

DIRECT EVIDENCE FOR AN ELECTRON TRANSFER
MECHANISM IN THE REACTIONS OF LITHIUM THIOALKOXIDES WITH ORGANIC SUBSTRATES

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The degree of polar and radical character exhibited in reactions of metal alkyls, metal hydrides and typical nucleophiles ($M-Y$, where $Y = OR, SR$ and NR_2) with various organic substrates has been the subject of considerable interest for several years.¹⁻³ The mechanisms of these reactions have been proposed mainly on the basis of studies such as: stereochemical observations, kinetics, product formation and radical trapping. Recently we demonstrated the involvement of a single electron transfer (SET) pathway in reactions of main group metal alkyls, metal hydrides, metal alkoxides and metal amides with organic substrates such as alkyl halides, polynuclear hydrocarbons and dimesityl ketone.^{2,4} Although these reactions, in general, were regarded previously as nucleophilic in nature, the occurrence of SET has been clearly established by spectroscopic (visible and EPR) studies as well as by product formation studies using cyclizable probes. In view of these results, we have decided to extend our studies to include other nucleophilic species such as lithium thioalkoxides which have been considered to participate as class nucleophiles in reactions which have been considered to be classic S_N2 processes.

Involvement of SET mechanisms in nucleophilic displacement reactions involving $LiSPh$ with alkyl halides has been recently suggested on the basis of radical trapping experiments.⁵ However, stereochemical studies concerning the reaction of *S*-2-octylsulfate with $LiSPh$ failed to provide any evidence in support of a radical intermediate and produced exclusively *R*-2-octylphenyl sulfide as the product, with complete inversion of configuration. In the course of our present studies on reactions of $LiSBu^n$ and $LiSPh$ with organic substrates such as aromatic ketones (benzophenone and dimesityl ketone, DMK), trityl halides (Ph_3CX ; where $X = Cl$ or Br) and polynuclear hydrocarbons (perylene, 2,3-benzanthracene and benz(a)pyrene), we have obtained direct (EPR spectroscopic) evidence supporting a SET mechanism. To the best of our knowledge these observations represent the first direct evidence ever to be obtained in such reactions.

Reaction of $LiSBu^n$ with benzophenone in THF at room temperature slowly produced a blue colored intermediate which was found to be paramagnetic in nature and exhibited a complex EPR spectrum (Fig. 1). The EPR spectrum was found to be different than that of free lithium benzophenone ketyl, $Ph_2\dot{C}OLi$. The intensity of the EPR signal increased slowly with time and the amount of radical intermediate after four days was $\approx 8\%$. Slow formation of the reduction product, Ph_2CHOH , was observed during the course of the reaction. The reaction produced only $\approx 3\%$ of the reduction product after four days.

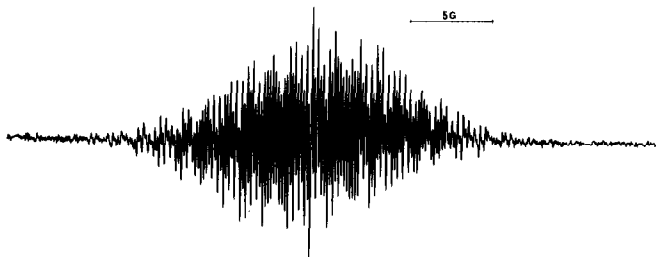
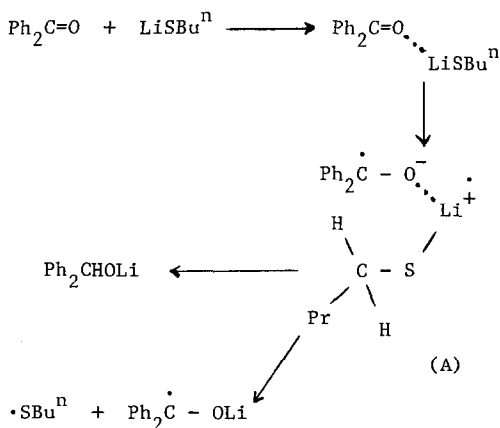


Figure 1: EPR spectrum of the radical intermediate formed in the reaction of benzophenone with LiSBu^n in THF at room temperature.

Since the EPR spectrum of the intermediate was found to be different from that of the free ketyl, it is quite likely that the spectrum is probably due to a radical pair intermediate (A in Scheme 1), similar to that we proposed earlier to describe the reaction of $\text{Mes}_2\text{C}=\text{O}$ with metal hydrides. Upon hydrolysis, such a radical pair normally reverts back to the starting ketone. The reduction of benzophenone to benzhydrol is probably occurring via a β -hydrogen atom transfer from the *n*-butylthiol radical. This process is similar to that of the Meerwein-Ponndorf-Verley reduction of benzophenone by alkoxide reagents which we also found recently to possess some radical character.⁶ The slow formation of reduction product in the case of the thioalkoxide reaction compared to the alkoxide reaction is probably due to the larger steric effect of the thioalkoxide reagent.

SCHEME 1



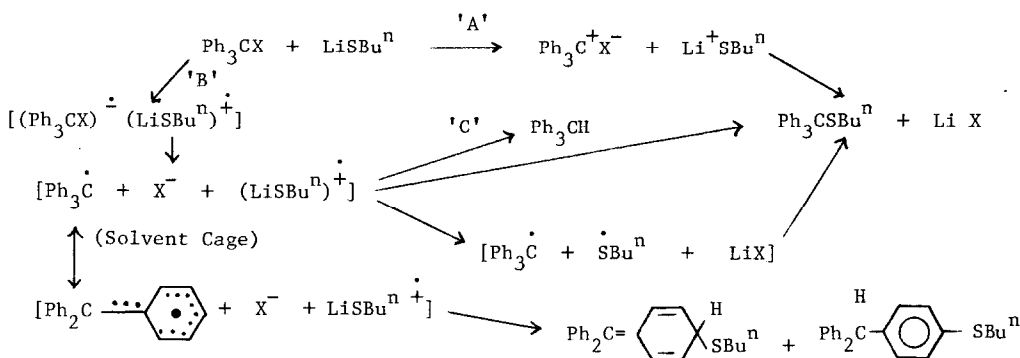
Formation of reduction product via a β -hydrogen atom transfer process is further supported by the fact that when LiSPH was allowed to react with benzophenone, no reduction product was observed, although the formation of a radical intermediate was confirmed by EPR spectroscopy. Incidentally,

the rate of electron transfer in the reaction of LiSPh with benzophenone was found to be much slower compared to the reaction of LiSBu^n with benzophenone. Additionally, the reaction of LiSPh was found to be sensitive to light. The difference between the reactivity of LiSBu^n and LiSPh can be related to the nucleophilicity of the reagents.³ Both of these reagents reacted with the sterically bulky dimesityl ketone to give a radical intermediate, however, in both cases, no reduction product formed.

LiSBu^n and LiSPh reacted readily with trityl halides (Ph_3CX ; where $\text{X} = \text{Cl}$ or Br) in THF at room temperature and the trityl radical $\text{Ph}_3\text{C}\cdot$ was observed (by EPR spectroscopy) in all cases. The concentration of the radical increased rapidly with time and reached a maximum within a few minutes (estimated maximum concentration of radical $\approx 1\text{-}10\%$). Beyond the maximum, the radical concentration decreased slowly with the concurrent formation of product. The products of the reactions were formed throughout the entirety of the reactions, i.e., during the increase as well as the decrease of the radical concentration.

The reactions of LiSBu^n with trityl halides produced reduction product (Ph_3CH) as well as substitution products [Ph_3CSBu^n and $\text{Ph}_2\text{CH}(\text{C}_6\text{H}_4\text{SBu}^n)$] whereas the reaction of LiSPh with trityl halides produced only substitution products. The formation of reduction product (Ph_3CH) in the former reaction can be explained on the basis of a β -hydrogen atom abstraction by trityl radical within the solvent cage, as demonstrated in Scheme 2.

SCHEME 2



'A' = Polar mechanism; 'B' = SET mechanism; 'C' = β -hydrogen atom abstraction.

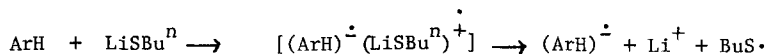
In the above reaction (Scheme 2) if the coupling of trityl radical with thiol radical is relatively fast compared to hydrogen atom abstraction, then the substitution product is expected to predominate. However, if the rate of hydrogen atom abstraction is faster than radical coupling, then the formation of Ph_3CH is expected to predominate. The coupling of radicals to give substitution products should be dependent on the steric parameters of the radicals. Indeed, when LiSBu^n was allowed to react with Ph_3CBr , Ph_3CH in $\approx 45\%$ yield was formed, whereas when LiSBu^n was allowed to react with sterically less bulky Ph_2CBr , almost exclusively only substitution products were formed. In

the latter reaction, if the radical intermediate $\text{Ph}_2\dot{\text{C}}\text{H}$ was formed, it would have reacted with the thiol radical at a much faster rate compared to the β -hydrogen abstraction process. A similar conclusion was drawn in the reaction of LiSPh with S-2-octylsulfate which yielded the completely inverted product without giving any racemization (rate of radical coupling faster than the rate of loss of optical activity). It is worth reporting here that in this reaction, the involvement of a radical process was suggested by the use of radical traps.⁵

In the reactions of LiSBu^{n} and LiSPh with trityl halides, the following observations were made: (a) the rate of radical intermediate formation as well as product formation was faster in the case of bromide than chloride; (b) the higher rates of both intermediate and product formation in the case of LiSBu^{n} , compared to that of LiSPh , is consistent with the nucleophilicity of the reagents; (c) both the reduction product ($\text{Ph}_3\dot{\text{C}}\text{H}$) as well as the substitution products were obtained in the reaction of trityl halides with LiSBu^{n} , whereas LiSPh gives only the substitution products.

SET reaction pathways have also been observed in reactions of LiSBu^{n} with polynuclear hydrocarbons of low reduction potential. When an excess of LiSBu^{n} (≈ 20 fold) was allowed to react with perylene, 2,3-benzanthracene and benz(a)pyrene in THF at room temperature, colored solutions formed that were EPR active. After mixing, the EPR signal increased slowly until after a week, radical concentrations measured to be about 10-30%. Heating the reactions increased the rate of electron transfer. The EPR spectra of the radical intermediates were found to be identical to that of the radical anions of the corresponding hydrocarbons thus suggesting the dissociation of the radical pair, into the radical anion, as shown in the following Scheme 3.

SCHEME 3



Characterization of the final product(s) of these reactions is in progress.

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