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Alkylidene-2*H*-Pyrans by Thermal Electrocyclic Ring Closure of (2Z)-Divinylallenals

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Abstract. Electrocyclic ring closure of (2Z)-divinylallenals **8** (including the *retro*retinal derivative **8a**), afforded the corresponding alkylidene-2*H*-pyrans, under very mild conditions (25 °C, 48 h). Initially, an equilibrium between **8a** and the kinetic product *E*-**9a** was observed, but this gradually reverted to the thermodynamically more stable **Z-9a**.
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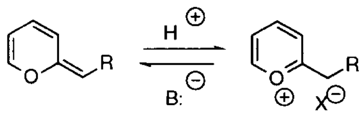
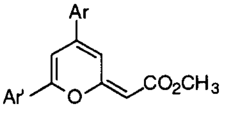
Alkylidene-2*H*-pyrans (**1**) have rarely been described in the chemical literature, and references to the parent system relate merely to its role as the α-anhydro conjugate base of pyrylium salts **2**.[1] The elusive nature of these cyclic enol ethers **1** is most likely due to the tendency of their reactive exocyclic ene moiety to protonate in the presence of acid. Some clues as to how to stabilize **1** were present in the first reports describing preparation of methylene-2*H*-pyrans.[2] Subsequently, substitution of the pyran ring with an electron-withdrawing group, and/or extension of its conjugation with phenyl substituents (e.g. **3**), led to compounds with extended lifetimes, allowing inclusion of this structural subunit in pyrylium dyes.[3] Alternative approaches to stabilization of pyran-2-ylidenes are metallation, which has allowed the reactivity of carbene complexes of Cr (**4a**), Mo and W to be explored;[4] formation of the corresponding 2*H*-pyran-2-iminium chlorides (**4b**), which have been isolated and characterized following treatment of push-pull enynes with HCl;[5] or incorporation of the 2*H*-pyran subunit in bicyclic heteroaromatic systems (**5**) such as those described by de Meijere *et al.*[6]



1 **2**



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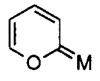
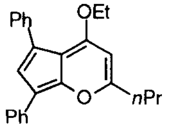


4a M = $Cr(CO)_5$
4b M = $NMe_2^+X^-$



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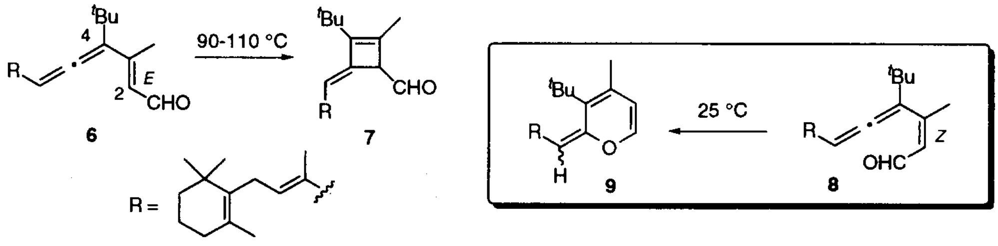
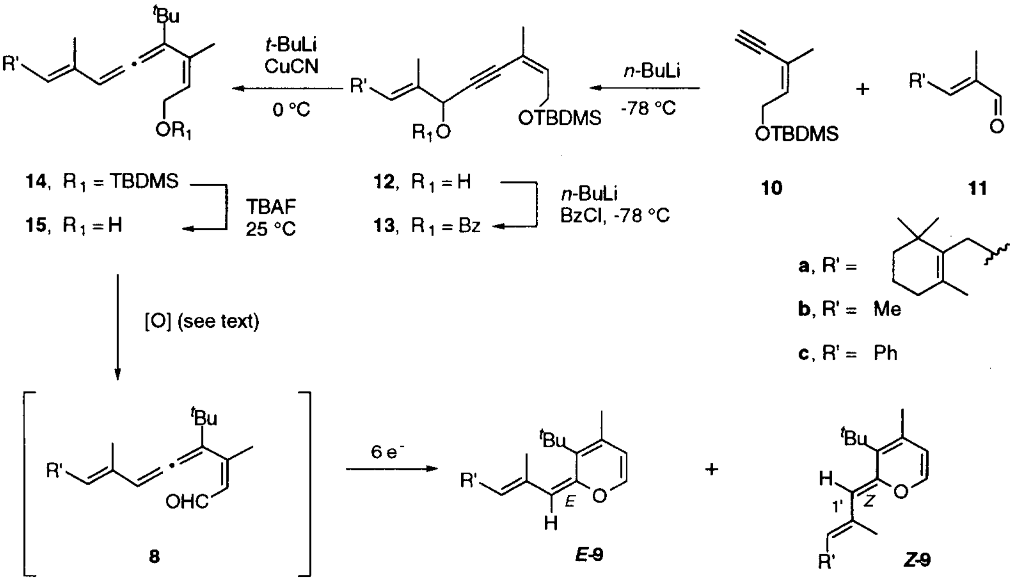
Our interest in alkylidene-2*H*-pyrans derives from our work on the pericyclic reactions of divinylallenes. Hitherto, we have reported that in the peri-, regio- and torquoselective electrocyclization of (2*E*)-divinylallenals **6** to functionalized alkylidenecyclobutenes **7**, C-4 alkyl substituent of **6** exerts a strong steric effect that may be enhanced by subtle electronic effects due to the electron-withdrawing group at the C-2 terminal.[7] Recently, we have been examining the feasibility of altering the regiochemistry of this electrocyclization by changing the geometry of one of the double bonds flanking the allene unit from *E* to *Z*. Here, we report the results for (2*Z*)-divinylallenals **8**, which undergo electrocyclization to alkylidene-2*H*-pyrans **9** that can be isolated even though they lack a stabilizing effect of the types described above.

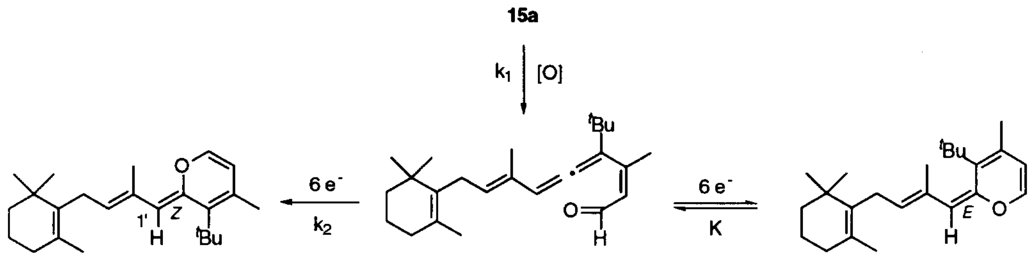


Substituted divinylallene silyl ethers **14a-c** were prepared in 76%, 75% and 70% yield, respectively, following our usual procedure,[7] by regioselective (and, presumably, *anti*-selective)[8] S_N2' displacement of propargylic benzoates **13a-c** (obtained in 97%, 93% and 98%, respectively, from **12a-c**) by the higher-order heterocuprate derived from CuCN and *t*-BuLi.[8] The precursor alcohols **12a-c** were prepared in 88%, 92% and 97% yield, respectively, by treating aldehydes **11a-c** with the TBDMS-protected (*Z*)-pent-2-en-4-yn-1-ol **10**. Deprotection of the silyl ethers with fluoride gave divinylallenols **15a-c** in 77%, 70% and 85% yield, respectively.[9]



Oxidation of alcohol **15a** with a variety of methods (MnO_2,[10] Dess-Martin periodinane,[11] TPAP/NMO,[12] Swern conditions[13]...) gave a mixture of compounds, among which the expected divinylallenal **8a** was easily identified by the characteristic doublet at δ ~ 10.1 ppm (J = 8.0 Hz) in its ^{1}H NMR spectrum.[7] However, upon standing of the reaction, this signal and others attributed to **8a** slowly disappeared, being replaced by signals due to other components of the original mixture of oxidation products. After about 48 h at room temperature, a single product appeared to have formed, an analytical sample of which was obtained by chromatography on silica gel and identified as *Z*-alkylidene-2*H*-pyran *Z*-**9a** by virtue of the distinctive doublets due to H-5 and H-6 of the 2*H*-pyran moiety (J = 5.1 Hz). Observation of a strong nOe between the signals for the *t*-butyl group and H-1' confirmed the *Z*-stereochemistry. The minor component of the mixture presented an analogous spectrum, and was assigned the structure *E*-**9a**.

In order to determine whether divinylallenal **8a** intervenes in the conversion of *E*-**9a** to *Z*-**9a**, a dilute solution of **15a** in CD_2Cl_2 was treated with TPAP/NMO at 20°C in an NMR tube and the reaction was monitored by ^{1}H NMR. Oxidation of **15a** to divinylallenal **8a** was complete in about 31 minutes, the first-order rate constant (k_1) being 0.117 ± 0.003 min^{-1}. Analysis of the integrals for **8a**, *E*-**9a** and *Z*-**9a** revealed that after 48 h equilibrium was reached and a constant ratio of *E*-**9a** to **8a** (K= 0.45) had built up; and also that formation of *Z*-**9a** followed first-order kinetics with rate coefficient (k_2) 0.057 ± 0.008 h^{-1}. This experiment strongly suggests that the kinetic product of the electrocyclization of **8a** is initially *E*-**9a**, which promptly undergoes ring-opening back to divinylallenal **8a**, presumably due to some steric effect of the bulky *t*-butyl group. Meanwhile, the competing electrocyclization of **8a** to the thermodynamic product *Z*-**9a** is irreversible, and so after 48 h at 20 °C this *Z*-alkylidene-2*H*-pyran is obtained as the only product.



Z-**9a**
thermodynamic product

8a

E-**9a**
kinetic product

Compounds **15b** and **15c** showed similar behaviour, but the alkylidene-2*H*-pyrans formed (*Z*-**9b** and *Z*-**9c**) suffered extensive decomposition upon work-up and could not be fully characterized.[14]

To our knowledge, **Z-9a** is the first alkylidene-2*H*-pyran to be isolated that is not stabilized by a conjugated-aryl or electron-withdrawing substituent. We can only speculate on its formation by the facile electrocyclic ring-closure of divinylallenals **8**. This reaction could qualify as a *pseudopericyclic* process, as defined by Lemal[15a] and later extended by Birney,[15b-g] the apparently low activation energies for the 6e⁻ electrocyclization being in keeping with a more or less planar transition state in which there is disconnection in the cyclic array of overlapping orbitals, which have been reported to be favoured in allenes and ketenes, and by the presence of lone-pair of electrons. Work to elucidate the nature of the mechanism of this reaction and its synthetic applications is in progress and will be reported in due course.

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