

removed, and the mixture was stirred at ambient temperature for 1 h. Water was added, and the mixture was extracted thoroughly with ether. The ether extract was washed (water, brine), dried (MgSO<sub>4</sub>), filtered, and then concentrated. The resulting viscous oil was chromatographed through a short column (25 × 170 mm; dry silica gel; lbpe, benzene, and then 5% acetone-benzene) to afford after concentration 1.72 g (93%) of a reasonably pure vinylallenone mixture (<sup>1</sup>H NMR integration of the C-18 methyl group signal indicated the presence of a 12.2: 1 ratio of (6*R*)- to (6*S*)-allenes). Chromatography of the mixture on a 50 × 2 cm dry silica gel column (benzene) afforded first pure (6*S*)-allene **6d** (66.8 mg, 3.6%) and then second the major (6*R*)-allene **6a** (1.012 g, 55%).

**Photolysis of (6*R*)-Vinylallenone 6a.** An ice-cooled nitrogen-purged solution of (6*R*)-allene **6a** (0.987 g, 2.68 mmol) in isooctane (spectrograde, freshly distilled from LiAlH<sub>4</sub>, 500 mL) was irradiated through quartz with a 100-W Hanovia medium-pressure lamp as previously described.<sup>2d</sup> Monitoring by HPLC or <sup>1</sup>H NMR indicated that a photostationary state (~1:1 ratio of 6*R* and 6*S* isomers) was reached within 15 min. Concentration and then chromatographic separation (75 × 2.5 cm dry silica column; benzene and then 2% acetone-benzene) afforded (6*S*)-allene **6d** (427.4 mg, 43%; 77% based on recovered 6*R* isomer) and (6*R*)-allene **6a** (434.2 mg, 44%).

**(1*R*,6*R*)- (6*b*) and (1*S*,6*R*)-1-Hydroxy-A-nor-9,10-secocholesta-5(10),6,7-triene (6*c*).** A solution (0 °C) of (6*R*)-A-nor-vinylallenone **6a** (169 mg, 0.46 mmol) in 0.4 M cerium(III) chloride heptahydrate/methanol solution (1.2 mL) was treated with NaBH<sub>4</sub> (17.1 mg, 0.46 mmol). After being stirred for 5 min, the mixture was warmed to room temperature and subjected to conventional processing (H<sub>2</sub>O quench and then ether-water workup) to afford a 1:1 mixture of **6b** and **6c**. Semipreparative HPLC (10% ethyl acetate/Skellysolve B) followed by concentration and drying afforded spectrally and chromatographically pure **6b** (less polar; 79 mg, 46%) and **6c** (more polar; 66 mg, 39%). LiAlH<sub>4</sub> in ether gave similar results (34% **6b**, 30% **6c**), but NaBH<sub>4</sub> in methanol appeared to effect carbon-carbon double bond reduction.

**(1*S*,6*S*)- (6*f*) and (1*R*,6*S*)-1-Hydroxy-A-nor-9,10-secocholesta-5(10),6,7-triene (6*e*).** The NaBH<sub>4</sub>-CeCl<sub>3</sub>/methanol reduction of **6d** (45 mg, 0.12 mmol) was carried out exactly as described for **6a** in the preceding experiment. The crude mixture consisted of a 1:1 ratio of **6f** and **6e** (HPLC). Semipreparative HPLC afforded **6f** (less polar; 15 mg, 34%) and **6e** (more polar; 16 mg, 36%). LiAlH<sub>4</sub> in ether reduction gave similar results (27% **6f**, 37% **6e**), whereas NaBH<sub>4</sub> in methanol appeared to effect carbon-carbon double bond reduction.

**Thermolysis of 6*R* Ketone 6a.** A solution of 6*R* ketone **6a** (482 mg, 1.31 mmol) in freshly distilled *n*-decane (24 mL) was heated (140 °C, N<sub>2</sub>) for 24 h. Monitoring by analytical HPLC (10% ethyl acetate/Skellysolve B) revealed that **6a** was nearly completely consumed after 24 h. Chromatographic removal of *n*-decane (short silica gel column, elution with lbpe and then 5% acetone/benzene), concentration, and then preparative HPLC

(single injection, multiple shave/recycle) of the resulting residue under the same conditions yielded five significant fractions. Isolated in order of increasing elution time were **11** (31 mg, 6%), **12** (26 mg, 5%), 6*R* ketone **6a** (7 mg, 2%), **13** (169 mg, 35%), and **14** (29 mg, 6%). Each of the five components was obtained as an oil except **14** (amorphous foam). It was also noted that 6*S* ketone **6b** could not be detected as one of the products.

**Thermolysis of 6*S* Ketone 6b.** As described in the preceding experiment, thermolysis of **6b** (133 mg, 0.36 mmol; 10 mL of *n*-decane 140 °C, 24 h, N<sub>2</sub>) and then a similar workup followed by semipreparative HPLC afforded in order of elution **11** (~9 mg, 7%), **12** (~6 mg, ~5%), **6b** (trace), **13** (52 mg, 39%), and **14** (~4 mg, ~3%).

**Thermal Control Experiments of 11-14.** In parallel experiments, **11** (2.0 mg), **12** (3.5 mg), **13** (6.0 mg), and **14** (3.5 mg) dissolved in *n*-decane (~1.0 mL) were heated (140 °C, N<sub>2</sub>) for 24 h. Each separate thermolysis revealed by analytical HPLC (10% ethyl acetate/Skellysolve B) the presence of peaks (in varying ratios) with the same retention times as those of authentic specimens of 11-14 as well as other unidentified peaks. The complexity of the product mixtures precluded further studies on the positive identification of the components.

**Acid Rearrangement of (6*R*)-A-Norvinylallenone 6a.** A solution (25 °C, N<sub>2</sub>) of (6*R*)-A-norvinylallenone **6a** (475 mg, 1.29 mmol) in chloroform (3 mL) was treated with a 20% (w/v) SbCl<sub>5</sub>/CHCl<sub>3</sub> solution (30 mL) and stirred for 18 h. Quenching with 40% (w/v) tartaric acid/water (40 mL) and a conventional workup (lbpe and water extraction, NaHCO<sub>3</sub> wash) yielded a multicomponent crude oil (394 mg). Semipreparative HPLC (20% ethyl acetate/Skellysolve B; single injection, multiple shave/recycle) followed by concentration and drying of the appropriate fractions afforded in order of elution (6*S*)-vinylallenone **6d** (93 mg, 20%), starting (6*R*)-vinylallenone **6a** (63 mg, 13%), and *trans*-isotachysterone **13** (87 mg, 18%). Treatment of **6a** with a 50-mol excess of trifluoroacetic acid in methylene chloride for 1 h afforded only recovered starting material.

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**Registry No.** **4a**, 74398-26-8; **4b**, 67632-48-8; **4c**, 67670-78-4; **4d**, 74398-27-9; **4e**, 67670-79-5; **4f**, 67670-80-8; **6a**, 79421-01-5; **6b**, 79421-02-6; **6c**, 79421-03-7; **6d**, 79421-04-8; **6e**, 79421-05-9; **6f**, 79421-06-0; **9**, 74398-28-0; **10**, 22117-97-1; **11**, 79421-07-1; **12**, 79421-08-2; **13**, 79421-09-3; **14**, 79421-10-6.

**Supplementary Material Available:** Spectral and analytical data (13 pages). Ordering information is given on any current masthead page.

## Reactions of Copper(I) Halide Complexes of Trivalent Phosphorus with Vinylic Halides<sup>1</sup>

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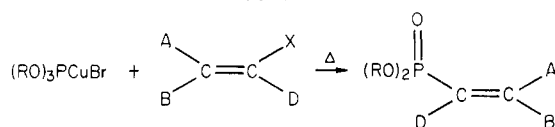
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The direct formation of the vinylic carbon to phosphorus bond has been accomplished via reaction of vinylic halides with copper(I) halide complexes of trialkyl phosphites. In addition, formation of varying amounts of vinylic chlorides may be observed if the reaction is performed by using vinylic bromides with copper(I) chloride complexes of trialkyl phosphites. This halogen-exchange reaction may be made synthetically useful through the employment of copper(I) chloride complexes of triaryl phosphites or phosphines.

In support of a program of directed syntheses of organophosphorus compounds of potential biological activity,<sup>2</sup>

it has been of interest to develop new methods for the generation of carbon-phosphorus bonds, in particular

Scheme I



vinyl carbon-phosphorus bonds.<sup>3</sup> Although a variety of methods are available for their generation, only most recently have feasible methods been reported for direct substitution of a halide or other leaving group at vinylic carbon by phosphorus.<sup>1,4</sup>

Prior attempts to effect a direct Michaelis-Arbuzov-type reaction on a vinylic halide have met with failure<sup>5-7</sup> or at best quite limited results.<sup>8,9</sup> Similar limited results had previously been obtained when transition-metal salts were used as catalysts.<sup>10-12</sup> However, experimental evidence gave promise that general synthetic techniques might be developed by using transition-metal-associated systems; this has now been realized by the use of palladium(0) with dialkyl phosphites<sup>4</sup> and the present effort using copper complexes of trialkyl phosphites.

Other efforts have demonstrated that copper(I) halide complexes of trialkyl phosphites are capable of undergoing binding interactions with unsaturated linkages. Of particular note are the phosphorylation of aromatic iodides,<sup>13</sup> a reaction analogous to the Michaelis-Arbuzov reaction, and catalytic activity associated with binding to olefinic linkages.<sup>14,15</sup> Because of this and the relative ease with which they may be prepared,<sup>14,16</sup> trialkyl phosphite-copper(I) halide complexes were deemed reasonable candidates for effecting phosphorus substitution for halide at vinylic carbon.

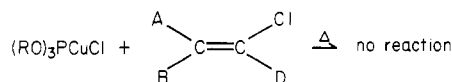
In the present work we describe optimal reaction conditions for the generation of aryl-substituted vinylphosphonate esters from the corresponding vinylic halides. These reactions proceed with high yield and high retention of the original olefin stereochemistry using copper(I) halide complexes of trialkyl phosphites.

In addition to this phosphorylation reaction, a halide-exchange reaction occurs under particular reaction conditions. Halide exchange catalyzed by copper(I) complexes has been noted previously for aromatic systems<sup>17,23</sup> and

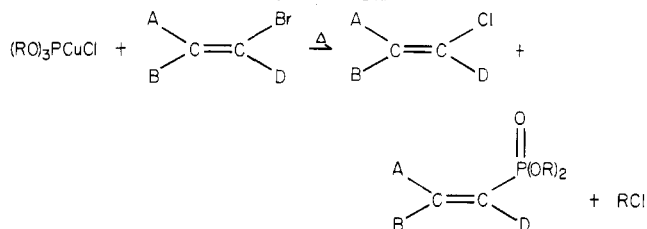
Table I

reaction system	vinylic halide	phosphite complex	% yield of phosphonate
1	A, D = H; B = Ph; X = Cl (E only)	triisopropyl phosphite-CuBr	76 (E only)
2	A, B = Ph, Me; D = H; X = Cl (Z/E, 1/1.4)	triethyl phosphite-CuBr	85 (Z/E, 1/1.7)
3	A, B = Ph, Et; D = H; X = Cl (Z/E, 1.7/1)	triisopropyl phosphite-CuBr	82 (Z/E, 1/1)
4	A, B = Ph; D = H; X = Br	triethyl phosphite-CuBr	95
5	A, B = Ph; D = H; X = Br	triisopropyl phosphite-CuBr	96
6	A, B = H; D = Ph; X = Cl	triethyl phosphite-CuBr	26
7	A, B = H; D = Ph; X = Cl	triisopropyl phosphite-CuBr	49

Scheme II



Scheme III



under special conditions for  $\beta$ -bromostyrene with copper(I)<sup>24</sup> and nickel(II)<sup>25</sup> systems. The present effort has produced a set of reaction conditions for conversion of vinylic bromides into vinylic chlorides in high yield and with high retention of olefin stereochemistry.

While the results described in the present report include only aryl-substituted systems, work on aliphatic systems is in progress.

## Results and Discussion

Complexes of triethyl and triisopropyl phosphites with copper(I) bromide were prepared according to the method of Wulfman et al.<sup>16</sup> These complexes, freshly prepared, were used in reaction with substituted vinylic halides by heating the mixture in the absence of solvent at 200 °C for several hours. After removal of the metal by chelation, the corresponding substituted vinylphosphonate diesters were isolated by using either vacuum distillation or column

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Table II

reaction system	vinylic bromide	phosphite complex	% yield ( <i>Z/E</i> ratio)	
			chloride	phosphonate
8	A, B = Ph; D = H	triethyl phosphite-CuCl	29	51
9	A, B = Ph; D = H	triisopropyl phosphite-CuCl	46	44
10	A, B = Ph, Et; D = H ( <i>Z/E</i> , 2.8/1)	triethyl phosphite-CuCl	20 (1.7/1)	50 (1.5/1)
11	A, B = Ph, Et; D = H ( <i>Z/E</i> , 2.8/1)	triisopropyl phosphite-CuCl	40 (1.7/1)	50 (1.5/1)
12	A, B = Ph, Me; D = H ( <i>Z/E</i> , 1/1.3)	triethyl phosphite-CuCl	34 (1.1/1)	52 (1.1/1)
13	A, B = Ph, Me; D = H ( <i>Z/E</i> , 1/1.3)	triisopropyl phosphite-CuCl	43 (1.1/1)	39 (1.1/1)
14	A, D = H; B = Ph ( <i>E</i> only)	triethyl phosphite-CuCl	39 ( <i>E</i> only)	52 ( <i>E</i> only)
15	A, D = H; B = Ph ( <i>E</i> only)	triisopropyl phosphite-CuCl	48 ( <i>E</i> only)	48 ( <i>E</i> only)
16	( <i>E</i> )-1-bromovinyl cyclohexene	triethyl phosphite-CuCl	28 ( <i>E</i> only)	47 ( <i>E</i> only)
17	( <i>E</i> )-1-bromovinyl cyclohexene	triisopropyl phosphite-CuCl	47 ( <i>E</i> only)	44 ( <i>E</i> only)
18	A, B = H; D = Ph	triisopropyl phosphite-CuCl	61	28

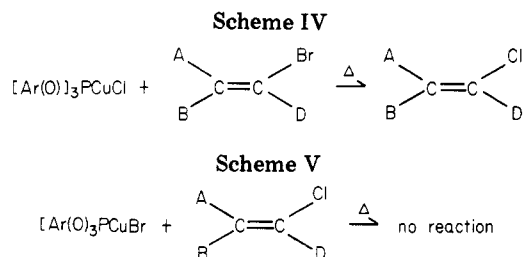
chromatographic techniques (Scheme I). In addition, as would be anticipated for a reaction involving a Michaelis-Arbuzov-type expansion of phosphorus valence, there could be isolated the appropriate alkyl halide. The yields for a selection of reactions are shown in Table I.

Several points of interest should be noted from the data in Table I. First, the reactions involving  $\alpha$ -chlorostyrene (reaction systems 6 and 7) proceed with significantly lower yields than those involving a  $\beta$ -chlorostyrene structure. This parallels the decreased yields observed by Hirao et al.<sup>14</sup> upon changing from the  $\beta$ -bromostyrene to the  $\alpha$ -bromostyrene reactant with the palladium catalyst. Second, the reaction appears to be stereoselective. If the starting vinylic halide is purely *E*, only *E* product is obtained; with an *E/Z* mixture there appears to be a preference for *E* product formation, although it is not overwhelming.

When freshly prepared complexes of triethyl or triisopropyl phosphite with copper(I) chloride were treated with the substituted vinylic halides, somewhat different results were observed. With substituted vinylic chlorides, no generation of vinylic phosphonates could be observed, and starting materials could be recovered quantitatively (Scheme II). With the substituted vinylic bromides, formation of the corresponding substituted vinylphosphonate diesters could be observed, much as noted above with the copper(I) bromide complexes, but with lower absolute conversion. In addition, a sizable portion of the starting material could be recovered as the vinylic chloride (Scheme III). The yields of those materials based on the starting vinylic bromide are indicated in Table II.

As regards yields of halide-exchange and phosphonation reactions, it may be noted that in the competition between these two routes the isopropyl ester systems produce higher yields of vinylic chlorides than do the ethyl ester systems. This may be viewed simply as a result of more efficient transfer of halide to carbon from the intermediate with the bulkier phosphorus substituent.

The lack of reactivity of the vinylic chlorides with the copper(I) chloride-trialkyl phosphite complexes is also interesting in this vein. Chloride appears to compete quite effectively with the phosphorus substituent in transfer from the intermediate bound stage to carbon. When chloride is the *only* halide in the system, transfer of phosphorus to carbon is a relatively poor process. Presumably with longer reaction times some substituted vinylphosphonate esters might be observed.



It should again be noted that the reactions exhibit, at most, only a slight variation in product stereoisomer distribution from that of the starting material, and starting with a pure *E* vinylic bromide, only *E* vinylic phosphonate and vinylic chloride are generated. Moreover, it is found that the *alkyl* halide recovered is solely alkyl chloride; in the final displacement on the phosphorus ester, only chloride is participating.

In light of the competing halogen-exchange reaction, use of copper(I) as a catalyst for vinylic phosphonate generation proceeds best if the halide in both reagents is bromide. The work of Hirao et al.<sup>4</sup> using palladium involved only vinylic bromides.

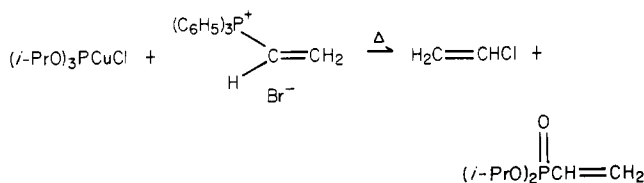
These results also indicate that a synthetically feasible route for the conversion of vinylic bromides to vinylic chlorides might be available with the copper(I) chloride system if phosphonate formation could be suppressed. An approach to this would be to use a phosphite incapable of completing the valence-expansion reaction or a phosphine as the complexing ligand.

To this end a series of experiments were performed with triphenyl phosphite and triphenylphosphine complexes of copper(I) chloride in reaction with vinylic bromides (Scheme IV). The results are summarized in Table III. All of the systems investigated gave yields of isolated and purified vinylic chloride product greater than 85% with virtually complete maintenance of the original olefinic stereochemistry. All attempts to perform the reverse exchange (Scheme V), bromide for chloride, failed. Starting materials could be recovered quantitatively. These data indicate that a successful method for the direct phosphonylation of vinylic halides has been obtained by using a first-row transition-metal catalyst, along with a synthetically viable method for halide exchange at vinylic carbon. A topic of some interest is the mechanistic relationship between these two processes, that is if a common intermediate might be invoked for them. To this end several

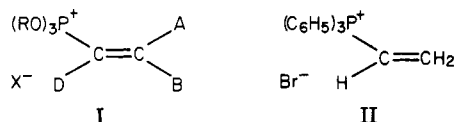
Table III

reaction system	vinyllic bromide	copper(I) reagent	% yield of vinyllic chloride (Z/E ratio)
19	A, D = H; B = Ph (E only)	triphenyl phosphite-CuCl	94 (E only)
20	A, D = H; B = Ph (E only)	triphenyl phosphine-CuCl	98 (E only)
21	A, B = Ph, Me; D = H (Z/E, 1/1.4)	triphenyl phosphite-CuCl	85 (Z/E, 1/1.4)
22	A, B = Ph, Me; D = H (Z/E, 1/1.4)	triphenyl phosphine-CuCl	98 (Z/E, 1/1.3)
23	A, B = Ph, Et; D = H (Z/E, 4.2/1)	triphenyl phosphite-CuCl	97 (Z/E, 4.2/1)
24	A, B = Ph; D = H	triphenyl phosphite-CuCl	95
25	A, B = Ph; D = H	triphenyl phosphine-CuCl	96

Scheme VI



experiments were performed by using a species which is an analogue of a reasonable postulated precursor to the vinyllic phosphonate species. The quasi-phosphonium species I would seem to be a plausible immediate precursor



to the vinyllic phosphonate products in view of the involvement of such species in the normal Michaelis-Arbuzov reaction.<sup>7</sup> The readily available triphenylvinylphosphonium bromide II<sup>26</sup> might be viewed as an analogue of I which is incapable of undergoing the final step of the Michaelis-Arbuzov reaction but could possibly revert to a common intermediate (for phosphonylation and halide exchange) under the proper reaction conditions.

When II was heated with copper(I) chloride or bromide in the absence of solvent or in dry diglyme, no reaction could be observed, and starting material could be recovered quantitatively. However, when the triisopropyl phosphite complex with either copper(I) chloride or copper(I) chloride and 0.1 molar equiv of triphenylphosphine were heated with II, vinyl chloride could be isolated as a product. In the former of these two cases there could also be isolated diisopropyl vinylphosphonate (Scheme VI). This observation would seem to support the postulation of a common intermediate for phosphonation and halide exchange, one that is capable of being generated from the species II. It should be noted that II might be considered as a cul de sac transient species in the halide-exchange reaction with triphenylphosphine as the copper(I) chloride complex.

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This observation also points to the requirement for a copper species which is ligated with a strong  $\pi$  donor for olefinic complexation. This requirement has been noted in a number of other copper complex catalyzed reactions.<sup>17,19,27-31</sup> Why this should be critical for the reaction requires further detailed consideration. Recent considerations by Eisenstein and Hoffmann<sup>32</sup> have indicated the feasibility of such processes when particular electronic characteristics are present for the interacting transition-metal species. It should be noted, however, that complexation with a system of the type  $d(10)ML_2$ , such as the triphenylphosphine complex with copper(I) chloride, is indicated not to lead to activation for nucleophilic attack. This might be taken as indicative of the action of an intermediate copper species of higher oxidation state than that of the initial phosphite complex.

### Experimental Section

**Reagents.** All solvents and liquid reagents used in the preparation of the vinyllic halides and copper(I) halide complexes, and in the performance and work-up of the reactions, were distilled prior to use, with the exception of anhydrous ether and 95% ethanol.

Cuprous bromide and cuprous chloride were prepared fresh prior to use by a standard method.<sup>33</sup> The trivalent phosphorus complexes of these materials were also prepared fresh prior to use by following the method of Wulfman et al.<sup>16</sup> The  $\beta$ -bromostyrene and (*E*)-1-(bromovinyl)cyclohexene were commercial materials (Aldrich) and were distilled prior to their use in the phosphonation reactions. The  $\beta$ -chlorostyrene used in the phosphonation reaction was prepared by using the halide-exchange reaction described herein. The  $\alpha$ -chlorostyrene was prepared by a previously reported method.<sup>34</sup>

The following compounds were prepared according to the general method described by Kobrich et al.<sup>35</sup> 1-chloro-2-phenylpropene, 1-bromo-2-phenylpropene, 1-bromo-2-phenyl-1-butene, 1-chloro-2-phenyl-1-butene, 1-bromo-2,2-diphenylethene. The outline for their preparation is as follows.

The (halomethyl)triphenylphosphonium bromide<sup>35</sup> (0.1 mol) was placed in a 1-L three-necked flask equipped with a mechanical stirrer, a condenser and a nitrogen inlet tube. After the system had been purged with nitrogen, 200 mL of anhydrous ether was added followed by 0.09 mol of piperidine. Then there was added dropwise with vigorous stirring 0.09 mol of *tert*-butyllithium in *n*-pentane. After a clear solution resulted, the ketone (0.085 mol) was added dropwise followed by refluxing for 30 min. After the mixture cooled, the solids were filtered and washed several times with ether. The filtrate was washed successively with 2 N sulfuric acid (2  $\times$  100 mL) and saturated sodium bicarbonate (2  $\times$  100 mL) solutions, dried, and concentrated under reduced pressure. The crude product was purified by chromatography on neutral alumina (activity 1), being eluted with hexane. Yields of pure substances ranged from 24% to 40%. All substances generated gave satisfactory IR and NMR (proton) spectra and satisfactory elemental analyses for C and H within 0.35%. These data for all compounds of interest in this work are given in Tables IV and V which are available as supplementary material.

The  $\alpha$ -bromostyrene was prepared as follows: In a 200-mL three-necked flask equipped with an addition funnel, an HBr inlet tube, and a condenser topped with a drying tube was placed 0.03

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mol of phenylacetylene in 60 mL of anhydrous ether. The solution was saturated with HBr, and 0.03 mol of triphenylphosphine in 20 mL anhydrous ether was added. After the mixture was refluxed for 30 h, the solid material was filtered and the filtrate concentrated under reduced pressure. The residue was distilled [69 °C (2.8 torr)] to give pure  $\alpha$ -bromostyrene in 84% yield.

**General Procedure for Vinylic Phosphonate Preparation.** To a 50-mL round-bottomed flask equipped with a short Vigreux column topped with a Dean-Stark trap, a condenser, and a nitrogen inlet tube were placed 0.05 mol of the copper(I) halide complex of the trialkyl phosphite and 0.035 mol of the vinylic halide. The mixture was heated at 200 °C for 1 h, alkyl halide produced being collected in the Dean-Stark trap. After cooling to room temperature, the reaction mixture was poured into 60 mL of toluene. There was then added 5 mL of ethylenediamine dropwise with stirring. The solid material was filtered and washed with toluene, and the combined toluene portions were washed with 10 mL of 10% hydrochloric acid followed by 10 mL of water, dried over magnesium sulfate, and concentrated under reduced pressure. The residue was chromatographed on silica gel (eluted with a hexane-ethyl acetate gradient) to separate the vinylic phosphonate and vinylic halide. The vinylic phosphonate was then vacuum distilled.

**General Procedure for Halide-Exchange Reactions.** To a 25-mL round-bottomed flask equipped with a condenser and nitrogen inlet tube were placed 0.02 mol of the copper(I) chloride complex of either triphenyl phosphite or triphenylphosphine and 0.018 mol of the vinylic bromide. The mixture was heated at 160–190 °C for 1.5 h. After the mixture cooled 25 mL of pentane was added. The solid material was filtered and washed with pentane; the solid material could be identified as the copper(I) bromide complex of either triphenyl phosphite or triphenylphosphine. The filtrate was concentrated under reduced pressure to give crude product which was purified by chromatography on silica gel, elution being performed with hexane.

**Analysis.** All IR spectra were measured by using a Perkin-Elmer 598 spectrophotometer, and NMR spectra were measured by using a Varian EM-360 instrument. Elemental analyses were

performed by Guelph Chemical Laboratories and by Galbraith Laboratories.

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**Registry No.** (*E*)-Diethyl 2-(1-cyclohexenyl)vinylphosphonate, 78463-01-1; (*E*)-diisopropyl 2-(1-cyclohexenyl)vinylphosphonate, 78463-02-2; diethyl 1-phenylvinylphosphonate, 25944-64-3; diisopropyl 1-phenylvinylphosphonate, 79373-28-7; diethyl 2-phenylvinylphosphonate, 20408-33-7; diisopropyl 2-phenylvinylphosphonate, 78463-00-0; (*E*)-diethyl 2-phenyl-2-methylvinylphosphonate, 20408-29-1; (*Z*)-diethyl 2-phenyl-2-methylvinylphosphonate, 78462-97-2; (*E*)-diisopropyl 2-phenyl-2-methylvinylphosphonate, 78462-99-4; (*Z*)-diisopropyl 2-phenyl-2-methylvinylphosphonate, 78462-98-3; (*E*)-diethyl 2-phenyl-2-ethylvinylphosphonate, 78462-94-9; (*Z*)-diethyl 2-phenyl-2-ethylvinylphosphonate, 78462-93-8; (*E*)-diisopropyl 2-phenyl-2-ethylvinylphosphonate, 78462-96-1; (*Z*)-diisopropyl 2-phenyl-2-ethylvinylphosphonate, 78462-95-0; diethyl 2,2-diphenylvinylphosphonate, 78462-91-6; diisopropyl 2,2-diphenylvinylphosphonate, 78462-92-7; 1-chloro-2,2-diphenylethene, 4541-89-3; (*E*)-2-chlorostyrene, 4110-77-4; (*Z*)-1-chloro-2-phenylpropene, 16917-31-0; (*E*)-1-chloro-2-phenylpropene, 16917-32-1; (*Z*)-1-chloro-2-phenyl-1-butene, 78463-03-3; (*E*)-1-chloro-2-phenyl-1-butene, 64245-19-8; 1-bromo-2,2-diphenylethene, 13249-58-6; 1-chlorostyrene, 618-34-8; (*Z*)-1-bromo-2-phenyl-1-butene, 78463-05-5; (*E*)-1-bromo-2-phenyl-1-butene, 64245-20-1; (*Z*)-1-bromo-2-phenylpropene, 19647-26-8; (*E*)-1-bromo-2-phenylpropene, 16917-35-4; (*E*)-2-bromostyrene, 588-72-7; (*E*)-1-bromo-2(1-cyclohexenyl)ethene, 78463-06-6; 1-bromostyrene, 98-81-7; triisopropylphosphite-CuBr, 61918-60-3; triethylphosphite-CuBr, 72287-27-5; triethylphosphite-CuCl, 14221-63-7; triisopropylphosphite-CuCl, 39721-89-6; triphenylphosphite-CuCl, 24484-07-9; triphenylphosphine-CuCl, 22176-30-3.

**Supplementary Material Available:** Table IV containing C and H elemental analyses and Table V containing NMR and IR spectral data (6 pages). Ordering information is given on any current masthead page.

## Reaction of Carbohydrate Halides with Magnesium. Novel C-C Coupling of Sugar Derivatives via Organometallic Intermediates<sup>1</sup>

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The reaction of 3-deoxy-3-*C*-(iodomethyl)-1,2:5,6-di-*O*-isopropylidene- $\alpha$ -D-allofuranose (**1c**) with sublimed magnesium in refluxing tetrahydrofuran gave dimer **2** and only traces of the 3-deoxy-3-methyl derivative **1d**. Similarly methyl 5-deoxy-5-iodo-2,3-*O*-isopropylidene- $\beta$ -D-ribofuranoside (**3b**) afforded the 5-5'-coupled compound **4**, and 6-deoxy-6-iodo-1,2:3,4-di-*O*-isopropylidene- $\alpha$ -D-galactofuranose (**5a**) yielded the 6-6'-joined derivative **6**. 3-Deoxy-3-iodo-1,2-*O*-isopropylidene-DL-glycerol (**7b**) was also readily converted to dimer **8**. The interaction of **1c** with **3b** gave the unsymmetrical product **9** in addition to dimers **2** and **4**. Similarly, halogeno sugars **1c** and **5a** gave compound **10** along with derivatives **2** and **6**. Dimer formation was also predominant in reaction of iodide **1c** with magnesium in the presence of compounds such as benzonitrile or *N*-phthaloyl-L-phenylalanine 2-pyridyl thioester (**11a**), which otherwise effectively trap the Grignard reagents. Compound **11a** afforded smoothly the corresponding ketone **11b** after treatment with CH<sub>3</sub>MgBr. On the other hand, 5'-deoxy-5'-iodo-2',3'-*O*-isopropylidene-*N*<sup>3</sup>-methyluridine (**3d**) gave neither dimer nor the Grignard reagent. In addition, the dimer formation from iodo derivative **1c** was inhibited in the presence of **3d**. Compound **2** resulted also from the reaction of **1c** with *n*-butyllithium in tetrahydrofuran, whereas the interaction of **1b** produced only 3-deoxy derivative **1d**. The possible reaction mechanism and the role of complexation in reactants and hypothetical transition states are discussed.

Reaction of alkyl or aryl halides with magnesium (Grignard reaction) is one of the most widely used methods

of synthetic organic chemistry.<sup>3</sup> Applications of Grignard reagents in the carbohydrate field are also well docu-