Sargent and Bank obtained much larger yields of dimeric hydrocarbons in their experiments on the reduction of alkyl iodides with sodium naphthalene in 1,2-dimethoxyethane.[1] In experiments performed since learning of their results, the fact that significant amounts of 2,3-dimethylbutane are formed from isopropyl iodide in this reaction has been confirmed in our laboratories, our conditions being somewhat different from theirs (lower concentrations).[7] It is also our understanding from Professor Sargent that bromides and chlorides give much diminished yields of dimeric hydrocarbons in their hands.[8] We agree with him that a possible source of the difference in behavior may lie in the greater reactivity of the iodides in the first, radical-producing step of the reaction, so that the higher peak transient concentration of radicals may make radical coupling much more favorable in the reactions of the iodides than for the bromides and chlorides. Other alternatives exist, but present data do not permit distinctions among these.

In principle, the relative rate constants for reactions 3 and 4 can be obtained from experiments such as ours. In practice, questions of efficiency of mixing and state of aggregation of sodium naphthalene at these relatively high concentrations render accurate, consistent, and meaningful values difficult to obtain. However, all our experiments thus far suggest that k_4/k_3 is at least 10^3 l. mole^{-1}. Since k_3 is probably at least near 10^5 sec^{-1} (from considerations of rates of reactions like (2) and the fact that (3) is much faster than (2)) k_4 is at least 10^8 l. mole^{-1} sec^{-1}, which is near the diffusion-controlled limit. It would not be unreasonable for a reaction such as (4) to be diffusion controlled.

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(7) Results of Mr. C. D. Smith.

(8) Conversation with Professor Sargent.

(9) We have recently learned of results of S. J. Cristol and R. V. Barbour (*J. Am. Chem. Soc.*, **88**, 4262 (1966)) which parallel those reported here in cholesteryl systems.

John F. Garst, P. Wayne Ayers, Robert C. Lamb
Department of Chemistry, The University of Georgia
Athens, Georgia 30601

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Radical Intermediates in the Oxygenation of a Grignard Reagent

Sir:

The oxygenation of the Grignard reagent prepared from either 1,2,6-tribromohexane or 6-bromo-1-hexene[1] yields both 5-hexen-1-ol and cyclopentylcarbinol in a ratio of about 3:1. In contrast, carbonation[2] and hydrolysis (dilute HCl) of the same Grignard reagent give open-chain and cyclic products in ratios of about 20:1. Neither oxygenation, nor carbonation, nor hydrolysis of the Grignard reagent formed from cyclopentylmethyl bromide results in open-chain products. Table I presents the data.

Table I. Reactions of Grignard Reagents[a]

Process	Products, %	
	From 6-Bromo-1-hexene	
Oxygenation	5-Hexen-1-ol, 74 (75)	Cyclopentylcarbinol, 26 (25)
Carbonation	6-Heptenoic acid, 95 (97)	Cyclopentylacetic acid, 5 (3)
Hydrolysis	1-Hexene, 93 (96)[b]	Methylcyclopentane, 7 (4)[b]
	From Cyclopentylmethyl Bromide	
Oxygenation	5-Hexen-1-ol, 0	Cyclopentylcarbinol, 100
Carbonation	6-Heptenoic acid, 0	Cyclopentylacetic acid, 100
Hydrolysis	1-Hexene, 0	Methylcyclopentane, 100

[a] Reactions carried out as described in ref 3. Yield figures in the table refer in each case to the distribution of products between the two indicated. The absolute yields, based on alkyl halide consumed in the Grignard preparations, were in each case 70–80%. The figures in parentheses refer to nonvacuum-manifold reactions, while the others refer to vacuum-manifold experiments. [b] The Grignard was prepared, in this case, from 1,2,6-tribromohexane. In general, Grignard preparations from this halide gave the same results, within experimental error, as those from 6-bromo-1-hexene.

These facts constitute strong evidence that the oxygenation of these Grignard reagents proceeds through free alkyl radicals.

Clearly, the Grignard preparations from the cyclopentylmethyl and 5-hexenyl bromides do not lead to the same mixture of Grignard reagents. The exclusively cyclic nature of the products derived from the cyclopentylmethyl bromide and the very small quantities of cyclic products obtained from the open-chain halides in the carbonation and hydrolysis of the reagents suggests strongly that the 5-hexenyl and cyclopentylmethyl Grignard reagents do not interconvert at all under our reaction conditions.[3,4] The small amounts of cyclic products obtained from the carbonation and hydrolysis reactions of the Grignard reagent prepared from open-chain materials are presumed to reflect the presence of like quantities of cyclopentylmethylmagnesium bromide in the Grignard reagent as initially prepared.[6]

The formation of cyclic product in the oxygenation therefore requires that some intermediate in the reac-

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(1) R. C. Lamb and P. W. Ayers, *J. Org. Chem.*, **27**, 1441 (1962).

(2) R. C. Lamb, P. W. Ayers, and M. K. Toney, *J. Am. Chem. Soc.*, **85**, 3482 (1963).

(3) Grignard reagents were prepared by direct reaction of magnesium metal with the halides in diethyl ether, with and without moderation of an ice bath. The preparations were carried out in rigorously degassed vessels on a vacuum manifold. Solvent was distilled into the vessels from storage over sodium benzophenone ketyl. The magnesium metal was pretreated by heating with dry iodine, after which the excess iodine was removed by evacuation. In some earlier, nonvacuum-manifold preparations, a nitrogen atmosphere was employed and the magnesium was untreated. Both methods led to the same final results. Gaseous carbon dioxide and oxygen were employed for carbonations and oxygenations, and syringes were employed for introducing dilute HCl in the hydrolyses. Oxygenation, carbonation, and hydrolyses were done both at room temperature (vacuum-manifold experiments) and ice-bath temperatures (earlier experiments). Analyses were by vapor phase chromatography.

(4) The lack of interconversion of the Grignard reagents is consistent with similar findings for the corresponding alkylsodium species in 1,2-dimethoxyethane, although in the latter case the organoalkali compounds were undoubtedly being destroyed quite rapidly, as they were formed, through reaction with the solvent.[5]

(5) J. F. Garst, P. W. Ayers, and R. C. Lamb, *J. Am. Chem. Soc.*, **88**, 4260 (1966).

(6) Cyclization during Grignard preparation would be expected if free radicals are involved in this process, as proposed by others.[7] The present observation constitutes additional evidence on this point.

(7) (a) C. Rüchardt and H. Trautwein, *Ber.*, **95**, 1197 (1962); (b) H. M. Walborsky and A. E. Young, *J. Am. Chem. Soc.*, **86**, 3288 (1964); (c) D. J. Patel, C. L. Hamilton, and J. D. Roberts, *ibid.*, **87**, 5144 (1965).

tion cyclize. This renders difficult the defense of any mechanism for the oxygenation of primary Grignard reagents in which the initial step is the addition of the Grignard reagent to oxygen, and in which the carbon oxygen bond thus formed is never thereafter ruptured.[8] On the other hand, the results conform to the predictions of mechanisms involving free-radical intermediates, since the tendency of the 5-hexenyl radical to cyclize to the cyclopentylmethyl radical is well documented.[2,5,9] The most reasonable pathways are those involving one-electron transfer from the Grignard reagent, reactions 1 and 2 being possible steps in such

$$\mathrm{RMgX} + \mathrm{O_2} \longrightarrow \mathrm{R}\cdot + \mathrm{XMgO_2} \tag{1}$$

$$\mathrm{RMgX} + \mathrm{ROO}\cdot \longrightarrow \mathrm{R}\cdot + \mathrm{ROOMgX} \tag{2}$$

mechanisms. Reaction 1 might be an initiation step of a chain process or simply the first step of a nonchain process. Reaction 2 might be a propagation step of a chain process. In any event, the cyclization of the 5-hexenyl radical would then compete with other reactions destroying that species.[10] Ample precedent and analogy for these reactions exists in the work of others, the most extensive pertinent studies being those of Russell and co-workers, who have presented evidence that many carbanion oxidations proceed *via* similar one-electron transfer processes, and specifically suggested the inclusion of Grignard oxidations in this family.[11]

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(8) C. Walling and S. A. Buckler, *J. Am. Chem. Soc.*, 77, 6032 (1955); also, C. Walling, "Free Radicals in Solution," John Wiley and Sons, Inc., New York, N. Y., 1957, pp 465–466. The radical scavenger experiments of Walling and Buckler bear directly on chain processes only. As they recognized, it is possible that no effect of inhibitors was observed because these were insufficiently reactive radical traps.

(9) (a) C. Walling and M. S. Pearson, *J. Am. Chem. Soc.*, **86**, 2262 (1964); (b) R. G. Garwood, C. J. Scott, and B. C. L. Weedon, *Chem. Commun.*, 14 (1965).

(10) Since the cyclization of 5-hexenyl cannot compete with cage reactions,[2] reaction 1 followed by cage recombination would lead exclusively to noncyclic alkyl hydroperoxide salt, an over-all result which is indistinguishable here from direct nucleophilic addition of the Grignard reagent to oxygen. If the usually formulated alkoxide producing reaction, RMgX + ROOMgX → 2 ROMgX,[8] is presumed to proceed *without* the intervention of radicals, and if it accounts for all the alkoxide, then at least 50% of the alkyl hydroperoxide must be produced through radical pathways. We prefer to postulate that it is 100%, but that the extent of cyclization is limited by competition of other reactions, including cage recombination, with the radical cyclization. It is possible that all noncyclic hydroperoxide arises in radical cage reactions and that all radicals escaping cage recombination cyclize, although the data certainly do not require this.

(11) A summary appears in G. A. Russell, E. G. Janzen, A. G. Bemis, E. J. Geels, A. J. Moye, S. Mak, and E. T. Strom, "Selective Oxidation Processes," Advances in Chemistry Series, No. 51, American Chemical Society, Washington, D. C., 1965, Chapter 10.

Robert C. Lamb, P. Wayne Ayers, Myron K. Toney, John F. Garst
Department of Chemistry, The University of Georgia
Athens, Georgia 30601
Received July 18, 1966

Electron-Transfer Reaction of Radical Anions with Cholesteryl and Cyclocholestanyl Chlorides

Sir:

Garst and his co-workers[1] have investigated the reaction of sodium naphthalene radical anion with 5-hexenyl and cyclopentylmethyl bromides and chlorides. The olefinic halides gave mixtures of 1-hexene and methylcyclopentane, in the C_6 hydrocarbon products, while only the latter C_6 hydrocarbon was observed in the reaction of the halomethylcyclopentanes. These authors concluded that electron transfer from the radical anion results in the formation of a free radical and halide ion, that the olefinic radical is partially cyclized to cyclopentylmethyl radical, and that the two organic radicals are converted by a second mole of radical anion to carbanions, which are then protonated by solvent.

We wish now to report our results on the reaction of sodium biphenyl radical anion with cholesteryl chloride (I) and β-cyclocholestanyl chloride (II), from which we have arrived at substantially identical conclusions. Our work in this system derived from our interest in homoallylic and cyclopropylcarbinyl free radicals.[2] Reduction of the isomeric chlorides led to monomeric hydrocarbon products in good yields (58–84%). Chloride I gave only 5-cholestene (III), while chloride II gave mixtures of III and 3α,5α-cyclocholestane (IV). These diverse results show that the radical and/or carbanion intermediates derived from I and II are different and do not equilibrate completely before being trapped, are consistent with our previous conclusions[2] regarding the nonexistence of nonclassical homoallylic radicals, and extend those conclusions to carbanions.

The product ratio, IV/III, from reduction of chloride II was observed to be independent of the hydrogen atom donating ability of the reaction medium (as classified on the Bridger–Russell scale[3]), using benzene, toluene, tetralin, and a 1 *M* solution of triphenyltin hydride in benzene as solvents, but depended quite markedly on the concentration of the sodium biphenyl radical anion and on the temperature of the reaction. For example, reaction of II with 0.01 *M* sodium biphenyl in 1,2-dimethoxyethane at 25° gave 11% IV and 89% III while reaction of II with 1.0 *M* sodium biphenyl at 25° gave 20% IV and 80% III. Reaction of II in 1.0 *M* sodium biphenyl at −20° yielded 41% IV and 59% III, while reaction at −70° yielded 60% IV and 40% III.

In each experiment the reaction was quenched after several minutes by addition of water to destroy excess radical anion, steam distillation to remove biphenyl, and column chromatography on 10% silver nitrate on neutral alumina; IV was obtained by elution with olefin-free *n*-pentane and III by elution with 5% benzene in Skellysolve B. Compounds IV and III were identified by comparison with authentic samples.[4]

Our results indicate that the course of the reduction of II involves the initial transfer of an electron from the radical anion to the chlorine atom resulting in the loss of chloride ion and formation of the cyclocholestanyl free radical V.[5]

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(1) J. F. Garst, P. W. Ayers, and R. C. Lamb, *J. Am. Chem. Soc.*, **88**, 4260 (1966).

(2) See, *inter alia:* S. J. Cristol and D. I. Davies, *J. Org. Chem.*, **29**, 1282 (1964), and S. J. Cristol, G. D. Brindell, and J. A. Reeder, *J. Am. Chem. Soc.*, **80**, 635 (1958).

(3) R. F. Bridger and G. A. Russell, *ibid.*, **85**, 3754 (1963).

(4) IV reported by F. S. Prout and B. Riegel, *ibid.*, **74**, 3190 (1952); III reported by W. G. Dauben and R. H. Takemura, *ibid.*, **75**, 6302 (1953).

(5) Dissociative electron capture by alkyl halides with resulting formation of halide ion and alkyl radical has been reported: R. F. Claridge and J. E. Willard, *ibid.*, **87**, 4992 (1965).