

ELECTRON-IMPACT-INDUCED ION FRAGMENTATION OF POLYFUNCTIONAL N-CYCLOHEXYLCARBAMATES

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Abstract—Mass spectra at 70, 15 and 10 eV are reported for methyl N-cyclohexylcarbamate, methyl N-*trans*-2-iodocyclohexylcarbamate, allyl N-cyclohexylcarbamate and allyl N-*trans*-2-iodocyclohexylcarbamate. Principal modes of ion fragmentation including hydrogen and skeletal rearrangements are discussed in terms of individual functional groups and their interaction, and are consistent in many cases with mechanisms previously proposed for other compounds. The effects of the iodo and the allyl groups, when present, predominate in the spectra. The application of McLafferty's 'active site' concept to these polyfunctional compounds is found to be useful.

INTRODUCTION

MUCH of the previous work on the 'mechanistic' approach to electron-impact-induced fragmentation of positive organic ions has considered characteristic behavior of certain functional groups.¹ It is of interest also to study compounds with several functional groups, each of which in the absence of the others would be expected to have a strong effect on the route of fragmentation, i.e. to provide an 'active site' (hypothetical localized charge or unpaired electron)² at which electronic changes may result in decomposition.

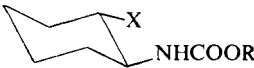
Carbamates (urethanes) are important as pesticides, pharmaceuticals, polymers and derivatives for characterization of alcohols. Previous mass spectrometric studies have considered the ionic fragmentation of some carbamates.^{3 to 9} Lewis reports the mass spectrum of ethyl N-cyclohexylcarbamate and concludes that this compound shows a fragmentation pattern dominated by effects 'not directly induced by an obvious functional group.'⁴ He suggests that the spectrum is characteristic more of the cyclohexylamine moiety than of the carbamate group.

The present work was undertaken to obtain fragmentation patterns for other N-cyclohexylcarbamate derivatives, to rationalize the observed fragmentation and compare it with that of related compounds, and to determine the extent of competition or interaction among the parts of these polyfunctional molecules. The compounds studied are methyl N-cyclohexylcarbamate (I), methyl N-*trans*-2-iodocyclohexylcarbamate (II), allyl N-cyclohexylcarbamate (III) and allyl N-*trans*-2-iodocyclohexylcarbamate (IV).

RESULTS

The masses and abundances of the principal ions from each of the carbamates at each ionizing energy are given in Table 1. Peaks of low intensity which are not tabulated correspond mainly to ions of low mass believed to be small hydrocarbon ions arising from fragmentation of the cyclohexane ring. Ion abundances reported are based on at least four spectral scans made on each of at least two different days.

TABLE I. PRINCIPAL PEAKS IN THE MASS SPECTRA OF N-CYCLOHEXYLCARBAMATE DERIVATIVES^a

Assignment				
	(I) R = CH ₃ X = H	(II) R = CH ₃ X = I	(III) R = CH ₂ CH = CH ₂ X = H	(IV) R = CH ₂ CH = CH ₂ X = I
[M] ⁺	157(7, 11, 22)	283(1·2, 1·9, 5)	183(6, 16, 25 ^b)	309(3·5, 4·0, 9)
[M - X] ⁺	—	156(23, ^b 41, ^b 56 ^b)	—	182(22, 40, ^b 36 ^b)
[(M - X) - CO ₂] ⁺	—	—	—	138 ^c (6, 12, 11)
[(M - X) - NH ₂ COOR] ⁺	—	81 ^d (16, 14, 12)	—	81(8, 10, 10)
[M - R] ⁺	142(0, 2·5, 2·7)	—	142(0, 13, 15)	—
[M - C ₃ H ₆ X] ⁺	114(32, ^b 47, ^b 44 ^b)	114(3·5, 6, 2·7)	140(9, 18, ^b 23)	140(0·8, 0, 0)
[(M - C ₃ H ₆ X) - CO ₂] ⁺	—	—	96(7, 9, 5)	96(2·1, 0, 0)
[M - C ₃ H ₈ X] ⁺	88(2·2, 3·8, 2·2)	88 ^e (14, 18, 14)	—	—
[M - C ₆ H ₈ X] ⁺	76(12, 18, 15)	76(11, 19, 11)	102(5, 9, 9)	102(1·6, 4·4, 8)
[COOR] ⁺	59(3·4, 0, 0)	59(3·9, 0, 0)	—	—
[R] ⁺	15(1·6, 0, 0)	15(2·4, 0, 0)	41(25, ^b 14, 5)	41(27, ^b 21, 20)
[R - H ₂] ⁺	—	—	39(5, 0, 0)	39(3·8, 0, 0)

^a Mass numbers are listed followed in parentheses by relative abundance as percent of total ionization at 70, 15 and 10 eV respectively.

^b Base peak.

^c Measured mass 138·123; [C₃H₆N]⁺ requires 138·129.

^d Measured mass 81·072; [C₆H₉]⁺ requires 81·070.

^e Measured mass 88·041; [C₃H₈NO₂]⁺ requires 88·040.

DISCUSSION

All spectra show the expected molecular ion peak, and in no case do peaks corresponding to possible pyrolysis products^{5,10} or impurities have significant abundances. Thus the carbamate spectra are not obscured by the presence of other neutral species in the ion source.

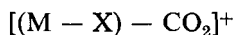
[M]⁺

The molecular ion in each case is the only odd-electron ion of significant abundance, and in the cases of II and IV it is the only ion to contain iodine. The relative abundances of this ion are comparable to those previously reported for the molecular ions of such related compounds as ethyl N-cyclohexylcarbamate,⁴ N-acetylcyclohexylamine,¹¹ cyclohexylamine¹² and iodocyclohexane¹³ where the molecular ion is 3 to 6% of the total ionization at 70 eV.

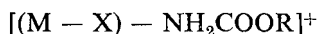
[M - X]⁺

Although this peak is insignificant when X = H, it is the base peak of II and the second most intense peak of IV at 70 eV. At the low ionizing energies it is the base peak for both these compounds, indicating that its formation is the most energetically favored fragmentation. The abundance of this ion as percent of total ionization is independent of whether R is methyl (II) or allyl (IV) at 70 and 15 eV in spite of important differences in the fragmentation-directing influence of these two R groups.

(See below.) Loss of a neutral iodine atom from aliphatic iodides is considered to arise from heterolytic cleavage of the C—I bond when the iodine atom provides the active site.¹⁴ That iodicyclohexane has an even more intense $[M - I]^+$ peak than the carbamates is consistent with the observation that the effect of the halogen atom is 'diluted' in the larger molecules.^{13,14}



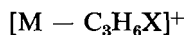
The peak at m/e 138 in the spectrum of IV is shown by mass measurement to correspond to $[C_9H_{16}N]^+$, or loss of the elements of I and CO_2 . This ion is of moderate abundance and is of interest in that it is unique to IV in the present series of compounds, and it must involve skeletal rearrangement. Since $[M - CO_2]^+$ is not observed for any of these compounds, it seems that loss of I occurs previous to or concurrent with loss of CO_2 . The ratio of the abundance of $[M - I - CO_2]^+$ to that of $[M - I]^+$ for IV is constant at 0.3 for all ionizing energies considered. This implies no significant endothermicity for loss of CO_2 from $[M - I]^+$.



Mass measurement showed m/e 81 in the spectra of II and, presumably, IV to correspond to $[C_6H_9]^+$. The decrease in the ratio of intensity of $[C_6H_9]^+$ to that of $[M - I]^+$ as ionizing energy decreases and failure to observe $[M - NH_2COOR]^+$ for any carbamate are consistent with the formation of $[C_6H_9]^+$ from $[M - I]^+$. The representation $[M - HI - NHCOOR]^+$ is considered a poor choice since $[M - HI]^+$ is not observed here and is unlikely in iodides in general.¹⁴ Formation of $[C_6H_9]^+$, cyclohexenyl ion, has been reported for other 1,2-disubstituted cyclohexanes. It is the base peak in the 70 eV spectra of *trans*-1,2-dichlorocyclohexane¹⁵ and *trans*-1,2-dibromocyclohexane.¹⁶ This ion is an important one also in the fragmentation of *trans*-2-chlorocyclohexanol.¹⁵ In these cases, $[C_6H_9]^+$ is reported to arise from initial loss of a halogen atom, followed by loss of the other ring substituent along with a hydrogen atom transferred from the ring. The present results indicate that a similar process gives $[C_6H_9]^+$ from II and IV.

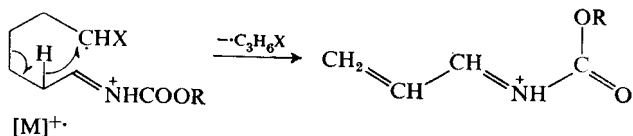


Ions at m/e 142, corresponding to loss of $R\cdot$, are observed in the low energy spectra of I and III. This process has been reported to give rise to the base peak in the mass spectra of some alkyl N-(1-phenylethyl) carbamates with increased relative abundance at low ionizing energy. It has been suggested that the resulting ion is stabilized by a bicyclic structure involving the phenyl ring.⁹ Since in the present case this kind of ion stabilization is impossible and since the R groups are smaller and less likely to be lost as free radicals, the observed abundances of $[M - R]^+$ are reasonable. The sums of the relative abundances of $[M - R]^+$ and $[R]^+$, involving cleavage of the same bond, are nearly constant with respect to ionizing energy for I or for III. This suggests that although the two processes obviously compete with each other, they are essentially unaffected by the other processes occurring in these molecules.



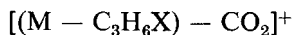
This ion is observed for all the present carbamates. It gives rise to the base peak of I at all ionizing energies considered. Comparing I with II and III with IV respectively,

it is seen that changing X from H to I reduces the 70 eV abundance of this ion by a factor of about nine in each case. This may be attributed to competition from fragmentation triggered at the iodine active site. Substitution of R = allyl for R = methyl results in a four-fold decrease in abundance. The process giving $[M - C_3H_6X]^+$ is apparently an α cleavage of the ring followed by hydrogen transfer to the radical site, which is predominant in the mass spectra of cycloalkylamines, cycloalkanols, cycloalkanones,¹⁷ and ethyl N-cyclohexylcarbamate.⁴

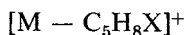


When X = I this type of mechanism could involve initial rupture of either the 1-2 or the 1-6 ring bonds leading to expulsion of $\cdot C_3H_6I$ or $\cdot C_3H_7$ respectively. Only the former is observed in accordance with the expectation that cleavage of the more highly substituted bond is favored. Similar results have been obtained by Cambon *et al.*,¹⁵ who find loss of $\cdot C_3H_6Cl$ from *cis* and *trans*-2-chlorohexanol by an analogous process to yield the base peaks in the mass spectra of these compounds. They report no $[M - C_3H_7]^+$ from either compound.

Stereochemical considerations can give an alternate explanation of the relative intensities of the $[M - C_3H_6X]^+$ peak in these four carbamates. The presence of the iodine in II and IV would increase the extent of equatorial conformers in these compounds compared to I and III. In addition, the larger ester group in III and IV would increase the equatorial conformer content compared with I and II. If this fragmentation process requires an axial alignment for the carbamate group, the observed relative intensities could be due primarily to steric factors. Further studies are necessary to test this hypothesis.



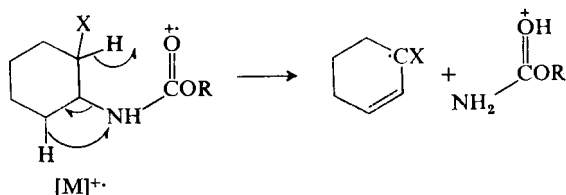
This rearrangement ion is believed to give rise to m/e 96 in the spectra of III and IV, which have R = allyl. The ratio of the abundance of m/e 96 to that of m/e 140 for III decreases significantly as ionizing energy is decreased, indicating that m/e 96 may arise from $[M - C_3H_6X]^+$.



Mass measurement indicates the formulation of m/e 88 in the spectrum of II as $[C_3H_6NO_2]^+$. The same is presumed for m/e 88 from I. A hydrogen transfer will give $CH_2=NHCOOR$. Then failure to observe this ion in III or IV may be due to breakdown of $CH_2=NHCOOCH_2CH=CH_2$ to give the resonance-stabilized allyl ion via heterolytic cleavage of the O-allyl bond. A similar breakdown of $CH_2=NHCOOCH_3$ from I or II should be more endothermic and thus less favored.



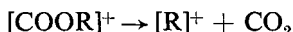
Double hydrogen rearrangement has been shown to be important in the fragmentation of cycloalkylamides.^{11,18} A similar process explains the m/e 76 peaks from I and II and the m/e 102 peaks from III and IV.



Other resonance structures may be written for the resulting ion. Again, further breakdown of this ion to give allyl ion explains the lower abundance of $[M - C_6H_8X]^+$ observed when $R = \text{allyl}$. There is no significant difference in the abundance of this ion in the spectra of I compared to those of II. The tendency of the abundance of this ion to be decreased by competition from a process such as that yielding $[M - X]^+$ when $X = I$ instead of H appears to be balanced by a possible enhancement of $[M - C_6H_8I]^+$ by greater stabilization of the resulting cyclohexenyl radical.

$[COOR]^+$

An ion is detected at m/e 59 in the 70 eV spectra of I and II. It apparently corresponds to the ion $[COOR]^+$ resulting from cleavage of the C—N bond of the carbamate group. This ion is not observed for $R = \text{allyl}$, and it was not reported for ethyl carbamates.⁴ Consider the degradation reaction



If $R = \text{methyl}$, this reaction has a ground state endothermicity of 30 kcal,^{19,20} while if $R = C_2H_5$, it has a ground state endothermicity of only 11 kcal.¹⁹ It then seems reasonable that while $[COOR]^+$ is observed in spectra in the former case, only $[R]^+$ is observed in the latter. We are not aware of a determination of the heat of formation of $[COOCH_2CH=CH_2]^+$, if this ion actually exists, but it is expected that its degradation to give $+CH_2CH=CH_2$ should occur readily. This fits the present observations. Low to moderate abundances of $[COOCH_3]^+$ are reported for methyl esters.²¹

$[R]^+$

The strong tendency of ion fragments containing the R group to fragment further to $[R]^+$ when $R = \text{allyl}$ has already been considered. It is expected also that direct formation of $+CH_2CH=CH_2$ should occur readily when the allyl group is present.²² Thus m/e 41, corresponding to the allyl ion, is the base peak in the spectra of III and IV at 70 eV, with the same relative abundance for each. Both I and II give the same low abundance of m/e 15 at 70 eV, corresponding to $[CH_3]^+$.

$[R - H_2]^+$

Dehydrogenation of the allyl ion accounts for the m/e 39 peak²³ in the 70 eV spectra of III and IV. If one takes the value of 255 kcal mole⁻¹ for the heat of formation of the $[C_3H_3]^+$ ion,¹⁹ the dehydrogenation of allyl ion is 39 kcal mole⁻¹ endothermic, and failure to observe m/e 39 at low ionizing energy is expected. The question of whether $[C_3H_3]^+$ from a variety of sources has the propargyl or the cyclopropenyl structure has not been settled, although the latter is supposed to be more stable.^{19,24}

CONCLUSIONS

The principal peaks in the mass spectra of the cyclohexylcarbamate derivatives (I to IV) are attributed to the eleven types of fragmentation discussed. Each of these

may be considered to arise from the molecular ion with an active site² on either the nitrogen, oxygen, or iodine atom or the allyl group, resulting from loss of one of the corresponding nonbonding electrons on the heteroatom or a π electron of the allyl group. In this series of compounds, the fragmentation-inducing power of these sites is iodine > allyl > nitrogen > oxygen. Thus the fragmentation is best compared to that of iodides, allyl compounds, amines and/or carbonyl compounds rather than to that of carbamates in general. The concept of 'active site' is shown to be a useful one for this series of polyfunctional compounds. It is hoped that further work will permit a general, more quantitative treatment of the fragmentation paths of such compounds.

EXPERIMENTAL

Synthesis of compounds

Materials. Cyclohexene (Chemical Samples, 99%), cyclohexylisocyanate (Ott Chemical) and allyl alcohol (Shell) were used as supplied. The silver cyanate was prepared as described by Hassner and Heathcock.²⁵ The iodine was a resublimed grade, and all the other chemicals and solvents were of reagent grade or better.

Methyl *N*-cyclohexylcarbamate (I). Cyclohexylisocyanate (25.0 g, 0.20 mole) was refluxed with methanol (80 g, 2.5 mole) for 18 hrs and the excess solvent removed by vacuum distillation. The solid was recrystallized from methanol to yield 24.7 g (78% of theory) of a white, crystalline solid, m.p. 74 to 75°C (Lit.²⁶ 75°C).

Methyl *N*-trans-2-iodocyclohexylcarbamate (II). Cyclohexene (4.1 g, 0.05 mole) was stirred with iodine (12.7 g, 0.05 mole) and silver cyanate (10.0 g, 0.067 mole) in methylene chloride at -20°C to prepare 2-iodocyclohexylisocyanate.^{27,28} The silver salts were removed by filtration after 2 hrs reaction and methanol (100 ml) was added. The solution was stirred until (2 days) no NCO peak (2250 cm⁻¹) was observed in the i.r. spectrum. This reaction was run at room temperature to avoid cyclization to an oxazolidone.¹⁰ After removal of the solvents, the solid was recrystallized twice from acetone to yield 11.0 g (87% of theory) white needles, m.p. 134 to 135°C (Lit.²⁷ 135°C).

Allyl *N*-cyclohexylcarbamate (III). Cyclohexylisocyanate (32.5 g, 0.26 mole) was refluxed for 2 days with allyl alcohol (30.0 g, 0.52 mole). The excess allyl alcohol was extracted with water, the product dried and then recrystallized from petroleum ether at -15°C to yield 39.3 g (82% of theory) of a pale yellow liquid, m.p. 14 to 15°C. This material decomposes on heating to approximately 130°C at atmospheric pressure. The infrared spectrum is consistent with the proposed compound.

Allyl *N*-trans-2-iodocyclohexylcarbamate (IV). The preparation of this compound paralleled that of II except that allyl alcohol (5.8 g, 0.10 mole) was added to the 2-iodocyclohexylisocyanate solution. After stirring for 2 days at room temperature, the solvent was removed and the solid recrystallized twice from acetone to yield 11.4 g (73% of theory) of a white crystalline solid, m.p. 107 to 108°C. Infrared spectra are consistent with the proposed structure which was confirmed by elemental analysis: Found: C, 39.36; H, 5.23; N, 4.85; I, 41.03. C₁₀H₁₆NO₂I requires: C, 38.85; H, 5.22; N, 4.53; I, 41.05.

Mass Spectra

Spectra were obtained with a CEC (DuPont) 21-491 double focusing mass spectrometer operating at a nominal resolution of 2.5×10^3 (10% valley). In cases where mass measurements are reported, this resolution is sufficient to distinguish among the possible fragment compositions which can be derived from the molecular formula of the sample. Carbamates were introduced via a direct probe inlet at 50 to 75°C. Since III is a liquid at room temperature, it was frozen in liquid nitrogen immediately before sample introduction to minimize premature evaporation. The ion source was operated at 130°C. At higher temperatures carbamates may pyrolyze to the corresponding alcohol and isocyanate⁵ or to a 2-oxazolidone in the case of II and IV.¹⁰ Fragmentation patterns were obtained at ionizing energies of 70, 15 and 10 eV as read on a digital voltmeter. Reference samples for mass measurements were introduced via a heated gas inlet.

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