Electron-impact Induced Fragmentation of Three-membered Heterocycles. Part III.[1] *N*-t-Alkylaziridine-1-carboxamides

By **I. Lengyel** * and **D. B. Uliss**, Department of Chemistry, St. John's University, Jamaica, New York 11432, U.S.A.
F. D. Greene, Department of Chemistry, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, U.S.A.

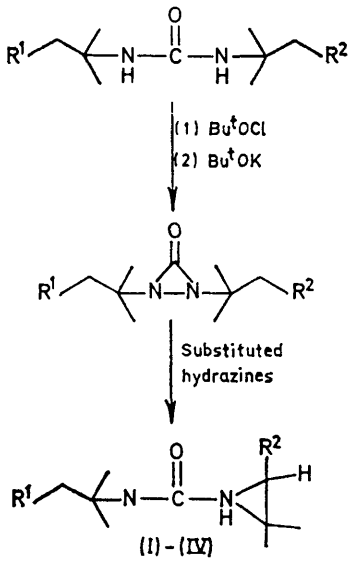
A comparative study of the electron-impact induced fragmentation of four *N*-t-alkylaziridine-1-carboxamides has been undertaken by conventional and high-resolution mass spectrometry. The main paths of fragmentation can be interpreted in terms of the unrearranged molecular structure. The base peak in all aziridinecarboxamides is due to elimination of a t-alkyl isocyanate from the molecular ion, involving rearrangement of the N–H hydrogen to the aziridine nitrogen atom. α-Cleavage, with ejection of one of the alkyl groups attached to the tertiary carbon, is a major competing process. Fission of both the CO–NH bond and the CO–aziridine bond occurs, leading to isocyanate and aziridinium-type ions, respectively. There is no compelling evidence to indicate common intermediates in the fragmentation of an aziridinecarboxamide and the structural isomer *N*-t-alkylimidazolidin-2-one. Based on mass spectral evidence, the diaziridinone ⟶ aziridinecarboxamide isomerization is not reversible.

A DANGER [2,3] in the use of mass spectrometry in structure elucidation is that many bond fissions effected by electron bombardment are accompanied by rearrangements. After ionization, isomerizations may precede fragmentation.[4] Therefore it is essential to the proper interpretation of mass spectra that isomerization in molecular ions

[1] Part II, I. Lengyel, F. D. Greene, and J. F. Pazos, *Org. Mass Spectrometry*, 1970, **3**, 623.
[2] P. Brown and C. Djerassi, *Angew. Chem.*, 1967, **79**, 481; *cf.* P. Brown and C. Djerassi, *Angew. Chem. Internat. Edn.*, 1967, **6**, 477.
[3] R. G. Cooks, *Org. Mass Spectrometry*, 1969, **2**, 481.
[4] Part I, I. Lengyel, D. B. Uliss, M. M. Nafissi-V, and J. C. Sheehan, *Org. Mass Spectrometry*, 1969, **2**, 1239.

and skeletal rearrangements, and migrations of atoms or groups in fragment ions, be recognized and taken into account. Strained small rings with heteroatoms and/or bearing heteroatom-containing substituents are especially prone to undergo rearrangements, even in low-energy chemical reactions in solution.[5]

As part of an investigation of the physical, chemical, and spectral properties of three-membered heterocyclic compounds we have studied the mass-spectral fragmentation of four *N*-t-alkylaziridine-1-carboxamides (*N*-t-alkylcarbamoylaziridines).* Our aims, in particular, were to determine whether certain skeletal isomerizations known to be effected readily by chemical means (*see below*) have mass spectral parallels, and whether fragmentation of aziridinecarboxamides proceeds through



(I) $R^1 = R^2 = H$
(II) $R^1 = R^2 = Me$
(III) $R^1 = R^2 = Ph$
(IV) $R^1 = H$, $R^2 = Ph$

SCHEME 1

intermediates common with related isomeric heterocycles. A correlation of the electron-impact induced fragmentation of diaziridinones and the structurally isomeric aziridinecarboxamides has previously been imtimated: a number of abundant ions in the mass spectra of diaziridinones were interpreted as originating from rearranged aziridinecarboxamide molecular ions.[1]

Diaziridinones [6] in solution undergo oxidation–reduction and rearrangement reactions (in the presence of substituted hydrazines), in which the rearrangement products are aziridinecarboxamides.[7] The chemical isomerization of aziridinecarboxamides to imidazolidinones and oxazolines (in the presence of sodium iodide or sulphuric acid) has been reported.[8] The mass spectra of *N*-acylaziridines have been discussed in terms of electron-impact induced rearrangement to oxazolines.[9] Aziridinones (α-lactams) have been shown [4] to fragment partly *via* valence-isomerized (imino-α-lactone) molecular ions.

RESULTS AND DISCUSSION

While ethyleneimine itself and simple *N*-alkylaziridines display a rather straightforward electron-impact induced fragmentation pattern,[10] incorporation of additional heteroatoms results in a different and more complex set of decomposition paths (*cf.* 70 eV low-resolution spectra, Table). Most fragmentations observed in aziridinecarboxamides (I)—(IV) can be rationalized in terms of ionization at one of the nitrogen atoms, as was suggested by Baldwin *et al.* from ionization-potential measurements for the closely related ureas.[11]

To elucidate mechanistic details of the principal fragmentations and to ascertain the ions' elemental compositions, a combination of specific deuterium labelling, high-resolution mass measurement, and metastable peak correlation was employed. Metastable correlations were calculated by computer, by use of a programme similar to the one written by Rhodes *et al.*[12] Final assignments were made manually by use of intensity data from m_1 and m_2.†

The base peak in all aziridinecarboxamides (I)—(IV) arises from fragmentation of the molecular ion into aziridinium ion *h* and a neutral alkyl isocyanate moiety (Scheme 2). This path, supported by the appropriate metastable peak at *m/e* 88·0 for compound (IV), represents a clean reversal of the synthetic reaction used [7] to prepare aziridinecarboxamides (from aziridines and isocyanates). Ion *h* at *m/e* 147 from compound (III) is shifted to *m/e* 148 in the spectrum of the N–D analogue, indicative of a four-membered transition state for the rearrangement and pinpointing the origin of the migrating hydrogen atom. The prominent peaks *g* and *i*, and the moderately abundant ion *j*, are derivable from *h* by α-cleavage. Metastable peaks are present for transitions $h \longrightarrow g$ and $h \longrightarrow i$, and the appropriate one-mass-

* For a brief summary see I. Lengyel and F. D. Greene, Second International Congress of Heterocyclic Chemistry, July 7—11, 1969, Montpelier, France, Abstracts No. B-40, p. 92.

† Elemental composition of ions and metastable ions and transitions are listed in Supplementary Publication No. SUP 20422 (5 pp., 1 microfiche). For details see Notice to Authors No. 7 in *J. Chem. Soc.* (*A*), 1970, Issue No. 20 (items less than 10 pp. are supplied as full-size copies).

[5] L. A. Paquette, 'Principles of Modern Heterocyclic Chemistry,' Benjamin, New York, 1968, pp. 1—52, and references therein.

[6] F. D. Greene, J. C. Stowell, and W. R. Bergmark, *J. Org. Chem.*, 1969, **34**, 2254.

[7] F. D. Greene, W. R. Bergmark, and J. G. Pacifici, *J. Org. Chem.*, 1969, **34**, 2263.

[8] H. W. Heine, W. G. Kenyon, and E. M. Johnson, *J. Amer. Chem. Soc.*, 1961, **83**, 2570.

[9] T. Z. Papoyan, I. I. Chervin, and R. G. Kostyanovskii, *Izvest. Akad. Nauk S.S.S.R., Ser. khim.*, 1968, 1530.

[10] Q. N. Porter and J. Baldas, 'Mass Spectrometry of Heterocyclic Compounds,' Wiley-Interscience, New York, 1971, pp. 296—299, and references therein.

[11] M. A. Baldwin, A. M. Kirkien-Konasiewicz, A. G. Loudon, A. Maccoll, and D. Smith, *J. Chem. Soc.*, (*B*), 1968, 34; *Chem. Comm.*, 1966, 574; see also, S. W. Tam, *Org. Mass Spectrometry*, 1966, **2**, 729.

[12] R. E. Rhodes, M. Barber, and R. L. Anderson, *Analyt. Chem.*, 1966, **38**, 48.

unit shifts to higher *m/e* values are observed in the spectra of the *N*-deuterioaziridinecarboxamides. An alternative fragmentation path of the molecular ions is α-cleavage by loss of alkyl radicals or a hydrogen atom giving rise to the series of even-electron ions *a*, *b*, *c*, and *d* (corresponding to elimination of $R^1CH_2^{\bullet}$, $CH_3^{\bullet}$, $H^{\bullet}$ and $R^{2\bullet}$, respectively).

Normalized 70 eV mass spectra of *N*-t-alkylcarbamoylaziridines (I)—(IV) and 4,4-dimethyl-1-t-butylimidazolidin-2-one (V) [a]

2,2-Dimethyl-*N*-t-butylaziridine-1-carboxamide (I)

27 (18), 28 (37), 29 (30), 30 (33), 31 (2), 32 (31), 39 (18), 40 (6), 41 (39), 42 (27), 43 (20), 44 (6·5), 53 (7), 54 (8), 55 (24·5), 56 (73), 57 (52), 58 (80·5), 59 (8), 69 (7·5), 70 (33), 71 (100), 72 (19), 81 (4), 82 (2), 83 (4·5), 84 (39), 85 (5), 97 (3), 98 (3·5), 99 (4·5), 101 (3·5), 113 (5), 114 (6), 115 (5), 155 (6), 156 (1·5), 170 (14), 171 (1·3)

N-(1,1-Dimethylpropyl)-2,2,3-trimethylaziridine-1-carboxamide (II)

27 (8), 28 (16), 29 (9), 30 (4), 32 (3), 39 (8), 40 (2), 41 (27), 42 (36), 43 (30), 44 (10), 55 (16), 56 (11), 57 (22), 58 (51), 59 (4), 61 (2), 67 (2), 68 (3·5), 69 (18), 70 (42), 71 (23), 72 (19), 73 (2·5), 83 (3), 84 (68), 85 (100), 86 (15), 95 (2), 96 (2), 97 (3), 98 (2·5), 99 (1·5), 101 (2·5), 112 (6), 113 (5), 128 (2), 129 (3), 169 (6), 183 (3), 198 (4)

N-(1,1-Dimethyl-2-phenylethyl)-2,2-dimethyl-3-phenylaziridine-1-carboxamide (III)

27 (3), 28 (6·5), 29 (3·5), 32 (2), 39 (4), 41 (10), 42 (12), 43 (6), 51 (2·5), 53 (3), 55 (6), 56 (6·5), 57 (5), 58 (55), 59 (5), 65 (6), 68 (3), 69 (3·5), 70 (3), 71 (4), 77 (7), 78 (2), 79 (4), 83 (4), 84 (21), 85 (3), 89 (5), 90 (8), 91 (58), 92 (12), 103 (3), 104 (5), 105 (6), 106 (3), 115 (4), 116 (3), 117 (6), 118 (3), 119 (2), 129 (2), 130 (7), 131 (13), 132 (16), 133 (6), 134 (3), 145 (2), 146 (91), 147 (100), 148 (17), 149 (3), 173 (2), 174 (21), 175 (5), 188 (3), 191 (3), 215 (3), 231 (30), 232 (5), 233 (2), 307 (2·5), 321 (1·5), 322 (2·5)

2,2-Dimethyl-3-phenyl-*N*-t-butylaziridine-1-carboxamide (IV)

27 (6), 28 (18), 29 (24), 30 (4), 32 (3), 38 (2), 39 (13), 40 (4), 41 (28), 42 (22), 43 (17), 44 (3), 50 (2), 51 (5), 52 (2), 53 (3·5), 54 (2), 55 (17), 56 (15), 57 (33), 58 (51), 59 (6), 63 (3), 64 (3·5), 65 (7), 67 (2), 68 (3), 69 (12), 70 (9), 71 (11), 72 (5), 77 (19), 78 (7), 79 (14), 81 (4), 83 (11), 84 (10), 85 (8), 89 (14), 90 (26), 91 (58), 92 (8), 97 (6), 98 (5), 99 (7), 103 (6), 104 (22), 105 (17), 106 (9), 111 (3), 115 (8), 116 (6), 117 (10), 118 (5), 119 (6), 129 (7), 130 (18), 131 (20), 132 (27), 133 (7), 134 (5), 144 (3), 145 (10), 146 (91), 147 (100), 148 (32), 149 (6), 155 (5), 157 (6), 158 (5), 159 (4), 169 (5), 174 (11), 175 (4), 191 (5), 193 (3), 231 (4·5), 245 (3), 246 (2·5)

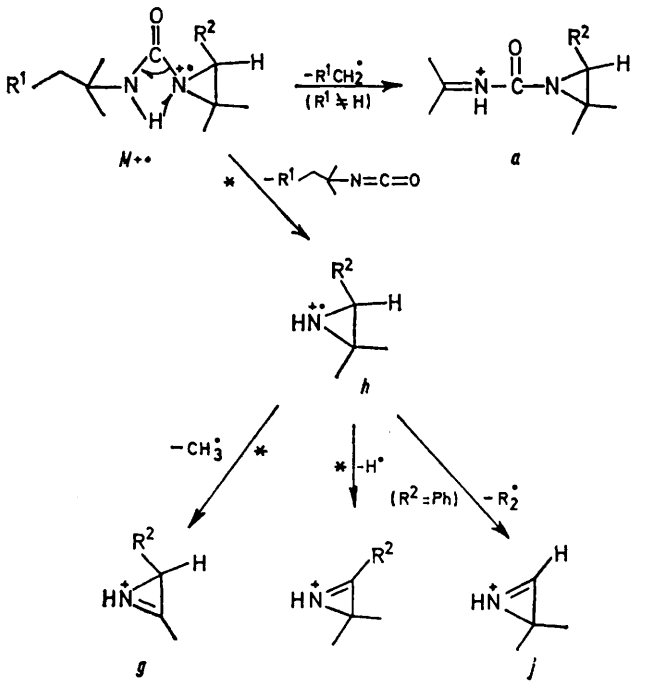
4,4-Dimethyl-1-t-butylimidazolidin-2-one (V)

27 (11), 28 (20), 29 (25), 30 (15), 31 (2), 32 (5), 39 (17), 40 (5), 41 (42), 42 (28), 43 (8), 44 (4), 50 (2), 51 (3), 52 (4), 53 (5), 54 (5·5), 55 (41), 56 (21), 57 (28), 58 (23), 59 (2), 65 (2), 67 (4), 68 (3), 69 (3·5), 70 (18), 71 (5), 72 (6), 75 (1·5), 76 (2·5), 80 (2), 81 (3), 82 (3·5), 83 (3), 84 (3·5), 81 (1·5), 91 (1·5), 92 (1·5), 93 (2), 95 (15), 96 (6), 97 (4), 98 (4·5), 99 (37), 100 (4), 103 (1·5), 104 (2·5), 105 (4), 111 (3), 112 (100), 113 (18), 114 (6), 115 (3), 125 (1·5), 126 (1·5), 127 (2), 139 (6), 154 (2), 155 (94), 156 (13), 157 (2), 170 (8), 171 (1·5)

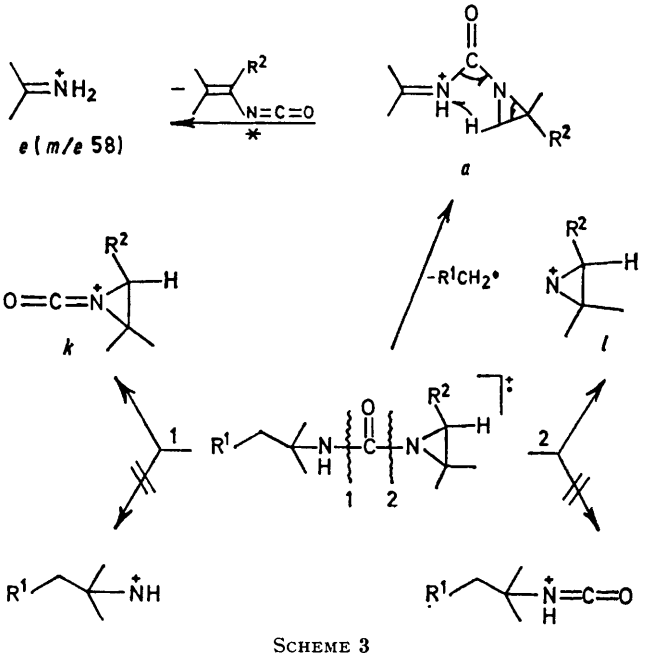
[a] Data as *m/e* values followed by ion abundances in parentheses.

Subsequent decomposition of ion *a* [supported by metastable peaks for (I), (II), and (III)] leads to iminium ion *e*, *m/e* 58 (C_3H_8N), prominent in all spectra. Specific deuteriation on nitrogen causes ion *e* to shift to *m/e* 59, indicating a C ⟶ N hydrogen migration. Elimination of a stable neutral particle, a conjugated isocyanate (supplying part of the driving force for this process) *via* a six-membered transition state is depicted in Scheme 3.

Cleavage of the CO–NH bond (path 1, Scheme 3) occurs in the molecular ion of all aziridinecarboxamides with the



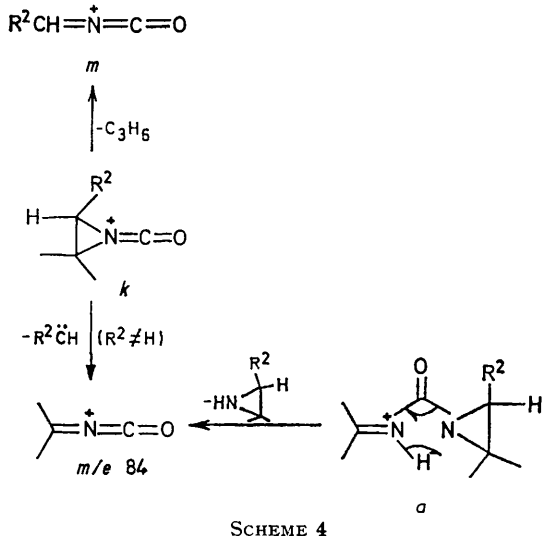
SCHEME 2



SCHEME 3

charge retained by the oxygen-containing fragment (Scheme 3, *k*). Fission of the carbonyl–aziridinyl bond (path 2, Scheme 3) also occurs, but in this case the charge is carried by the aziridine fragment *l*. Ions *l* and *i*, being tautomers, are indistinguishable by conventiona lor

high-resolution mass spectrometry. However, they become distinguishable by labelling. In the mass spectra of the *N*-deuteriated analogues of (III) and (IV), ions *l* and *i* (*m/e* 146) (Schemes 3 and 2, respectively) should differ by one mass unit. If *m/e* 146 were entirely due to



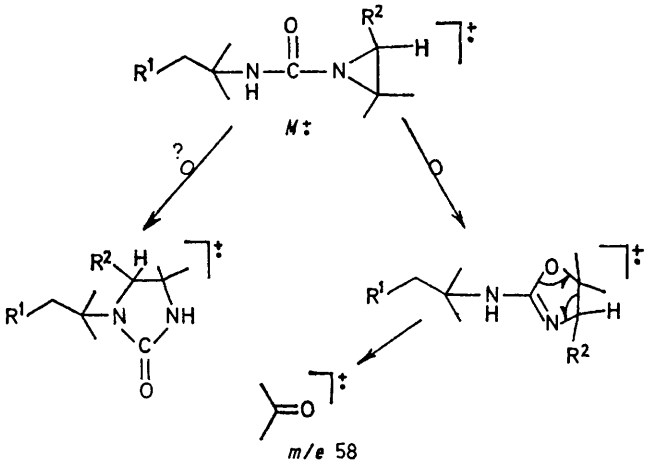
SCHEME 4

i, it should shift to *m/e* 147 whereas if species *l* were the sole component, it should remain unshifted. In fact, the mass spectra of the *N*-deuteriated samples show a 10% shift from *m/e* 146 to *m/e* 147, indicating the presence of both *l* and *i*, with the former predominating.

An ion of varying intensity at *m/e* 84 is present in the spectra of all aziridinecarboxamides. This ion is shown to be C_4H_6NO for (III) by high-resolution mass measurement. One quarter of the very large *m/e* 84 peak in (II) is also C_4H_6NO (the other three quarters in this case is $C_5H_{10}N$, *viz.*, ion *i* in Scheme 2). One possible pathway of formation of *m/e* 84 (C_4H_6NO) for (II), (III), and (IV) is from ion *k* by extrusion of an alkene (R^2CH) portion (Scheme 4). Ion *k* cannot be the precursor for *m/e* 84 (C_4H_6NO) in (I; $R^2 = H$), as the elimination of carbene (CH_2) is a highly endothermic process, the heat of formation of methylene $\Delta H°_{f,298}(g) = 93{\cdot}7$ kcal mol^{-1}.[13] Fission of the carbonyl–aziridinyl bond in ion *a*, with migration of the *N*-hydrogen atom to the aziridine nitrogen (Scheme 4) provides an alternative route to ion *m/e* 84. In electron-impact rearrangements migration of atoms or groups usually occurs to electron-deficient sites.[14] In the case of *a* ⟶ *m/e* 84, migration occurs from an electron-deficient site. Apparently, the stabilities of the product ion (resonance) and of the neutral fragment eliminated provide sufficient driving force at 70 eV.*

The molecular ion of aziridinecarboxamide (I) loses the elements of isobutene (*m** at 76·5) to give a moderately abundant ion at *m/e* 114 (*M* − 56). The mass spectrum of (II) also exhibits an ion, albeit a weak one, at *m/e* 128 ($C_6H_{12}N_2O$), corresponding to the loss of an alkene (C_5H_{10}) from the molecular ion. *A priori* the alkene ejected in these fragmentations could originate either from the *N*-t-alkyl substituent (McLafferty rearrangement) or from the aziridine ring and its substituents (transannular ring cleavage). The absence of the related *M* − 56 ion from the spectrum of (IV) clearly points to the latter alternative. The corresponding ion, *viz.*, *m/e* 190, $C_{11}H_{14}N_2O$, is also absent from the spectrum of (III). The neutral alkane is eliminated from the aziridine ring and the charge retained by the fragment of lower ionization potential (Stevenson's rule [15]).

Some of the fragmentations described above (*m/e* 84 and the olefin fragmentations) could also be interpreted in terms of decomposition of imidazolidinones or oxazolines. Of interest in this connection is the ion at *m/e* 58, part of which is C_3H_6O. This species cannot be derived from the original molecule by simple bond cleavages, but is derivable from the oxazoline parent ion (Scheme 5). The oxazoline is not available at this time for direct comparison, but 4,4-dimethyl-1-t-butylimidazolidin-2-one (V) has been synthesized by an independent and unequivocal route (see Experimental section). An examination of the 70 eV mass spectrum and the observed



SCHEME 5

metastable peaks reveal no close analogy with the fragmentation of carbamoylaziridine (I). The major fragmentation paths for the imidazolidinone (V) are depicted in Scheme 6.

An interesting and non-predictable fragmentation was discovered in compound (IV); ring cleavage accompanied by hydrogen migration to the benzylic carbon leads to both an abundant tropylium ion (*m/e* 91) and a weak $(M - 91)^+$ species at *m/e* 155. The fact that *m/e*

* It should be noted that the relative abundance of *m/e* 84 is strongly dependent on the electron energy: at 20 or 12 eV *m/e* 84 becomes small (1—5%).

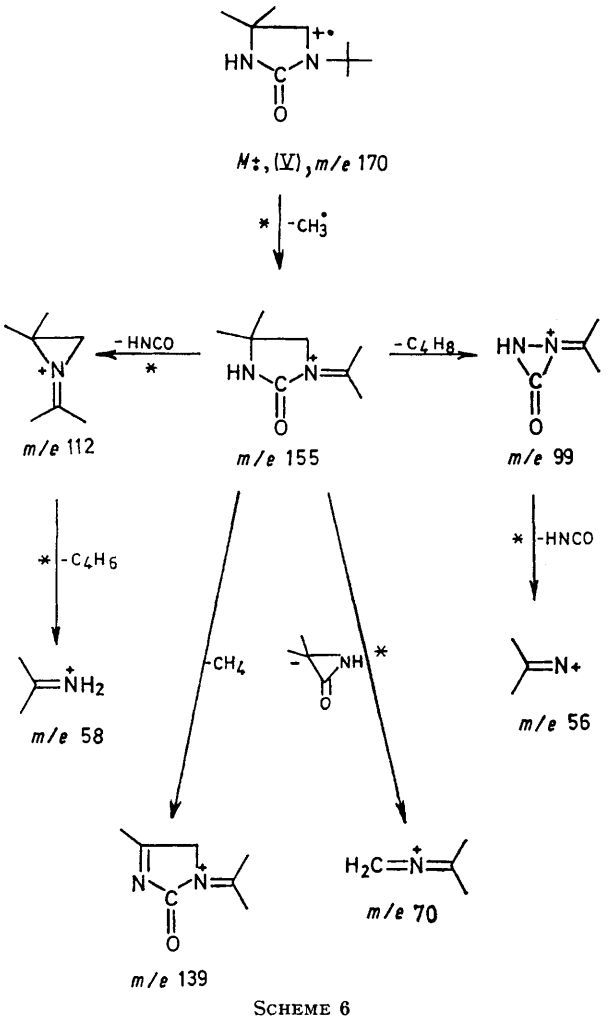
[13] J. L. Franklin *et al.*, 'Ionization Potentials, Appearance Potentials, and Heats of Formation of Gaseous Positive Ions,' NSRDS–NBS 26, Washington, D.C., 1969.

[14] H. Budzikiewicz, C. Djerassi, and D. H. Williams, 'Mass Spectrometry of Organic Compounds,' Holden-Day, San Francisco, 1967, p. 19.

[15] D. P. Stevenson, *Discuss. Faraday Soc.*, 1951, **10**, 35.

91 remains unshifted in the spectrum of the *N*-deuteriated analogue of (IV) shows that the migrating hydrogen was originally attached to carbon, and that the rearrangement proceeds through a four-membered transition state.

Conclusion.—While the mass spectra of aziridinecarboxamides (I)—(IV) do exhibit close similarity to



SCHEME 6

those of the identically substituted and isomeric diaziridinones,[1] there is no evidence for electron-impact promoted rearrangement of aziridinecarboxamides to diaziridinones in the molecular ion. On the other hand, aziridinecarboxamides partly rearrange to the isomeric oxazolines upon electron-impact, as shown by the *m/e* 58 (C_3H_6O) ion in (II). Fragmentation of a model imidazolidin-2-one (V) and its structural isomer aziridinecarboxamide (I) proceeds from unrelated molecular ions *via* different paths. The base peak in (I)—(IV) arises by expulsion of an alkyl isocyanate. A competing primary process is elimination of alkyl radicals with preferential loss of the group of greater stability ($C_7H_7^{\bullet} > C_2H_5^{\bullet} > CH_3^{\bullet}$).

EXPERIMENTAL

The conventional (low-resolution) mass spectra were recorded at 70 eV and 50 μA on a Hitachi RMU-6D single-focusing instrument. Samples were introduced directly into the ion source at 60—120 °C. The ion source temperature was 75—100 °C.

The high-resolution measurements were performed on a CEC 21-110C double-focusing instrument at 200 °C source temperature, samples being introduced *via* the solid probe, and the plate processed by an IBM 1800 computer system.[16]

The unlabelled aziridine samples were of analytical purity; synthesis and physical constants have been described.[6,7] The N–D labelled aziridinecarboxamides were prepared by exchange in deuteriomethanol (MeOD) at room temperature.

4,4-Dimethyl-1-t-butylimidazolidin-2-one (V).—2,2-Dimethylethyleneimine and t-butylamine were made to react by Clapp's procedure [17] to give a 27% yield of *2-methyl-N(1)-t-butylpropane-1,2-diamine*, b.p. 58—60 °C at 21 mmHg; i.r. (film): 3390 and 3300 cm^{-1} (N–H); δ 0·91 (s, 2H), 1·0—1·1 (16H), and 2·28 p.p.m. (s, 2H). The 0·91 p.p.m. signal disappears on addition of D_2O; m.s.: *m/e* 145, 144, 129, 72, and 58 (Found: C, 66·5; H, 13·85; N, 19·3. $C_8H_{20}N_2$ requires C, 66·6; H, 14·0; N, 19·4%). By means of the procedure of Martell and Frost,[18] the diamine (6·93 g, 48·1 mmol) and urea (3·61 g, 60·1 mmol) were refluxed until ammonia no longer evolved. The product was distilled, and the fraction of b.p. 145—155 °C at 13 mmHg was collected. The liquid rapidly solidified, m.p. 134—148 °C. Preparative t.l.c. (E. Merck, Silica Gel) showed two components, R_F 0·56 and 0·74. The band at R_F 0·56 was removed, eluted with methanol, and evaporated to yield the crude imidazolidinone. Two recrystallizations from hexane gave 60·1% of *compound* (V), m.p. 152—154 °C. The i.r. spectrum (KBr) showed strong absorptions at 3200 cm^{-1} (N–H) and 1660 cm^{-1} (C=O). The ^1H n.m.r. spectrum ($CDCl_3$) showed δ 1·00 (s, 1H, N–H), 1·28 (s, 6H, *gem*-dimethyl), 1·38 (s, 9H, t-butyl), and 3·17 p.p.m. (s, 2H, methylene) (Found: C, 63·6; H, 10·6; N, 16·3. $C_9H_{18}N_2O$ requires C, 63·5; H, 10·7; N, 16·45%). The band at R_F 0·74 has been identified as 4,4-dimethyl-2-oxo-1-t-butylimidazolidine-3-carboxamide from mass and i.r. spectra.

This investigation was supported by the National Science Foundation (to F. D. G.). We thank Professor K. Biemann and his associates for the element maps, which were obtained at the High Resolution Mass Spectrometry Facility at the Department of Chemistry, Massachusetts Institute of Technology, supported by National Institutes of Health. We thank Dr. R. V. Mark, St. John's University, for the synthesis of the imidazolidinone model compound.

[2/257 *Received*, 7*th February*, 1972]

[16] K. Biemann, P. Bommer, and D. M. Desiderio, *Tetrahedron Letters*, 1964, 1725.

[17] L. B. Clapp, *J. Amer. Chem. Soc.*, 1948, **70**, 184.

[18] A. E. Martell and A. E. Frost, *J. Amer. Chem. Soc.*, 1950, **72**, 1032.