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**PRODUCTION OF PROTONATED METHANOL IONS VIA
'INTERMOLECULAR' REACTIONS WITHIN
VAN DER WAALS CLUSTERS OF DIMETHYL ETHER**

by

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Production of Protonated Methanol Ions via "Intermolecular" Reactions within van der Waals Clusters of Dimethyl Ether

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Abstract: We report in this communication the first observation of protonated methanol generated within singly charged ion clusters of dimethyl ether. By studying the variation of ion intensity as a function of cluster size, we note that the ion cluster with the empirical formula of $(CH_3OCH_3)_2(CH_3OH_2)^+$ is exceptionally intense in the mass spectrum. This novel "magic number" we feel is due to the enhanced stability of 2 dimethyl ether molecules bonding (via hydrogen bonds) directly to the two hydroxy hydrogens. The formation of this cluster ion is rationalized in terms of a mechanism employing a trimethyloxonium cation which undergoes an internal rearrangement followed by decomposition to form protonated methanol and ethylene.

Mass spectrometric studies of van der Waals clusters have proliferated during the last decade and much has been learned concerning the formation and physical properties of many cluster systems[1]. The study of chemical reactions within clusters has also attracted considerable attention driven by the desire to create a conceptual bridge between the two seemingly disparate fields of gas phase and condensed phase chemistry.

Various groups have recently observed the generation of new cluster ions which are not observed in typical gas-phase bimolecular reactions (i.e., chemistry which can only occur within a cluster). These new processes include the generation of $(NH_3)_nN_2H_8^+$ ions from ammonia clusters[2], $(CH_3OCH_3)_nH_3O^+$ ions from dimethyl ether clusters[3], $(CH_3F)_nCH_3CH_3^+$ ions from methyl fluoride clusters[4] and most recently $(C_2H_4F_2)_{n\geq4}H^+$ from clusters of 1,1-difluoroethane[5]. We feel this body of work has revealed a new class of chemical reactions within clusters, and hope to employ these systems to further study the role played by ion solvation in the reaction dynamics within cluster ions. To that end, we have reinvestigated neat clusters of dimethyl ether (DME) and have observed a new cluster ion of the formula $(DME)_nCH_3OH_2^+$.

Our molecular beam apparatus consists of a Campargue-type beam source[6] and has been described previously[7]. The cluster beam is generated from neat DME (Linde, min. purity[8] 99.0%) expanded at 1.5 atm through a 250 μm orifice. The mass spectrometer is an Extrel C-50 (200 W, 3/8' ' diameter rods, open design ionizer) capable of unit mass resolution and uniform sensitivity up to m/z = 1400. The electron emission current for these experiments was kept at 0.65 mA. During beam operation the pressure in the mass spectrometer chamber was kept below 5×10^{-7} torr.

Figure 1 shows a typical 70 eV electron impact mass spectrum of DME clusters extending from the dimer to the trimer. In addition to the expected peaks there are two additional peaks corresponding to the hydronium ion (which has been reported before[3]) and protonated methanol ions, both solvated by 2 DME molecules. This sequence of peaks is observed throughtout the entire cluster mass spectrum to the limit of our sensitivity.

We have based our identification of the $(DME)_nCH_3OH_2^+$ ions not only on mass assignment of that particular sequence of peaks, but also on the observation of a strong 'magic' numbers in the DME cluster mass spectrum (i.e., cluster size values at which variations in an otherwise smoothly varying ion distribution occur). Magic numbers provide important clues as to the structure of the cluster ion and the identity of the central ionic moiety[9]. The top of figure 2 represents a plot of ion intensity of $(DME)_nCH_3OH_2^+$ as a

function of n for a variety of electron energies. For energies above 20eV, a prominent magic number at n = 2 is exhibited. As shown at the bottom of figure 2, we believe this is due to hydrogen bonding of 2 DME molecules directly to the hydroxy hydrogens of the protonated methanol. This type of 'magic number' stability within hydrogen bonded ion clusters has previously been demonstrated by Stace and Moore[10].

It is interesting to now note that while the $CH_3OCH_2^+$ cation is extremely intense in the monomer mass spectrum of DME (~ 20% of all ion intensity), the same <u>cluster</u> cation $(DME)_nCH_3OCH_2^+$ is now substantially reduced in intensity (Figure 1). We postulate that this lowered intensity of the fragment cation is due to the $CH_3OCH_2^+$ being consumed in an ion-molecule reaction within the cluster. One likely candidate, is the ion-molecule reaction of the $CH_3OCH_2^+$ cation with a neutral DME (within the bulk cluster) to form a trimethyloxonium cation intermediate by loss of formaldehyde.

$$CH_3OCH_2^+ + (CH_3)_2O \rightarrow (CH_3)_3O^+ + CH_2O \qquad (1a)$$
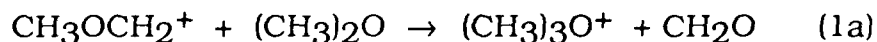
This type of ion-molecule reaction has been previously observed by Harrison and Young through the use of a tandem mass spectrometer[11]. This newly formed trimethyloxonium cation may then undergo a rearrangement to form a protonated methanol cation and ethylene.

$$(CH_3)_3O^+ \rightarrow CH_3OH_2^+ + C_2H_4 \qquad (1b)$$
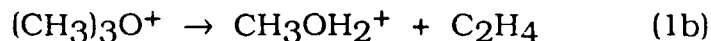
This mechanism is similar to that observed for the decomposition of $(CH_3)_2O$ over zeolite catalysts. The most commonly accepted mechanism for such a decomposition involves just such a trimethyloxonium intermediate[12]. This intermediate is believed to undergo, within the zeolite, a Stevens type rearrangement giving methyl ethyl ether (methoxyethane), which then generates the olefin products via elimination. van Hooff, et al.[13] also observed that conversion of DME over a zeolite catalyst gave comparable amounts of ethylene and propene as primary olefins and, once again, methoxyethane was believed to play a role as an intermediate.

We speculate that the DME cluster reactions leading to the formation of protonated methanol, involve an intermediate similar to that found to occur on the zeolite catalysts. That is, following formation of the trimethyloxonium ion within the DME cluster (rxn. 1a), excess energy derived from the ionization/reaction processes can drive a simple rearrangement reaction (rnx. 1b) to form the products of protonated methanol and ethylene. For the

case of DME clusters, we postulate that the internally generated trimethyloxonium ion internally isomerizes to protonated methoxyethane:

$$CH_3 - \overset{\overset{\displaystyle H}{|}}{O^+} - CH_2CH_3 \qquad (2)$$
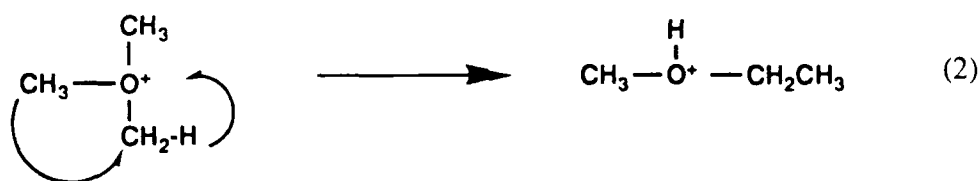
where it then forms protonated methanol via elimination of ethylene. This analogous process has previously been reported for the collisional activation of the monomer $(CH_3)_3O^+$ ion[14]. However recent additional work appears to be at variance with that original result[15]. This varience could be due to the thermodynamic instability of the bare $(CH_3)_3O^+$, in that unimolecular dissociation can now effectively compete with the rearrangement reaction (2). However, within the solvating environs of a cluster, this unstable intermediate may be stabilized on a long enough time scale to now allow it to undergo this rearrangement reaction.

To gain additional insight into this mechanism we have measured the appearance potentials of the relevant cluster ions observed in this experiment. We observe that the $(CH_3)_3O^+$ cation and the $M_n(CH_3OH_2)^+$ cations all have the same appearance potential (12.5-12.7 eV)[16]. This result is consistent with the conjecture that the $M_n(CH_3OH_2)^+$ ions are produced via a $(CH_3)_3O^+$ intermediate.

As a further probe, we generated mixed clusters of DME-H_2O, via bubbling the gas through a reservoir containing water at room temperature and observed that the ions corresponding to the formula $(DME)_nCH_3OH_2^+$ decreased a factor of three in intensity, compared to a pure DME expansion[17]. This effect is consistent with the proposed mechanism (2) in that a water molecule would presumbly strongly hydrogen bond directly to the oxygen end of the trimethyloxonium cation. This additional water molecule then sterically hinders any possible rearrangement, thereby quenching the reaction. Just such a mechanism has recently been suggested by Tzeng et. al. [18] to explain the quenching of an acetone dehydration reaction in mixed clusters of acetone and water.

Acknowledgments

References

(1) Märk, T. D., *Int. J. Mass. Spectrom. Ion Proc.* **1987** *79*, 1 and references therein; Castlemann, A. W., Jr.; Märk, T. D. in "Gaseous Ion Chemistry and Mass Spectroscopy", ed. Futrell, J. H. **1986**, 259, and references therein.

(2) Garvey, J. F.; Bernstein, R. B. *Chem. Phys. Lett.* **1988**, *143*, 13. Coolbaugh, M. T.; Peifer, W. R.; Garvey, J. F. *Chem. Phys. Lett.* **1989**, *156*, 19.

(3) Garvey, J. F.; Bernstein, R. B. *J. Am. Chem. Soc.* **1987**, *109*, 1921.

(4) Garvey, J. F.; Bernstein, R. B. *Chem. Phys. Lett.* **1986**, *126*, 394; Garvey, J. F.; Bernstein, R. B. *J. Phys. Chem.* **1986**, *90*, 3577.

(5) Coolbaugh, M. T.; Peifer, W. R.; Garvey, J. F. *J. Phys. Chem.* **1990**, in press.

(6) Campargue, R.; Lebehot, A. *9th Int. Symp. Rarefied Gas Dynamics*, Göttingen **1974**, *11*, 1. Campargue, R. *J. Phys. Chem.* **1984**, *88*, 4466.

(7) Peifer, W. R.; Coolbaugh, M. T.; Garvey, J. F. *J. Phys. Chem.* **1989**, *93*, 4700.

(8) Independent mass spectral analysis of the contents of the cylinder used revealed the absence of any methanol and less then 0.1% H_2O.

(9) Peifer, W. R.; Coolbaugh, M. T.; Garvey, J. F. *J. Chem. Phys.* **1989**, *91*, 6684.

(10) Stace, A. J.; Moore, C. *J. Phys. Chem.* **1982**, *86*, 3681.

(11) Harrison, A. G.; Young, A. B. *Int. J. Mass Spectrom. Ion Proc.* **1989**, *94*, 321.

(12) van der Berg, M.P.; Wolthuizen, J.P.; van Hooff, J.H.C. "Proceedings of the Vth Conference on Zeolites", Naples Italy, **1980**, p. 649; Olah, G.A., *Pure Appl. Chem.*, **1981**, *53*, 201;

(13) van Hooff, J.H.C.; van der Berg, J.P.; Wolthuizen, J.P.; Volmer, A. *Proc. Int. Zeolite Conf., 6th*, **1983**, 489.

(14) Sigsby, M. L.; Day, R. J.; Cooks, R. G. *Org. Mass Spectrom.* **1979**, *14*, 274.

(15) Farcasiu, D.; Pancirov, R. G. *Int. J. Mass Spectrom. Ion Proc.* **1986**, 74, 207.

(16) Coolbaugh, M. T.; Vaidyanathan, G.; Peifer, W. R.; Garvey, J. F. in preparation

(17) This result also suggests that the protonated methanol ion is not produced via a reaction between the DME cluster and a water impurity. In particular, within the sensitivity of our apparatus, we do not observe ions of the formula $M_n(CH_3OD_2)^+$ or $M_n(CH_3OHD)^+$ when we generate mixed clusters of DME-D_2O, which would be the obvious ion products if such a side reaction was occurring.

(18) Tzeng, W. B.; Wei, S.; Castleman, A. W. Jr. *J. Am. Chem. Soc.* **1989**, *111*, 6035.

Figure 1) Raw mass spectrum of neat dimethyl ether clusters at 70 eV from 80-140 amu. Major ion peaks are identified by their empirical formulas $(M - (CH_3)_2O)$.
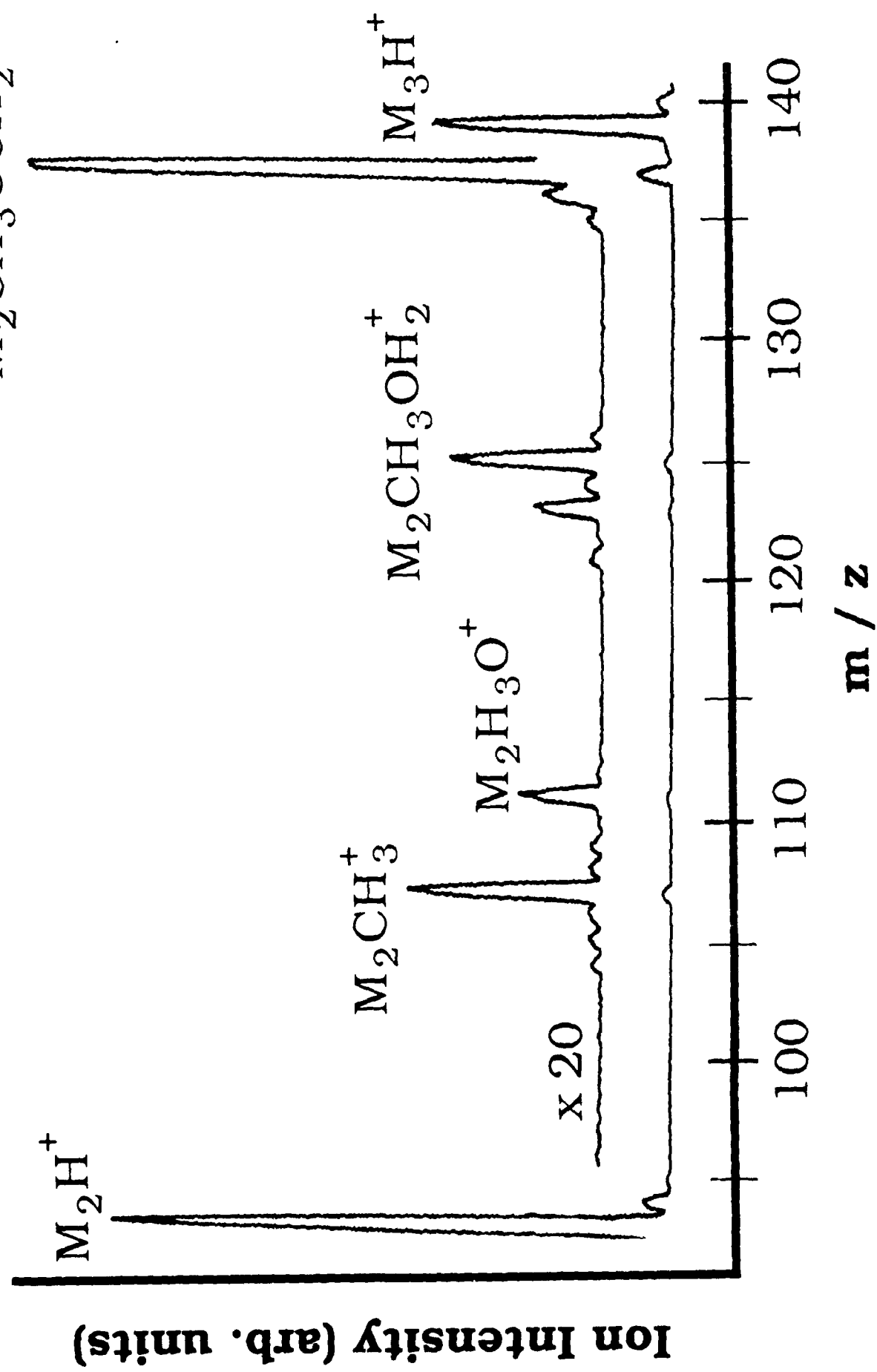
Ion Intensity (arb. units)

m / z

M_2H^+

$M_2CH_3^+$

x 20

$M_2H_3O^+$

$M_2CH_3OH_2^+$

$M_2CH_3OCH_2^+$

M_3H^+

Figure 2: (top) Plot of [$((CH_3)_2O)_n$-$CH_3OH_2^+$] ion intensity as a function of n for a variety of electron energies (15 eV - 70 eV). Note prominent magic number for n = 2

(bottom) Proposed structure for the $((CH_3)_2O)_2$-$CH_3OH_2^+$ cluster ion. This species is the most prevalent of all cluster ions in the series [$((CH_3)_2O)_n$-$CH_3OH_2^+$] and is believed to be a protonated methanol molecule with two DME molecules hydrogen bonded to it. The dark circles correspond to carbon atoms, the shaded circles correspond to oxygen atoms while the open circles are hydrogen atoms

$M_nCH_3OH_2^+$

15 eV
20 eV
30 eV
40 eV
50 eV
60 eV
70 eV

n = # of DME molecules

Ion Intensity (arb. units)

$M_2CH_3OH_2^+$