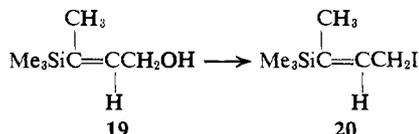


method suffers from the fact that the starting 3-chloro-2-butenol (from the hydrolysis of commercial 1,3-dichloro-2-butene, a mixture of *Z* and *E* isomers) is not stereochemically homogeneous. The final iodide is a 5:1 mixture of *Z* and *E* isomers.

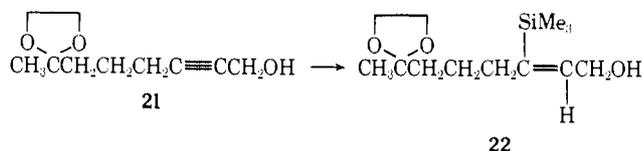
A similar mixture (*Z/E* 4:1) could be obtained more simply by sodium borohydride reduction of the unsaturated aldehyde **18**¹⁰ available in essentially two steps from propargyl *tert*-butyl ether.

The pure *E* isomer of **17** could be made by applying Corey's method¹¹ to the readily available trimethylsilylpropargyl alcohol **7**.² Reduction with lithium aluminum hydride, followed by trapping with iodine at -78° and coupling of the pure *Z* iodo alcohol (bp 62° (0.08 mm)) with lithium dimethylcuprate gave in 70% yield from **7** the pure *E* isomer **19** (bp $85-87^\circ$



(9 mm)): nmr δ (CCl_4) 5.80 (1 H, t, $J = 6$ Hz of q, $J = 1$ Hz, $\text{HC}=\text{C}$) 1.71 (3 H, d, $J = 1$ Hz, CH_3). The alcohol was converted to the chloride (triphenylphosphine-carbon tetrachloride, 60% yield, bp $55-56^\circ$ (12 mm)) which then gave the *E* iodide **20** (sodium iodide-2-butanone, 50° , 1 hr, evaporative distillation at 60° (20 mm)) in 80% yield.

The instability of some cuprates makes this method unsatisfactory for the synthesis of certain homologs of **6** in which $\text{R} \neq \text{H}$. After many attempts, the most general route to homologs was found to involve introduction of the silane function as the last step in the synthesis, as illustrated for the synthesis of **22**. Alkyla-



tion of the dianion of propargyl alcohol (2 equiv of lithium amide in liquid ammonia-tetrahydrofuran) with the dioxolane of iodopropyl methyl ketone gave a 90% yield of **21**, bp $99-107^\circ$ (0.1 mm). Reduction and iodination (as in **17** to **18**) then gave the crude *Z* iodo alcohol. Silylation of the hydroxyl group (hexamethyldisilazane-trimethylchlorosilane-pyridine) coupling with trimethylchlorosilane (as in **14** to **15**) and hydrolysis of the silyl ether (5% potassium carbonate in 30% aqueous methanol, 42 hr, room temperature) gave, in 41% overall yield from propargyl alcohol, the silylated allylic alcohol **22** (6, $\text{R} = \text{CH}_3\text{C}(\text{O})_2\text{CH}_2\text{-CH}_2\text{H}_2$, $\text{X} = \text{OH}$) which should be useful for bis-annulation reactions by the vinylsilane method.¹²

(10) R. Mantione and Y. Leroux, *J. Organometal. Chem.*, **31**, 5 (1971).

(11) E. J. Corey, J. A. Katzenellenbogen, N. W. Gilman, S. A. Roman, and B. W. Erickson, *J. Amer. Chem. Soc.*, **90**, 5618 (1968).

(12) We thank the National Science Foundation and the National Institutes of Health for their support of this work.

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Received February 19, 1974

Reactions of LiCuHR. Selective Removal of Halo and Mesyloxy Groups and Reduction of α,β -Unsaturated Ketones

Sir:

We wish to outline the scope and limitation of reactions utilizing Cu(I) complexes which can be conventionally represented by LiCuHR ($\text{R} = \text{alkyl and alkynyl}$). These mixed ate complexes achieve two operations, (i) reductive removal of halo and mesyloxy groups and (ii) conversion of α,β -unsaturated ketones to the corresponding saturated compounds, and are evaluated in terms of reagent-to-substrate ratio, structure of R, solvent effect, temperature, and substrate. Of special significance is the superb selectivity of the newer reagents, compared to one [$2\text{LiAlH}(\text{OCH}_3)_3 + \text{CuI}$] previously reported,¹ and, moreover, invariable ligand transfer of hydrogen rather than the R group in all cases examined attracts mechanistic interest.² For instance, LiCuH($n\text{-C}_4\text{H}_9$) converts ethyl 12-mesyloxy-stearate almost quantitatively into ethyl stearate within 2 hr at 25° , and cyclohex-3-enyl mesylate provides cyclohexene without a detectable amount of cyclohexadiene. A summary of results is given below.

There are several methods to prepare CuH.³ The Whitesides procedure^{3c} is adopted and is used throughout this work.^{4,5} An equimolar amount of LiR was added to a stirred suspension of CuH either in ether or tetrahydrofuran maintained at -40° .^{6,7}

Removal of Halo and Mesyloxy Groups.^{1,8} Using 2-bromononane, we have examined reaction variables that influence the reactivity of the ate complexes and the yield of product (*n*-nonane contaminated with a minute amount (3-4%) of *n*-nonene). Table I entries 1-4 show that 4 molar equiv of the cuprate is required to complete the reduction within a short reaction time. Of several complexes differing in R, the reaction pro-

(1) S. Masamune, P. A. Rossy, and G. S. Bates, *J. Amer. Chem. Soc.*, **95**, 6452 (1973).

(2) In the absence of accurate rate data, we cannot exclude the (remote) possibility of disproportionation ($2\text{LiCuHR} \rightleftharpoons \text{LiCuH}_2 + \text{LiCuR}_2$) although such a reaction has not been confirmed for the cuprate species. See (a) H. O. House, D. G. Koespell, and W. J. Campbell, *J. Org. Chem.*, **37**, 1003 (1972); (b) G. H. Posner, C. E. Whitten, and J. J. Sterling, *J. Amer. Chem. Soc.*, **95**, 7788 (1973). For approximate reaction rates of LiCu($n\text{-C}_4\text{H}_9$)₂, see, e.g., (c) G. M. Whitesides, W. F. Fischer, Jr., J. S. Filippo, Jr., R. W. Bashe, and H. O. House, *ibid.*, **91**, 4871 (1969); (d) E. J. Corey and G. H. Posner, *ibid.*, **90**, 5615 (1968).

(3) (a) E. Wiberg and W. Henle, *Z. Naturforsch. B*, **7**, 250 (1952); (b) J. A. Dilts and D. F. Shriver, *J. Amer. Chem. Soc.*, **90**, 5769 (1968); **91**, 4088 (1969); (c) G. M. Whitesides, J. S. Filippo, Jr., E. R. Stredronsky, and C. P. Casey, *ibid.*, **91**, 6542 (1969); G. M. Whitesides and J. S. Filippo, Jr., *ibid.*, **92**, 6611 (1970); (d) S. A. Bezman, M. R. Churchill, J. A. Osborn, and J. Wormald, *ibid.*, **93**, 2063 (1971); (e) M. A. Kazankova, I. G. Malykhina, M. B. Terenina, and I. F. Lutsenko, *J. Gen. Chem. USSR*, **42**, 2129 (1972).

(4) The ate complex derived from CuH that is prepared from CuBr and $(\text{C}_2\text{H}_5)_2\text{SnH}^{3e}$ resulted in poor yields of reduction products for reasons as yet unknown to us.

(5) Although reductive removal of some halides with CuH was previously noted (ref 3c), we found that 1-bromononane was virtually unaffected with CuH in either ether or THF at -40° for 12 hr, conditions under which the reduction was complete with most of the ate complexes.

(6) An alkynyl lithium solution was prepared from the alkyne and halide-free methyl lithium available from the Foote Mineral Co. H. O. House and W. F. Fischer, Jr., *J. Org. Chem.*, **33**, 949 (1968).

(7) The 1:1 ratio of CuH/RLi should be accurately followed. An excess of either reagent greatly decreases the yield of products. CuH is uniformly brown (light to dark) and any mottling or separation of pale yellow solid (presumably CuI) should not be observed.

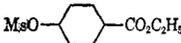
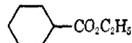
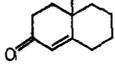
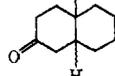
(8) Other methods are (a) R. O. Hutchins, B. E. Maryanoff, and C. A. Milewski, *Chem. Commun.*, 1097 (1971); (b) C. W. Jefford, D. Kirkpatrick, and F. Delay, *J. Amer. Chem. Soc.*, **94**, 8905 (1972); (c) H. C. Brown and S. Krishnamurthy, *ibid.*, **95**, 1669 (1973); (d) R. E. Ireland, D. C. Muchmore, and U. Hengartner, *ibid.*, **94**, 5098 (1972).

Table I. Reduction of 2-Bromononane with LiCuHR^a

Entry	LiCuHR R	Molar ratio reagent/substrate	Solvent	Reaction time (hr)	Temp, °C	% yield
1	<i>n</i> -C ₄ H ₉	1:1	(C ₂ H ₅) ₂ O	1 and 3	25	15 and 15
2	<i>n</i> -C ₄ H ₉	2:1	(C ₂ H ₅) ₂ O	1 and 3	25	26 and 26
3	<i>n</i> -C ₄ H ₉	3:1	(C ₂ H ₅) ₂ O	1 and 3	25	58 and 70
4	<i>n</i> -C ₄ H ₉	4:1	(C ₂ H ₅) ₂ O	1	25	100
5	<i>i</i> -C ₄ H ₉	4:1	(C ₂ H ₅) ₂ O	3 and 12	25	35 and 80
6	<i>i</i> -C ₃ H ₇	4:1	(C ₂ H ₅) ₂ O	3	25	25
7	C≡C- <i>n</i> -C ₃ H ₇ ^b	4:1	(C ₂ H ₅) ₂ O	4	0	3-5
8	C≡C- <i>n</i> -C ₃ H ₇ ^b	4:1	(C ₂ H ₅) ₂ O	4	25	40
9	C≡C- <i>n</i> -C ₃ H ₇ ^b	4:1	THF	4	25	0
10	<i>n</i> -C ₄ H ₉	4:1	(C ₂ H ₅) ₂ O	1	0	70
11	<i>n</i> -C ₄ H ₉	4:1	THF	1	0	~0
12	<i>n</i> -C ₄ H ₉	4:1	THF	3	25	10

^a All runs were performed on a 6 mmol scale with respect to the reagent. The yields are based on relative glpc peak areas, corrected for the sensitivity of the detector, using decane as reference. ^b References 6 and 14.

Table II. Reduction with 4 Molar Equiv of LiCuH(*n*-C₄H₉) in Ether at 25°^a

Entry	Substrate	Time (hr)	Product	% yield
1		1		85
2	1-Bromoadamantane	2	Adamantane	70
3	1-Bromonaphthalene	3	Naphthalene	95
4	<i>n</i> -Octyl tosylate	2.5	<i>n</i> -Octane	80
5	Cyclohexyl tosylate	2.5	Cyclohexane	80
6	Cyclohex-3-enyl tosylate	2	Cyclohexene (no diene)	75
7	1-Methylheptyl mesylate	1	<i>n</i> -Octane	100
8	Ethyl octanoate	2	Octan-1-ol	2-3
9	<i>n</i> -Heptyl acetate	2	Heptanol	20
10	Heptaldehyde ^b	0.5	Heptan-1-ol	100
11	Cyclohexanone ^b	0.5	Cyclohexanol	100
12	2-Bromononane and ethyl octanoate	2	Nonane and ethyl octanoate	95 and 100
13	Ethyl 12-mesyloxystearate	2	Ethyl stearate	100 90 (isolated)
14		0.5		100
15	Ethyl 12-bromostearate	2	Ethyl stearate	85 (isolated)
16		0.5 (-40°)		95
17		0.5 (-40°)		95
18		2 (-40°)	 cis/trans 7:3 ^c	85 (isolated) ^d

^a The conditions are the same as in Table I. Naphthalene was used as glpc reference in the case of the enone reductions. ^b Cf. L. T. Scott and W. D. Cotton, *J. Chem. Soc., Chem. Commun.*, 320 (1973); E. J. Corey and I. Kuwajima, *J. Amer. Chem. Soc.*, 92, 395 (1970). ^c Cis: R. L. Augustine and A. D. Broom, *J. Org. Chem.*, 25, 802 (1960). Hydrogenation over Pd/C performed in our laboratory provided a 93:7 mixture of the cis and trans compounds. ^d 15% of the starting material recovered.

ceeded most satisfactorily with LiCuH(*n*-C₄H₉) (entries 4-9) and the reactivity significantly decreased in the case of R = alkynyl, as might be expected. Diethyl ether is definitely superior to tetrahydrofuran as a solvent (entries 4, 10-12, 8, 9). Preliminary kinetic studies of the reduction of 2-bromononane with LiCuH(*n*-C₄H₉) over a temperature range of -40 to 20° showed that the reduction followed roughly second-order kinetics. The smooth increase in rate as the temperature is raised indicates at least that the reagent is stable and undergoes no dramatic change in structure

and degree of aggregation in solution over a wide range of temperature.²

The above information recommends 4 equiv of LiCuH(*n*-C₄H₉) in ether at 25° as a satisfactory reduction medium, and these conditions have been applied to a variety of substrates. Table II summarizes the results obtained with representative examples. Reduction of primary,⁹ secondary, and tertiary halides and mesylates (or tosylates) proceeded well (entries 1-7)

(9) Some primary bromides (but not mesylates or tosylates) underwent elimination. This aspect is under investigation.

and requires no comment except that the homoallylic tosylate provided the corresponding alkene without complication (entry 6), as noted earlier. The aldehyde and ketone (*vide infra*) were reduced readily to the corresponding hydroxy compounds and again no incorporation of the $n\text{-C}_4\text{H}_9$ group into the product is rather surprising. The ester group resisted reduction (entries 8 and 9) and in fact survived completely in both inter- and intramolecular competitive experiments (entries 12–15).

The selectivity evidently enhances the synthetic utility of the reagent.¹⁰ Similar competition reactions with the earlier Cu(I) reagent¹ were erratic presumably due to incomplete formation of the Cu(I) ate complex, a small but variable amount of $\text{LiAlH}(\text{OCH}_3)_3$ remaining in the reaction medium.

Reduction of α,β -Unsaturated Ketones to Saturated Ketones.¹¹ Although aldehydic and ketonic compounds (Table II, entries 10, 11) are readily reduced with the ate complexes, the carbonyl groups may survive as enolates, if 1,4- rather than 1,2-addition to the α,β -unsaturated carbonyl systems proceeds.¹² The resulting enolate then would be utilized directly for further reactions such as alkylation and Michael addition.¹³ An extensive search for the optimal reaction conditions to achieve the conversion of cyclohex-2-enone to cyclohexanone has been pursued in a manner similar to that described earlier. In short, the reactivity of LiCuHR as well as the yield of product decreases in the order of $\text{R} = n\text{-C}_4\text{H}_9 > \text{C}\equiv\text{C-}t\text{-C}_4\text{H}_9 > \text{C}\equiv\text{C-}n\text{-C}_3\text{H}_7$, hydrogen being the only ligand transferred (no observable formation of 3-butylcyclohexanone with $\text{LiCuH}(n\text{-C}_4\text{H}_9)$). Because of the higher susceptibility of the α,β -unsaturated carbonyl system to this reduction than halo and mesyloxy groups, the reaction is complete within 0.5 hr at -40° with $\text{LiCuH}(n\text{-C}_4\text{H}_9)$ (4 equiv) (entry 16), and even with reagents with $\text{R} = \text{alkynyl}$ (4 equiv) it proceeded to provide an acceptable yield of product, although somewhat higher temperatures were required. However, use of 6 molar equiv of the latter reagents (alkynyl) in ether improves the yield of cyclohexanone. Thus, the product was formed in 50 and 90% yields in 1 hr using $\text{LiCuH}(\text{C}\equiv\text{C-}t\text{-C}_4\text{H}_9)$ at -40° and 0° , and in 30 and 90% yields under the same conditions with $\text{LiCuH}(\text{C}\equiv\text{C-}n\text{-C}_3\text{H}_7)$.¹⁴ Tetrahydrofuran does not offer any advantages over ether and appears to retard the reaction and induces side reactions in the case of $\text{R} = n\text{-C}_4\text{H}_9$. We conclude that 4 molar equiv of $\text{LiCuH}(n\text{-C}_4\text{H}_9)$ in ether at -40° represents optimal conditions for the reduction of α,β -unsaturated ketones, achieving efficient, high yield conversion under mild conditions and with operational simplicity.

According to the Whitesides procedure,^{3c} 6.0 mmol

(10) Compare this selectivity with that observed or expected for the methods quoted in ref 8.

(11) For recent reviews on related subjects, see (a) G. H. Posner, *Org. React.*, **19**, 1 (1972); (b) J. F. Normant, *Synthesis*, 63 (1972).

(12) A recent view on the mechanistic aspect of cuprate reactions, see H. O. House and M. J. Umen, *J. Org. Chem.*, **38**, 3893 (1973), and references cited therein.

(13) *E.g.*, ref 11b, p 79; J. E. Dubois, C. Lion, and C. Moulineau, *Tetrahedron Lett.*, 177 (1971); C. Wakselman and M. Mondon, *ibid.*, 4285 (1973); G. H. Posner and J. J. Sterling, *J. Amer. Chem. Soc.*, **95**, 3076 (1973); R. K. Boeckman, Jr., *ibid.*, **95**, 6867 (1973).

(14) For the use of a so-called nontransferable group as one of the cuprate ligands, see E. J. Corey and D. J. Beames, *J. Amer. Chem. Soc.*, **94**, 7210 (1972), and ref 2b.

of CuH was prepared under argon at -50° in a 50-ml round-bottomed flask, equipped with a magnetic stirrer and sealed with a rubber septum. After the CuH was washed with four 20-ml portions of cold (-50°) ether, 15 ml of cold (-40°) ether was added with stirring and then 6.0 mmol of cold $n\text{-BuLi}$ in hexane (Foote Mineral Co.) was syringed into the flask over 1 min. The resulting dark brown solution (reagent partially insoluble) was stirred for 10 min. After addition of 610 mg (1.5 mmol) of ethyl 12-mesyloxystearate in 1 ml of ether, the cooling bath was removed and stirring was continued for 2 hr at room temperature. The reaction mixture was poured into aqueous saturated ammonium chloride solution, the ethereal layer was decanted and the aqueous layer was washed with 50 ml of ether. The combined ether extracts were processed in the usual manner to provide 400 mg (85%) of ethyl stearate (silicic acid chromatography). The same procedure was applied to 246 mg (1.5 mmol) of 6-methylbicyclo[4.4.0]dec-1-en-3-one, except that the reaction temperature was maintained at -40° . The products weighed 246 mg (98%), consisting of 6-methylbicyclo[4.4.0]decan-3-ones (85%) and starting material (15%) (Table II, entry 18).

Acknowledgment. The authors thank the Defense Research Board of Canada and Hoffmann-La Roche Inc., for financial support.

(15) 1967 National Research Council (Canada) Science Scholarship Awardee.

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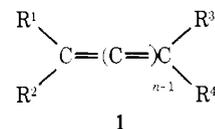
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Received February 6, 1974

A Stereoselective Synthesis of Partially Substituted 1,2,3-Butatriene Derivatives via Hydroboration

Sir:

We wish to report the first stereoselective synthesis of 1,2,3-butatriene derivatives. Almost a century ago van't Hoff¹ made a well-accepted prediction that cumulenes (**1**) with odd numbers of double bonds should



be capable of exhibiting *cis-trans* isomerism. Recent studies, both experimental² and theoretical,³ have indicated that although the energy barrier to the *cis-trans* isomerization of hexapentaenes ($n = 5$) is too low to permit separation of the two stereoisomers at ambient temperatures, separation of tetrasubstituted *cis*- and *trans*-1,2,3-butatrienes is feasible. To date, however, no methods appear to have been available for the stereoselective synthesis of 1,2,3-butatriene derivatives.⁴

(1) J. H. van't Hoff, "Die Lagerung der Atome in Raume," Verlag F. Vieweg und Sohn, Braunschweig, 1877, p 14.

(2) (a) R. Kuhn and K. L. Scholler, *Chem. Ber.*, **87**, 598 (1954); (b) R. Kuhn and D. Blum, *ibid.*, **92**, 1483 (1959); (c) R. Kuhn and B. Schulz, *ibid.*, **98**, 3218 (1965); (d) R. Kuhn, B. Schulz, and J. C. Jochims, *Angew. Chem., Int. Ed. Engl.*, **5**, 420 (1966).

(3) M. J. S. Dewar and E. Haselback, *J. Amer. Chem. Soc.*, **92**, 590 (1970).

(4) For an extensive review, see H. Fischer in "The Chemistry of Alkenes," S. Patai, Ed., Interscience, New York, N. Y., 1964, pp 1025–1159.