The Effect of Triphenylphosphine in the GoAgg^{II} System.

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Abstract: The usual formation of ketone and alcohol under $GoAgg^{II}$ conditions [FeCl₃•6H₂O (cat.), H₂O₂ in pyridine-acetic acid] can be totally replaced by the formation of the corresponding mono-alkyl substituted derivatives by addition of PPh₃ and alkali metal salts.

Gif systems involve the activation of saturated hydrocarbons in pyridine-acetic acid with a catalytic amount of iron salts (Fe^{II}, Fe^{III}) in the presence of an oxidant (O₂, H₂O₂) to give as the major product of the reaction the corresponding ketone and a small amount of alcohol.¹ Recently, we have reported that triphenyl phosphine is an ideal reducing agent to prove the formation of the alkyl hydroperoxide reaction intermediate by reduction to the corresponding alcohol in the oxidation of saturated hydrocarbons with the Gif^{IV} system [FeCl₂•4H₂O (cat.), Zn and O₂].² Evidence for the formation of alkyl hydroperoxide was first reported in the GoAgg^{II} H₂O₂ system by following the course of the oxidation of ¹³C-cyclohexane by ¹³C NMR.³ Based on results obtained in the Gif^{IV} (Fe^{II} cat., Zn^0 , O_2) system it was thought that PPh₃ could be applied to the GoA gg^{II} H₂O₂ system to reduce the intermediate alkyl hydroperoxide to the corresponding alcohol giving us the opportunity to change the normal chemoselectivity (major ketone, minor alcohol) observed in the GoAgg^{II} H₂O₂ system. Surprisingly a different effect to the one expected was observed. Our first experiments were carried out with cyclooctane 1 as a substrate; when equimolar amounts of hydrogen peroxide and triphenylphosphine were added to a normal $GoAgg^{II}$ H₂O₂ system, the formation of the corresponding alcohol 3 and ketone 2 was suppressed and replaced by the appearance of a new product in comparable amounts. Analysis by GC/MS and NMR showed that the new product of the reaction was chlorocyclooctane 4. Reaction conditions were optimized and the best yield of chlorocyclooctane was observed when 1 mmol of FeCl3•6H2O and 10 mmol of hydrogen peroxide were used. Addition of 10 mmol of LiCl did not increase the vield of the reaction. The amount of FeCl₃•6H₂O used in the normal $GoAgg^{II}$ H₂O₂ system is 0.25 mmol, but in the case of the chlorination reaction, iron chloride has two roles; the first is to make the species responsible for the activation process (formally $Fe^{V}=O$),⁴ the second is to furnish the chloride ion needed for the formation of the chloroalkane. By adding a variable amount of triphenyl phosphine to the GoAgg^{II} system we have shown that the relative formation of cylooctanone 2 and chlorocyclooctane 4 was affected as shown in Table 1 and that the total activation

was constant. When 8 or 10 mmol of PPh₃ was used, chlorocyclooctane 4 was the only product observed in comparable amount to the normal oxidation products cyclooctanone 2 and cyclooctanol 3, which are formed in the absence of PPh₃.



PPh3	2	3	4	2 + 3 + 4
(mmol)	(mmol)	(mmol)	(mmol)	(mmol)
0	0.84	0.17		1.01
2	0.69	0.13	0.20	1.02
4	0.46	0.09	0.46	1.01
6	0.30	0.06	0.72	1.08
8	0.05	0.03	1.20	1.28
10	traces	traces	1.10	1.10

Table 1 : Effect of the amount of triphenylphosphine added to the GoAggII H2O2 system.⁵

The formation of mono-alkyl derivatives using t-butylhydroperoxide (TBHP) as an oxidant has been previously described.⁶ Using the GoAgg^{IV} TBHP system, it was shown that the reaction was not a free radical-type process and that a large number of mono-alkyl derivatives could be obtained in reasonable yield by addition of NaN₃, LiCl, NaSCN and other alkali metal salts.⁷ We have tried to add NaN₃ to a GoAgg^{II} H₂O₂ system using different amounts of triphenyl phosphine⁸ and we have observed the same effect as that found in the GoAgg^{II} H₂O₂ chlorination reaction. As shown in **Table**

PPh ₃	2	3	5
(mmol)	(mmol)	(mmol)	(mmol)
0	1.39	0.25	0.15
2	0.91	0.13	0.73
4	0.63	0.13	1.17
6	0.29	0.06	1.69
8	0.13	0.06	1.60

2 when 8 mmol of triphenyl phosphine is added, the exclusive formation of azidocyclooctane 5 is observed.

Table 2: Effect of the amount of triphenyl phosphine in the GoAgg^{II} system in the presence of NaN₃.⁸

The oxidation of cyclooctane in the presence of 15 mmol of NaSCN and 10 mmol of triphenyl phosphine was also carried out resulting in the formation of 0.31 mmol of thiocyanatocyclooctane 6.9

Aware that the mechanism of the GoAgg^{II} H_2O_2 reaction could be changed by the addition of triphenylphosphine we have studied the oxidation of adamantane using 10 mmol of PPh₃.¹⁰ This reaction afforded a mixture of 2-chloroadamantane 8 (0.29 mmol), 1-chloroadamantane 9 (0.09 mmol), and the *o*- and *p*-pyridine-coupled products 10 and 11 (0.12 and 0.06 mmol respectively) giving a C^2/C^3 value of 1.0. In the absence of triphenyl phosphine the C^2/C^3 value is 1.1,¹¹ so it is clear that the nature of the activation process is not changed by the addition of triphenyl phosphine.

The oxidation of triphenyl phosphine by hydrogen peroxide was monitored in a separate experiment and we have found that triphenyl phosphine oxide was formed quantitatively in less than 10 min., suggesting that the formation of the oxidizing species (Fe^V=O) must also take place in less than 10 min.

We made many efforts in the past to prepare chlorides and bromides by addition of these anions to the GoAgg^{II} (H₂O₂) and GoAgg^{III} (H₂O₂ + ligand) systems without any formation of chlorinated or brominated products. In contrast covalent reagents like CCl₄ and BrCCl₃ do trap with both systems.¹² Both types of reagent trap well in GoAgg^{IV} TBHP and GoAgg^V systems (GoAgg^{IV} + an extra ligand usually picolinic acid).⁷ The simplest explanation of all these facts is that ^VFe-C species are rapidly reduced by H₂O₂ with generation of oxygen in GoAgg^{II} and other H₂O₂ based systems.¹ In contrast *t*butylhydroperoxide is an inefficient reagent for reducing the ^VFe-C to ^{III}Fe-C. Thus in GoAgg^{IV} TBHP system the ^VFe-C species has time to react with anions and ligand couple to furnish the alkyl derivative and ^{III}Fe. In the GoAgg^{II} system the hydrogen peroxide reduces so fast the ^VFe-C species that only the process of oxygen insertion into ^{III}Fe-C is seen. The addition of PPh₃ (10 mmol) is in excess with respect to the H_2O_2 (10 mmol), because the latter is oxidizing Fe^{III} to Fe^V and reducing this back to Fe^{III} . If the rate of reduction of Fe^V back to Fe^{III} is slower than the reverse process then, when all the H_2O_2 has been consumed the iron will be in the Fe^V state. Be this as it may, the competition between Fe^{III} and triphenylphosphine for the H_2O_2 is such that the Fe^{III} reaction is faster. The intermediate Fe^{III} -O-OH must also fragment faster than it is reduced by PPh₃ and thus it affords the Fe^V species. The surprising speed of the Fe^{III} reactions deserves further mechanistic study.

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- 5. Reaction conditions: cyclooctane (38 mmol), pyridine (30.0 mL), acetic acid (3.0 mL), FeCl₃•6H₂O (1 mmol), PPh₃ (variable amounts) were introduced into an Erlenmeyer flask. The reaction mixture was cooled to 0°C and hydrogen peroxide (10 mmol) was added at this temperature. Analysis of reaction products was effected by G.C. after 6 h of reaction.
- For transformation of alkanes into bromides, chlorides and azides by iron-TBHP systems, see:
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- Reaction conditions: cyclooctane (38 mmol), pyridine (30.0 mL), acetic acid (3.0 mL), Fe(NO₃)₃•9H₂O (1 mmol), NaN₃ (15 mmol), PPh₃ (variable amounts) were introduced into an Erlenmeyer flask. The reaction mixture was cooled to 0°C and hydrogen peroxide (10 mmol) was added at this temperature. Analysis of reaction products was effected by G.C. after 6 h of reaction.
- 9. Reaction conditions . Same as ref. 8 NaSCN (15 mmol) instead of NaN₃.
- 10. Reaction conditions Same as ref. 5 Adamantane (7.5 mmol) instead of cyclooctane.
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