transformations to benzenoids and suggest the importance of free-radical triggering mechanism in the aromatization of **1**.

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Supplementary Material Available: Spectral data (^{1}H NMR, IR, and MS) for all new compounds, X-ray data for **7b**, and experimental details for the syntheses of **6** and **7b** (25 pages). Ordering information is given on any current masthead page.

Identification of Protonated β-Hydroxycarbonyl Compounds by Reactive Collisions in Tandem Mass Spectrometry

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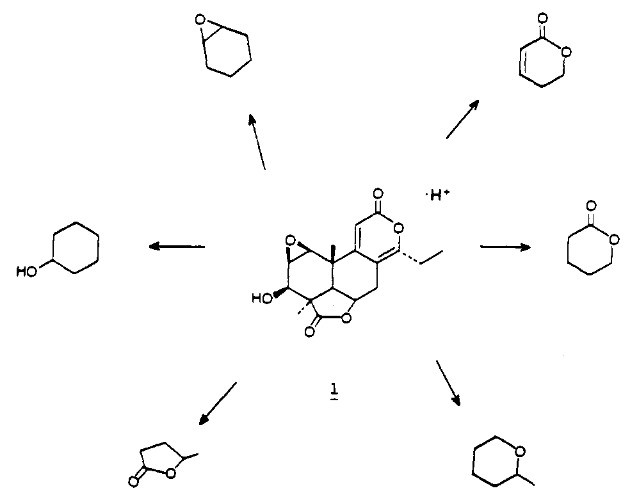
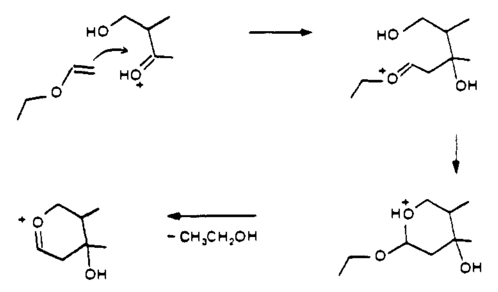
The special complications associated with mass spectrometric characterization of complex organic ions, e.g., biomolecules, have attracted much interest recently.[1,2] It is now evident that conventional ion activation methods often do not deposit high enough energies to cause decomposition of large organic ions in the microsecond time scale typical for tandem mass spectrometers.[2,3] The use of selective bimolecular reactions to identify specific functional groups is a potential solution to some of these problems. However, while reactive collisions have been successfully used to distinguish small isomeric ions,[4] few neutral reagents are known that would undergo predictable, structurally diagnostic reactions with ions containing a specific functional group.[5,6] We report here the first known bimolecular gas-phase reaction that shows a significant degree of selectivity toward a specific arrangement of functional groups in *mono- as well as polyfunctional* organic cations and discuss the mechanism of the reaction in the light of current evidence.

Our study was prompted by the discovery[7] that some complex organic ions (e.g., **1**, Scheme I) give a curious, abundant product ion upon low-energy collisions with ethyl vinyl ether[8] in the center quadrupole of a triple quadrupole mass spectrometer. This product ion formally corresponds to exchange of one of the protons of the reactant ion to a vinyl group, while ethanol is eliminated. We decided to study the nature of this previously unknown reaction by examining the reactivity of a number of mono- and polyfunctional cations toward ethyl vinyl ether, including ions containing functional groups present in the complex-protonated molecules (Scheme I) that were earlier found[7] to undergo the reaction of interest. The experiment[7,9] involves protonation of the sample molecules in the ion source of a triple quadrupole mass spectrometer (isobutane chemical ionization), followed by mass-selection of these ions with the first quadrupole mass filter for reactions occurring in the center quadrupole (ion kinetic energy 0.5 eV, nominal ethyl vinyl ether pressure 2 mTorr). The products were analyzed by scanning the third quadrupole. We discovered that only those model ions that contain *a carbonyl group and a hydroxy group in close proximity* undergo the reaction of interest. For example, protonated diacetone alcohol and protonated 4-hydroxy-3-methyl-2-butanone undergo "vinylation" and collision-induced dehydration as the only primary reactions, the product of the former reaction consisting of up to 40% of the total product ion distribution.

Scheme I



Scheme II



Several bond-making, bond-breaking steps must be involved in the complex series of events ultimately resulting in addition of C_2H_2 in protonated β-hydroxy carbonyl compounds ("vinylation") upon collisions with ethyl vinyl ether. In Scheme II, a reasonable mechanism is presented that is supported by a variety of experimental results, including the following: (i) The yield of the reaction shows a first-order dependence on ethyl vinyl ether pressure. (ii) The reaction proceeds rapidly only for reactant ions with a hydroxy group in β-position with respect to a carbonyl group, e.g., protonated 3-hydroxy-2-butanone does not react. (iii) The use of methyl vinyl ether results in an ionic product with the same m/z value as is obtained for ethyl vinyl ether. (iv) Deuterium-labeling experiments indicate that one of the hydroxyl hydrogens of the protonated hydroxycarbonyl compound is lost in ethanol. (v) When both the hydroxyl hydrogens of the reactant ion are replaced by deuteriums, the production retains one deu-

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[1] See, for example: (a) McLafferty, F. W. *Science* **1981**, *214*, 280. (b) Rinehart, K. L., Jr. *Science* **1982**, *218*, 254. (c) Burlingame, A. L.; Baillie, T. A.; Derrick, P. J. *Anal. Chem.* **1986**, *58*, 165R.

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[4] See, for example: (a) Lehman, T. A.; Bursey, M. M. *Ion Cyclotron Resonance Spectrometry*; John Wiley & Sons: New York, 1978. (b) DePuy, C.; Grabowski, J. J.; Bierbaum, V. M. *Science* **1982**, *218*, 955. (c) Levsen, K. *Fundamental Aspects of Organic Mass Spectrometry*; Verlag Chemie: New York, 1978. (d) Holmes, J. L. *J. Org. Mass Spectrom.* **1985**, *20*, 169.

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[9] For other studies of ion–molecule reactions in a triple quadrupole mass spectrometer, see, for example: (a) Bates, J. H.; Tedder, J. M. *J. Chem. Soc., Perkin Trans. 2* **1983**, 1263. (b) Fetterolf, D. D.; Yost, R. A. *Int. J. Mass Spectrom. Ion Processes* **1984**, *62*, 33. (c) Tabet, J. C.; Guenat, C. *Adv. Mass Spectrometry, Part B* **1985**, 831. (d, Kinter, M. T.; Bursey, M. M. *J. Am. Chem. Soc.* **1986**, *108*, 1797.

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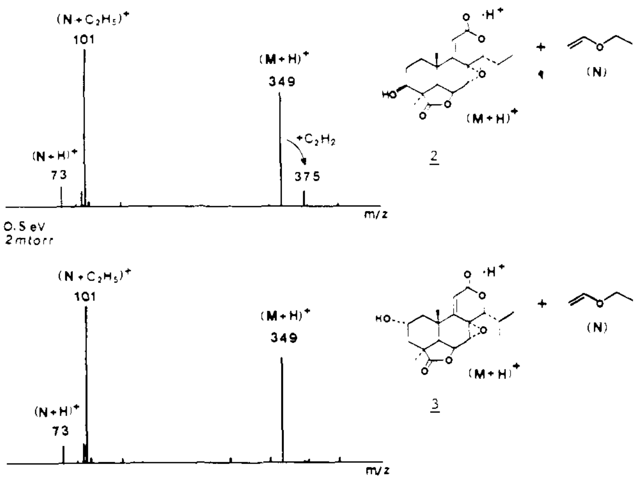
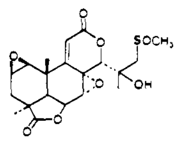


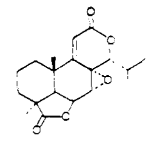
Figure 1. The product distributions obtained for two protonated, isomeric diterpenoid dilactones upon collisions with ethyl vinyl ether in the center quadrupole of a triple quadrupole mass spectrometer. The base peak (101^+) arises from ethylation of ethyl vinyl ether by protonated ethyl vinyl ether (73^+).[5c,7]

terium at a nonacidic site, as evidenced by the fact that this deuterium cannot be exchanged to a hydrogen atom upon collisions with ethyl vinyl ether. The large difference in the heat of formation of simple neutral alkyl vinyl ethers and alcohols ($\Delta(\Delta H_f) = -22$ kcal/mol for ethyl vinyl ether and ethanol) is the most likely driving force for this entropically disfavored reaction. We estimate the reaction to be at least 4 kcal/mol exothermic for protonated 4-hydroxy-2-butanone and ethyl vinyl ether.[10] Note that the proton affinities of β-hydroxycarbonyl compounds are comparable to the proton affinities of alkyl vinyl ethers.[10] This precludes efficient competition by the reaction that usually dominates the ion chemistry of alkyl vinyl ethers, i.e., deprotonation of the reactant ions.

The most intriguing result of this study is the discovery that "vinylation" of organic ions by alkyl vinyl ethers is highly selective toward different oxygen-containing functionalities and that this behavior is not limited to simple model ions but applies to complex polyfunctional ions as well. Under the same conditions, only dissociation and deprotonation reactions were observed for a number of protonated alcohols, ethers, aldehydes, ketones, esters, lactones, and epoxides, including mono- and polyfunctional, saturated and unsaturated, cyclic and acylic as well as aromatic molecules. To test the selectivity of the "vinylation" reaction more rigorously, we decided to examine the reactivity of polyfunctional molecules that *only* differ by the position of the hydroxy group expected to be necessary for the reaction. The isomeric diterpenoid dilactones **2** and **3** (Figure 1) present a challenging test since these protonated molecules are difficult to distinguish on the basis of their dissociation product distributions. However, due to steric constraints in the isomer **3**, only **2** is expected to exchange a proton to a vinyl group upon collisions with ethyl vinyl ether. We found that protonated **2** does indeed undergo the reaction of interest, giving a product ion with a relative abundance of up to 10% of the base peak (101^+), while **3** only gives a trace at the mass value of interest ($\leq 1\%$ of the base peak; Figure 1). Moreover, the reaction seems to be independent of the structure of the rest of the molecule. For the six diterpenoid dilactones (**1**–**6**) shown in Scheme 1, Figure 1, and below, the reaction is limited to those molecules (**1**, **2**, **6**) that contain a 3-hydroxy functionality in the A ring.



4



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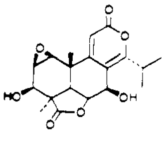

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[10] ΔH_f of protonated 4-hydroxy-2-butanone was estimated to be ≥ 62.9 kcal/mol by assuming that the proton affinity of 4-hydroxy-2-butanone is equal to or less that of acetyl acetone (i.e., $\leq 207.8 \pm 5$ kcal/mol[11]), and estimating ΔH_f for neutral 4-hydroxy-2-butanone (estimated to be -95.4 kcal/mol by the method of Benson[12] and using ΔH_f of 2-butanone: -57.5 kcal/mol[11]); ΔH_f of α-deprotonated 4-hydroxy-4-methylpyran was estimated to be $+80.9$ kcal/mol by the method of Benson[12] and using $\Delta H_f = +129$ kcal/mol for α-deprotonated pyran;[11] ΔH_f of ethyl vinyl ether is -34 kcal/mol;[11] ΔH_f of ethanol is -56.1 kcal/mol.[11]

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A Double-Stranded DNA Fragment Shows a Significant Decrease in Double-Helix Stability After Binding of Monofunctional Platinum Amine Compounds

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The antitumor drug *cis*-diamminedichloroplatinum(II) (cDDP[1]) preferentially binds to two neighboring guanine bases of DNA.[2-4] It has been suggested that this chelation induces a serious distortion of the DNA, resulting in a denaturation up to several base pairs.[5,6] Recently, NMR studies and molecular mechanics of oligonucleotides containing eight or more base pairs showed that the distortion is small; all base pairs, even those of the platinated guanines, are observed.[7,8] Nevertheless, the melting temperature (T_m) appeared to be lowered by 10–20 °C. These phenomena have been attributed to a "kinked" cDDP-DNA structure.[9,10]

For a detailed understanding of the working mechanism of cDDP not only the ultimate structural change but also the distortion resulting from the first binding step is important.

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(1) Abbreviations: cDDP, *cis*-PtCl$_2$(NH$_3$)$_2$; tDDP, *trans*-PtCl$_2$(NH$_3$)$_2$; dien, diethylenetriamine; dsNONA, d(TCTCGTCTC)·d(GAGACGAGA); Pt(dien)-dsNONA, Pt(dien)[d(TCTCGTCTC)-N7(5)]·d(GAGACGAGA); Pt(NH$_3$)$_3$-dsNONA, Pt(NH$_3$)$_3$[d(TCTCGTCTC)-N7(5)]·d(GAGACGAGA); T_m, melting temperature.

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