and 2% 1-butanol in a total yield of 100% was realized.

General Procedure for Stereoselectivity Study. The reduction of 3,3,5-trimethylcyclohexanone is described as representative. To a 10-m*l* vial capped by rubber septum was added 2 m*l* of the STDEA stock solution (1.50 M, 3 mmol). The vial was kept in a ice-water bath and to this was added 0.75 m*l* of a 2 M solution of the compound (1.5 mmol) in THF. The reaction mixture was stirred for 3 h at that temperature and then hydrolyzed by 3 N HCl. The aqueous layer was saturated with potassium carbonate, and the organic layer was subjected to GC analysis to indicate the presence of 92% *trans* alcohol. The results are summarized in Table 3.

Acknowledgements. This work was supported by the Organic Chemistry Research Center-KOSEF. The generous supply of sodium aluminum hydride by Ethyl Corporation is gratefully acknowledged.

References

1. Cha, J. S.; Lee, J. C. *Bull. Korean Chem. Soc.* **1993**, *14*, 469.
2. Cha, J. S.; Lee, J. C.; Lee, S. E.; Lee, H. S. *Org. Prep. Proced. Int.* **1992**, *24*, 327.
3. Cha, J. S.; Min, S. J.; Lee, J. C.; Lee, H. S.; Lee, S. E. *Org. Prep. Proced. Int.* **1992**, *24*, 335.
4. Cha, J. S. *Bull. Korean Chem. Soc.* **1992**, *13*, 670.
5. (a) Cha, J. S.; Lee, J. C.; Lee, S. E.; Kim, J. M.; Kwon, O. O.; Lee, H. S.; Min, S. J. *Tetrahedron Lett.* **1991**, *32*, 6903. (b) Cha, J. S.; Lee, S. E.; Lee, H. S.; Kim, J. M.; Kwon, O. O.; Min, S. J. *Tetrahedron Lett.* **1992**, *13*, 338.
6. Cha, J. S.; Lee, S. E. *Bull. Korean Chem. Soc.* **1992**, *13*, 451.
7. Cha, J. S.; Kim, J. M.; Jeong, M. K.; Kwon, O. O.; Kim, E. J. *Org. Prep. Proced. Int.* **1994**, *26*, in press.
8. Cha, J. S.; Jeoung, M. K.; Kim, J. M.; Kwon, O. O.; Lee, J. C. *Org. Prep. Proced. Int.* **1994**, *26*, 552.
9. Cha, J. S.; Kim, J. M.; Jeoung, M. K. *Bull. Korean Chem. Soc.* **1994**, *15*, 000.
10. Cha, J. S.; Brown, H. C. *J. Org. Chem.* **1993**, *58*, 4727.
11. Brown, H. C.; Weissman, P. M.; Yoon, N. M. *J. Am. Chem. Soc.* **1966**, *88*, 1458.
12. Zakharkin, L. I.; Maslin, D. N.; Gavrilenko, V. V. *Tetrahedron* **1969**, 5555.
13. Cha, J. S.; Kim, J. M.; Jeoung, M. K.; Lee, K. D. *Bull. Korean Chem. Soc.* **1992**, *13*, 710.
14. Brown, H. C.; Kramer, G. W.; Midland, M. M. *Organic Synthesis via Boranes*; Wiley-Interscience: New York, 1975.