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Unusual oxidative free-radical additions of 1,3-dicarbonyl compounds to benzonorbornadiene and oxabenzonorbornadiene

Raşit Çalışkan,[a,b] Tarık Pekel,[b] William H. Watson[c,†] and Metin Balci[d,*]

[a]Department of Chemistry, Süleyman Demirel University, 32260 Isparta, Turkey
[b]Department of Chemistry, Ankara University, 06100 Ankara, Turkey
[c]Department of Chemistry, Texas Christian University, Fort Worth, TX 76129, United States
[d]Department of Chemistry, Middle East Technical University, 06531 Ankara, Turkey

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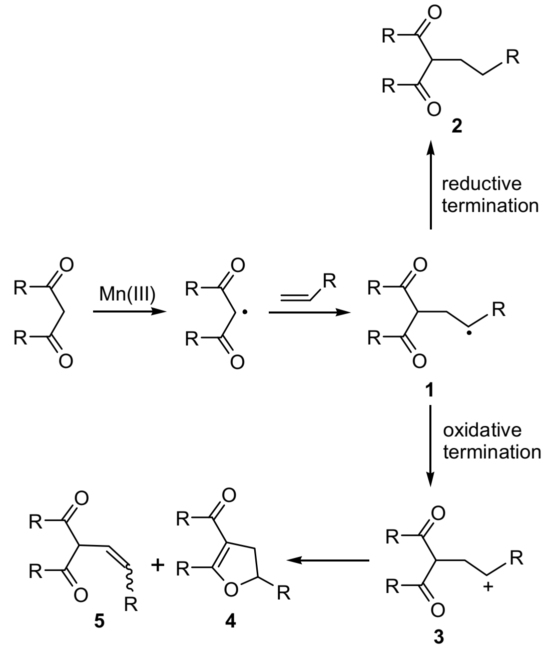
Abstract—Benzonorbornadiene and oxabenzonorbornadiene were reacted with dimedone and acetylacetone in the presence of $Mn(OAc)_3$ and $Cu(OAc)_2$. The reaction of benzonorbornadiene with dimedone gave the dihydrofuran addition product, whereas the reaction with acetylacetone produced, in addition to the dihydrofuran derivative, a rearranged product. On the other hand, oxanorbornadiene gave unusual products such as the cyclopropanated compound and the product arising from the addition of two moles of dimedone. The mechanism of formation of the products is discussed.

Radical cyclization of alkenes is one of the most important methods for the synthesis of cyclic compounds. The one electron oxidant $Mn(OAc)_3$ has been used for many years for the oxidative addition of acetic acid to alkenes to give γ-lacones.[1] Generally, an oxidatively or reductively generated radical can add intra- or intermolecularly to double bonds forming new radicals (see **1**). This cyclization can be terminated by hydrogen atom transfer, which reduces the functionality in the molecule.[2,3] If the radical is terminated oxidatively, the radical center in **1** forms a carbocation **3** that can react with a nucleophile to give dihydrofuran **4**[4] (Scheme 1). Proton loss would result in the formation of an alkene **5**.[3]

$Mn(OAc)_3$ is also involved in the termination step and rapidly oxidizes the radical to a carbocation. Furthermore, Heiba and Dessau showed that the use of $Cu(OAc)_2$ as a co-oxidant converts secondary alcohols to alkenes 350 times faster than when Mn(III) is used alone.[5] In order to follow the mode of $Mn(OAc)_3$ oxida-



Scheme 1.

Keywords: Manganese triacetate; Free radicals; Cycloaddition; Rearrangement; Benzonorbornadiene; Oxabenzonorbornadiene.

* Corresponding author. E-mail: mbalci@metu.edu.tr

[†] To whom correspondence concerning the X-ray analysis should be addressed.

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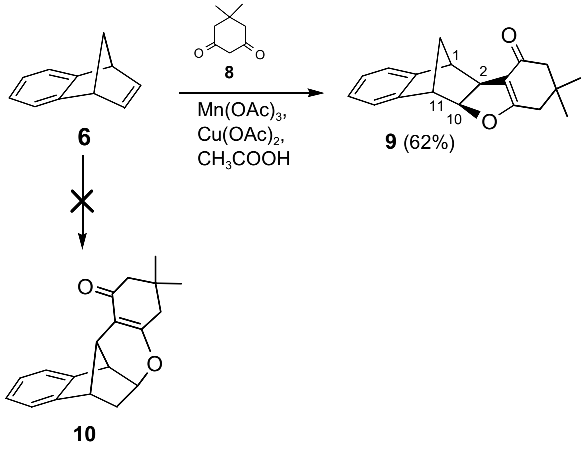
tion and to see whether the second oxidation takes place before or after the cyclization reaction, we generated secondary radicals of type **1** in bicyclic systems. If the oxidation takes place before cyclization, then it is likely that the non-classical carbocation formed would undergo rearrangement.[6] On the other hand, it is well known that the 2-norbornyl radical does not undergo rapid rearrangement.[7] In this communication, we report the novel reactions of enolizable 1,3-diketones with manganese(III) acetates and bicyclic olefins.

Dimedone (**8**) and acetylacetone were chosen as model compounds to explore the reactions. Benzonorbornadiene (**6**)[8] and oxabenzonorbornadiene (**7**)[9] were chosen as radical acceptor alkenes. Treatment of a mixture of dimedone (**8**), $Mn(OAc)_3$, and $Cu(OAc)_2$ in acetic acid with benzonorbornadiene (**6**) in the ratio of 2:1 (2 h at 50 °C) gave the dihydrofuran adduct **9** in a 62% yield. Careful examination of the reaction mixture did not reveal the formation of any rearranged product **10** (Scheme 2).



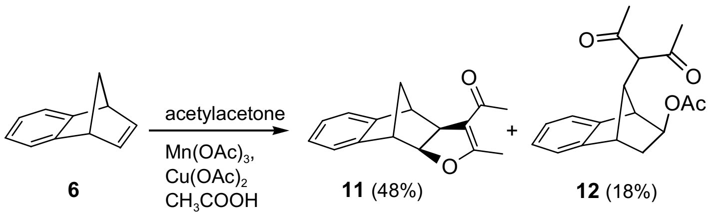
Scheme 2.

The *exo*-configuration of the dihydrofuran ring was confirmed by measuring the coupling constants between H-1 and H-2, and between H-10 and H-11, respectively. The absence of any coupling between these protons confirms the *endo*-orientation of the protons H-2 and H-10 (*exo*-orientation of the dihydrofuran ring). In the case of *exo*-orientation of these protons, a high value of $J_{1,2}$ ($J_{10,11}$) (3.5–5.0 Hz) would be expected.[6a,10]

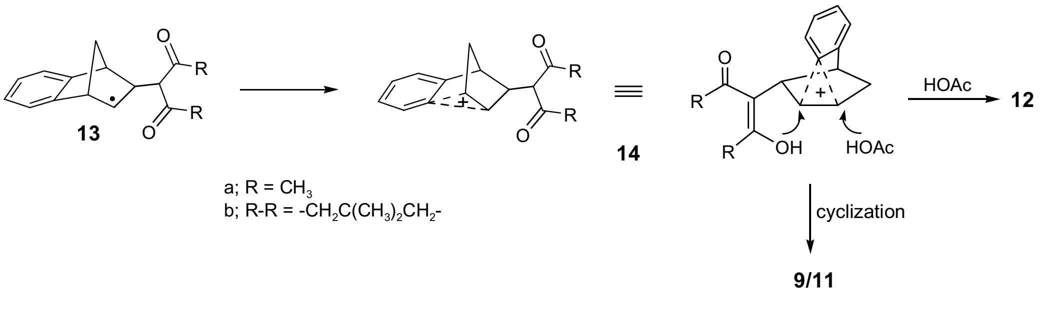
On the other hand, the reaction of benzonorbornadiene (**6**) with acetylacetone, $Mn(OAc)_3$, and $Cu(OAc)_2$ in acetic acid gave two separable products, **11** and **12** in 48% and 18% yields, respectively (Scheme 3).

The formation of the dihydrofuran adducts **9** and **11** is straightforward. We assume that the primarily formed radicals (generated from the 1,3-dicarbonyl compounds) add to the double bond in benzonorbornadiene forming a new radical **13**. The resulting radicals **13a/b** are oxidized by a second equivalent of $Mn(OAc)_3$ (or $Cu(OAc)_2$) to the cations **14a/b**, which undergo rapid cyclization with the enol forms to give **9** and **11**. The absence of the rearranged product (having a structure similar to that of **12)** in the case of the reaction with dimedone is probably due to its complete enolization so that the cyclization overwhelms external nucleophilic attack of acetic acid (Scheme 4).[11]

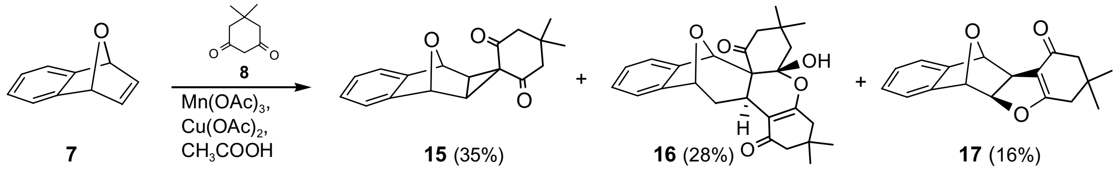
In a second system, we examined the oxidation of oxabenzonorbornadiene with $Mn(OAc)_3$ and $Cu(OAc)_2$ under the same reaction conditions with dimedone and acetylacetone. Treatment of **7** with $Mn(OAc)_3$ and $Cu(OAc)_2$ yielded three different products **15–17** in yields of 35%, 28%, and 16%, respectively (Scheme 5). Analysis of the ^1H and ^{13}C NMR spectra of **15** indicated the presence of a symmetrical addition product.[12] The presence of a three-membered ring was established by measuring the coupling constant $^1J_{CH} = 177$ Hz of the cyclopropyl carbons with attached protons. The exact



Scheme 3.



Scheme 4.



Scheme 5.

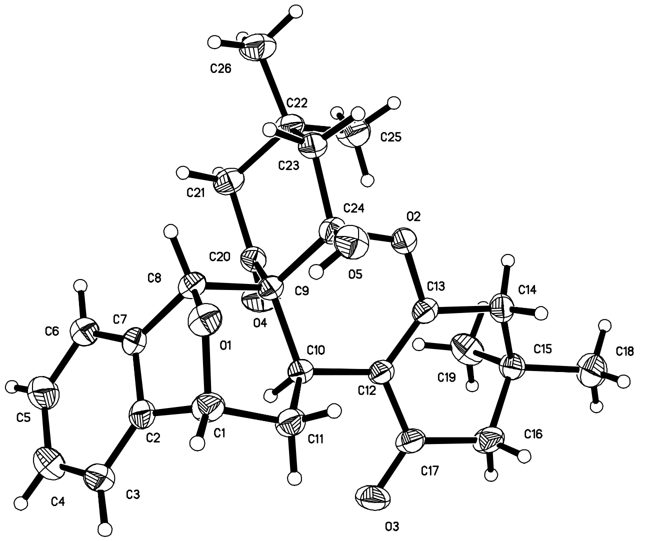
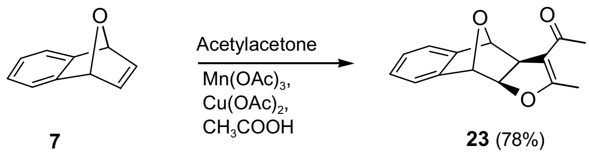


Figure 1. Thermal ellipsoid drawing of compound **16**.

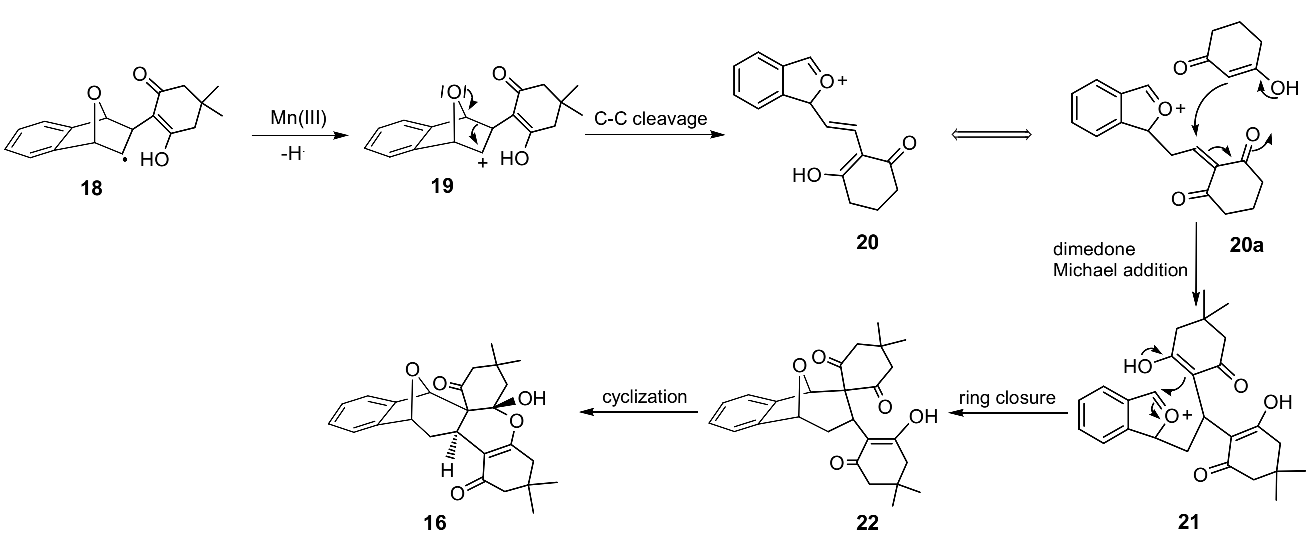
configuration of compound **16** formed by the addition of 2 mol of dimedone to **7** was determined by X-ray crystallographic analysis (Fig. 1).

The behavior of the oxanorbornadiene **7** can be attributed to the oxygen atom located at the bridge. The addition of dimedone to oxabenzonorbornadiene gives the cyclic radical **18**. Since dimedone is an easily enolizable compound, the enol functionality can interact with the bridge oxygen atom resulting in hydrogen bonding. This restricted conformation of the molecule is suitable for the formation of a cyclopropane ring. Oxidative termination would result in the formation of the cyclopropane compound **15**. For formation of the adduct **16**, we assume that the primarily formed cyclic radical **18** can be further oxidized to the cation **19**. Fragmentation of **19** will relieve ring strain to give the stable cation **20**. Dimedone, as its enol, will readily add to **20** forming **21**, which ring-closes to give 22.[13] Finally, intramolecular cyclization of **22** results in the formation of **16** (Scheme 6).

The oxidative cyclization of acetylacetone with oxanorbornadiene gave **23** as the sole product in 78% yield (Scheme 7). Since acetylacetone is not extensively enolized, we assume that it cannot form hydrogen bonds with the bridge oxygen atom. It therefore undergoes the normal addition reaction. Careful examination of the reaction mixture did not reveal the formation of any rearranged products. At this stage we assume that oxidation of the radical **13** takes place before the cyclization reaction. Because of the complete enolization of dimedone, subsequent cyclizations dominate. In order to have



Scheme 7.



Scheme 6.

more insight into the reaction mechanism, further experiments with different 1,3-dicarbonyl compounds and heterobicyclic systems are currently under investigation.

Crystallographic data (excluding structure factors) for the structure in this letter **16** have been deposited with the Cambridge Crystallographic Data Centre as supplementary with publication number CCDC 241820. Copies of the data can be obtained free of charge upon application to CCDC, 12 Union Road, Cambridge CB2 1EZ, UK [fax: +44(0)-1223336033 or e-mail: deposit@ccdc.cam.ac.uk].

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