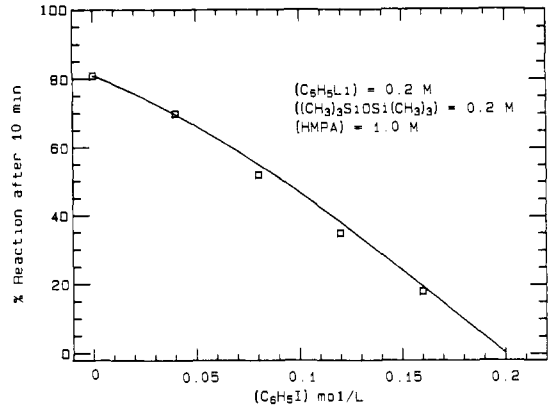

Figure 3. Effect of iodobenzene on the rate of reaction of phenyllithium with hexamethyldisiloxane in THF/1.0 M HMPA at −78 °C (test 3). The points are experimental, the line was calculated by using $k_3 = 3.55 \times 10^{-4}$ L mol^{-1} s^{-1} (test 3) and $K = 1.2 \times 10^{-7}$ L mol^{-1} (eq 1).

hydrofuran, in contrast to early results of Wittig, Meyer, and Lange, who demonstrated both by vapor pressure osmometry and a metalation test that no interaction occurs in *ether*.[10] This result prompted us to study solvent effects on the iodine system (eq 1) by running test 2 in solutions containing hexamethylphosphoric triamide (HMPA). The small difference between the control and C_6H_5Li/C_6H_5I runs in THF rapidly became very large with increasing HMPA concentration (Figure 2). In fact, *the addition of HMPA to a solution of C_6H_5Li/C_6H_5I actually lowers its reactivity*. Apparently, increases in concentration of the (presumably unreactive) complex **3** as HMPA concentration was increased more than compensated for the higher reactivity of the remaining free phenyllithium. This dramatic solvent effect can be understood in terms of the differences in solvation requirements for the two sides of eq 1. In contrast to phenyl anion, which binds tightly to lithium in a cyclic dimeric structure,[11] the diphenyliodinate anion probably cannot provide a good coordination site for lithium cation, and hence its formation is strongly favored by improved solvation of Li^+.

To more carefully define the stoichiometry of the interaction between phenyllithium and iodobenzene in solutions containing HMPA, test 3 was developed. Figure 3 presents the results of

Test 3

$$C_6H_5\text{-}Li + C_6H_5M + (CH_3)_3SiOSi(CH_3)_3 \xrightarrow{k_3} C_6H_5\text{-}Si(CH_3)_3 + LiOSi(CH_3)_3$$

this test. The reactivity of the solution decreased monotonically as iodobenzene was added. The complexation is now essentially quantitative and occurs with exact 1:1 stoichiometry.[8] If the assumption is again made that the reaction follows second-order kinetics and that the complex is unreactive toward hexamethyldisiloxane, a value of $K > 1.2 \times 10^7$ L mol^{-1} can be estimated.[12]

Attempts to observe the complex **3** by ^{13}C NMR spectroscopy have been frustrated by the occurrence of rapid exchange processes.

The results presented here demonstrate that phenyllithium and iodobenzene interact reversibly in a strongly solvent-dependent fashion to form a 1:1 complex which we believe is the hypervalent iodine "ate" complex $(C_6H_5)_2I^-Li^+$ (a 10-I-2 anion[13]). This result has direct bearing on understanding the mechanism of the metal–halogen exchange, which we feel is best represented as proceeding via a discrete "ate" complex (e.g. **2**, **3**) intermediate. Further studies on other lithium–metalloid exchanges are in progress.

Acknowledgment. We thank the donors of the Petroleum Research Fund, administered by the American Chemical Society, and the National Science Foundation for financial support. Mark Dorow and Dr. Steven L. Peake performed preliminary experiments and we thank them for their contribution to this project.

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(12) This result is based on the formation of less than 0.04% of $C_6H_5Si(CH_3)_3$ when test 3 was run for 96 h at −80 °C with 2 equiv of iodobenzene. If the complex (presumably $(C_6H_5)_2I^-Li^+$) is itself reactive toward hexamethyldisiloxane, then the equilibrium constant would be correspondingly larger. From the results obtained it can be calculated that the "ate" complex is $<10^{-5}$ as reactive as phenyllithium.

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Reaction of Cyanomethyl Complex $(\eta^5\text{-}C_5H_5)Re(NO)(PPh_3)(CH_2CN)$ with *n*-BuLi/TMEDA; Generation, Stereospecific Alkylation, and Basicity of a Transition-Metal-Substituted Carbanion

Guy L. Crocco and J. A. Gladysz*

Department of Chemistry, University of Utah
Salt Lake City, Utah 84112

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Transition-metal alkyls are the cornerstone of organometallic chemistry. However, little is known regarding the acid/base chemistry of the C–H bonds of alkyl ligands. In particular, the deprotonation of neutral metal alkyl complexes at C_α, as depicted in eq i, is to our knowledge unprecedented.[1] We have begun to

$$L_nMCH_2X + B:^- \rightarrow [L_nM\ddot{C}HX]^- + BH \qquad \text{(i)}$$

probe the acid/base chemistry of chiral cyclopentadienyl rhenium alkyl complexes[2] and report here (1) the first deprotonation of a neutral metal alkyl complex at the ligating carbon, (2) the stereospecific alkylation of the resulting conjugate base, and (3) a qualitative determination of the effect of the rhenium moiety upon the C_α–H ion pair acidity.[3]

Reaction of cyanomethyl complex $(\eta^5\text{-}C_5H_5)Re(NO)(PPh_3)(CH_2CN)$ (**1**, in THF)[4] with *n*-BuLi/TMEDA (1.0 equiv, −78 °C) and then $CH_3OSO_2CF_3$ gave cyanoethyl complex (*SR,RS*)-$(\eta^5\text{-}C_5H_5)Re(NO)(PPh_3)(CH(CH_3)CN)$ ((*SR,RS*)-**2**) in 75% yield upon workup (eq ii).[5] The gross structure of (*SR,RS*)-**2** followed readily from its spectroscopic properties,[5] and its stereochemistry was established by an independent synthesis of the opposite diastereomer, (*SS,RR*)-**2**. Diastereomer (*SS,RR*)-**2** was obtained in 91% yield from the reaction of $PPN^+{}^-CN$[6] with "kinetic" ethylidene complex *sc*-$[(\eta^5\text{-}C_5H_5)Re(NO)(PPh_3)(=CHCH_3)]^+PF_6^-$ (**3**, eq iii).[7] Nucleophilic additions to this[7] and related[8] alkylidene complexes have been shown to preferentially occur from a direction anti to the PPh_3, enabling

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(5) Microanalytical, mass spectral, IR, and NMR (^1H, ^{13}C, ^{31}P) data for each new compound are given in the supplementary material. Isotopically labeled compounds were synthesized by modifications of published routes to unlabeled compounds. For all compounds, the absolute configuration at rhenium is specified first.

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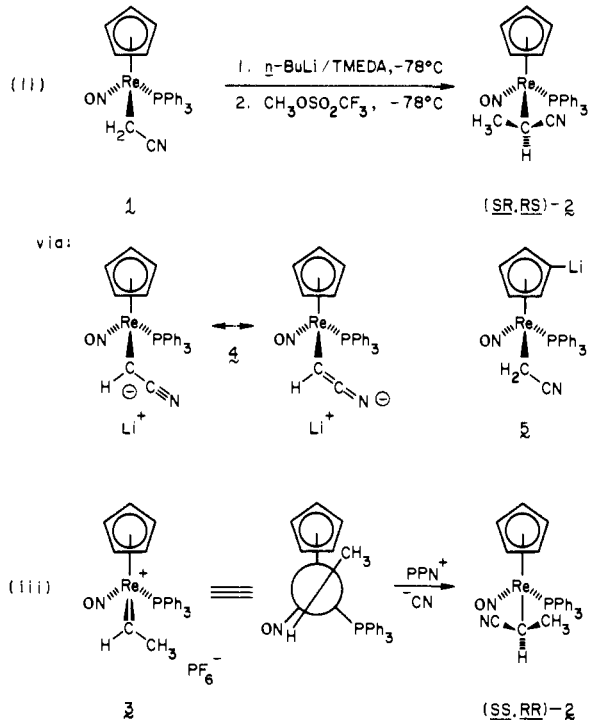

a rigorous assignment of product stereochemistry. Complex (*SS,RR*)-**2** was not formed (detection limit, <1%) in eq ii, as determined by ^{1}H NMR, ^{31}P NMR, and HPLC analyses of the crude reaction mixture.

Evidence was sought for the apparent precursor to (*SR,RS*)-**2**, deprotonated complex $Li^+[(\eta^5\text{-}C_5H_5)Re(NO)(PPh_3)(\ddot{C}HCN)]^-$ (**4**).[3a] The reaction of **1** with *n*-BuLi/TMEDA was monitored by ^{31}P NMR at −98 °C. Two resonances (32.15 ppm, br; 25.71 ppm, sh) appeared immediately. The relative areas of these resonances (ca. 2:1) did not change over the course of 3 h. Upon warming (−78 °C, 2.5 h, or −25 °C, 0.5 h), the 25.71 ppm resonance disappeared and the 32.15 ppm resonance sharpened. The spectrum was unchanged by subsequent cooling (−98 °C, 3 h). Addition of $CH_3OSO_2CF_3$ to any of these solutions (−98, −78, −25 °C) gave exclusively (*SR,RS*)-**2**, as observed by ^{31}P NMR monitoring.

Deuterium labeling experiments were conducted to provide additional information on the intermediates described above. Reaction of $(\eta^5\text{-}C_5H_5)Re(NO)(PPh_3)(CD_2CN)$ (**1**-d_2; 91:9 d_2/d_1)[5] with *n*-BuLi/TMEDA and $CH_3OSO_2CF_3$ as in eq ii gave a 31:69 mixture of (*SR,RS*)-**2**-d_2/(*SR,RS*)-**2**-d_1, as determined by mass spectral analysis. An identical reaction of $(\eta^5\text{-}C_5D_5)Re(NO)(PPh_3)(CH_2CN)$ (**1**-d_5; 86:14 d_5/d_4) gave a 62:38 mixture of (*SR,RS*)-**2**-d_5/(*SR,RS*)-**2**-d_4. These data indicate that **1** can be deprotonated either on the CH_2CN ligand (major) to give **4** (32.15 ppm) or the $\eta^5\text{-}C_5H_5$ ligand (minor) to give $(\eta^5\text{-}C_5H_4Li)Re(NO)(PPh_3)(CH_2CN)$ (**5**, 25.71 ppm). Interestingly, only (*SR,RS*)-**2** is obtained when $CH_3OSO_2CF_3$ is added to mixtures of **4** and **5** at temperatures where **4** and **5** do not (or are slow to) equilibrate. One possible explanation is that initially formed (*SR,SR*)-**2** might equilibrate **4** and **5**. Such equilibrations have abundant precedent in organic enolate alkylations.[9]

We sought to determine whether the ion pair acidity[3] of **1** was greater or less than that of CH_3CN ($pK_a(H_2O)$ = 31.5).[10] Hence, in a ^{31}P NMR monitored experiment, **4** (−78 °C) was treated with 3 equiv of CD_3CN. Immediate conversion to **1**-d_x occurred. The solution was kept at 25 °C for 8 h. The **1**-d_x was isolated and shown to be extensively deuterated (d_0:d_1:d_2:d_3:d_4:d_5:d_6:d_7 = <1:6:12:20:31:21:9:1). This established that **4** was not quenched by adventitious proton sources, and that additional H/D exchange between **1** and the resulting $^-CD_2CN$ occurred. Hence, **1** is less acidic than CH_3CN, and the $(\eta^5\text{-}C_5H_5)Re(NO)(PPh_3)$ moiety can be considered a carbanion destabilizing substituent.

Extensions of the above chemistry were explored. First, reaction of **1** with *n*-BuLi/TMEDA and then *n*-C_4H_9I as in eq ii gave (*SR,RS*)-$(\eta^5\text{-}C_5H_5)Re(NO)(PPh_3)(CH(n\text{-}C_4H_9)CN)$ ((*SR,RS*)-**6**)[5] in 53% yield after workup. The product stereochemistry and the reaction stereospecificity were established exactly as was done for (*SR,RS*)-**2** in eq ii and iii. Second, reaction of (*SR,RS*)-**2** with *n*-BuLi/TMEDA and then $CH_3OSO_2CF_3$ as in eq ii gave methylcyclopentadienyl complex (*SR,RS*)-$(\eta^5\text{-}C_5H_4CH_3)Re(NO)(PPh_3)(CH(CH_3)CN)$ ((*SR,RS*)-**7**)[5] in 84% yield upon workup. This reaction proceeded cleanly via an intermediate with a ^{31}P NMR resonance (25.15 ppm) very close to that of **5**. Accordingly, this species is assigned the structure $(\eta^5\text{-}C_5H_4Li)Re(NO)(PPh_3)(CH(CH_3)CN)$ (**8**).

In conclusion, we have established that transition-metal alkyls can be deprotonated as in eq i and that the resulting conjugate base can, when appended to the chiral $(\eta^5\text{-}C_5H_5)Re(NO)(PPh_3)$ moiety, be stereospecifically alkylated. Since the rhenium–carbon σ bond in $(\eta^5\text{-}C_5H_5)Re(NO)(PPh_3)(R)$ complexes can be cleaved with high stereoselectivity both at rhenium and carbon,[11] these transformations should have utility in asymmetric organic synthesis. Efforts to understand the basis for the stereospecificity of eq ii, and to synthesize other transition-metal substituted carbanions, are in progress.

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Supplementary Material Available: Table of microanalytical, mass spectral, IR, and NMR (^{1}H, ^{13}C, ^{31}P) data for new compounds (4 pages).[5] Ordering information is given on any current masthead page.

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Structure of the Alkali-Labile Product Formed during Iron(II)–Bleomycin-Mediated DNA Strand Scission

Hiroshi Sugiyama, Cheng Xu, Natesan Murugesan, and Sidney M. Hecht*

Departments of Chemistry and Biology
University of Virginia
Charlottesville, Virginia 22901

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The bleomycins are a group of glycopeptide-derived antibiotics employed clinically for the treatment of certain malignancies including squamous cell carcinomas and Hodgkin's disease.[1] The bleomycins appear to mediate their therapeutic effects primarily at the level of DNA strand scission,[2] a transformation that can be effected by any of four metallobleomycins.[3] The O_2-dependent

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