Manganese(III) acetate has a more complicated structure than the formula Mn(OAc)\(_3\) indicates. It is an oxo-centered trimer of three manganese ions held together by six bridging acetates.\(^{10,13}\) Three representations for this structure are shown in Figure 1. It is often convenient in discussing reactions of this compound to use one of the abbreviated structures [frequently Mn(OAc)\(_3\)].

![Figure 1. Three representations for manganese(III) acetate](image)

A. Addition of a CH-Acidic Compound to a Carbohydrate With an Electron-Rich Double Bond

1. Possible Reaction Mechanisms

The mechanism for the Mn(OAc)\(_3\)-promoted addition of a CH-acidic compound to a molecule with an electron-rich double bond depends upon the rate of formation of the Mn\(^{III}\) enolate 1 (Scheme 1).\(^2,11\) If enolization is slow, formation of 1 will be rate-determining, a condition that will cause the overall rate of reaction to be independent of the concentration of the unsaturated compound 3. Such a situation prevails for most CH-acidic compounds; in particular, it exists for monocarbonyl and less acidic 1,3-dicarbonyl compounds.\(^2,11\) Once a manganese enolate forms in a reaction of this type, it undergoes an electron transfer that produces the radical 2, an intermediate that then adds to the unsaturated reactant 3. Another possibility for formation of the radical 2 is oxidation of the enol 4 by Mn(OAc)\(_3\) to give the radical cation 5, which deprotonates to produce 2 (Scheme 2).\(^8,12\)
An unsubstituted \( \beta \)-keto ester enolizes too rapidly for \( \text{Mn}^{\text{III}} \) enolate formation to be rate-determining.\(^2,11\) When such a compound, or one comparably CH-acidic, reacts with \( \text{Mn(OAc)}_3 \), the process has a new slow step. Addition of the manganese enolate to the unsaturated reactant becomes rate-determining; thus, the rate of the reaction shown in Scheme 3 will depend on the concentration of both 6 and 3.

2. Regioselectivity

The reaction shown in eq 1 (and described mechanistically in Scheme 4) involves a regiospecific addition of the malonyl radical 9 to the electron-rich double bond in 3,4,6-tri-O-acetyl-D-glucal (7).\(^6,7\) [Some carbon-centered radicals are oxidized to cations by \( \text{Mn(OAc)}_3 \), but due to the electron-withdrawing groups attached to the radical center, the malonyl radical 9 resists oxidation to the corresponding cation (Scheme 4).] Addition of 9 to the glycal 7 produces the nucleophilic radicals 10 and 11, each of which is oxidized to a cation that then captures acetic acid and deprotonates to give a mixture of
anomeric acetates (Scheme 4). Manganese(III) acetate does not oxidize simple primary and secondary radicals, but the radicals 10 and 11 can be oxidized because their reactions produce the highly resonance-stabilized cations 12 and 13, respectively.
Atomic orbital coefficients can be useful in explaining regioselectivity in a radical-addition reaction if, as is usually the case, the reaction has an early transition state. In such a reaction the rate constant for the carbon–carbon bond-forming step depends on the magnitude of the atomic orbital coefficients of the interacting frontier orbitals.\(^7\)–\(^9\) In the reaction shown in Scheme 4 the frontier orbitals are the partially filled, \(p\)-type orbital of the radical 9 (the LUMO) and the HOMO of the D-glucal 7. The most effective position for bonding in 7 is at C-2 because the atomic orbital coefficient for the HOMO in 7 is larger at C-2 than at C-1 (Figure 2).\(^{14}\)
3. Stereoselectivity

The stereoselectivity of radical addition to a glycal is controlled by differences in accessibility of the two faces of the ring. In the reaction shown in Scheme 4, the acetoxy group nearest the carbon atom that bonds with the incoming radical projects onto the β face of the ring; for this reason, bonding occurs preferentially from the less-hindered α face. Once the adduct radicals are oxidized to cations, capture of acetic acid occurs primarily from the face of the ring less hindered at C-1, that is, the face opposite to that upon which the malonyl group (R) at C-2 is projecting.

B. Addition of a CH-Acidic Compound to a Carbohydrate With a Less Electron-Rich Double Bond

Radical addition to 14, a carbohydrate with a double bond that is less electron-rich than that found in the D-glucal 7, takes place in the Mn(OAc)₃-promoted reaction shown in eq 2. Because the electrophilic malonyl radical 9 adds more slowly to 14 (Scheme 5) than to 7 (Scheme 4) and because the adduct radical 18 is not oxidized by Mn(OAc)₃, new types of reaction take place. In the first of these, 18 abstracts a hydrogen atom to form the addition product 15. The potential oxidation of 18 to 19 (Scheme 5) fails because 19 is not a sufficiently stable cation.

![Orbital interactions in addition of the radical 9 to the glycal 7](image)

---

<table>
<thead>
<tr>
<th>CH₂(CO₂Me)₂ reaction time</th>
<th>product yields</th>
</tr>
</thead>
<tbody>
<tr>
<td>present 8 h</td>
<td>15: 22% 16: 20% 17: 9%</td>
</tr>
<tr>
<td>absent 60 h</td>
<td>15: -- 16: 61% 17: 29%</td>
</tr>
</tbody>
</table>
Lactone formation, a second type of reaction pictured in Scheme 5, owes its existence to the relatively slow rate of addition of the electrophilic radical 9 to the unsaturated carbohydrate 14, a compound with a double bond that is less electron rich than that in the glycal 7. The relatively slow rate of addition 9 to 14 provides sufficient time for the radical 20 to form. When 20 adds to the double bond in 14, the adduct radical 21 forms and then cyclizes to the lactones 16 and 17. If dimethyl malonate is excluded from the reaction mixture and the reaction time is extended, 16 and 17 are produced in much higher yield (eq 2). In the sequence that generates these lactones (Scheme 5), the two manganese(III) ions that are participating in lactone formation are held in close proximity due to their positions in the oxo-centered trimer containing the acetate-bridged Mn(III) ions (Figure 1). Other examples of lactone formation from reaction of Mn(OAc)₃ with unsaturated carbohydrates are known.

C. Oxidation of a Radical Formed From a Selenide

In the reaction shown in Scheme 4 the adduct radical to be oxidized by Mn(OAc)₃ is produced by an addition reaction,
but radicals capable of reacting with this oxidizing agent can be formed in other ways. The radical $22$, for example, is produced by carbon–selenium bond homolysis (Scheme 6). Once $22$ forms, the electron transfer process takes over and Mn(OAc)$_3$ oxidizes $22$ to the resonance-stabilized cation $23$. Capture of methanol by $23$ leads to the observed diastereomeric mixture of products.$^{18}$

![Scheme 6](image)

**Contributors**

- Roger W. Binkley (Cleveland State University) and Edith R. Binkley (Cleveland Heights-University Heights school system)