MASS SPECTRA AND STRUCTURE OF 4-AMINOURACILS

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The stability of the molecules of substituted 4-aminouracils with respect to electron impact depends on three factors: the ratio of the various tautomeric forms of the excited molecular ion, the stabilizing effect of electron-donor substituents bonded to the nitrogen atoms in the uracil molecule, and the possibility of the existence of intramolecular hydrogen bonding in the molecular ion. The latter factor is due to the development of the corresponding conformation.

A study of the mass spectra of a number of substituted 4-aminopyrimidines [1-3] has made it possible to draw definite conclusions regarding the strong effect of the ratio of the various tautomeric forms of the excited molecular ion on the dissociative ionization. The effective influence of various functional groups in the ring on the isomerization of the molecular ion and the path of disintegration in the first steps has also been noted.

In the present communication the mass spectra of 4-aminouracil (I), 4-amino-3-methyluracil (II), 4-amino-1-methyluracil (III), 4,5-diaminouracil (IV), 4,5-diamino-3-methyluracil (V), and 4,5-diamino-1,3-dimethyluracil (VI) are discussed. The mass spectra of these compounds (Table 1) were obtained for the

TABLE 1. Mass Spectra of Amino-Substituted Uracils*

4-Aminouracil (I)

26 (7,5), 27 (29,2), 29 (34,2), 30 (10,0), 31 (66,7), 36 (9,6), 38 (5,8), 39 (12,9), 40 (20,8), 41 (38,3) 42 (42,5), 43 (100,0), 45 (24,2), 46 (8,6), 51 (3,3), 53 (3,3), 54 (2,5), 55 (14,2), 56 (8,3), 57 (13,3), 60 (10,3), 61 (3,3), 65 (2,1), 66 (3,3), 67 (9,2), 68 (43,3), 69 (4,6), 71 (5,0), 73 (3,3), 79 (4,6), 81 (4,2), 82 (2,5), 83 (6,7), 84 (16.7), 85 (8,8), 87 (2,5), 95 (2,5), 97 (5,0), 98 (3,3), 99 (20,8), 100 (3,8), 109 (3,3), 111 (3,3), 127 (83,3), 128 (6,3)

4-Amino-3-methyluracil (II)

27 (8,6), 29 (6,1), 30 (35,5), 31 (5,1), 39 (4,6), 40 (19,4), 41 (32,3), 42 (32,3), 43 (16,5), 52 (3,6), 53 (5,1), 54 (6,3), 55 (17,6), 56 (8,2), 57 (45,2), 58 (4,9), 68 (21,7), 69 (8.6), 70 (14,8), 82 (75,8), 83 (4,9), 97 (12,5), 98 (21,7), 113 (8,6), 141 (100,0), 142 (7,9)

4-Amino-1-methyluracil (III)

27 (5,9), 29 (8,9), 30 (10,5), 39 (5,3), 40 (16,0), 41 (24,5), 42 (30,6), 43 (48,4), 45 (4,4), 54 (3,3), 55 (8,7), 56 (13,3), 57 (4,3), 58 (6,3), 67 (5,9), 68 (64,5), 69 (8,7), 70 (3,1), 84 (46,8), 85 (5,9), 98 (4,3), 99 (3,5), 111 (19,7), 112 (6,6), 113 (10,2), 141 (100.0), 142 (8,4)

4,5-Diaminouracil (IV)

26 (5,5), 27 (15,2), 29 (19,5), 30 (4,8), 31 (9,5), 39 (5,7), 41 (19,5), 42 (18,6), 43 (85,6), 45 (25,5), 46 (5,0), 51 (6,0), 53 (6,4), 54 (9,0), 55 (17,4), 56 (8,3), 57 (16,2), 60 (12,9), 67 (5,7), 68 (3,8), 69 (16,4), 70 (13,3), 71 (73,8), 72 (6,7), 73 (9,5), 77 (12,9), 78 (4,8), 81 (7,4), 82 (5,5), 83 (9,5), 84 (5,0), 85 (5,7), 87 (3,8), 95 (5,0), 96 (4,3), 97 (11,4), 98 (6,4), 99 (4,8), 100 (3,8), 105 (13,3), 111 (4,0), 114 (23,3), 122 (5,5), 125 (10,2), 129 (4,5), 142 (100,0), 143 (9,0), 147 (4,0), 148 (4,5), 149 (6,2)

4,5-Diamino-3-methyluracil (V)

27 (6,5), 29 (13,2), 30 (36,2), 40 (3,5), 41 (5,0), 42 (21,3), 43 (38,3), 45 (8,0), 53 (11,3), 54 (6,9), 55 (12,7), 56 (17,4), 57 (66,0), 58 (66,0), 68 (5,9), 69 (4,8), 70 (8,6), 71 (4,1), 83 (4,8), 84 (9,8), 85 (16,5), 111 (4,3), 139 (15,6), 156 (100,0), 157 (8,3)

4,5-Diamino-1,3-dimethyluracil (VI)

27 (3,6), 29 (7,6), 30 (25,7), 41 (3,8), 42 (18,1), 43 (22,7), 53 (6,7), 54 (4,7), 55 (10,2), 56 (15,5), 57 (45,7), 58 (82,9), 59 (6,1), 68 (4,4), 69 (3,4), 70 (5,1), 83 (4,4), 84 (14,0), 85 (22,2), 170 (100,0), 171 (9,5)

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*The peaks with intensities greater than 3% of the maximum peak are presented.

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TABLE 2. W_M and $S_{1/2}$ Values and Intensities of the Characteristic Ions* in the Mass Spectra of I–III for an Ionizing-Electron Energy of 70 eV

Ionic composition	Compound I R=H R′=H R″=NH₂	Compound II R=H R′=CH₃ R″=NH₂	Compound III R=CH₃ R′=H R″=NH₂
W_M	11,1	18,0	20,0
$S_{1/2}$	<6,0	5,0	4,0
Structure C (path 1)			
$(M-RNCO)^+$ (fragment ion d)	2,2	3,9	9,4
$(d-R'')^+$	5,8	13,6	12,9
$(d-CO)^+$	1,1	2,7	2,7
$[(d-CO)-R'']^+$	2,8	1,1	3,2
$(d-C_2HO)^+$	13,3	8,1	9,7
$(d-R''CN)^+$	5,7	1,5	6,1
$(M-RR'N_2CO)^+$ (fragment ion f)	1,4	1,5	1,7
$(f-H)^+$	5,8	3,9	12,9
$(f-CO)^+$	5,1	5,8	4,9
Σ_1	43,2	42,1	63,5
Structure D (path 2)			
$(M-CO)^+$ (fragment ion k)	2,8	1,5	2,0
$(M-C_2H_2O)^+$	1,2	0,5	0,6
$(k-R'N{=}NR)^+$	1,4	1,5	1,7
$[(k-R'N{=}NR)-CO]^+$	5,1	5,8	4,9
Σ_2	10,5	9,3	9,2
Σ_1/Σ_2	4,3	4,5	6,9

*In percent of the total current.

first time under spectral recording conditions similar to those described in [2, 3]. For a more correct comparison, we also obtained the mass spectrum of uracil itself, which was discussed in detail in [4].

The stabilities of the molecules of I–VI relative to electron impact (W_M), which are the ratios of the intensity of the polyisotopic peak of the molecular ion to the total current in percent, and the disintegrative selectivities ($S_{1/2}$), which are equal to the number of the most intense peaks in the mass spectra that constitute half of the total ion current, are given in Tables 2 and 3. The intensities of the peaks of some characteristic ions are also presented in Tables 2 and 3.

It is known that predominance of the keto form is characteristic for 2,4-dihydroxypyrimidines, but in our examination of the dissociative ionization of these compounds we also took into account the possibility of the existence of an excited molecule as one of the monoenol forms. Amino-substituted uracils may also exist in the imine form, but the tautomeric equilibrium is probably shifted more in favor of the formation of the amino form because of the slight lability of the hydrogen atoms of the amino group. Thus the 4-aminouracil molecule in the excited state may exist in different tautomeric forms (structures A–D), and the stability of the molecular ion and the path of disintegration are then determined to a considerable extent by the predominance of one or another structure.

For example, the introduction of an amino group into the 4 position of the uracil ring leads to a sharp decrease in the W_M value (23.7 for uracil and 11.1 for I). This decrease in the stability is associated not

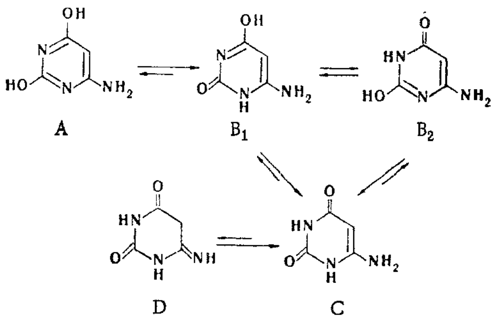


TABLE 3. W_M and $S_{1/2}$ Values and Intensities of the Characteristic Ions* in the Mass Spectra of IV-VI for an Ionizing-Electron Energy of 70 eV

Ionic composition	Compound		
	IV R=H R'=H	V R=H R'=CH_3	VI R=CH_3 R'=CH_3
W_M	12,9	18,8	22,1
$S_{1/2}$	9.0	4,0	3,0
Disintegrative processes observed at 70 and 15 eV			
$(M-NH_3)^+$	1,3	2,9	—
$(M-CONRCO)^+$	9,6	3,1	4,9
(fragment ion g)			
$(g-H)\cdot$	1,7	1,8	3,1
$(g-2H)^+$	2,1	0,9	0,9
$(g-HCN)^+$	8,4	12,4	18,3
$[(g-HCN)-R']^+$	11,1	7,2	5,0
Disintegrative processes observed only at 70 eV			
$[(g-HCN)-H]^+$ or $[(g-H)-HCN]^+$	11,1	12,4	10,1
$[(g-HCN)-2H]^+$ or $[(g-H)-H_2CN]^+$	2,4	3,3	3,4
$[(g-HCN)-NH_2]^+$	—	4,0	4,0

*In percent of the total current.

only with an increase in the volume of the molecule and the appearance of an additional channel for disintegration but rather with the possibility of the existence of I in imine form D. The higher W_M values for II and III (18.0 and 20.0 respectively) as compared with I are associated with the stabilizing effect of the electron-donor methyl substituent attached to the nitrogen atom. An effect of this sort was previously observed for N-methyl derivatives of piperidine [5] and indole [6].

One might have expected a decrease in the W_M value with the introduction of a second amino group into the ring of the uracil molecule, especially since the selectivity of the disintegration of IV falls sharply ($S_{1/2}$ of I is 6.0 as compared with 9.0 for IV). However, the stability of the IV molecule with respect to electron impact in this case not only does not decrease but, on the contrary, increases by 16 rel. %; the W_M value of IV is 12.9. This fact provides evidence that the development of a new channel of disintegration is not a factor that determines the change in W_M. Stabilization of the molecular ion is most likely realized through conformational phenomena, which, in the general case, must be taken into account in the same way as the presence of tautomeric structures. An examination of Dreiding models shows that the relative orientation of the 4-amino and carbonyl groups in IV allows for the possibility of the existence of an intramolecular hydrogen bond that stabilizes the ring.

The presence of one or two methyl substituents attached to the ring nitrogen atoms (V and VI) increases W_M (18.8 and 22.1, respectively), and this sort of phenomenon was observed for monoamino-substituted uracils (II and III).

The disintegration of I-III may proceed via two paths: from the molecular ion of structure C with localization of the positive charge on the oxygen atom in the uracil molecule (path 1) and from structure D, in which the charge is localized on the imino group (path 2). The prevailing tautomeric form is the molecular ion with structure C. The ratio of the sums of the fragment ions obtained during disintegration via a mechanism proceeding via path 1 is greater by a factor of four to seven than the sum of the fragment ions formed as a result of disintegration via path 2.

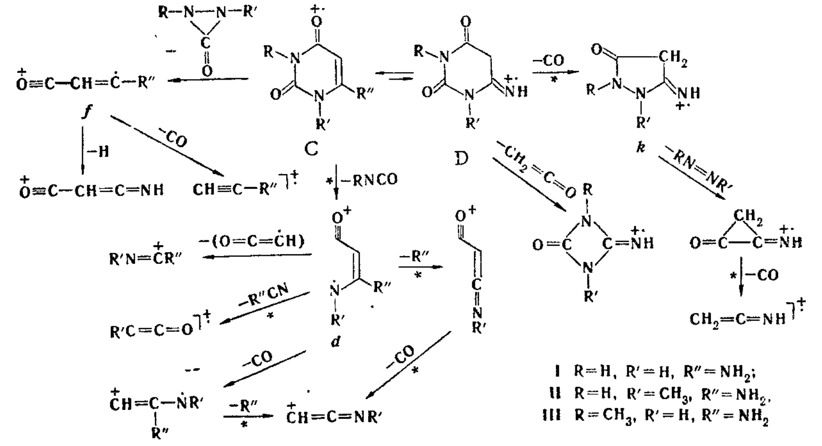
As the ionizing-electron energy decreases (to 15 eV), the intensities of the peaks of ions with masses 113, 99, 98, 84, and 69 (structures d, f, and k), which are formed in the first steps of the disintegration, increase by a factor of two or three. The majority of the paths of disintegration of the molecular ion are confirmed by the presence of the corresponding metastable peaks. The maximum peak in the spectra of I-III is the molecular ion peak.

Isomeric compounds II and III are readily identified from the presence of intense peaks of ions with masses 98 and 82 for II and 84 and 68 for III, which are formed as a result of detachment of an RNCO particle from the molecular ion and subsequent detachment of an R" particle. Thus, the position of the methyl group (R or R') in the uracil ring is fixed clearly during the analysis of the mass spectra of these isomers.

Detachment of a neutral CO particle from the molecular ion is possible only when the molecular ion of I-III exists in the form of structure D.

In contrast to the uracil molecule itself and the molecules of I-III, where the positive charge in the molecular ion is localized primarily on the oxygen atom (structure C), during the disintegration of IV-VI the charge is concentrated primarily on one of the nitrogen atoms of the amino group. A study of the dissociative ionization of these compounds leads to the conclusion that the structure of the molecular ion corresponds primarily to imine structure D (Table 3).

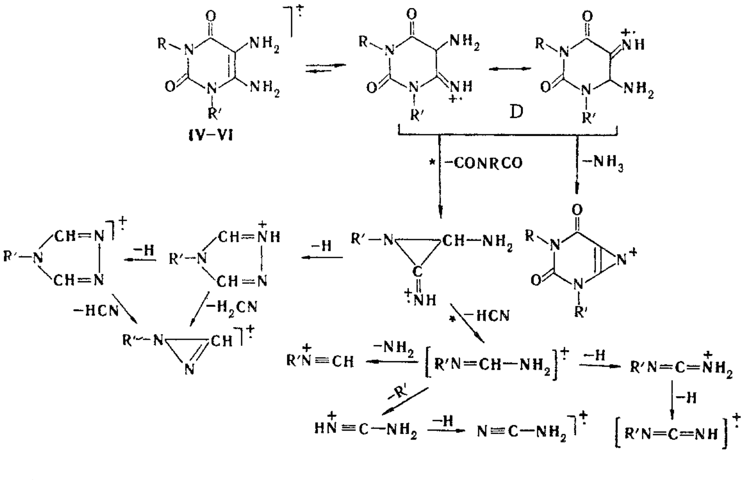
Thus the molecular ion in the investigated series of compounds (I-VI) exists as tautomeric forms with structures C and D. The peaks of fragment ions, the formation of which is associated with elimination of an RNCO particle from the molecular ion (structure d for I-III), and the peaks of quite a number of fragment ions of secondary origin, which arise directly from structure d, are absent in the mass spectra of these compounds.



I R=H, R'=H, R''=NH$_2$;
II R=H, R'=CH$_3$, R''=NH$_2$,
III R=CH$_3$, R'=H, R''=NH$_2$

The increase in the selectivity of disintegration of the IV-VI molecules as the ionizing-electron energy decreases makes it possible to determine the mechanism of dissociative ionization and to describe the formation of the characteristic ions in the first stages. The number of disintegrative paths is confirmed by the presence of the corresponding metastable peaks.

The dissociative ionization of isomerized molecular ion D (the imine form) commences with destruction of the uracil ring with elimination of a neutral CONRCO particle; this leads to the formation of a cyclic ion radical with mass $[M-(CONRCO)]^+$ (structure g). The indicated fragment disintegrates via two paths: 1) by a process associated with successive loss of two hydrogen atoms, which leads to the formation of the corresponding forms of the triazole ion; 2) by elimination of a neutral HCN particle with the development of an ion with mass $(g-HCN)^+$ and subsequent detachment of an R' radical from this fragment to give an ion of the $H\overset{+}{N}\equiv C-NH_2$ form.



All of the processes described above are low-energy processes, inasmuch as they proceed under conditions of bombardment by 20 and 15 eV electrons, during which the fraction of structure g in the total ion current of the ion radical itself increases by a factor of two to four for a nominal ionizing-electron energy of 15 eV, and this peak becomes secondary in intensity (after the molecular peak) in the spectrum.

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