position of unsaturation within long-chain alkenes and the successful application of this technique for the structure elucidation of natural products. In each case, the number of cleavage products expected were seen, and unambiguous identification could be made since summation of the carbon atoms in the cleavage products always yielded the number of carbons known to be in the alkenyl chain, based on mass spectrometric analysis of the parent compound.

Relative to previous methods that involved initial separation of the ozonolysis products prior to mass spectral analysis, direct analysis by CI mass spectrometry obviates the need to define conditions useful for product purification and avoids the potential destruction of unstable products. The method requires no adaptation of the source or reagent gases required for CI mass spectral analysis.

Experimental Section

Materials. All chemical ionization mass spectrometry experiments were performed on a Finnigan 4600 gas chromatograph–mass spectrometer. Methane was used as the reagent gas for all positive ion spectra. Pulsed positive ion negative ion chemical ionization (PPINICI)[9] employed a mixture of methane–nitrous oxide (95:5). A standard direct exposure probe was utilized for all spectra with a program of 0.050–0.650 V at 0.020 V/s. The pressure of the source was 0.35 Torr.

The acetylation and ozonolysis reactions were performed in the same manner for all of the 5-alkenylresorcinols studied. These are illustrated here for 1,3-dihydroxy-5-hexadec-*cis*-8′enylbenzene.

Acetylation of 1,3-Dihydroxy-5-heptadec-*cis*-8′-enylbenzene. A solution containing 1.2 mg (3.5 μmol) of 1,3-dihydroxy-5-heptadec-*cis*-8′-enylbenzene in 500 μL of dry pyridine under argon was cooled to 0 °C and treated dropwise with 200 μL (216 mg; 2.1 mmol) of acetic anhydride. The combined solution was stirred under argon at 25 °C for 3 h. The reaction mixture was quenched by the addition of an ice chip and extracted with $CHCl_3$. The chloroform extract was washed with water, dried over $MgSO_4$, and concentrated to afford 1,3-diacetoxy-5-heptadec-*cis*-8′-enylbenzene (11) as an oily product: yield $\sim$1.5 mg; silica gel HPTLC (9:1 $CHCl_3$–CH_3OH) R_f 0.78; CI mass spectrum (positive ion), m/z 431 $(M + H)^+$.

Ozonolysis of 1,3-Diacetoxy-5-hexadec-*cis*-8′-enylbenzene (11). A solution containing 1.6 mg (3.7 μmol) of 1,3-diacetoxy-5-hexadec-*cis*-8′-enylbenzene in 250 μL of CS_2 was cooled to −78 °C and saturated with O_3. Excess O_3 was removed with a stream of argon, and the reaction mixture was treated with solid triphenylphosphine (1.0 mg; 3.8 μmol). The resulting solution was allowed to warm to room temperature and was employed directly for mass spectrometric analysis.

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Registry No. 1, 117940-45-1; 2, 26153-38-8; 3, 2765-11-9; 4, 117940-46-2; 5, 7311-34-4; 6, 117940-47-3; 7, 57179-37-0; 8, 111047-32-6; 9, 117940-48-4; 10, 111-71-7; 11, 117940-49-5; 12, 124-19-6; 13, 117940-50-8; 14, 117940-51-9; 15, 114679-03-7; 15 (diacetate), 117940-52-0; 16, 66-25-1; 17, 542-78-9; trifurcatal A2, 22910-86-7; 1,3-dihydroxy-5-heptadec-*cis*-8′-enylbenzene, 52483-19-9; 1,3-dihydroxy-5-(14′-(3″,5″-dihydroxyphenyl)tetradec-*cis*-6′-enyl)benzene, 52483-24-6.

Supplementary Material Available: Chemical ionization mass spectra of the products resulting from ozonolysis of **1**, **6**, **11**, **13**, and **15** and from a control reaction in which a solution of CS_2 alone was treated with O_3 and then with $(C_6H_5)_3P$ (7 pages). Ordering information is given on any current masthead page.

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Observation of Diazonium Ion–Crown Ether Molecular Complexes in the Gas Phase by Field Desorption and Fast Atom Bombardment Mass Spectrometry

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Although host–guest complexation between diazonium salts and crown ethers is quite well documented in solution through kinetic, thermodynamic, and spectroscopic studies,[1–4] the extent and mode of this interaction in the gas phase has not been addressed.

We have recently shown that fragile carbocation and carbodication salts as well as onium ions can be ejected and intact monocations observed by desorption–ionization techniques.[5] Intact dication ejection was also achieved with several dication salts.[6] In relation to these studies we have utilized field desorption (FD) and fast atom bombardment (FAB) mass spectrometry to examine diazonium/crown complexation and to provide the first comparison with solution studies. The results are summarized in Table I.

In solution, the stability of the diazonium/crown complex is strongly dependent on both electronic and steric factors.[2] Electron-donating substituents increase the diazo character and weaken complexation, whereas electron-withdrawing groups increase the positive charge at nitrogens and favor complexation. ^{15}N NMR studies are also in accord with this view.[7]

The steric requirement for the formation of a diazonium/crown complex is more stringent than that for an anilinium/crown complex.[2] The accepted host–guest model in solution is an insertion-type complex (IC) for the diazonium ion,[8] for which one X-ray structure is already available, and a charge-transfer complex (CT) for the anilinium ion (Scheme I).[2]

Just how general is the IC model for diazonium ions? (a) In a detailed study, Zollinger et al.[9] investigated the kinetics of dediazoniation of crown-complexed diazonium ions for comparison with uncomplexed ArN_2^+. It was found that the kinetics were essentially the same. This means that the same intermediate, i.e., a tight aryl cation/nitrogen molecule pair, has to be involved. However,

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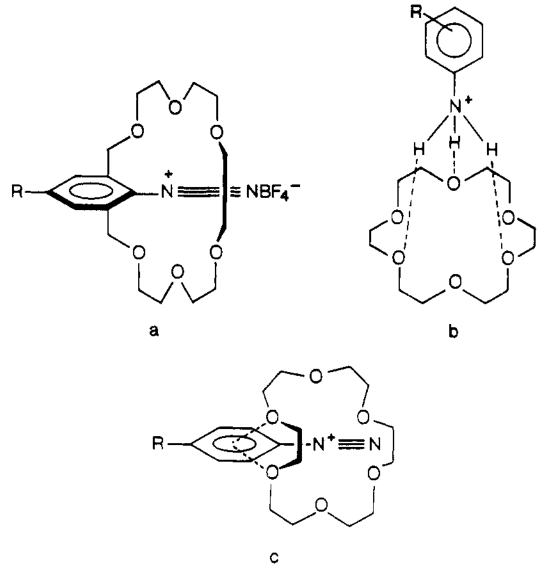
Table I. Principal Ions in FD and FAB Mass Spectra of $ArN_2^+BF_4^-$/Crown Complexes

substit	diazonium (ArN_2^+)	crown	ion (*m/z*) and rel intensity	
			FDMS[a]	FAB-MS[a]
	PhN_2^+	18-C-6	105 (100) ArN_2^+, 369 (100) ArN_2^+(crown), 633 (29) ArN_2^+ (Crown)$_2$	105 (100) ArN_2^+, 297 (68) $(ArN_2^+)_2BF_4^-$, 369 (55) ArN_2^+(Crown)
	PhN_2^+	24-C-8[b]	565 (100) ArN_2^+(crown)	105 (70) ArN_2^+, 565 (15) ArN_2^+(crown), 297 (12) $(ArN_2^+)_2BF_4^-$
o-Me	PhN_2^+	18-C-6	647 (100) ArN_2^+(crown)$_2$, 383 (22) ArN_2^+(crown), 119 (18) ArN_2^+	119 (59) ArN_2^+, 325 (14) $(ArN_2^+)_2BF_4^-$, 383 (5) ArN_2^+(crown)
o-Me	PhN_2^+	24-C-8[b]	579 (100) ArN_2^+(crown)	119 (22) ArN_2^+, 325 (3) $(ArN_2^+)_2BF_4^-$, 579 (1) ArN_2^+(crown)
2,4,6-Me_3	PhN_2^+	18-C-6	147 (100) ArN_2^+, 411 (52) ArN_2^+(crown)	147 (80) ArN_2^+, 381 (48) $(ArN_2^+)_2BF_4^-$, 411 (25) ArN_2^+(crown)
2,4,6-Me_3	PhN_2^+	24-C-8[b]	607 (100) ArN_2^+(crown)	147 (39) ArN_2^+, 381 (5) $(ArN_2^+)_2BF_4^-$
p-Br	PhN_2^+	18-C-6	183 (17) ArN_2^+, 185 (18) ArN_2^+	449 (23) ArN_2^+(crown), 447 (22) ArN_2^+(crown), 185 (13) ArN_2^+, 183 (12) ArN_2^+
p-Br	PhN_2^+	24-C-8[b]	643 (21) ArN_2^+(crown), 645 (19) ArN_2^+(crown)	185 (11) ArN_2^+, 183 (9) ArN_2^+, 643 (tiny) ArN_2^+(crown), 645 (tiny) ArN_2^+(crown)
p-NO_2	PhN_2^+	18-C-6	414 (98) ArN_2^+(crown), 678 (100) ArN_2^+(crown)$_2$, 150 (70) ArN_2^+, 942 (4) ArN_2^+(crown)$_3$	414 (53) ArN_2^+(crown), 150 (48) ArN_2^+, 387 (14) $(ArN_2^+)_2BF_4^-$
m-NO_2	PhN_2^+	24-C-8[b]	150 (18) ArN_2^+	150 (22) ArN_2^+, 414 (20) ArN_2^+(crown)
	anthracene-1-N_2^+	18-C-6	178 (tiny) $(C_{14}H_{10})^+$	205 (12) ArN_2^+, 469 (5) ArN_2^+(crown)
	anthracene-1-N_2^+	24-C-8[b]	178 (48) $(C_{14}H_{10})^+$, 665 (19) ArN_2^+(crown)	178 (60) $(C_{14}H_{10})^+$, 205 (5) ArN_2^+

[a] Unless indicated otherwise, the base peaks were due to the corresponding protonated crowns or a crown fragment. In some cases a Na^+/Crown complex was also observed. [b] Dicyclohexano-24-crown-8.

Scheme I. Schematics of an Inserion Complex (IC) (a), a Charge-Transfer Complex (CT) (b), and σ-Base/π-Acid Interactions in a 1:1 Complex (c)



the crown cavity size is too small to accommodate such an intermediate in an insertion-type complex. Thus it became necessary to invoke a CT complex in this case. (b) Gokel et al.[4] found that whereas the equilibrium constant for complexation decreases in the order 21-crown-8 (1) > 18-crown-6 (2) > dicyclohexano-24-crown-8 (3), the opposite order is indicated in the IR and UV band shifts for complexed versus uncomplexed forms. This could be satisfactorily explained through a "modified" IC model, proposing crown puckering and interaction between the oxygen lone pairs (σ-base) with the π-acidic aromatic ring.

Results and Discussion

The FAB mass spectrum of benzenediazonium ion/18-crown-6 shows an abundant ArN_2^+ ion (*m/z* 105), a two cation–one anion cluster [$(C_2A)^+$; *m/z* 297], and a diazonium ion/crown (1:1) complex (*m/z* 369). In the FD-MS (Figure 1), apart from a 1:1 complex, a one cation–two crown complex (1:2) is also detected (*m/z* 633). Whereas solution studies indicate that crown 3 is rather poor for complexation to benzenediazonium ion,[1] it appears to complex well in the gas phase. In fact, the 1:1 complex of PhN_2^+ with 3 (*m/z* 565) is detected in high abundance, especially by FD-MS.

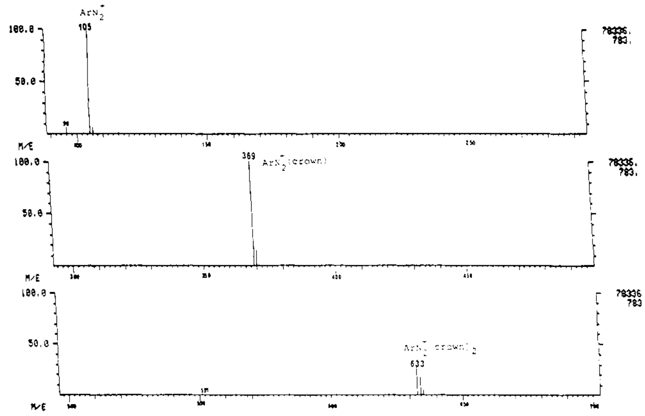


Figure 1. FD-mass spectrum of benzenediazonium ion/18-crown-6 showing the intact ArN_2^+, the 1:1 complex, and a 1:2 complex. The tiny peak at *m/z* 96 is due to the Schiemann product (PhF).

Unlike in solution,[2] the presence of an *o*-methyl group has little effect on gas-phase complexation and a 1:2 complex with 18-crown-6 (*m/z* 647) is detected by FD/MS. With 3 only the 1:1 complex is detectable (*m/z* 579). The uncomplexed intact ArN_2^+ (*m/z* 119) and the $(C_2A)^+$ cluster (*m/z* 325) are observed in the FAB mass spectrum.

2,4,6-Trimethylbenzenediazonium ion, which is known not to complex with 18-crown-6 in solution,[8] does, in fact, exhibit a 1:1 complex with this crown (*m/z* 411). It also gives a 1:1 complex with the larger crown 3 (*m/z* 607).

We then examined the effect of substituents on complex detection in the gas phase. With *p*-bromobenzenediazonium ion, apart from the intact cation, the ArN_2^+/18-crown-6 1:1 complex is detected by FAB-MS (*m/z* 447, 449). A diazonium/crown 1:1 complex is also observed with the larger 3 (*m/z* 643, 645). The results with *p*-nitrobenzenediazonium ion are remarkable; apart from a 1:1 complex (*m/z* 414), a 1:2 complex (*m/z* 678) as well as a 1:3 complex (*m/z* 942) are also observed (Figure 2).

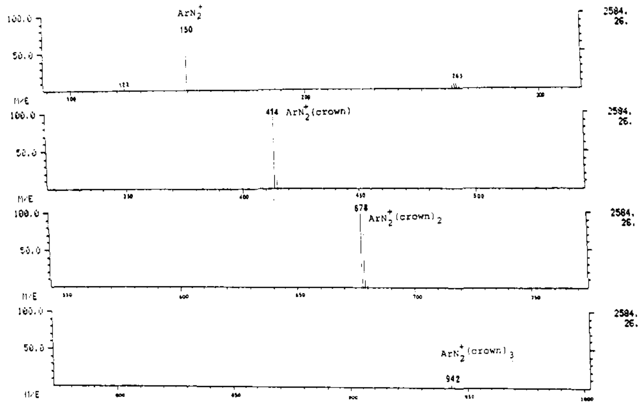


Figure 2. FD-mass spectrum of *p*-nitrobenzenediazonium ion/18-crown-6 showing the intact ArN_2^+ and 1:1, 1:2, and 1:3 complexes. Peaks at m/z 123 and 265 are due to $PhNO_2$ (homolytic dediazoniation product) and protonated crown, respectively.

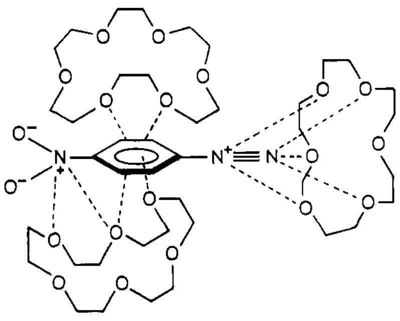
In order to examine the effect of peri steric interaction on the complexation, we also studied anthracene-1-diazonium ion with crowns **2** and **3**. A 1:1 complex was detected in both cases (m/z 469 and 665, respectively). In addition, the intact ArN_2^+ (m/z 205 was observed in low abundance (FAB-MS) and anthracene (m/z 178) was detected, indicative of some homolytic dediazoniation.

We also examined the use of a sila-crown, namely, 1,1-dimethylsila-14-crown-5 for complexation with *p*-*tert*-butylbenzenediazonium ion and *p*-nitrobenzenediazonium ion; no complexation could be detected. Only the intact cations (ArN_2^+) and the uncomplexed crown were observed.

Comparison between Complexation in Solution and Gas Phase. The steric requirement for complex formation appears to be far less in the gas phase than in solution and complexation is observed both in the presence of ortho substituents and peri interactions. This suggests that charge transfer (CT) is the preferred complexation mode, which does not require close approach of the crown to diazonium ion. Nevertheless, the inability of a sila-crown-5 to form a charge-transfer complex indicates that the cavity size is still important.

Observation of diazonium/crown 1:2 complexes may be adequately explained by adopting the proposed solution structures[4] involving a π-acid complex. However, the σ-base to π-acid interaction must now involve a second crown molecule (Scheme Ic). The 1:3 complex observed with *p*-nitrobenzenediazonium ion indicates that a third crown may be complexed to the nitro group, via CT interactions with the nitrogen or via the "positive" oxygen in the extended conjugation form, creating an "encapsulated" diazonium ion with a hypothetical structure shown in Scheme II.

Scheme II. Hypothetical Representation of an "Encapsulated" Diazonium Ion within a 1:3 Complex



In conclusion, it should be pointed out that although a relationship between host–guest cluster ion detection in the gas phase and complexation in solution has not been established,[11] our study does raise the question as to the viability of "higher order complexation" in solution. Could the difficulty in obtaining a fully consistent picture based on combined spectroscopy and kinetics be, in part, due to intervention by higher order complexes, possible existence of which has not so far been considered in solution measurements? In drawing a parallel, it can be said that our gas-phase observations are adequately explained through a charge-transfer model and by σ-base/π-acid interactions; both mechanisms have been recently proposed in order to explain complexation in solution in cases where the IC model is not satisfactory.[4,9]

Experimental Section

The crowns were highest purity commercially available (Aldrich, Fluka) samples and were used as received. The diazonium ions were prepared by conventional diazotization ($NaNO_2 + HBF_4$) of the anilines and were purified as previously described.[10]

Sample Preparation. To a slurry of the diazonium ion in dry CH_2Cl_2 was added a 1–2-fold molar excess of the corresponding crown and the mixture was vortexed until homogeneous. Turbid or heterogeneous samples were filtered to remove uncomplexed diazonium ion.

FAB and FD mass spectral data were acquired by use of a Finnigan MAT 311A/INCOS 2400 mass spectrometer system equipped with an EI/FD/FAB ion source. For FAB-MS, high energy xenon (8 kV) was used to effect sputtering. Spectra were recorded only in the positive ion mode. The samples were directly deposited on the stainless steel FAB probe. Standard high temperature activated carbon emitters were used for FD-MS. Samples were deposited onto the emitter by using the normal dipping technique.

Registry No. $PhN_2^+BF_4^-$/18-C-6 (1:1), 74879-30-4; $PhN_2^+BF_4^-$/18-C-6 (1:2), 117983-92-3; $PhN_2^+BF_4^-$/24-C-8 (1:1), 117983-93-4; *o*-$MeC_6H_4N_2^+BF_4^-$/18-C-6 (1:2), 117983-94-5; *o*-$MeC_6H_4N_2^+BF_4^-$/24-C-8 (1:1), 118017-02-0; 2,4,5-$Me_3C_6H_2N_2^+BF_4^-$/18-C-6 (1:1), 117983-96-7; 2,4,6-$Me_3C_6H_2N_2^+BF_4^-$/24-C-8 (1:1), 117983-97-8; *p*-$BrC_6H_4N_2^+BF_4^-$/18-C-6 (1:1), 85106-18-9; *p*-$BrC_6H_4N_2^+BF_4^-$/24-C-8 (1:1), 117983-98-9; *p*-$O_2NC_6H_4N_2^+BF_4^-$/18-C-6 (1:1), 74317-27-4; *p*-$O_2NC_6H_2^+BF_4^-$/18-C-6 (1:2), 76276-03-4; *p*-$O_2NC_6H_4N_2^+BF_4^-$/18-C-6 (1:3), 117983-99-0; *m*-$O_2NC_6H_4N_2^+BF_4^-$/24-C-8 (1:1), 117984-00-6; anthracene-1-$N_2^+BF_4^-$/18-C-6 (1:1), 117984-01-7; anthracene-1-$N_2^+BF_4^-$/24-C-8 (1:1), 117984-03-9.

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Facile Synthesis of Optically Pure (2*R*,3*R*)- and (2*R*,3*S*)-3-Fluoroglutamic Acids Using Glutamate Dehydrogenase

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The development of syntheses of 3-fluoro amino acids[1,2] has been prompted by their interest as potential kcat inhibitors and tools for the elucidation of enzymatic reactions mechanisms.

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