(7.0 mL) was placed in a two-necked flask under an argon stream. The atmosphere was changed to hydrogen, and the mixture was stirred at room temperature (for 7 h) until hydrogen uptake ceased. Then, the reaction temperature was raised to the refluxing point of solvent, and the reaction was performed for another 6 h. The product **3g** was isolated by Kugelrohr distillation (pot temperature 85 °C/0.07 mmHg) in 96% yield.

Analytical Procedure. The identification of products was made by ^{1}H and ^{13}C NMR and IR spectral and elemental analysis, which were all consistent with those of authentic samples.

The ^{1}H NMR spectra were obtained at 270 MHz with a JEOL GSX-270 and the ^{13}C NMR spectra at 25.05 MHz with a JEOL JNM FX-100 spectrometers. Samples were dissolved in CDCl$_3$, and the chemical shifts were expressed relative to tetramethylsilane as an internal standard. Elemental analyses were performed at the Microanalytical Center of Kyoto University. GLC analyses were performed on a Shimadzu GC-8APF chromatograph equipped with a glass column (3 mm × 3 m) packed with Silicone OV-17 (5% on Chromosorb W(AW), 60–80 mesh) or PEG-HT (5% on Uniport HP, 60–80 mesh). The products were isolated by a vacuum distillation with a Kugelrohr apparatus. The yield of indole (**3a**) was determined by GLC with naphthalene as the internal standard.

5-Methoxyindole (3c): white solid; mp 48.5–50.0 °C; ^{1}H NMR (270 MHz, CDCl$_3$) δ 3.81 (s, 3 H, CH_3O), 6.43 (br, 1 H, indole-3-H), 6.84 (dd, 1 H, indole-2-H, J = 2.7, 8.1 Hz), 7.02–7.16 (m, 3 H, Ar), 7.98 (br, 1 H, NH); ^{13}C NMR (25.05 MHz, CDCl$_3$) δ 55.69 (q, CH$_3$O), 102.03 and 102.13 (d and d, indole-C^3 and Ar), 111.47 and 112.00 (d and d, Ar), 124.60 (d, indole-C^2), 127.95 and 130.67 (s and s, Ar), 153.78 (s, CH$_3$O-C). Anal. Calcd for C$_9$H$_9$NO: C, 73.4; H, 6.2; N, 9.5; O, 10.9. Found: C, 73.31; H, 6.20; N, 9.27; O, 11.15.

6-Chloroindole (3e): white solid; mp 88.1–88.8 °C; ^{1}H NMR (270 MHz, CDCl$_3$) δ 6.52 (br, 1 H, indole-3-H), 7.09 (dd, 1 H,

indole-2-H, J = 1.8, 8.4 Hz), 7.14–7.55 (m, 3 H, Ar), 8.06 (br, 1 H, NH); ^{13}C NMR (25.05 MHz, CDCl$_3$) δ 102.57 (d, indole-C^3), 110.64 (d, indole-C^7), 120.27 and 121.24 (d and d, Ar), 124.45 (d, indole-C^2), 126.16 and 127.56 (s and s, indole-C^6 and C^3-C-C^4), 135.78 (s, N-C-C^7). Anal. Calcd for C$_8$H$_6$ClN: C, 63.4; H, 4.0; Cl, 23.4; N, 9.2. Found: C, 63.22; H, 3.90; Cl, 23.24; N, 9.28.

3-Methylindole (3h): white solid; mp 98.0–98.5 °C; ^{1}H NMR (270 MHz, CDCl$_3$) δ 2.30 (s, 3 H, CH_3), 6.82 (br, 1 H, indole-2-H), 7.10–7.21 (m, 4 H, Ar), 7.56 (d, 1 H, NH, J = 7.3 Hz); ^{13}C NMR (25.05 MHz, CDCl$_3$) δ 9.55 (q, CH_3), 110.74 (d, indole-C^7), 111.09 (s, indole-C^3), 118.48 (d, indole-C^4), 118.77 (d, indole-C^6), 121.46 (d, indole-C^2 and -C^5), 127.85 (s, C^3-C-C^4), 135.82 (s, N-C-C^7). Anal. Calcd for C$_9$H$_9$N: C, 82.4; H, 6.9; N, 10.7. Found: C, 82.36; H, 6.89; N, 10.69.

Homocoupling of Alkyl Halides and Cyclization of α,ω-Dihaloalkanes via Activated Copper

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The homocoupling of alkyl halides utilizing a highly activated form of zerovalent copper has been studied. Allyl and benzyl halides produce high yields of their respective homocoupled dimers 1,5-hexadiene and 1,2-diphenylethane. An 83% yield of tetradecane was produced from *n*-heptyl iodide. The yield drops substantially for the corresponding bromo and chloro compounds. The yield is also strongly solvent and temperature dependent. Secondary and tertiary alkyl iodides and bromides produce moderate to low yields of homocoupling accompanied by substantial amounts of the corresponding alkane and alkenes. The copper-mediated cyclization of α,ω-dihaloalkanes has also been examined. The yield of cycloalkanes is moderate to high for the smaller rings with the yield decreasing substantially as the ring size increases. The compound *meso*-1,2-dibromo-1,2-diphenylethane was found to produce exclusively *trans*-stilbene in high yield. The activated copper was produced by reducing CuI·PR$_3$ with a preformed solution of lithium naphthalenide. Complexes using triethylphosphine and tri-*n*-butylphosphine were both studied. The product yields were found to be similar in both cases.

Introduction

Organocopper compounds are increasingly being used in organic synthesis due in large measure to their ability to undergo substitution reactions with alkyl halides and 1,4-addition reactions with α,β-unsaturated carbonyl compounds.[1] Our research endeavors have been aimed at developing a form of copper with sufficient reactivity to allow the direct oxidative addition of the metal to organic halides to produce organocopper compounds without

utilizing the traditional lithium and Grignard precursors. This approach would allow the functionalization of organocopper reagents in ways not permitted when the traditional highly reactive precursors are used.

Rieke and Ebert have recently reported the successful development of such a form of activated copper.[2] Rieke and co-workers have further developed stable functionalized primary alkylcopper reagents and have explored the reactions of these compounds with epoxides, acid chlorides, and α,β-unsaturated ketones.[3] In the course of further

(1) (a) Posner, G. H. *Org. React.* **1975**, *22*, 253 and references cited therein. (b) Posner, G. H. *Org. React.* **1972**, *19*, 1 and references cited therein.

(2) (a) Ebert, G. W.; Rieke, R. D. *J. Org. Chem.* **1984**, *49*, 5280. (b) Ebert, G. W.; Rieke, R. D. *J. Org. Chem.* **1988**, *53*, 4482.

Table I. Reactions of Allyl and Benzyl Halides with Activated Copper

no.	R, alkyl	X, halide	temp, °C	product	% yield[a]		
					1 min	10 min	1 h
1[b]	allyl	Cl	25	RR	59	56	–
2	allyl	Br	25	RR	81	85	88
3	allyl	Br	65	RR	95	95	95
4	allyl	I	25	RR	85	92	92
5[b]	allyl	I	–40	RR	21	29	35
6	benzyl	Cl	25	RR	48	48	48
				RH	27	27	27
7	benzyl	Cl	85	RR	–	71	–
				RH	–	7	–
8	benzyl	Br	–40	RR	78	87	88
				RH	1	1	1
9	benzyl	Br	25	RR	84	92	95
				RH	2	4	4
10	benzyl	Br	85	RR	–	97	–
				RH	–	2	–
11	benzyl	I	25	RR	85	90	97
				RH	4	4	4

[a] A 1-mL aliquot of the reaction mixture was withdrawn at the specified time and quenched with 0.25 mL of 0.01 M HCl and then analyzed by GC using the internal standard method. Thus, any organocopper present at the time of the quench appears as reduced product "RH". [b] Propene was observed but not quantified in these reactions.

developing and studying this zerovalent copper reagent in our own laboratory, it has been observed that alkyl halides, when treated with activated copper, frequently undergo homocoupling in good yields. we have since completed a study of this reaction and herein report the results.

Results and Discussion

Allyl and Benzyl Halides. Allyl and benzyl halides homocouple in good yields as shown in Table I. As expected, the order of decreasing halide reactivity is I, Br, Cl. The homocoupling of the iodides is quite facile even at low temperatures as demonstrated by entries 5 and 8. A significant amount of the reduced product, toluene, is found in the room-temperature reaction of benzyl chloride.

Scheme I provides a plausible mechanism to explain the formation and subsequent coupling of allyl- and benzyl-copper intermediates. Step 1 consists of the oxidative addition of copper to the alkyl halide producing the alkylcopper and copper(I) halide in a manner analogous to that of lithium.[4] At temperatures above 0 °C, allyl and benzyl cuprates are known to thermally decompose to give their respective homocoupled products in good yield along the elemental copper[5] (step 2). At lower temperatures, these organocopper compounds have greater stability but will react quickly with alkyl iodides or bromides present to produce the corresponding coupled products[6] (step 3). Thus, at higher temperatures both steps 2 and 3 may contribute to coupling, while at lower temperatures step 3 would likely be the dominant coupling mode.

Scheme I

$$RX + 2Cu^0 \rightarrow RCu + CuX \quad (1)$$

$$2RCu \rightarrow RR + 2Cu^0 \quad (2)$$

$$RCu + RX \rightarrow RR + CuX \quad (3)$$
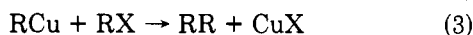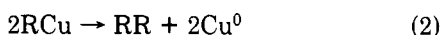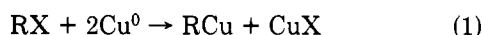
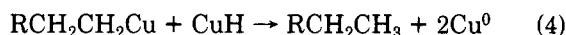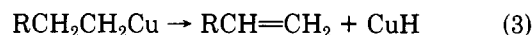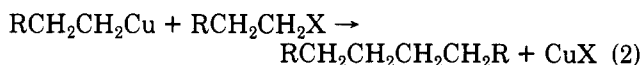**Primary Alkyl Halides.** The n-heptyl halides were selected to represent the class of primary alkyl halides. It

can be seen from Table II that, under similar conditions, n-heptyl halides are less reactive and provide lower yields of homocoupling than do the allyl and benzyl halides.

The reaction of n-heptyl iodide with activated copper gives predominantly tetradecane but is always accompanied by some reduction and elimination to produce respectively heptane and 1-heptene. As illustrated in entries 1–6, the yield is slightly temperature dependent and more strongly solvent dependent with the highest yield of tetradecane being produced at room temperature in a THF/DMF solvent mixture (entry 6).

At room temperature n-heptyl chloride (entry 9) does not completely react with the activated copper and leaves about 30% of the starting material unconsumed. The major products of the n-heptyl chloride and bromide reactions are the reduced and eliminated compounds accompanied by small amounts of homocoupling.

A possible mechanism to explain these reactions is given in Scheme II. The initial formation of the organocopper

Scheme II

$$RCH_2CH_2X + 2Cu^0 \rightarrow RCH_2CH_2Cu + CuX \quad (1)$$

$$RCH_2CH_2Cu + RCH_2CH_2X \rightarrow$$
$$RCH_2CH_2CH_2CH_2R + CuX \quad (2)$$

$$RCH_2CH_2Cu \rightarrow RCH=CH_2 + CuH \quad (3)$$

$$RCH_2CH_2Cu + CuH \rightarrow RCH_2CH_3 + 2Cu^0 \quad (4)$$

and the subsequent coupling reaction (steps 1 and 2 of Scheme II) are identical to steps 1 and 3 of Scheme I and can account for the homocoupled product. The elimination and reduction compounds could be accounted for by a mechanism put forth by Whitesides, Casey, Stedronsky, and San Fillippo, Jr.,[7] in their study of the thermal decomposition of n-butylcopper. Their work indicates that primary alkylcopper compounds tend to thermally decompose to produce the 1-alkene and CuH. The CuH then reacts with additional alkylcopper, producing the alkane and copper metal (steps 3 and 4 of Scheme II). Based upon this mechanism, it appears that the rate of substitution on n-heptyl iodide by n-heptylcopper is faster than the rate of β-elimination for n-heptylcopper over the temperature range studied. For the bromide, however, the

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(5) Tamura, M.; Kochi, J. K. *J. Organomet. Chem.* **1972**, *42*, 205.

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(7) Whitesides, G. M.; Stedronsky, E. R.; Casey, C. P.; San Fillippo, J., Jr. *J. Am. Chem. Soc.* **1970**, *92*, 1426.

Table II. Reactions of *n*-Heptyl Halides with Activated Copper

no.	halide	solvent[a]	temp, °C	product[b]	% yield[c] 1 min	10 min	1 h
1	I	THF	−60	RR	49	50	50
				RH + E	15	16	17
2	I	DME	−40	RR	53	55	54
				RH + E	20	21	18
				RX	0	0	0
3	I	DME	25	RR	44	51	57
				RH + E	16	17	21
				RX	2	1	0
4	I	DME	40	RR	57	60	61
				RH + E	30	30	30
				RX	0	0	0
5	I	DME	85	RR	50	49	48
				RH + E	46	49	50
				RX	0	0	0
6	I	THF/DMF	25	RR	83	83	83
				RH + E	15	15	15
				RX	0	0	0
7	Br	THF	25	RR	3	3	3
				RH	7	8	8
				E	36	37	37
				RX	0	0	0
8	Br	THF	−40	RR	20	22	24
				RH	7	5	4
				E	15	16	18
				RX	0	0	0
9	Cl	THF	25	RR	3	4	5
				RH	0	0	0
				E	28	29	29
				RX	32	30	26

[a] THF, tetrahydrofuran; DME, 1,2-dimethoxyethane, DMF, *N,N*-dimethylformamide. [b] RR, tetradecane; RH, heptane; E, 1-heptene; RX, starting material. [c] See footnote *a* of Table I.

Table III.[a] Reactions of Secondary Alkyl Halides with Activated Copper

no.	RX	temp, °C	% yield[b] RR	RH	elimination
1	2-iodopropane	25	41	−	−
2	2-iodopentane	25	−	39	18
3	2-iodopropane	−78	29	−	−
4	2-iodopentane	−78	−	32	37
5	2-bromopropane	25	18	−	−
6	2-bromopentane[c]	25	−	26	20
7	2-bromopropane[c]	−78	14	−	−
8	2-bromopentane[c]	−78	−	16	40

[a] All reactions were run in tetrahydrofuran. An additional equivalent of tri-*n*-butylphosphine was added to the activated copper prior to the addition of the alkyl halide. The reactions were monitored for 0.5 h but were found to be essentially complete in 1 min. See footnote *a* of Table I for analysis procedures. [b] RR = 2,3-dimethylbutane, RH = pentane, Elimination products are 1-pentene and 2-pentene and are reported together. [c] Approximately 30% of the starting material remained.

elimination reaction is faster than substitution at room temperature, but these relative rates are reversed at −40 °C.

Secondary Alkyl Halides. The 2-halopropanes and 2-halopentanes were selected to represent the class of secondary alkyl halides. Table III shows that the yield of homocoupled product is moderate for the iodides and somewhat low for the bromides. A comparison of Table III with Table II shows that, under similar conditions, secondary alkyl halides tend to homocouple to a lesser extent and undergo elimination and reduction to a greater extent than the corresponding primary alkyl halides. Mechanistically, these reactions may also plausibly follow Scheme II.

Tertiary Alkyl Halides. To represent the class of tertiary alkyl halides, *tert*-butyl halides and 2-halo-2-methylbutanes were chosen. It can be seen in Table IV that the yield of coupled product is low for both the iodides and bromides. By comparing Tables IV, III, and II, we observe that, under similar conditions, tertiary halides produce less homocoupling and undergo more reduction

and elimination than do the corresponding secondary or primary alkyl halides. Tertiary alkyl Grignard reagents have been reported to undergo homocoupling with yields in the range of 30–50%.[8] We also noted in these experiments that the 1-alkenes always predominated over the 2-alkenes in the secondary and tertiary alkyl halide reactions, indicating that the eliminations are under kinetic control.

Cyclization of *α,ω*-Dihaloalkanes. Since the copper-mediated coupling of primary alkyl iodides was found to be facile, we turned our attention to the reaction of *α,ω*-diiodoalkanes with the goal of producing carbocycles. Table V lists our results.

The formation of methylcyclopropane in good yield was not unexpected. Many metals are capable of cyclizing 1,3-dibromopropane in good yield.[9] The 14% yield of cyclobutane we achieved was disappointing. In spite of

(8) March, J. *Advanced Organic Chemistry: Reactions, Mechanisms, and Structures*; McGraw-Hill: New York, 1968; p 353.

(9) Kochi, J. J.; Singleton, D. M. *J. Org. Chem.* **1968**, *33*, 1027.

Table IV.[a] The Reactions of Tertiary Alkyl Halides with Activated Copper

			% yield[b]		
no.	RX	temp, °C	RR	RH	elimination
1	*t*-butyl iodide	25	30	–	–
2	*t*-butyl iodide	–78	14	–	–
3	*t*-butyl bromide	25	21	–	–
4	2-bromo-2-methylbutane	25	–	42	48
5	*t*-butyl bromide	–78	11	–	–
6	2-bromo-2-methylbutane	–78	–	41	46

[a] All reactions were run in tetrahydrofuran. The reactions were monitored for 0.5 h but were found to be essentially complete in 10 min. See footnote a of Table I for analysis procedures. [b] RR = 2,2,3,3-tetramethylbutane, RH = 2-methylbutane; elimination products were 2-methyl-1-butene and 2-methyl-2-butene and are reported together.

Table V.[a] The Reactions of α,ω-Dihaloalkanes with Activated Copper

no.	reagent	temp, °C	Carbocycle	yield, %	other products[b] (yield, %)
1	1,3-dibromobutane	–70	methylcyclopropane	97	
2	1,4-diiodobutane	–70	cyclobutane	14	butane & butenes (12) C8 compounds (20)
3	1,5-diiodopentane	–45	cyclopentane	40	pentane & pentenes (13) C_{10} compounds (20)
4	1,5-dibromopentane	–45	cyclopentane	5	pentane & pentenes (5) C_{10} compounds (30)
5	1,6-diiodohexane	–20	cyclohexane	18	hexane & hexenes (21) C_{12} compounds (2)
6	1,8-diiodooctane	–45	cyclooctane	0	octane (22), octenes (34) C_{16} compounds (5)

[a] All reactions were run in tetrahydrofuran. The reactions were monitored for 0.5 h, but were found to be essentially complete in 10 min. The Cu^0/RX_2 ratio was 4/1. The activated copper was preformed, cooled to the reported temperature, and the dihaloalkane slowly dripped into the stirring mixture. See footnote a of Table I for analysis procedures. [b] Usually both the alkene and alkadiene were present. Thus, for the cyclopentane reaction, both pentene and 1,4-pentadiene were present. Except for entry 1, there were always some unidentified products in the reaction mixture.

Scheme III

meso-stilbene dibromide   *trans*-stilbene
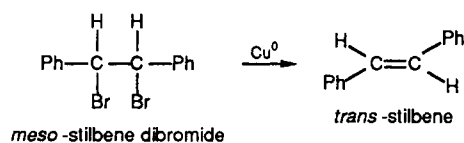
numerous efforts, we were unable to improve upon it. While some metals do cyclize 1,4-diiodobutanes in high yield,[10] others do not.[11] Copper appears to fall into the latter catagory.

Entry 3 shows a moderate yield of cyclopentane from 1,5-diiodopentane. Several solvent and temperature combinations were tested, but the yield was found to be rather insensitive to these changes. The corresponding dibromide cyclized in very low yield.

In general, for metal-mediated reactions, a dramatic decrease in cyclized product is found for chains of six carbons or more. We find activated copper to be no exception. The reaction of 1,6-diiodohexane with our copper produced cyclohexane in a 12% yield. This is somewhat better than cyclizations reported using lithium.[10] In the reaction of 1,8-diiodooctane with activated copper, no detectable amount of cyclooctane was found. This is typical of metal-mediated reactions with 1,8-dihaloalkanes.

Vicinal Dibromide Dehalogenation. The compound *meso*-1,2-dibromo-1,2-diphenylethane (*meso*-stilbene dibromide) undergoes elimination with activated copper to produce an 80% yield of *trans*-stilbene as shown in Scheme III. No *cis*-stilbene was detectable by GC analysis. This data agrees with results obtained by Posner and Ting[12] and by House and Ro[13] who report exclusive formation of *trans*-stilbene. The yield of stilbene we observe

compares favorably with yields obtained using other metals.[14]

In other experiments, *cis*-stilbene was found to isomerize to *trans*-stilbene under the same reaction conditions used to effect elimination from stilbene dibromide. Thus, we have not determined the degree of stereoselectivity for this reaction. That question is currently under investigation.

Conclusions

In summary, we have found that the activated zerovalent copper homocouples allyl and benzyl halides and primary alkyl iodides in good yield. Secondary and tertiary alkyl halides homocouple in moderate to low yields accompanied by substantial amounts of elimination and reduction products.

The α,ω-diiodoalkanes three, five, six, and eight carbons in length cyclize in yields comparable to those mediated by other metals. The yield of cyclobutane was somewhat lower than yields reported utilizing other active metals.

The copper-induced elimination of bromine from *meso*-stilbene dibromide provided an 80% yield of the alkene. The reaction produced exclusively *trans*-stilbene.

For the allyl and benzyl halide homocoupling reactions, activated copper was prepared by reducing either the triethylphosphine complex or the tri-*n*-butylphosphine complex of CuI. The homocoupling yields were comparable in both cases and did not depend upon the choice of trialkyl phosphine. However, Rieke and co-workers have shown that the choice of phosphine does influence the degree of homocoupling found for low-temperature reactions of primary alkyl halides with activated copper.[3a,d,e]

Experimental Section

General Information. Melting points were determined on a Laboratory Devices' Mel-Temp melting point apparatus and were uncorrected. Boiling points were uncorrected. Infrared

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(14) (a) Takahashi, S.; Suzuki, Y. *Chem. Lett.* **1974,** 1363. (b) Vig, O. P.; Sharma, S. D.; Kapur, J. C. *J. Ind. Chem. Soc.* **1969,** *46,* 167.

spectra were recorded on a Beckman Acculab 4 IR spectrophotometer or a Perkin-Elmer Model 1710 FT-IR spectrophotometer neat between NaCl plates or as KBr disks. ^{1}H NMR spectra were recorded on a Perkin-Elmer/Hitachi R-20A (60 MHz) spectrometer. ^{13}C NMR spectra were recorded on a JEOL FXQ-90 (90 MHz) spectrometer. ^{1}H and ^{13}C NMR chemical shifts are reported in ppm (δ) with Me$_4$Si as an internal shift reference. High-resolution mass spectra were performed by the Analytical Services Division of the Department of Chemistry at the State University of New York at Buffalo; Buffalo, NY.

All manipulations were carried out on an Argon/vacuum dual manifold system. The Airco prepurified argon was further purified by passing it through a catalyst column (Chemical Dynamics Corp. R3-11) and then through a column of anhydrous CaSO$_4$ followed by a column of granular potassium hydroxide. The solvents 1,2-dimethoxyethane (DME) and tetrahydrofuran (THF) were freshly distilled under argon from sodium/potassium alloy. Alkali metals were handled under an argon atmosphere in a Lab ConCo. glovebox equipped with an air circulator and purifying system similar to that described for the argon/vacuum dual manifold.

Experimental Setup. All reactions were carried out in 50-mL two-neck round-bottom flasks equipped with a reflux condenser and a rubber septum and containing a small Teflon clad stirring bar. The top of the condenser was fitted with a tubing connector containing a stopcock, which, in turn, was connected to the argon/vacuum manifold. All glassware was oven-dried over night and assembled hot or taken into the glovebox while still hot and assembled and charged.

Chemicals. All chemicals purchased were reagent grade or better and used as received unless otherwise stated.

Gas Chromatography Analysis. GC analyses were performed on either a Perkin-Elmer Model 990 or a Gow-Mac Model 550P gas chromatograph. Both instruments are temperature programmable and equipped with thermal conductivity detectors. All analyses were performed by the internal standard method using authentic samples of the products to determine accurate response factors. The following columns were used: Column I consisted of 5% SE-30 (Perkin-Elmer) on a Chromasorb-P (Analabs) support packed in a $^1/_8$ in. × 10 ft stainless steel column. Column II consisted of a 3% OV-17 (Altech Assoc.) liquid phase on a Chromasorb-W (Analabs) support in a $^1/_8$ in. by 10 ft stainless steel column. Column III consisted of a 5% Carbowax-20M (Perkin-Elmer) liquid phase on a Chromasorb-W (Analabs) support packed in a $^1/_8$ in. × 10 ft stainless steel column. These same packings were also used in $^1/_4$ in. × 10 ft stainless steel preparative columns.

Formation of CuI·PR$_3$. The copper complexes were prepared by the method of Kauffman and Teter[15] utilizing either triethyl- or tributylphosphine (Aldrich or Organometallics Inc.) and CuI (Lancaster). The complexes were recrystallized once, dried under vacuum over night, and stored in tightly stoppered bottles under refrigeration until needed. Both complexes will keep several months under these conditions.

Formation of Lithium Naphthalenide and Biphenylide. Typically, oven-dried glassware was placed in the glovebox and charged with lithium metal (11 mmol) and either naphthalene or biphenyl (12 mmol). The glassware was then assembled as described under experimental setup and attached to the argon/vacuum manifold. Freshly distilled THF or DME (15–20 mL) was syringed into the flask, and stirring commenced. At 25 °C the reduction took approximately 2 h in THF and 3 h in DME. The reduction was judged complete when no solid lithium could be found. The finished reduction was dark green when naphthalene was used and deep blue with biphenyl. The solutions should be used as soon as possible. Lithium and biphenyl were purchased from Aldrich and the naphthalene from Fisher.

Formation of Activated Copper. Lithium naphthalenide or biphenylide was prepared as previously described. To one neck of another 50-mL two-neck round-bottomed flask was attached a tubing connector containing a stopcock which, in turn, was connected to the manifold. The other neck was fitted with a septum. The flask was evacuated and refilled with argon. Under a flow of argon, CuI·PR$_3$ (10 mmol) was placed into this vessel.

The complex salt was dissolved by syringing into the flask freshly distilled THF or DME (5–10 mL) and gently swirling. The copper salt solution was then drawn up into a syringe and quickly injected into the stirring solution of preformed lithium naphthalenide or lithium biphenylide. After about 1 min, the brown suspension/solution of activated copper was ready for subsequent reactions. The activated copper could be kept for a few hours and used with only a slight loss of reactivity, but for best results the preparation should be used as soon as possible.

Typical Reaction Procedure. To a flask containing activated copper (10 mmol) was added a suitable internal standard (typically 3 mmol). The temperature was appropriately adjusted and stirring commenced. The alkyl halide (typically 5 mmol) was then added to the mixture via syringe. One-milliliter aliquots were removed via syringe at timed intervals and quenched with HCl (0.01 M, 0.5 mL). The organic layer from the quench was analyzed by GC. The remaining contents of the flask were subjected to the workup and isolation procedure to obtain individual products for spectroscopic identification and characterization as necessary.

Workup and Isolation Procedures. The contents of the reaction flask (typically 20–45 mL) were poured into HCl (0.01 M, 50 mL). Methylene chloride (25 mL) was added, the mixture was stirred, and the layers were separated. The organic layer was washed three times with distilled water and dried over MgSO$_4$. Volatile components were isolated by either fractional distillation or preparative GC. For the higher boiling compounds, the solvent and lower boiling components were first removed by rotary evaporation, and then the remaining compounds were separated by flash chromatography.[16]

Homocoupling of Allyl and Benzyl Halides. The allyl halides were purchased from Aldrich and were reacted in THF using toluene as an internal standard. Benzyl halides were reacted in DME using decane as the internal standard. Benzyl bromide and chloride were purchased from Fisher and Benzyl iodide from Alpha. The activated copper for these reactions were produced from the lithium naphthalenide reduction of either CuI·P(Et)$_3$ or CuI·P(n-Bu)$_3$. The reactions were run as indicated for a typical procedure. For specific reaction times, temperatures, and product yields see Table I. The reactions were analyzed by GC (column I). Identities of the products were established by comparing them to authentic commerical samples.

Homocoupling of n-Heptyl Halides. The n-heptyl halides were purchased from Aldrich. Activated copper was produced from lithium naphthalenide and CuI·P(n-Bu)$_3$. The reactions were run as indicated for a typical procedure with decane used as the internal standard. For specific reaction times, temperatures, solvent choices, and product yields see Table II. For entry 6 of Table II, 20 mL of freshly distilled and degassed DMF (20 mL) was added to the reaction flask after the formation of the activated copper, but before the addition of n-heptyl iodide. The reactions were analyzed by GC (column II). Identities of the products were established by comparing them to authentic commerical samples.

Homocoupling of Secondary Alkyl Halides. Isopropyl bromide and iodide and 2-bromopentane were purchased from Aldrich. The 2-iodopentane was purchased from Pfaltz and Bauer. Activated copper was produced from lithium naphthalenide and CuI·P(n-Bu)$_3$. The reactions were run as indicated for a typical procedure with decane added for an internal standard and THF as the solvent. An additional equivalent of tri-n-butylphosphine was added to the activated copper prior to the addition of the alkyl halide. For specific reaction temperatures and product yields, see Table III. The reactions were analyzed by GC (column III). Identities of the products were established by comparing them to authentic commercial samples.

Homocoupling of Tertiary Alkyl Halides. All of the tertiary alkyl halides were purchased from Aldrich. Activated copper was prepared from lithium naphthalenide and CuI·P(n-Bu)$_3$. The reactions were run as indicated for a typical procedure using THF as the solvent and decane as the internal standard. For specific reaction temperatures and product yields, see Table IV. The reactions were analyzed by GC (column III). Identities of the products were established by comparing them to authentic commercial samples.

(15) Kauffman, G.; Teter, L. *Inorg. Synth.* **1963**, 7, 9.

(16) Still, W. C.; Kahn, M.; Nitra, A. *J. Org. Chem.* **1978**, 43, 2923.

Cyclization Procedure for the Dihaloalkanes. The dihaloalkanes were purchased from Aldrich and used as received. The typical experimental setup previously described was modified by using a three-neck 100-mL round-bottomed flask in place of the two-neck flask. Two of the necks were equipped with a septum and condenser as described before. To the third neck was attached a liquid addition funnel sealed at the top with a septum. Activated copper (16.5 mmol), made from lithium naphthalenide and CuI·P(n-Bu)$_3$ in THF, was prepared in the three-neck flask. An internal standard was added (typically 3 mmol), the temperature of the flask was adjusted, and stirring was initiated. For the 1,5-dihaloalkanes, nonane was used as the internal standard. In all other reactions decane was used. The dihaloalkane (4 mmol) was syringed into the addition funnel followed by THF (5–10 mL). The apparatus was shaken gently to mix the solutions thoroughly. The dihaloalkane solution was then added slowly (0.5 h) to the activated copper solution. For specific reaction temperatures and product yields see Table V. Aliquots (1 mL) were removed via syringe at timed intervals (1, 10, 30, 60, 120 min) and quenched with HCl (0.01 M, 0.2 mL). Most of the reactions were found to be complete within 10 min after all of the starting material was added. The organic layer from the quenched aliquot was analyzed by GC (columns II, III). Yields and identities of the cyclized product for 1,3-dibromobutane and 1,4-diiodobutane were established by the independent synthesis of methylcyclopropane by the method of Demjanow,[17] and cyclobutane by the method of Cason and Way.[18] The identities of all other cyclized compounds were established by comparing them to authentic commercial samples.

Formation of *trans*-Stilbene from *meso*-Stilbene Dibromide. *meso*-Stilbene dibromide was purchased from Aldrich. The reaction was carried out at room temperature as indicated for a typical cyclization procedure using nonane as the internal standard. The reaction was found to be complete in 10 min from the time all of the starting material was added. GC analysis (column I) showed an 83% yield of *trans*-stilbene with no detectable amount of *cis*-stilbene present.[19] In another experiment,

cis-stilbene was treated with activated copper under the conditions stated above, and it was found that 80% of the *cis*-stilbene had isomerized to the trans compound in 1 min. At the end of 10 min the conversion was over 90%.

(17) Demjanow, J. *Ber.* **1895**, *28*, 21.
(18) Cason, J.; Way, R. L. *J. Org. Chem.* **1949**, *14*, 31.
(19) The limit of detectability of *cis*-stilbene on our GC is ca. 2% under the conditions of reaction.

Chlorofluorocarbene from Reaction of Fluorotrichloromethane with Reduced Titanium. Synthesis of 1-Chloro-1-fluorocyclopropanes

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Generation of chlorofluorocarbene by reaction of CFCl$_3$ with reduced titanium at 0 °C, in the presence of various alkenes, produces 1-chloro-1-fluorocyclopropanes in good yield. Evidence from the syn/anti product ratios, including generation of chlorofluorocarbene from CFBr$_2$Cl, indicates that a free carbene and not a "carbenoid" species is involved. Solvent effects, effects of ratios of reagents, and the efficacy of other metals in this reaction were also examined. A cursory examination of PhCCl$_3$, CH$_3$CCl$_3$, and CF$_2$Br$_2$ in this reaction indicated that they are also useful carbene precursors, while CHCl$_3$, CHFBr$_2$, and CHFI$_2$ were all found to be ineffective.

In a recent communication,[1] we reported a new method for generating chlorofluorocarbene from CFCl$_3$. In this paper, we report the full range of alkenes that we have studied and the experimental details of these reactions. Furthermore, we will present evidence supporting the conclusion that free chlorofluorocarbene is the likely re-

active intermediate and that a "carbenoid" species is probably not involved.

Chlorofluorocarbene has been previously generated by the following methods: (a) thermolysis of PhHgCFCl$_2$ (an 89% yield of 7-chloro-7-fluorobicyclo[4.1.0]heptane from cyclohexene);[2] (b) base-induced decomposition of methyl dichlorofluoroacetate (60%);[3] (c) reactions of CHFCl$_2$ with

(1) Dolbier, W. R., Jr.; Burkholder, C. R. *Tetrahedron Lett.* **1988**, *29*, 6749.

(2) Seyferth, D.; Darragh, K. V. *J. Org. Chem.* **1970**, *35*, 1297.