

Activation of Low-Valent Titanium Reagents with Iodine: Facile Low-Temperature McMurry Reaction and *N/O*-Debenzylation/Deallylation[†]

Sanjay Talukdar, Sandip K. Nayak, and Asoke Banerji*

Bio-Organic Division, Bhabha Atomic Research Centre, Mumbai (Bombay)-400 085, India

Received September 18, 1997

A highly reactive, low-valent titanium (LVT) reagent has been prepared by the addition of substoichiometric amounts of iodine to the LVT species generated by Rieke's method (TiCl_3 -Li-THF). While the conventional McMurry reaction requires high temperatures and prolonged reaction times for the generation of olefins, the present activated LVT reagent is able to effect the reductive coupling of aliphatic as well as aromatic carbonyls to the corresponding olefins at lower temperatures and much reduced reaction times. The protocol is also useful for the intramolecular coupling reactions leading to the one-step synthesis of heterocycles. The temperature-controlled McMurry reaction provides enhanced diastereoselectivity and features an excellent chemoselectivity. In addition to the McMurry reaction, other SET-induced carbon-heteroatom (O, N) bond cleavages can also be carried out with the activated reagent at a fast rate and at a low temperature in high yields.

Introduction and Background

Designing reagents for selective organic transformations is an important domain of research in synthetic chemistry. For the transition-metal-based reagents in general, and for low-valent titanium (LVT) in particular, it is widely known^{1a-d} that the reactivity, reproducibility, and stereochemistry of reaction products vary greatly with the source of the metal, its method of preparation, and the experimental conditions. In a continuation of our work on the rational design of organometallic reagents,^{1b,2a-e} fine-tuning of the reactivity of LVT was achieved by using external ligands, including π -acid species such as pyridine, triphenylphosphine, and fullerenes. Very recently, the ligand effects on the McMurry pinacol reactions have been examined.³ Use of chemical redox agents^{4a,b} for the modulation of reactivity of organometallic electron-transfer processes offers attractive possibilities for the design of novel LVT-based reagents by controlling the redox potential of titanium complexes. The influence of redox agents on the reactivity of LVT-based reagents has not received much attention and is therefore long overdue. The present investigation deals with the modulation of the reactivity of LVT reagents using iodine as an external redox agent. The activated reagent performs McMurry's carbonyl coupling and other SET-induced reactions at lower temperatures and in improved yields.

The McMurry reaction^{1c,5a,b} finds applications in the synthesis of strained olefins to unusual molecules such as complex natural products including Taxol. The reaction proceeds by initial electron transfer followed by coupling to form a pinacolate which on deoxygenation liberates the olefin. The pinacolization can be carried out with a variety of reductants, but the deoxygenation is unique to LVT reagents. Although titanium is known for its high oxophilicity, the extrusion of oxygen from the pinacolates necessitates the use of solvent-reflux temperatures and prolonged reaction times. Despite the immense potential of the McMurry reaction in synthetic organic chemistry, the incompatibility of several functionalities under the conditions of the reaction limits its applications. Though, at lower temperatures, many of the otherwise reducible functionalities survive, the McMurry reaction at low temperatures primarily furnishes pinacols,^{5a,b,6a,b,7a-c} and the olefins are obtained only at higher temperatures and on prolonged reaction times. This, therefore, restricts its applications in the case of oxygenated complex natural products with semicompatible functionalities, where the introduction of olefinic double bonds is achieved by the initial pinacolization at lower temperatures followed by deoxygenation through indirect milder methods.^{5a} The development of a protocol for direct one-step olefination reaction at lower temperatures is therefore of prime importance and offers challenges to organic chemists.

For the synthesis of olefins at lower temperatures, the activation of LVT species becomes imperative. Reactive LVT reagents have been prepared using Rieke's protocol^{8a,b} involving reduction of titanium halides with an alkali metal (lithium, sodium, or potassium) in an ethereal or hydrocarbon solvent. However, the reactive metals have the intrinsic tendency toward deactivation and, therefore, require further depassivation or secondary activation. Several reagents such as iodine, methyl iodide, ethyl

[†] In respectful memory of the late Professor Sir Derek H. R. Barton.

(1) (a) Dams, R.; Malinowski, M.; Westdorp, I.; Geise, Y. H. *J. Org. Chem.* **1982**, *47*, 248. (b) Nayak, S. K.; Banerji, A. *J. Org. Chem.* **1991**, *56*, 1940. (c) Dushin, R. G. In *Comprehensive Organometallic Chemistry II*; Hegedus, L. S., Ed.; Pergamon: Oxford, 1995; Vol. 12, p 1071 and references therein. (d) Szymoniak, J.; Besancon, J.; Moise, C. *Tetrahedron* **1992**, *48*, 3867.

(2) (a) Banerji, A.; Nayak, S. K. *J. Chem. Soc., Chem. Commun.* **1990**, 150. (b) Nayak, S. K.; Kadam, S. M.; Talukdar, S.; Banerji, A. *J. Indian Inst. Sci.* **1994**, *74*, 401. (c) Talukdar, S.; Nayak, S. K.; Banerji, A. *Full. Sci. Technol.* **1995**, *3*, 327. (d) Balu, N.; Nayak, S. K.; Banerji, A. *J. Am. Chem. Soc.* **1996**, *118*, 5932 and references therein. (e) Talukdar, S. Ph.D. Thesis, 1997, University of Mumbai, Mumbai, India.

(3) Lipski, T. A.; Hilfiker, M. A.; Nelson, S. G. *J. Org. Chem.* **1997**, *62*, 4566.

(4) (a) Connelly, N. G.; Geiger, W. E. *Chem. Rev.* **1996**, *96*, 877 and references therein. (b) Hirao, T. *Chem. Rev.* **1997**, *97*, 2707 and references therein.

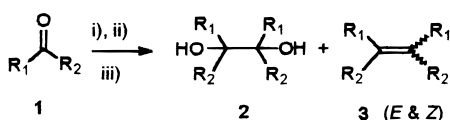
(5) (a) McMurry, J. E. *Chem. Rev.* **1989**, *89*, 1513. (b) Fürstner, A.; Bogdanovic, B. *Angew. Chem., Int. Ed. Engl.* **1996**, *35*, 2442 and references therein.

(6) (a) McMurry, J. E.; Rico, J. G. *Tetrahedron Lett.* **1989**, *30*, 1169. (b) McMurry, J. E.; Dushin, R. G. *J. Am. Chem. Soc.* **1990**, *112*, 6942.

Table 1. Comparative Reactivity of Various Low-Valent Titanium Reagents with Acetophenone (1a)

entry	LVT reagent	additive (equiv)	time (h), temp (°C)	% yield ^a (<i>dl:meso</i>) ^{b,c} of 2a	% yield ^a of 3a
1	TiCl ₃ -Li-THF	Nil	16, reflux	nil	89
2	TiCl ₃ -Li-THF	Nil	16, 0-5	87 (75:25)	trace
3	TiCl ₃ -Li-THF	I ₂ (0.25)	2, 0-5	nil	90
4	TiCl ₃ -Li-THF	I ₂ (0.25)	2, -40	trace	75
5	TiCl ₃ -Li-THF	I ₂ (0.125)	3.5, 0-5	nil	87
6	TiCl ₃ -Mg-THF	I ₂ (0.25)	18, 0-5	nil	80 ^d
7	TiCl ₃ -Li-THF	ethyl bromide (0.25)	5, 0-5	67 (80:20)	25
8	TiCl ₃ -Li-THF	1,2-dibromoethane (0.25)	5, 0-5	nil	87

^a All yields refer to isolated products (purity > 95%, analyzed by ¹H NMR). The products were fully characterized by comparison (TLC, mp, ¹H NMR, IR) with authentic samples.^{2d,11} ^b Ratios determined by ¹H NMR analysis of crude product mixtures. ^c Stereochemical assignments are made by comparison of spectroscopic data to that reported in the literature.^{2d} The stereoisomeric composition of stilbene mixture **3a** is presented in Table 3. ^d Considering 15% of recovered substrate **1a**.

Scheme 1

R₁ = (cyclo)alkyl, aryl; R₂ = (cyclo)alkyl, aryl, H

i) TiCl₃/Li/THF; ii) I₂ (0.25 eq) iii) Low Temp.

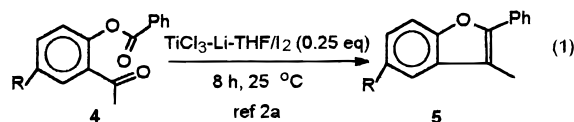
bromide, and especially 1,2-dibromoethane have been reported for the activation^{8a,b} of metals. Recent reports^{8a,b} on the effects of iodine on transition-metal-mediated transformations prompted us to investigate its effect on LVT reagents. Although iodine did not activate the commercial titanium powder,^{7c} herein, an efficient strategy for the preparation of a highly reactive LVT reagent by the addition of substoichiometric amounts of iodine to the Rieke's LVT (TiCl₃-Li-THF) species is presented.

Results and Discussion

Preparation of Activated LVT Reagent and McMurry Reaction. Coupling of acetophenone (R₁ = Ph, R₂ = CH₃; **1a**) to the corresponding stilbene, viz. 2,3-diphenyl-2-butene (**3a**), was chosen as a model reaction (Table 1, Scheme 1). The LVT was prepared in situ as a black slurry by reducing TiCl₃ with Li in THF (TiCl₃-Li-THF, reagent A). On addition of iodine (0.25 equiv), formation of a brown soluble species was observed. When **1a** (0.25 equiv to TiCl₃) was added to the modified TiCl₃-Li-THF-I₂ (reagent B), **3a** was obtained in 90% yield at 0-5 °C within 2 h without a trace of the intermediate pinacol, 2,3-diphenylbutane-2,3-diol (**2a**) (Table 1, entry 3). In contrast, in the absence of iodine, the pinacol **2a** was isolated in 87% yield even when the reaction was carried out for 16 h (Table 1, entry 2). Under McMurry's conditions,⁹ prolonged (16 h) reflux was required to obtain stilbene **3a** (89%, Table 1, entry 1). Using iodine (reagent B), **3a** was isolated as the major product (Table 1, entry 4), even at -40 °C. This clearly shows the dramatic role of iodine in augmenting the reactivity of LVT reagents. The reaction could also be carried out in comparable yield

using as low as 0.125 equiv of iodine, but with increased reaction time (Table 1, entry 5). Iodine is also effective in activating the Tyrlik's LVT reagent^{1c} (TiCl₃-Mg-THF), although its effect was comparatively less pronounced. Thus, using TiCl₃-Mg-THF-I₂ (0.25 equiv) reagent, **3a** was obtained in 80% yield after 18 h at 0-5 °C (Table 1, entry 6). Among the reactive alkyl halides, ethyl bromide and 1,2-dibromoethane were tried for the activation study. Using ethyl bromide, the carbonyl-olefin transformation resulted in a low yield (25%) of stilbene **3a** at 0-5 °C (Table 1, entry 7) (the major product was **2a**). In contrast, using 1,2-dibromoethane, **3a** (87%) was obtained after 5 h reaction (Table 1, entry 8). The diol **2a** was obtained as a diastereomeric (*dl:meso*) mixture (Table 1, entries 2 and 7), and their stereoisomeric composition has been assigned by comparison with the literature data.^{2d} The profile of the McMurry reaction using various additives as activators for LVT reagents establishes that TiCl₃-Li-THF-I₂ (0.25 equiv) (LVT-I₂, reagent B) is the best combination and, therefore, was used for further studies.

Generality and Chemoselectivity. To explore the generality and scope of reagent B, experiments were carried out using a variety of aryl carbonyls, such as aryl alkyl ketones (Table 1, entry 3; Table 2, entries 1, 2, and 7), diaryl ketone (Table 2, entry 3), and aryl aldehydes (Table 2, entries 4-6) (Scheme 1). The reaction is also applicable to the less reactive aliphatic carbonyls. Thus, the aliphatic aldehydes (Table 2, entries 8 and 9), as well as aliphatic ketones (Table 2, entries 10-12), undergo facile coupling to olefins at 25 °C. The scope of the low-temperature McMurry reaction for the synthesis of heterocycles,^{1c,5b,8b} via the intramolecular keto ester coupling of *o*-aryloxyacetophenones developed earlier in our laboratory,^{2a} was also explored. Thus, both 2-(benzoyloxy)acetophenone (**4a**) and 2-(benzoyloxy)-5-methoxyacetophenone (**4b**) on reaction with reagent B generated the corresponding benzofurans **5a** (62%) and **5b** (55%), respectively (eq 1), at 25 °C. The low-temperature



4a: R = H; **4b:** R = MeO

5a: R = H (Yield, 62%); **5b:** R = MeO (Yield, 55%)

(7) (a) Fürstner, A.; Weidmann, H. *Synthesis* **1987**, 1071. (b) Fürstner, A.; Csuk, R.; Rohrer, C.; Weidmann, H. *J. Chem. Soc., Perkin Trans. 1* **1988**, 1729. (c) Fürstner, A.; Hupperts, A. *J. Am. Chem. Soc.* **1995**, *117*, 4468.

(8) (a) Cintas, P. *Activated Metals in Organic Synthesis*; CRC Press: Boca Raton, **1993**. (b) Fürstner, A. *Active Metals—Preparation, Characterization, Applications*; VCH: Weinheim, **1996** and references therein.

(9) McMurry, J. E.; Fleming, M. P.; Kees, K. L.; Krepski, L. R. *J. Org. Chem.* **1978**, *43*, 3255.

reaction induced by iodine is also useful in performing the carbonyl coupling reaction chemoselectively in the presence of reducible functionalities, viz. aryl-OMe and alkyl and aryl halides which are otherwise incompatible

Table 2. Reductive Coupling of Carbonyls (1) to Olefins (3) at Low Temperature Using TiCl₃-Li-THF-I₂

entry	R ₁	R ₂	compd	time (h), temp (°C)	% yield ^a (<i>E/Z</i>) ^b of 3	ref
1	2-naphthyl	CH ₃	1b, 3b	8, 25	69 (48/52)	2d
2	2-naphthyl	CH ₃	1b, 3b	6, 0–5	93 (64/36)	2d
3	Ph	Ph	1c, 3c	5, 25	95	9
4	Ph	H	1d, 3d	3, 0–5	85 (only <i>E</i>)	7c
5	4-Cl-C ₆ H ₄	H	1e, 3e	2.5, 0–5	82 (only <i>E</i>)	2d
6	4-MeO-C ₆ H ₄	H	1f, 3f	3.5, 0–5	62 ^c (only <i>E</i>)	1d
7	Ph	(CH ₂) ₂ Cl	1g, 3g	5, 0–5	69 ^d	2e
8	<i>n</i> -C ₇ H ₁₅	H	1h, 3h	8, 25	80	7b
9	PhCH ₂	H	1i, 3i	4, 25	79	2e
10	<i>e</i>	<i>e</i>	1j, 3j	5, 25	88	9
11	<i>f</i>	<i>f</i>	1k, 3k	6, 25	71	9
12	<i>i</i> -Pr	<i>i</i> -Pr	1l, 3l	8, 25	59	9

^a All yields refer to isolated products (purity > 95%, analyzed by ¹H NMR); fully characterized by IR and ¹H NMR. ^b Ratios determined by ¹H NMR analysis of crude product mixtures as reported^{1d,2d,7c,11} in the literature. ^c 11% of **2d** was also formed. ^d 6% of 3,4-diphenylhex-3-ene was also isolated. ^e R₁, R₂ corresponds to cyclohexanone. ^f R₁, R₂ corresponds to cyclopentanone.

under reflux conditions^{10a–c} (Table 2, entries 5–7). Thus, the addition of I₂ not only accelerates McMurry's olefination at lower temperatures but also offers excellent chemoselectivity.

The isomeric ratio (*E/Z*) of the diastereomeric olefins **3a**, **3b**, and **3d–f** were determined on the basis of ¹H NMR spectroscopic data as is reported^{1d,2d,7c,11} in the literature. The stereochemical assignment of the tetra-substituted 2,3-biaryl olefin, i.e., 2,3-bis(2'-naphthyl)-2-butene (**3b**), obtained from 2-naphthyl methyl ketone (**1b**), was made by comparing the resonances of the allylic methyl protons for the *Z* (downfield signals) and *E* (upfield signals) isomers similar to the configurational assignments of 2,3-diphenyl-2-butene (**3a**) by Andersson.¹¹ A chromatographically pure diastereoisomeric mixture was used for the analysis.

Effect on Diastereoselectivity. The stereoselectivity during olefination is a function of the number of interdependent variables,^{1a–c} such as solvent, the nature of the active reagent (valences etc.), external auxiliaries,^{2d} temperature, and steric bulk of the groups. Stereoselectivity is therefore, amenable to tuning by judicious designing of reagents and reaction conditions.^{1b} In the present investigation it has been observed that the olefination at lower temperatures is attended with enhanced diastereoselectivity as compared to those obtained under higher temperatures and on prolonged reaction times. Thus, the reaction of acetophenone (**1a**) with reagent A required reflux conditions and generated the *E* isomer¹¹ of 2,3-diphenyl-2-butene (**3a**) (75%, Table 3, entry 1). However, using reagent B with the low-temperature pathway, *E* selectivity in **3a** could be augmented. Reactions at 0–5 °C and –40 °C were attended with 80% and 92% of *E* selectivity, respectively (Table 3, entries 4 and 5), offering enhanced diastereoselectivity. In the case of 2-naphthyl methyl ketone (**1b**), reaction with reagent A was attended with the preferential formation of the *Z* isomer (63%) of 2,3-bis(2'-naphthyl)-2-butene (**3b**) (Table 3, entry 6). However, in the presence of iodine (reagent B) complete reversal of the stereoselectivity in **3b** was observed on going down gradually to 0–5 °C (Table 3, entries 7 and 8).

***O/N*-Debenzylation/Deallylation with Reagent B.** The scope of the reagent B for other SET-induced

Table 3. Low-Temperature McMurry Reaction: Effect on Stereoselectivity

entry	substrate	reagents ^a	time (h), temp (°C)	stilbene (% yield)	<i>E/Z</i> ratio ¹¹
1	1a	A	16, reflux	3a (89)	75:25
2	1a	B	2, reflux	3a (80)	52:48
3	1a	B	2, 25	3a (92)	74:26
4	1a	B	2, 0–5	3a (90)	80:20
5	1a	B	2, –40	3a (75)	92:8
6	1b	A	16, reflux	3b (74)	37:63
7	1b	B	8, 25	3b (69)	48:52
8	1b	B	6, 0–5	3b (93)	64:36

^a A = TiCl₃-Li-THF, B = TiCl₃-Li-THF-I₂

reactions invented in our laboratory was also investigated. Thus, in a new approach to deprotection of alcohols/phenols, efficient protocols for LVT-mediated *O*-allyl/benzyl/propargyl bond cleavages were reported.^{12a,b} Although, *O*-benzyl/allyl ethers undergo cleavage readily, the reactions with *N*-allyl/benzylamines^{10b} are comparatively slow and require prolonged reflux (~22 h). In addition, the yields of *N*-allyl/benzyl bond cleavages are lower compared to their oxygen counterparts. It was therefore anticipated that the use of the activated LVT-I₂ system would enhance the yields of the reactions. Hence, a systematic study of the effect of LVT-I₂ system on otherwise sluggish and low-yielding *O/N*-debenzylation/deallylation was also carried out.

In a model reaction, when *N*-allyl-*N*-benzylaniline (**6a**) was subjected to the LVT-I₂ system (Scheme 2), the regioselective deallylation to *N*-benzylaniline (**6b**) at 25 °C required 16 h (76%, Table 4, entry 2). However, the yield of **6b** dropped down to 49% when the reaction was repeated in absence of iodine (reagent A) and required reflux temperature (Table 4, entry 1).

Generality and Utility. To explore the scope of the protocol, reactions were performed using a variety of *N/O*-benzyl/allyl substrates (Scheme 2). The cleavage of *O*-allyl bond in 4-(2-propenyloxy)biphenyl (**7a**) is facilitated when iodine-activated LVT species is used. Even at –10 °C, the deprotected 4-phenylphenol (**7b**) was obtained in a yield of 83% in only 1 h, while without I₂ **7b** was produced at reflux temperature (72%, 3 h) (Table 4, entries 3 and 4). The iodine-promoted mild protocol for the *N/O*-debenzylation has also been successfully employed for the removal of the benzyl moiety used for

(10) (a) Tyrlik, S.; Wolochowicz, I. *J. Chem. Soc., Chem. Commun.* **1975**, 781. (b) Talukdar, S.; Banerji, A. *Synth. Commun.* **1995**, *25*, 813. (c) Talukdar, S.; Banerji, A. *Synth. Commun.* **1996**, *26*, 1051.

(11) Isomeric ratio of **3a** are established using spectroscopic data, see: Andersson, P. G. *Tetrahedron Lett.* **1994**, *35*, 2609.

(12) (a) Kadam, S. M.; Nayak, S. K.; Banerji, A. *Tetrahedron Lett.* **1992**, *33*, 5129. (b) Nayak, S. K.; Kadam, S. M.; Banerji, A. *Synlett.* **1993**, 581.

Scheme 2

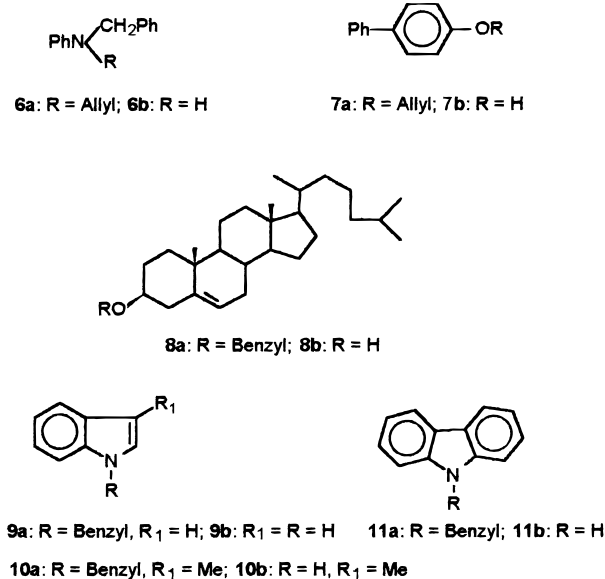


Table 4. Cleavage of *N/O*-Allyl/Benzyl Bonds Using TiCl₃-Li-THF-I₂ Reagent

entry	substrate	reagents ^a	time (h), temp (°C)	product (% yield ^b)	ref
1	6a	A	18, reflux	6b (49)	10b
2	6a	B	16, 25	6b (76)	10b
3	7a	A	3, reflux	7b (72)	12b
4	7a	B	1, -10	7b (83)	12b
5	8a	A	12, reflux	8b (60)	13
6	8a	B	5.5, 25	8b (79)	13
7	9a	B	16, 25	9b (85)	2e
8	9a	A	16, reflux	9b (52)	2e
9	10a	B	16, 25	10b (75)	2e
10	11a	B	16, 25	11b (80)	15b

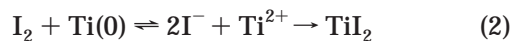
^a As is described in Table 3. ^b All yields refer to isolated products (purity > 95%, analyzed by ¹H NMR); fully characterized by IR and ¹H NMR.

the protection¹³ of the hydroxyl group in cholesterol. Debonylation of 3-(phenylmethoxy)cholest-5-ene (**8a**) using reagent A gave cholesterol (**8b**) in a yield of 60% after 12 h at reflux (Table 4, entry 5). However, using reagent B, the yield of the transformation increased to 79%, requiring only 5.5 h at 25 °C (Table 4, entry 6).

The improved method for the deprotection of alcohols and amines has been extended to indole and its derivatives. Protection of the indole nitrogen plays an important role in synthetic indole chemistry, including synthesis of indole natural products.¹⁴ Although the benzyl group is the most useful protecting group for indolic nitrogen, only limited methods are available for their deprotection.^{15a,b} However, using LVT-I₂ reagent, *N*-debonylation of a variety of indoles could be easily performed under milder conditions with high yields. Thus, the *N*-benzyl indole (**9a**) could be cleaved readily at 25 °C with 85% conversion (Table 4, entry 7). However, in the absence of I₂, debonylation results in only a

yield of 52% indole (**9b**) (Table 4, entry 8) at reflux temperature. Likewise, when *N*-benzyl skatole (**10a**) was subjected to reagent B, smooth deprotection produced skatole (**10b**) at 25 °C (75%) (Table 4, entry 9). Similarly, *N*-benzylcarbazole (**11a**) underwent ready cleavage of the benzyl moiety triggered by the LVT-I₂ reagent (Table 4, entry 10). Thus, the present protocol enhances the scope of the benzyl group for the *N*-protection of indoles.

Mechanistically, LVT species, generated in situ by the reduction of TiCl₃ with Li, is a suspension of titanium mostly in the zero valence state.^{1a} The significant role of chemical redox agents in influencing the electron-transfer reactions resulting in the chemical activation of organometallic complexes was comprehended in recent times.^{4a,b} It is proposed that, in the present case, the addition of iodine to the Rieke's LVT reagent drives the reaction toward the formation of TiI₂ species, demanded by the respective redox potential¹⁶ values (eq 2). TiI₂, in turn, disproportionates to a very reactive TiI species (eq 3), resulting in an increase in nascent, active reagents (probably the TiI₂-Ti system). This postulation is similar to the one for the activation of magnesium by iodine.¹⁷



Conclusions

An efficient protocol for the generation of highly reactive LVT reagent by using substoichiometric amounts of iodine has been developed. Compared to Rieke's activated LVT (TiCl₃-Li-THF) species, the present highly reactive LVT-I₂ (0.25 equiv) reagent displays unique reactivity wherein olefins can be generated directly from the carbonyls at 0 °C or even lower temperatures and at a faster rate as compared to the conventional high-temperature couplings. It features an enhanced chemo- and diastereoselectivity. The present reagent also performs the intramolecular keto ester coupling under milder conditions. In addition, SET-induced cleavage of *O/N*-allyl/benzyl bonds is influenced by the activated reagent. An expedient method for the debonylation of indoles and alcohols/phenols or amines has been formulated. The present investigation highlights the involvement of chemical redox agents in the organometallic electron transfer processes. This protocol is likely to find wider applications in preparative organic chemistry. It presents a unique conceptual advance which further defines its scope and applicability in classical McMurry reaction, particularly in the domain of oxygenated natural products. Insights enumerated herein open the doors on a variety of fronts for further endeavors using organometallic reagents and will encourage the use of redox agents for fine-tuning of their reactivities under redox potential control. Further studies in this direction for the preparation of novel LVT-based reagents using metal arenes as potential reductants for titanium halides are presently under investigation in this laboratory.

(13) Akiyama, T.; Hirofujii, H.; Ozaki, S. *Tetrahedron Lett.* **1991**, 32, 1321.

(14) Ketcha, D. M.; Lieurance, B. A.; Homan, D. F. *J. Org. Chem.* **1989**, 54, 4350.

(15) (a) Green, T. W.; Wuts, P. G. M. *Protective Groups in Organic Synthesis*, 2nd ed.; John Wiley & Sons: New York, 1991. (b) Sujuki, H.; Tsukuda, A.; Konda, M.; Aizawa, M.; Senoo, Y.; Nakajima, M.; Watanabe, T.; Yokoyama, Y.; Murakami, Y. *Tetrahedron Lett.* **1995**, 36, 1671.

(16) Standard reduction potentials (*E*⁰) of Ti²⁺/Ti and I₂/2I⁻ systems are -1.63 V and +0.54 V respectively, see: Braun, R. D. *Introduction to Instrumental Analysis*; McGraw-Hill International Edition: New York, 1987; p 700.

(17) Lai, Y.-H. *Synthesis* **1981**, 585.

Experimental Section

General Methods. General information regarding instruments, techniques, and source of chemicals used is the same as mentioned in our previous publication.^{2d} Lithium rods cut into small pieces were used for the reduction of titanium chlorides.

General Procedure for Iodine-Promoted LVT-Induced Carbonyl Couplings and *N,O*-Debenzylations/Deallylations. A mixture of TiCl_3 (1.55 g, 10 mmol) and Li (0.231 g, 33 mmol) in dry THF (50 mL) was refluxed (3 h, argon). After cooling, iodine crystals (0.635 g, 2.5 mmol) were added in portions and the mixture was stirred (5 min). On addition of iodine, the black suspension of LVT gradually turned brown. To the activated LVT-I_2 reagent, thus prepared, was added a carbonyl compound or *O,N*-allyl/benzyl derivative of ethers or

amines (2.5 mmol, 5 mL of THF). The reaction mixture was then stirred at different temperatures as indicated in Tables 1–4 for respective substrates. After completion (TLC), it was diluted with hexane and passed through Celite. Extraction with an ethyl acetate–hexane (20:80) mixture, followed by washing with brine and drying over Na_2SO_4 , yielded the crude product which was purified by preparative TLC (SiO_2 , hexane) to furnish olefins or the deprotected phenols/alcohols or amines.

All the products are known compounds and were characterized by comparison (mp, ^1H NMR, IR) with the literature data (references are presented in the Tables 1–4) for authentic samples.

JO971751V