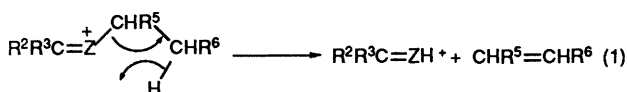


The Mechanism of Propene Elimination from the Immonium Ions $\text{CH}_2=\text{N}^+(\text{CH}_3)\text{CH}(\text{CH}_3)_2$ and $\text{CH}_2=\text{N}^+(\text{CH}_3)\text{CH}_2\text{CH}_2\text{CH}_3$

Richard D. Bowen,* Alex W. Colburn and Peter J. Derrick
Department of Chemistry, University of Warwick, Coventry, UK, CV4 7AL

It is shown by ^2H -labelling experiments that β -hydrogen transfer from the propyl group to the nitrogen atom is not an adequate general explanation for propene loss from $\text{CH}_2=\text{N}^+(\text{CH}_3)\text{C}_3\text{H}_7$ ions: β -hydrogen transfer occurs for $\text{CH}_2=\text{N}^+(\text{CH}_3)\text{CH}(\text{CH}_3)_2$, in which the *N*-alkyl substituent corresponds to a stable isopropyl cation; but α - and γ -hydrogen transfer dominate for $\text{CH}_2=\text{N}^+(\text{CH}_3)\text{CH}_2\text{CH}_2\text{CH}_3$, in which isomerisation of the unstable incipient *n*-propyl cation precedes propene expulsion.

Many 'onium' ions having the structure $\text{R}^2\text{R}^3\text{C}=\text{Z}^+\text{R}^1$ ($\text{Z} = \text{O}, \text{S}, \text{NH}, \text{NCH}_3$; $\text{R}^1 = \text{C}_n\text{H}_{2n+1}$, $n \geq 2$; $\text{R}^2, \text{R}^3 = \text{H}, \text{CH}_3, \text{C}_2\text{H}_5$) dissociate in the gas phase by elimination of an alkene, C_nH_{2n} , derived by hydrogen abstraction from the principal alkyl group, R^1 , attached to the heteroatom.^{1,2} This ubiquitous fragmentation has traditionally been rationalised in terms of a four-centre process, eqn. (1), in which cleavage of the $\text{Z}-\text{R}^1$ bond is accompanied by β -hydrogen transfer from R^1 to Z . Although both ^2H -labelling experiments³ and mechanistic considerations⁴ militate against this interpretation, particularly when R^1 is a primary alkyl group, eqn. (1) is still widely held to be an accurate general description of this important class of alkene elimination.



[$\text{Z} = \text{O}, \text{S}, \text{NR}^4$; $\text{R}^1 = \text{CHR}^5\text{CH}_2\text{R}^6$; $\text{R}^2, \text{R}^3, \text{R}^4, \text{R}^5, \text{R}^6 = \text{H}$ or alkyl]

An alternative, and more modern, view is that these fragmentations involve ion-neutral complexes (INCs)⁴⁻⁸ in which an incipient cation, $(\text{R}^1)^+$, is co-ordinated to the neutral species $\text{R}^2\text{R}^3\text{C}=\text{Z}$. Hydrogen transfer between the components of this INC then affords C_nH_{2n} and $\text{R}^2\text{R}^3\text{C}=\text{ZH}^+$. When $(\text{R}^1)^+$ is unstable with respect to 1,2-H or 1,2-alkyl shifts, rearrangement to a more stable isomer may precede hydrogen transfer. This possibility permits hydrogen transfer to take place from sites other than the original β -position in the unrearranged R^1 substituent.

The alternative descriptions of C_nH_{2n} loss are clearly distinguished by considering the behaviour of $\text{CH}_2=\text{N}^+\text{R}^1\text{R}^2$ ($\text{R}^1 = \text{C}_n\text{H}_{2n+1}$; $n \geq 2$; $\text{R}^2 = \text{H}, \text{D}, \text{CH}_3$ or R^1) immonium ions. These ions typically expel C_nH_{2n} as the major or sole dissociation channel.⁹ Moreover, the loss of C_nH_{2n} with extremely high selectivity ($\geq 99\%$) from $\text{CH}_2=\text{ND}^+\text{R}^1$ ions establishes that the hydrogen transfer from R^1 to N is unidirectional. If this step were reversible, the positional integrity of the ND entity would be destroyed, thus leading to a contribution of $\text{C}_n\text{H}_{2n-1}\text{D}$ elimination from $\text{CH}_2=\text{ND}^+\text{R}^1$. The unidirectional nature of the hydrogen transfer simplifies the interpretation of the ^2H -labelling data.

The reactions of metastable $\text{CH}_2=\text{N}^+(\text{CH}_3)\text{CH}(\text{CH}_3)_2$, **1**, and $\text{CH}_2=\text{N}^+(\text{CH}_3)\text{CH}_2\text{CH}_2\text{CH}_3$, **2**, are given in Table 1. Both **1** and **2** expel C_3H_6 ; **2** also loses C_2H_4 , but this fragmentation, which involves specific γ -hydrogen transfer in a manner isoelectronic to the retro 'ene' reaction,⁹ proceeds via a different mechanism to that pertaining to C_3H_6 expulsion. Table 2 summarises the relative abundances (RAs) of $\text{C}_3\text{H}_6-m\text{D}_m$ propenes that are eliminated from ^2H -labelled analogues of **1** and **2**.

Table 1 Reactions of metastable $\text{C}_5\text{H}_{12}\text{N}^+$ ions

Ion structure	Neutral species lost			
	C_2H_4		C_3H_6	
	RA ^a	$T_{\frac{1}{2}}^b$	RA ^a	$T_{\frac{1}{2}}^b$
$\text{CH}_2=\text{N}^+(\text{CH}_3)\text{CH}(\text{CH}_3)_2$			100	2.2 ^{c,e}
$\text{CH}_2=\text{N}^+(\text{CH}_3)\text{CH}_2\text{CH}_2\text{CH}_3$	76	73 ^d	24	3.0 ^{c,e}

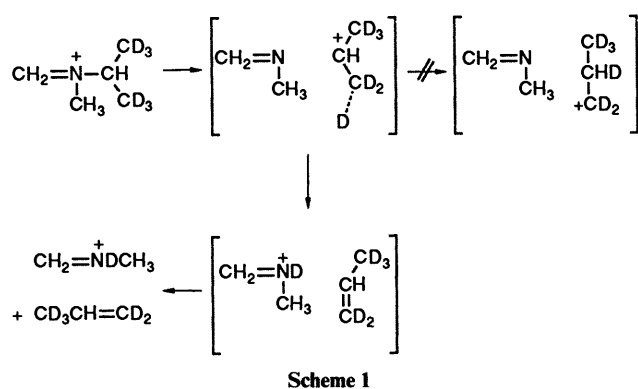
^a RA = Relative abundance, measured from product ion counts (corresponding to metastable peak areas) formed by dissociation of metastable ions in the second field-free region (between the magnetic and electric sectors) of a research mass spectrometer ('MMM'¹⁰) of unusually large dimensions equipped with a post-acceleration detector. In a typical experiment, $\text{CH}_2=\text{N}^+(\text{CH}_3)\text{CH}_2\text{CH}_2\text{CH}_3$ was generated by dissociative electron ionisation of a vaporised sample of $(\text{CH}_3\text{CH}_2\text{CH}_2)_2\text{NCH}_3$. The source pressure was 2×10^{-6} Torr, the nominal energy of the ionising electrons was 70 eV and the accelerating voltage was 8065 V. The $\text{C}_5\text{H}_{12}\text{N}^+$ immonium ions at m/z 86 were specifically transmitted through the magnetic sector and dissociation of metastable ions in the second field-free region was observed by means of Mass-Analysed Ion Kinetic Energy (MIKE) spectroscopy.¹¹ These MIKE spectra were recorded by repetitive microcomputer-controlled scanning of the electric sector voltage over the range of values required to transmit product ions formed in the second field-free region. The reported RA values were derived from integrated spectra, compiled from 100–200 individual MIKE scans, and normalised to a total metastable ion current of 100 units. ^b $T_{\frac{1}{2}}$ = kinetic energy release (in kJ mol⁻¹) estimated from the width at half-height of the associated metastable peak,^{11,12} after application of the usual correction for the width at half-height of the main beam.¹³ ^c Gaussian metastable peak. ^d Dish-topped metastable peak. ^e The increased KE release for propene loss from $\text{CH}_2=\text{N}^+(\text{CH}_3)\text{CH}_2\text{CH}_2\text{CH}_3$ is consistent with rate-limiting isomerisation to $\text{CH}_2=\text{N}^+(\text{CH}_3)\text{CH}(\text{CH}_3)_2$, prior to this fragmentation.¹⁴

Propene loss from ^2H -labelled analogues of **1** involves specific β -hydrogen transfer. Thus, $\text{CH}_2=\text{N}^+(\text{CH}_3)\text{CH}(\text{CD}_3)_2$ expels only C_3HD_5 , with no measurable signal for C_3D_6 elimination. These results are explicable either by eqn. (1) or by a mechanism involving INCs, Scheme 1. In the latter case, hydrogen exchange within the C_3HD_6 group does not compete with β -hydrogen transfer to nitrogen because the initial $(\text{CD}_3)_2\text{CH}^+$ cation is stable with respect to a 1,2-D-shift. The loss of slightly more (58%) $\text{C}_3\text{H}_3\text{D}_3$ via β -H transfer than $\text{C}_3\text{H}_4\text{D}_2$ (42%) via β -D transfer from $\text{CH}_2=\text{N}^+(\text{CH}_3)\text{CH}(\text{CD}_3)\text{CH}_3$ indicates that there is a small isotope effect (ca. 1.4:1) on the hydrogen transfer step. This finding is also consistent either with eqn. (1) or an INC-mediated route. According to the latter interpretation, elongation of the $\text{N}-\text{C}$ bond in $\text{CH}_2=\text{N}^+(\text{CH}_3)\text{CH}(\text{CD}_3)\text{CH}_3$ leads to a transition state for propene elimination in which either a β -C-H or a β -C-D bond is also partly broken.

Table 2 Propene losses from metastable $C_5H_nD_{12-n}N^+$ ions

Ion	Neutral species lost													
	C_3H_6		C_3H_5D		$C_3H_4D_2$		$C_3H_3D_3$		$C_3H_2D_4$		C_3HD_5		C_3D_6	
	RA ^a	T _‡ ^b	RA ^a	T _‡ ^b	RA ^a	T _‡ ^b	RA ^a	T _‡ ^b	RA ^a	T _‡ ^b	RA ^a	T _‡ ^b	RA ^a	T _‡ ^b
$CH_2=N^+(CH_3)CH(CD_3)_2$											100	2.2 ^c		
$CH_2=N^+(CH_3)CH(CH_3)CD_3$					42	2.3 ^c	58	2.3 ^c						
$CH_2=N^+(CH_3)CHDCH_2CH_3$	16	3.6 ^c	84	3.3 ^c										
$CD_2=N^+(CH_3)CH_2CH_2CH_3$	>99	3.1 ^c	<1											
$CH_2=N^+(CH_3)CD_2CH_2CH_3$			35	2.7 ^c	65	3.0 ^c								
$CH_2=N^+(CH_3)CH_2CD_2CH_3$			19	4.2 ^c	81	3.6 ^c								
$CH_2=N^+(CH_3)CH_2CH_2CD_3$			<1		41	3.1 ^c	59	3.3 ^c						

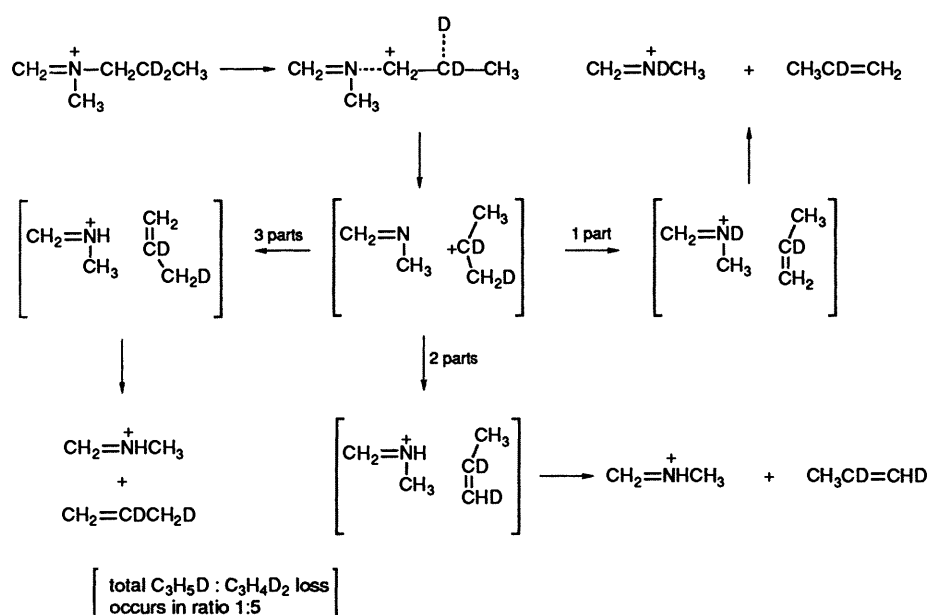
^a RAs normalised to a total of 100 units for propene loss; ²H-labelled analogues of **2** also expel ethylene. In a typical experiment, $CH_2=N^+(CH_3)CD_2CH_2CH_3$ was generated by dissociative electron ionisation of $CH_3CH_2CH_2-CH_2N(CH_3)CD_2CH_2CH_3$ and subjected to MIKES analysis in the manner described in footnote *a* to Table 1. The sample of $CH_3CH_2CH_2CH_2N(CH_3)CD_2CH_2CH_3$ was prepared by condensation of 1.5 equiv. of $CH_3CH_2CH_2CH_2NHCH_3$ with 1 equiv. of CH_3CH_2COCl in dichloromethane solution containing 1.2 equiv. of pyridine at $-30^\circ C$; the resultant $CH_3CH_2CH_2CH_2N(CH_3)COCH_2CH_3$ was then reduced with 3 equiv. of lithium aluminium deuteride in triglyme {triethylene glycol, dimethyl ether [$CH_3O(CH_2CH_2O)_3CH_3$]} solution at $60^\circ C$. ^{b,c} See footnotes to Table 1.



In contrast, an entirely different selectivity is observed in propene loss from ²H-labelled analogues of **2**. Specific β -hydrogen transfer is no longer found; indeed, there is a strong discrimination *against* the selectivity predicted by eqn. (1). Thus, $CH_2=N^+(CH_3)CH_2CD_2CH_3$, which according to eqn.

(1) would be expected to lose only C_3H_5D *via* β -D transfer, actually expels mainly (81%) $C_3H_4D_2$. Similarly, the loss of sizeable amounts (35 and 41%, respectively) of C_3H_5D and $C_3H_4D_2$, *via* D-transfer from the α - and γ -positions of $CH_2=N^+(CH_3)CD_2CH_2CH_3$ and $CH_2=N^+(CH_3)CH_2CH_2CD_3$, is inconsistent with β -hydrogen transfer from an unrearranged n-propyl substituent. Therefore, eqn. (1) is not a satisfactory general mechanistic description of propene loss from **2**.

However, the unexpected site selectivity in the hydrogen transfer step is explicable in terms of the mechanism involving rearrangement of the n-propyl entity within INCs. Thus, unidirectional isomerisation of the incipient $^+CH_2CD_2CH_3$ to $CH_2DCD^+CH_3$, followed by β -H or β -D transfer from one of the two methyl groups in the resultant isopropyl cation, predicts C_3H_5D and $C_3H_4D_2$ loss from $CH_2=N^+(CH_3)CH_2CD_2CH_3$ in the ratio 17:83, Scheme 2. Parallel arguments predict C_3H_5D and $C_3H_4D_2$ elimination in the ratio 33:67 from $CH_2=N^+(CH_3)CH_2CH_2CD_3$ (after isomerisation of $^+CD_2CH_2CH_3$ to $CHD_2CH^+CH_3$), C_3H_6 and C_3H_5D loss in the ratio 17:83 from $CH_2=N^+(CH_3)CHDCH_2CH_3$ (following rearrangement of $^+CHDCH_2CH_3$ to $CH_2DCH^+CH_3$), and $C_3H_4D_2$ and



$C_3H_3D_3$ expulsion in the ratio 50:50 from $CH_2=N^+(CH_3)CH_2CH_2CD_3$ (after isomerisation of $^+CH_2CH_2CD_3$ to $CH_3CH^+CD_3$). These predictions are in good agreement with experiment, especially when it is considered that no allowance is made for the influence of isotope effects.

The essence of the INC-mediated mechanism is that only one of the two original β -hydrogens is moved by the crucial 1,2-hydrogen shift in the incipient n-propyl cation to become part of a new methyl group in the resultant isopropyl cation. One of the six hydrogens in the two methyl groups of the isopropyl cation is then transferred to nitrogen. Consequently, the discrimination against β -D transfer in $CH_2=N^+(CH_3)CH_2CD_2CH_3$ is explained. Furthermore, the similar ratios of H- and D-transfer (81:19 and 84:16, respectively) found for $CH_2=N^+(CH_3)CH_2CD_2CH_3$ and $CH_2=N^+(CH_3)CHDCH_2CH_3$ are explicable because hydrogen transfer eventually occurs from an isopropyl cation ($CH_2DCD^+CH_3$ and $CH_2DCH^+CH_3$, respectively) containing a CH_2D and a CH_3 methyl substituent.

The same trends in the site-selectivity in the hydrogen transfer step are shown in propene loss from 2H -labelled analogues of $CH_2=N^+(CH_2CH_2CH_3)_2$, **3**. Moreover, there is a preference for eliminating propene from an intact C_3H_7 group rather than from a $C_3H_7-mD_m$ group in the same ion. Thus, $CH_2=N^+(CH_2CD_2CH_3)CH_2CH_2CH_3$ expels C_3H_6 in greater abundance (60%) than the sum ($7 + 33 = 40\%$) of C_3H_5D and $C_3H_4D_2$ loss. This discrimination cannot be attributed entirely to isotope effects in the final hydrogen transfer step because only the minor contribution from C_3H_5D elimination involves D-transfer. It appears that elongation of the N- C_α bond and/or the 1,2-H/D shift which converts the developing n-propyl cation into its isopropyl isomer could be influenced by isotope effects. The intervention of such isotope effects is consistent with the operation of an INC-mediated mechanism for propene loss.

In conclusion, the site selectivity in the hydrogen transfer step in propene loss from immonium ions such as **1**, **2** and **3** depends critically on the structure of the N-propyl group. Specific β -hydrogen transfer takes place in isopropyl substituents because the associated cation is stable with respect to 1,2-H/D shifts. In contrast, discrimination against β -hydrogen transfer occurs for n-propyl groups since rearrangement of the derived cation to an isopropyl isomer precedes hydrogen transfer. This behaviour should be general for alkene expulsion from onium ions in

which the relevant Z-alkyl group corresponds to a cation that can readily rearrange to a more stable isomer. These results undermine the traditional four-centre rationalisation for this class of alkene elimination because it takes no account of the structure of the Z-alkyl substituent. However, an INC-mediated mechanism provides a unifying explanation of the site selectivity in the hydrogen transfer step that accompanies alkene loss.

Acknowledgements

Financial support from the SERC (including an Advanced Fellowship to R. D. B.), the British Mass Spectrometry Society and the Leverhulme Trust (Research Fellowship and Grant to R. D. B.) is gratefully acknowledged. Special thanks are due to Mrs. Margaret Hill for preparing the typescript.

References

- 1 H. Budzikiewicz, C. Djerassi and D. H. Williams, *Mass Spectrometry of Organic Compounds*, Holden-Day, San Francisco, 1967.
- 2 F. W. McLafferty, *Interpretation of Mass Spectra*, University Science Books, Mill Valley, California, 3rd edn., 1980.
- 3 C. Djerassi and C. Fenselau, *J. Am. Chem. Soc.*, 1965, **87**, 5747, 5752; S. Sample and C. Djerassi, *J. Am. Chem. Soc.*, 1966, **88**, 1937; G. A. Smith and D. H. Williams, *J. Am. Chem. Soc.*, 1969, **91**, 5254.
- 4 R. D. Bowen, B. J. Stapleton and D. H. Williams, *J. Chem. Soc., Chem. Commun.*, 1978, 24; R. D. Bowen and D. H. Williams, *J. Am. Chem. Soc.*, 1980, **102**, 2752.
- 5 T. H. Morton, *Tetrahedron*, 1982, **38**, 3195.
- 6 D. J. McAdoo, *Mass Spectrom. Rev.*, 1988, **7**, 363.
- 7 R. D. Bowen, *Acc. Chem. Res.*, 1991, **24**, 364.
- 8 P. Longevialle, *Mass Spectrom. Rev.*, 1992, **13**, 157.
- 9 R. D. Bowen, *Mass Spectrom. Rev.*, 1991, **10**, 225.
- 10 P. G. Cullis, G. M. Neumann, D. E. Rogers and P. J. Derrick, *Adv. Mass Spectrom.*, 1980, **8**, 1729.
- 11 R. G. Cooks, J. H. Beynon, R. M. Caprioli and G. R. Lester, *Metastable Ions*, Elsevier, Amsterdam, 1973.
- 12 K. Levsen, *Fundamental Aspects of Organic Mass Spectrometry*, Verlag-Chemie, Weinheim, New York, 1978.
- 13 M. A. Baldwin, P. J. Derrick and R. P. Morgan, *Org. Mass Spectrom.*, 1976, **11**, 440.
- 14 G. Hvistendahl and D. H. Williams, *J. Am. Chem. Soc.*, 1975, **97**, 3097.

Paper 3/00543G

Received 27th January 1993

Accepted 28th January 1993