Elimination Reactions of Secondary and Tertiary Alcohols with Polystyryl Diphenylphosphine in Tetrachloromethane

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ABSTRACT

A cross-linked polystyrene was prepared by suspension copolymerization of styrene with 2% divinylbenzene. This cross-linked polymer was brominated in solution of bromine-tetrachloromethane in presence of ferric chloride catalyst. The cross-linked brominated polystyrene was allowed to react with lithium in tetrahydrofuran under nitrogen atmosphere and subsequently the mixture was reacted with diphenylphosphine chloride to produce the cross-linked polystyryl diphenylphosphine. A gel form of this polymer in tetrachloromethane is used effectively to convert primary alcohols to alkyl halides and secondary and tertiary alcohols to alkenes under very mild conditions. The results of homogeneous reaction of alcohols with triphenylphosphine in tetrachloromethane have been compared with heterogeneous reaction of alcohols with the use of cross-linked polymer. The advantages of this method for the conversion of alcohols to alkyl chloride and alkenes lie in its simplicity, its ability to be carried out under neutral pH, and its facile regeneration of the polymeric reagent. The mechanism of the reactions proceeds via intermolecular anti-E2 elimination. Polar solvent (acetonitrile) effects the rate of conversion and regioselectivity but not stereoselectivity. Steric hindrance is responsible for the low reactivity but higher selectivity.

Key Words: suspension polymerization, cross-linked polystyryl diphenylphosphine, elimination reactions of alcohols, substitution reactions, stereoselectivity

INTRODUCTION

The reaction of primary and secondary alcohols with triphenylphosphine-tetrachloromethane constitutes a mild and efficient method for conversion of alcohols into corresponding alkyl chloride [1–6]. Dabbagh et al. [3] have reported that elimination is the minor pathway for the reaction of erythro-3-deuterio-2-butanol with triphenylphosphine (>98% anti-elimination in favour of Saytzeff orientation with primary
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deuterium isotope effect of 2). 2-Methyl-2-propanol produced almost 90% 2-methylpropene (kH/kD: 2). Mechanism for this reaction proceeds via two steps [6]. Recently, this reaction was extended to stereo-selective synthesis of hindered olefins from model compounds 1,2,3-triphenyl-2-propanol (1) and 1,2-diphenyl-2-propanol (2) [4, 5]. They reported that triphenylphosphine in tetrachloromethane converted 100% of 2 to a mixture of 28% 1,2-diphenyl-2-chloropropane, 37% E-α-methyl stilbene (4), 35% of α-benzylstyrene (6), and a trace of Z-α-methyl stilbene (5) at 78 °C. They demonstrated that stereo-selectivity and regio-selectivity of elimination in concerted homogeneous reactions depend on the properties of the system and mainly on the steric interaction of the intermediate and/or transition state.

It was also reported [3] that, under homogeneous acidic condition, 2 produced kinetically controlled 6 approximately in equal amounts (1:1) with 4 in 0.4 h, rapidly converting to an equilibrium mixture of olefins (4/5: 4.30) in 2 h.

Steric interaction at transition state or intermediate is shown to be responsible for the observed selectivity. We extended the dehydration reactions of model compounds 1 and 2 over metal oxides. It was concluded that the dehydration of alcohols over metal oxides depends not only upon the steric interaction of the intermediate and/or transition state but it is also strongly dependent on the preparation conditions of the catalyst and reaction conditions. They suggested further that at lower temperatures the reaction in pure aluminium oxides proceeds via intermolecular E2 elimination and favours the Hofmann orientation but at higher temperature favour E1 and Saytzeff elimination.

Ph₃P + CCl₄ \rightarrow [Ph₃P-Cl]+ CCl₃ (1)

[Ph₃P-Cl]+ CCl₃ + ROH \rightarrow [Ph₃P-OR]+Cl- + CHCl₃

[Ph₃P-OR]+Cl- \rightarrow R-Cl + Alkene + Ph₃P=O (2)

Polymers were utilized as organic reagents as early as the beginning of 1960. These reagents behave similar to their smaller counterparts in many chemical transformations [7]. In 1963 Merrifield introduced the solid state technique for the synthesis [8] of the lipids utilizing polymeric reagents. Functionalized polymers were used not only to synthesize a new molecule but also utilized as catalyst, protecting groups and stationary phase in chromatography [9]. The major advantage of a functional polymer in comparison to smaller organic reagent is the ease of the separation of products from the reaction mixture by a single filtration and facile regeneration of polymer reagent and even more advantageous when the synthetic polymer are compared with poisonous volatile organic reagents.

The question raised here was whether cross-linked polymer with tertiary alcohols could be used in a stereoselective synthesis of hindered olefins. If so, what is then the mechanism of elimination for these reactions? What is the effect of polarity of solvent on the stereo-selectivity and regio-selectivity? How comparable are the dehydration of 2 in a heterogeneous system with that of homogeneous triphenylphosphine in tetrachloromethane and with that of semi-heterogeneous cross-linked diphenylphosphine polystyrene in tetrachloromethane?

EXPERIMENTAL

Styrene, divinylbenzene, 1-octanol, benzyl alcohol, chlorodiphenylphosphine, tetrachloromethane, tetrahydrofuran were purchased from Merck Chemical Co. Tetrahydrofuran was dried by refluxing with sodium and benzophenone and distilled under nitrogen atmosphere. 1,2,3-Triphenyl-2-propanol (1) and 1,2-diphenyl-2-propanol (2), and 1,2-diphenylethanol (3) were synthesized according to Scheme II.

Copolymerization of Styrene with 2% Divinylbenzene

Suspension polymerization was carried out in a 250 mL three-necked round-bottomed flask equipped with a mechanical stirrer, a condenser and a nitrogen purge
inlet. Then 120 mL of distilled water, 0.02 g of calcium phosphate and 0.1 g of polyvinyl alcohol were added to the flask, and the mixture was heated until its temperature raised to 90 °C. Finally 50 g (0.48 mol) of freshly distilled styrene (free from inhibitor), 0.2 g (0.00152 mol) of freshly distilled divinylbenzene and 0.2 g of benzoyl peroxide were added to the mixture. The mixture was heated at 90–95 °C for 6 h and the rate of mechanical stirrer was set on 1200 rpm. The resin was washed routinely to remove surface impurities. The following solutions were used at 60–80 °C, in each case with a contact time of 30–60 min with the resin, 1N NaOH, 1N HCl, H2O, DMF. The resin was washed at room temperature with methanol, acetone, benzene and diethyl ether. The resin was dried under reduced pressure at 50–57 °C.

**Bromination of Cross-linked Polystyrene**

To a suspension of 20 g (192 mmol) of cross-linked polystyrene and 0.2 g of anhydrous ferric chloride in 200 mL tetrachloromethane was added a solution of 12 mL (224 mmol) of bromine in 50 mL tetra-chloromethane at room temperature. The resulting mixture was stirred at ambient temperature for 24 h and filtered. The beads were washed with acetone until no brown filtrate was obtained, then with a mixture of dioxane-water (1:1) and followed by dioxane.

The brominated polymer was refluxed overnight in a soxhlet apparatus equipped with a dean-stark water separator using a mixture of benzene and dioxane (2:1), then dried in vacuum at 50 °C for 6 h.

**Phosphination of 2% Cross-linked Brominated Polystyrene**

A solution of 12.5 mL of THF and 4 mL (0.029 mol) of chlorodiphenylphosphine was added dropwise at 10 °C to a 0.7 g (0.1 mol) of lithium metal which was cut into pieces about 3×4 mm in size. The mixture was stirred for 12 h at room temperature. The lithium diphenylphosphine was transferred via Cannula into a 100 mL round-bottomed flask, equipped with a no-air stopper and teflon-coated magnetic stirring bar, which contained a degassed mixture of 2.5 g of 2% cross-linked brominated polystyrene preswelled in 150 mL THF. The mixture was stirred for 24 h at room temperature which was hydrolyzed with degassed acetone-water (3:1) and filtered. Then the resin was washed with water, acetone, chloroform, benzene and
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Scheme III

anhydrous diethylether. The polymer beads were dried under vacuum (6 h, 100 °C, 1 mm Hg).

Functionalized cross-linked polystyrene (CP) may be presented according to Scheme III.

General Procedure for Small-scale Reaction
A mixture of 0.158g (0.0015mol) of benzyl alcohol, 0.45g of polymer reagent, CP, 4 mL of tetrachloromethane and an internal standard were placed in a reflux condenser having a teflon-coated magnetic stirring bar. The flask was maintained under a nitrogen atmosphere, and was placed in an oil bath (80 °C) for 2 h, then it was withdrawn and cooled. The liquid phase was analyzed by GLC and $^1$H NMR spectroscopy. Procedures similar to that described for the conversion of benzyl alcohol to benzyl chloride were followed for all the small-scale reactions described in Table 1.

RESULTS AND DISCUSSION

The reactions of several primary, secondary and tertiary alcohols were studied with cross-linked polystyryl diphenylphosphine CP in tetrachloromethane. This polymer has the attractive feature that all the phosphorous containing by-products can be removed at the end of reaction from the products (alkyl halides from primary alcohols and alkenes from tertiary alcohols) by simple filtration of the polymer.

Polymer CP with primary alcohols (benzyl alcohol and 1-octanol) produced the desired products in high yield. Results are summarized in Table I. Primary alcohols give alkyl halide in good yields. Secondary alcohols produced a mixture of 22.5% alkyl halide, 5% alkene and 62.5% of unreacted alcohols. Tertiary alcohols give only the alkenes. Steric hindrance are responsible for the lack of formation of alkyl halide and for the poor conversion of compound 1. The conversion of this alcohol in a more polar solvent such as acetonitrile increases the rate of conversion at the expense of the loss of selectivity.

The conversion of 3 was low in producing 22.5% 1,2-diphenylethyl chloride and 5% E-1,2-diphenyl ethylene (3E). The more hindered alcohols 1 and 2 produced only 5% E-1,2,3-triphenyl propene (1E) and 22.5% E-1,2-diphenyl propene (4),
Table 1. Elimination and substitution reactions of cross-linked polystyryldiphenylphosphine (CP) in tetrachloromethane$^{a,b}$.

<table>
<thead>
<tr>
<th>Alcohol</th>
<th>Time (h)</th>
<th>Conc. (%)</th>
<th>Alkyl halide</th>
<th>Alkene</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzyl alcohol$^d$</td>
<td>2</td>
<td>85</td>
<td>Benzyl chloride</td>
<td></td>
</tr>
<tr>
<td></td>
<td>d</td>
<td>88</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>e</td>
<td>99</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-Octanol</td>
<td>2</td>
<td>84</td>
<td>1-Chlorooctane</td>
<td></td>
</tr>
<tr>
<td>1,2-Diphenyl ethanol (3)</td>
<td>9</td>
<td>27.5</td>
<td>1,2-Diphenyl ethyl chloride (22.5%)</td>
<td>E-1,2-Diphenylethylene (5%), (3E)</td>
</tr>
<tr>
<td>1,2-Diphenyl-2-propanol (2)</td>
<td>9</td>
<td>22.5</td>
<td></td>
<td>E-1,2-Diphenyl-1-propane (22.5%), (4)</td>
</tr>
<tr>
<td>1,2-Diphenyl-2-propanol (2)$^f$</td>
<td>9</td>
<td>29</td>
<td></td>
<td>E-1,2-Diphenyl-1-propane (18%), (4)</td>
</tr>
<tr>
<td>1,2,3-Triphenyl-2-propanol (1)</td>
<td>9</td>
<td>5</td>
<td></td>
<td>E-1,2,3-Triphenyl-1-propane (5%), (1E)</td>
</tr>
</tbody>
</table>

(a) All reactions were carried out in tetrachloromethane unless otherwise stated; (b) All yields were calculated by $^1$H NMR; (c) This work; (d) see ref. 13; (e) See ref. 14; (f) acetonitrile as a solvent.

respectively. In more polar solvent like acetonitrile conversion was increased to 29% at the expense of loss in regioselectivity (18% Saytzeff elimination and 11% Hofmann elimination). Of course, in certain cases the low conversion may not be of synthetic value but definitely has a mechanistic value which is discussed in the following section.

The stereochemistry of elimination for tertiary alcohols has been a matter of controversy for many years now. Generally, a well accepted mechanism for these reactions is carbonium ion (El). In certain cases the consideration of non-ionic mechanism for tertiary substrate is believed to be revolutionary and wrong.

However, there are many reports of non-ionic mechanism [4, 5, 10]. Recently, we studied the reactions of 1 and 2 with triphenylphosphine-tetrachloromethane, some of the results are summarized in Table 2. The energetics (e.g. energy of activation, $\Delta S^f$, $\Delta G^f$, $\Delta H^f$), the rate orders, selectivity, the kinetic isotope effect and optimization of molecular geometry of intermediates carried out by semiempirical methods (CNDO, MNDO, and AM1) [3, 10] all agreed with intermolecular $S_{n2}$ substitution and E2 elimination. The elimination reactions of 1 and 2 were extended to aluminium and thorium oxide. The results are summarized in Table 2. For these reactions, the energy of activation, entropy of activation, kinetics, isotope effect ($k_H/k_D$), selectivity, and semiempirical calculations (AM1) all agreed with concerted E2 elimination. For both homogeneous and heterogeneous reactions of 1 and 2 it was concluded that the stereochemistry and/or regioselectivity is controlled by the steric interactions of the intermediate and/or the transition state. These forces then regulate the conformer population of the intermediates giving the selected desired product [5]. The question raised here was, how comparable are these mechanisms with that of the reactions of 1 and 2 with 2% cross-linked polystyryldiphenylphosphine (CP) in tetrachloromethane shown in Scheme IV, Table 1, and also whether the steric hindrance of polymer-backbone influences the

\[
\begin{align*}
\text{PPh}_2 + \text{CCl}_4 & \rightarrow \text{Ph}_2\text{P} - \text{Cl} \quad \text{CCl}_3 \\
\text{Ph}_2\text{P} - \text{Cl} \quad \text{CCl}_3 + \text{ROH} & \rightarrow \text{Ph}_2\text{P} - \text{OR} \quad \text{CCl}_3 \\
& + \text{CHCl}_3 \\
\text{Ph}_2\text{P} - \text{OR} \quad \text{CCl}_3 & \rightarrow \text{RCl} + \text{Alkenes} + \text{Ph}_2\text{P} - \text{O}
\end{align*}
\]

Scheme IV
Table 2. Comparison of product distribution of dehydration reaction of 2 h\(^a\).

<table>
<thead>
<tr>
<th>Reagent</th>
<th>Solvent</th>
<th>Conc %</th>
<th>E%</th>
<th>Z%</th>
<th>1-Alk%</th>
<th>E/Z</th>
<th>Z-Alk/1-Alk</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPh(_3)(^b)</td>
<td>CCl(_4)</td>
<td>61.7(^c)</td>
<td>31</td>
<td>4</td>
<td>29</td>
<td>L(^d)</td>
<td>1.1</td>
</tr>
<tr>
<td>PPh(_3)(^b)</td>
<td>CH(_3)CN</td>
<td>90.5</td>
<td>56</td>
<td>7</td>
<td>26.5</td>
<td>8</td>
<td>2.40</td>
</tr>
<tr>
<td>P-PPh(_2)(^e)</td>
<td>CCl(_4)</td>
<td>22.5</td>
<td>100</td>
<td>Trace</td>
<td>Trace</td>
<td>V (L)</td>
<td>-</td>
</tr>
<tr>
<td>P-PPh(_2)(^e)</td>
<td>CH(_3)CN</td>
<td>29</td>
<td>62</td>
<td>0</td>
<td>38</td>
<td>V (L)</td>
<td>1.630</td>
</tr>
<tr>
<td>Al(_2)O(_3)-H(_9)</td>
<td>2-Hexanol</td>
<td>100(^h)</td>
<td>25</td>
<td>11</td>
<td>64</td>
<td>2.30</td>
<td>0.660</td>
</tr>
<tr>
<td>Al(_2)O(_3)-B(_9)</td>
<td>2-Hexanol</td>
<td>100(^h)</td>
<td>19</td>
<td>16</td>
<td>56</td>
<td>1.2</td>
<td>0.630</td>
</tr>
<tr>
<td>Al(_2)O(_3)-Pure(_9)</td>
<td>2-Hexanol</td>
<td>100(^h)</td>
<td>17</td>
<td>26</td>
<td>57</td>
<td>0.650</td>
<td>0.750</td>
</tr>
<tr>
<td>ThO(_2)(^g)</td>
<td>2-Hexanol</td>
<td>78(^h)</td>
<td>49</td>
<td>21</td>
<td>30</td>
<td>2.30</td>
<td>2.30</td>
</tr>
<tr>
<td>Equ.(^i)</td>
<td>Benzene</td>
<td>100</td>
<td>81</td>
<td>19</td>
<td>1</td>
<td>4.3</td>
<td>99</td>
</tr>
</tbody>
</table>

(a) Reaction time: 9 h and Temperature: 76 °C unless otherwise stated; (b) See ref. 4; (c) 36% allyl halide; (d) Large; (e) This work; (f) Very large; (g) See ref. 10; (h) 230 °C, 5 min; (i) Equilibrium, PhSO\(_3\)H, 70 °C, 2 h. ref. 5.

regioselectivity and/or stereoselectivity?

The low conversion of alcohols 1 and 2 to adducts indicates that the rate of formation of intermediates (7 and 8) is very slow due to steric hindrance.

According to the data presented in Table 1, the rate of conversion for alcohols (1) is similar (5%) for triphenylphosphine and polymer-bonded diphenylphosphine in 20 h. The latter, however, is more selective in producing 100% E-isomer (Tables 1, 2). The rate of conversion of 2 is somewhat lower for the polymer but shows much higher selectivity (Table 1). Triphenylphosphine in tetrachloromethane at 78 °C produced nearly equal amount of 1,2-diphenyl-2-chloropropane, E-1,2-diphenylpropene and 2,3-diphenyl-1-propene. The present data substantiate our earlier predictions that the steric interactions of the intermediates and/or transition state is responsible for the observed reactivity and/or selectivity. The intermediate conformers (7 and 8) with lowest energy gave the most stable products e.g., E-alkene. An ionic mechanism (E1) is rejected on the accounts of the observed stereoselectivity of the reaction. The ratios of E-alkene/Z-alkene and 2-alkenes/1-alkenes are far differed from that of the equilibrium composition (e.g., thermodynamic control with 4/5: 4.30). Reaction of 2 in a polar solvent like acetonitrile (where with triphenylphosphine-tetrachloromethane was shown to

![Scheme N](image-url)
proceed via E1 mechanism [4]) with CP favours E2 elimination.

In polar solvent the activation energy of polar intermediate is lowered (due to solvation) allowing 1-alkene intermediate conformer 9 to compete with E-isomer conformer intermediate 7, (Table 1 and Scheme V).

Another explanation for observed reactivity and selectivity in acetonitrile must be due to swelling. The mobility of more polar polymer bound intermediate is
Increased in acetonitrile, and hence increasing the interactions of two intermediates and that of the elimination process via anti-E2 mechanism (Scheme VI). All indications are against E1 mechanism. The EXAFS spectroscopy demonstrates a bimolecular clustering of two polymer functional groups (similar to intermolecular E2 and/or S_N2).

A very strong evidence for the intermolecular elimination by two polymer reactive ends is demonstrated by the following observations. The interaction of two active sites of 2% cross-linked by divinylbenzene (DVB) in styrene polymer bound Wilkinson's catalyst (10) was studied by Reed and coworkers [11, 12] with extended X-ray absorption fine structure (EXAFS) spectroscopy. They produced strong evidence that the catalyst can aggregate to form binuclear clusters (11) when attached to polymer (Scheme VII). The 2% cross-linked DVB-styrene copolymers are mobile enough to allow ligands attached to the polymer back beads to act as a chelates. Consequently, the 2% cross-linked copolymer is not rigid enough to prevent dimerization of the attached unstable species.

However, the 20% cross-linked polystyrene is less mobile and hence, dimer formation is substantially reduced. Therefore, 2% cross-linked polymer is mobile enough to interact and cause the elimination process. The polymer-backbone effects the dehydration similar to aluminium oxide-backbone (e.g. anti-E2 elimination [10]).

CONCLUSION

Keeping in mind the major advantage of the cross-linked polystyryl diphenylphosphine is a preferred reagent for the conversion of primary and secondary alcohols to alkyl halide with inversion of configuration. This reagent can be utilized in the stereoselectivities conversion of tertiary alcohols to alkenes. The mechanism of the reactions proceeds via intermolecular anti-E2 elimination. Steric hindrance is responsible for the low reactivity but higher selectivity.

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REFERENCES