Mass Spectroscopy of Pyrimidine Cyclonucleosides

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Abstract: Mass spectral data are presented for a number of pyrimidine cyclonucleosides, their trimethylsilyl derivatives, one permethyl derivative, and two peracetylated cyclonucleosides. One characteristic of the spectrum of a free cyclonucleoside is that there is present an abundant molecular ion peak. Fragmentation patterns were deduced by the use of isotopically labeled compounds and by precise mass determinations for the fragments. The fragmentation patterns observed for the O^6,5′-cyclonucleosides are classified as type 1, in which the ions have retained both the glycosidic and cyclonucleoside bonds; type 2, in which both the glycosidic bond and the bond between C-5′ of the sugar and oxygen is broken; and type 3, in which the glycosidic bond and the bond between oxygen and C-6 of the heterocyclic base is broken. The last-mentioned type of fragmentation is rarely observed. The mass spectra of the trimethylsilyl derivatives are characterized by moderately abundant M and M − 15 ions. The three types of fragmentation patterns observed with the free cyclonucleosides also are observed with their trimethylsilyl derivatives. In the latter compounds, however, type 1 fragmentation is much less frequently observed than in the former. Type 3 fragmentation again occurs only rarely. The thermal decomposition of O^2,2′-cyclouridine was examined in some detail.

During the course of an investigation of the synthesis of pyrimidine O^6,5′-cyclonucleosides from the appropriate 5-iodonucleosides,[1,2] mass spectrometry has been used as an analytical tool. It was found that the mass spectra of pyrimidine cyclonucleosides possess some unique and interesting features. Recent interest in cyclonucleosides[3-5] prompts us to report our studies of the mass spectra of O^6,5′-cyclonucleosides, derivatives, and related compounds.

Mass Spectra of Pyrimidine Cyclonucleosides

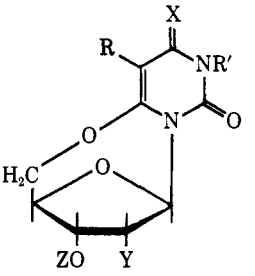
The fragmentation of radical cations of polycyclic compounds, such as cyclonucleosides, can occur by (1) cleavage of one bond to give a cation and a radical, or (2) cleavage of more than one bond either stepwise or simultaneously to give a neutral molecule and a new radical cation.[6] Relatively few cleavages of one bond which result in a net change in *m/e* are available to the radical cations of cyclonucleosides, and, therefore, multiple bond cleavages are expected to predominate.

The structures of all of the O^6,5′-cyclonucleosides and derivatives whose mass spectra were determined in this investigation are summarized in Table I. Low resolution mass spectral data for **1a–i**, inclusive, are presented in Tables II and III. Examination of these data shows that in contrast to the pyrimidine nucleosides themselves, and in agreement with the spectra of adenosine 8-cyclonucleosides,[3] the mass spectra of pyrimidine cyclonucleosides derived from uracil and cytosine have large molecular ion peaks.[4] Furthermore, it proves possible to classify the fragmentation patterns of the O^6,5′-cyclonucleosides into three types by examination of these spectra; by precise mass determinations of all ions of interest; and by comparison of the spectrum of **1a** with those of 5-deuterio-O^6,5′-cyclouridine and N–D and O–D exchanged **1a**.[7] One type of fragmentation pattern is that in which the fragments retain both the glycosidic and the cyclonucleoside bonds; these are designated type 1 cleavages (Scheme I). Such fragments serve to further differentiate pyrimidine cyclonucleosides from the corresponding ordinary nucleosides. The second type of fragmentation observed, designated type 2, involves cleavage of both the glycosidic bond and the bond between C-5′ and oxygen. Cleavage of the glycosidic bond and the bond between oxygen and C-6 will be referred to as type 3 fragmentation.

The *m/e* values of ions resulting from type 1 fragmentation of O^6,5′-cyclonucleosides (Scheme I) and their relative abundances[8] are given in Table II. A number of steps in this pattern involve the elimination of carbon monoxide from the base and water from the sugar. It should be noted that N-3 is retained in all but one of the fragments in Scheme I, in contrast to the fragmentation of 2,4-dioxopyrimidines,[9] in which N-3 is lost as HNCO. The exception is an abundant ion (**8**) found at *m/e* 110 for **1a**, **1b**, **1c**, **1g**, and **1h**, and at *m/e* 124 for **1d** and **1i**. The spectra of **1b** and N–D and O–D exchanged **1a** also contain *m/e* 110, supporting the exclusion of a structure which still contains N-3. The presence of C-5 in **8** is confirmed by *m/e* 111 in the spectrum of 5-deuterio-**1a** and by the aforementioned *m/e* 124 in **1d** and **1i**. The high resolution spectra assign *m/e* 110 the molecular formula $C_5H_4NO_2$, and *m/e* 124 from **1d** and **1i** the formula $C_6H_6NO_2$, in agreement with the azirene structure **8**. The fragmentation of thymine elucidated by Rice and coworkers supports such a structure too.[9] Structures **4** and **5** having four-membered base rings containing two nitrogens have no precedence in the fragmentation of simple

(1) D. Lipkin, C. T. Cori, and M. Sano, *Tetrahedron Lett.*, 5993 (1968).
(2) D. Lipkin and J. A. Rabi, *J. Amer. Chem. Soc.*, **93**, 3309 (1971).
(3) M. Ikedo, Y. Tamura, and M. Ikehara, *J. Heterocycl. Chem.*, 7, 1377 (1970).
(4) S. Tsuboyama and J. A. McCloskey, *J. Org. Chem.*, 37, 166 (1972).
(5) M. Ikehara, M. Kaneko, Y. Nakahara, S. Yamada, and S. Uesugi, *Chem. Pharm. Bull.*, **19**, 1381 (1971); M. W. Winkley, *Carbohyd. Res.*, **16**, 462 (1971); D. W. Miles, M. J. Robins, R. K. Robins, M. W. Winkley, and H. Eyring, *J. Amer. Chem. Soc.*, **91**, 824 (1969); *Chem. Eng. News*, 50, 24 (Sept 11, 1972).
(6) F. W. McLafferty, "Interpretation of Mass Spectra," W. A. Benjamin, New York, N. Y., 1966, Chapter 8.
(7) The exchanged material had the following deuterium content: 19% trideuterated, 38% dideuterated, 32% monodeuterated, and 11% nondeuterated **1a**.
(8) Throughout this paper, a number in parentheses following an *m/e* value represents the relative per cent abundance of the ion in a given spectrum. No isotopic corrections have been applied to the values given for relative abundances.
(9) J. M. Rice, G. O. Dudek, and M. Barber, *J. Amer. Chem. Soc.*, 87, 4569 (1965).

Table I



(1)[a]

Compd	Substituents R	R'	X	Y	Z
O^6,5'-Cyclouridine (**1a**)	H(D)	H	O	OH	H
N^3-Methyl-O^6,5'-cyclouridine (**1b**)	H	Me	O	OH	H
O^6,5'-Cyclo-2'-deoxyuridine (**1c**)	H	H	O	H	H
O^6,5'-Cyclothymidine (**1d**)	Me	H	O	H	H
O^6,5'-Cyclocytidine (**1e**)	H	H	NH	OH	H
O^6,5'-Cyclo-2'-deoxycytidine (**1f**)	H	H	NH	H	H
N^3-Methyl-2',3'-*O*-dimethyl-O^6,5'-cyclouridine (**1g**)	H	Me	O	OMe	Me
N^6-Acetyl-2',3'-*O*-diacetyl-O^6,5'-cyclocytidine (**1h**)	H	H	NAc	OAc	Ac
3'-*O*-Acetyl-O^6,5'-cyclothymidine (**1i**)	Me	H	O	H	Ac
2',3'-*O*-Bis(trimethylsilyl)-O^6-5'-cyclouridine (**1a**-Tms_2)[b]	H(D)	H	O	OTms	Tms
N^3-Trimethylsilyl-2',3'-*O*-bis(trimethylsilyl)-O^6,5'-cyclouridine (**1a**-Tms_3)	H	Tms	O	OTms	Tms
N^3-Methyl-2',3'-*O*-bis(trimethylsilyl)-O^6,5'-cyclouridine (**1b**-Tms_2)	H	Me	O	OTms	Tms
3'-*O*-Trimethylsilyl-O^6,5'-cyclo-2'-deoxyuridine (**1c**-Tms)	H	H	O	H	Tms
3'-*O*-Trimethylsilyl-O^6,5'-cyclothymidine (**1d**-Tms)	Me	H	O	H	Tms
2',3'-*O*-Bis(trimethylsilyl)-O^6,5'-cyclocytidine (**1e**-Tms_2)	H(D)	H	NH	OTms	Tms
N-Trimethylsilyl-2',3'-*O*-bis(trimethylsilyl)-O^6,5'-cyclocytidine (**1e**-Tms_3)	H	H	NTms	OTms	Tms
N-Trimethylsilyl-3'-*O*-bis(trimethylsilyl)-O^6,5'-cyclo-2'-deoxycytidine (**1f**-Tms_3)	H	H	NTms	H	Tms

[a] This structure, rather than the correct tautomeric one, is used for the cytosine derivatives and **1a**-Tms_3 too as a matter of convenience in tabulating data. [b] Tms = $(CH_3)_3Si$. The designation of a compound as **1a**-Tms_2 refers to O^6,5'-cyclouridine with two trimethylsilyl groups substituted for two labile hydrogen atoms, *i.e.*, in this case for the two hydroxyl hydrogens of **1a**.

Table II. Ions Corresponding to Type 1 Fragmentation of O^6,5'-Cyclonucleosides

Compd	Structures 1 ($M\cdot^+$)	2	3	4	5	6	7	8	9	10	11
1a	242 (43)[a]		196 (10)	168 (6)	126 (14)	154 (36)	153 (10)	110 (84)	213 (28)	183 (17)	155 (4)
1b	256 (51)		210 (4)	182 (7)		168 (36)	167 (5)	110 (100)	227 (14)	197 (11)	169 (4)
1c	226 (17)	198 (3)	180 (7)		126 (28)	154 (100)	153 (2)	110 (61)			155 (9)
1d	240 (17)	212 (1)	194 (2)		140 (12)[b]	168 (27)[b]	167 (3)[b]	124 (52)[b]			169 (2)[b]
1e	241 (13)					153 (5)	152 (5)			182 (1)[c]	154 (2)[c]
1f	225 (21)			167 (3)[c]		153 (17)	152 (46)				
1g[d]	284 (71)		224 (25)	196 (1)		168 (10)	167 (11)	110 (40)	241 (1)		
1h[d]	367 (94)					195 (7)	194 (12)	110 (16)			196 (13)

[a] The first number represents the *m/e* of a given ion; the second is the relative intensity from the low resolution spectra obtained on the MS 902 mass spectrometer. The spectra of **1g** and **1h**, however, were obtained on the M-66 spectrometer. [b] This ion occurs in the spectrum of **1i** also. [c] The intensity of this ion was too low for confirmation of its molecular formula from the high resolution spectrum. [d] Molecular formulas for the ions from this compound were not determined by precise mass measurements.

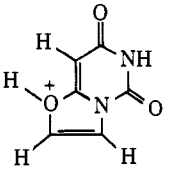
2,4-dioxopyrimidines, but are also supported by an ion from **1g** of *m/e* 200 (15) corresponding to (M − 2CO).

The loss of C-2' and C-3' is common to all O^6,5'-cyclonucleosides and results in ions **5**, **6**, **7**, and **11**, plus **10** from the ribose derivatives only. Ion **6c**[10] is the most abundant ion in the spectrum of **1c**. These ions afford the first detailed picture of the stepwise degradation of the ribose ring.[11]

(10) A designation such as **6c** refers to an ion of general structure **6**, Scheme I, which is specifically derived from O^6,5'-cyclodeoxyuridine. Analogously, **11e** refers to an ion of general structure **11** derived from O^6,5'-cyclocytidine.

(11) Fragmentation schemes involving C_2'–C_3' cleavage have been proposed: (a) S. H. Eggers, S. I. Biedron, and A. O. Hawtrey, *Tetrahedron Lett.*, 3271 (1966); (b) S. J. Shaw, D. M. Desiderio, K. Tsuboyama, and J. A. McCloskey, *J. Amer. Chem. Soc.*, **92**, 2510 (1970).

The structure assigned to *m/e* 153, **7**, is in disagreement with that proposed by Tsuboyama and McCloskey[4] (**12**) for this particular ion arising from **1a**.



12 (*m/e* 153)

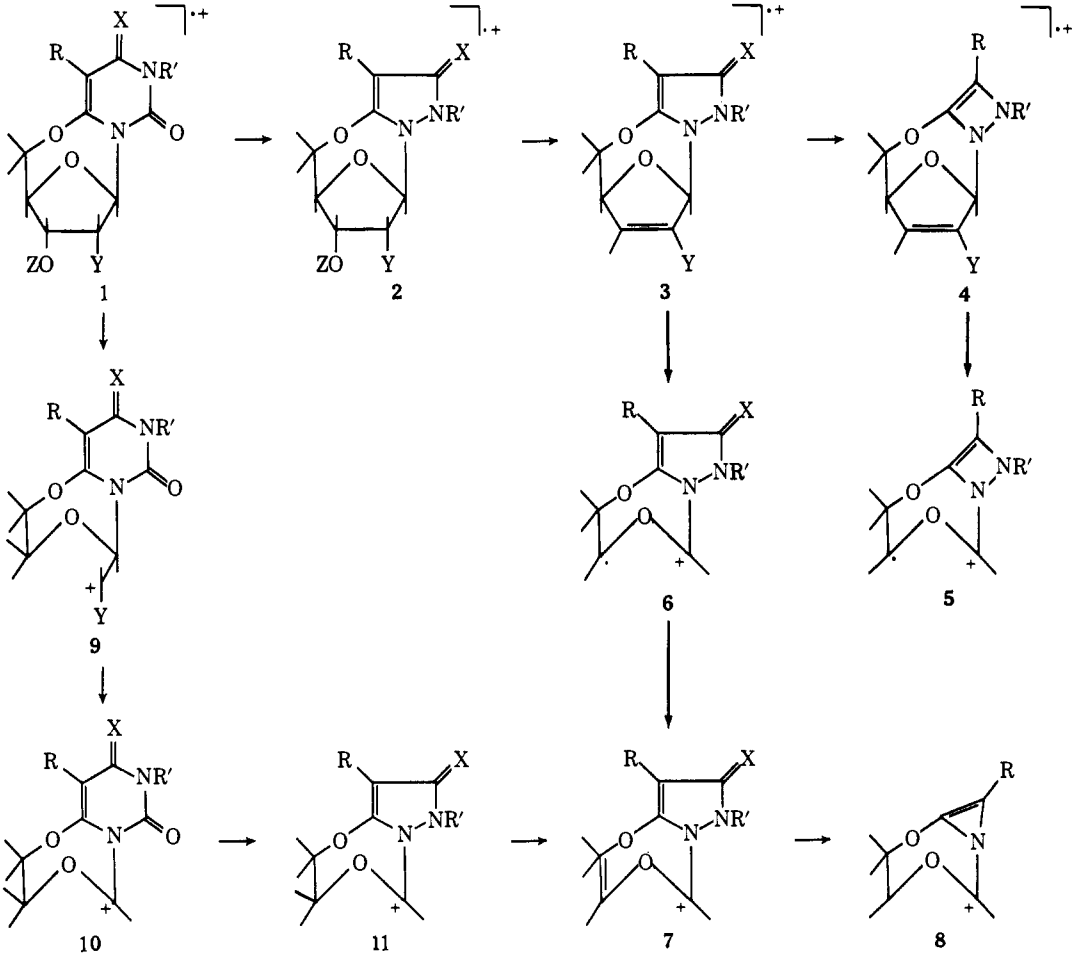
Structure **7** is the preferable one, since it does not involve rearrangement of the skeleton of the sugar. Furthermore, structure **13** for *m/e* 137 from O^2,2'-cyclo-

Table III. Ions Corresponding to Type 2 Fragmentation

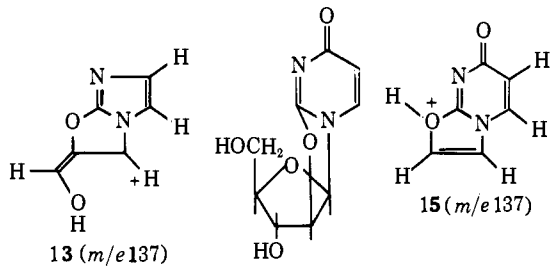
	Structures[a]				
	Sugar		Type 2 ions – $C_{5'}$–O		
Compd	**19**	**20**[b]	**21**[c]	**22**[c]	**23**
1a	115 (2)	97 (5)	129 (100)	128 (36)	
1b		97 (7)	143 (98)	142 (63)	
1c	99 (7)	81 (50)	129 (2)	128 (6)	
1d	99 (7)	81 (100)	143 (1)	142 (7)	
1e	115 (1)	97 (2)	128 (48)	127 (64)	111 (100)
1f	99 (4)	81 (69)	128 (33)	127 (94)	111 (100)
1g		111 (50)		142 (10)	
1h		139 (38)	170 (100)	169 (29)	111 (88)
1i		81 (100)		142 (1)	
1a-Tms_2		169 (8)	129 (74)[d]		
1a-Tms_3		169 (6)	129 (30)[d]	201 (5)	
				273 (37)[e]	
1b-Tms_2		169 (7)	143 (13)	142 (6)	
1c-Tms	171 (10)	81 (68)	129 (18)[d]		
1d-Tms	171 (3)	81 (100)			
1e-Tms_2		169 (13)	200 (20)[e]		111 (100)
1e-Tms_3		169 (36)	272 (32)[e]		111 (21)
					183 (94)[e]
1f-Tms_2		81 (31)	200 (70)	199 (100)	111 (6)
			272 (12)[e]		

[a] Molecular formulas were not determined by precise mass measurements for any of the ions from **1g**, **1h**, or from any of the Tms derivatives. [b] In those cases where Y is not H, this may be the isomeric structure with Y at C-3′. [c] An alternative structure for these is one in which the ring is contracted and a formyl group is substituted on N-1 (*e.g.*, **21′**). [d] *m/e* 129 is a commonly encountered sugar fragment, $H_2C{=}CHCHOTms^+$. In the spectrum of **5-*d*-1a**-Tms_2 there is no ion at *m/e* 130. It is presumed, therefore, that *m/e* 129 in the spectrum of **1c**-Tms also is this sugar fragment. Furthermore, *m/e* 129 also occurs in the spectrum of **1d**-Tms. [e] These ions contain an extra Tms group by transfer from the sugar.

Scheme I. Type 1 Fragmentation Pattern of O^6,5′-Cyclonucleosides



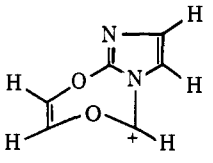
uridine (**14**) is preferable to the structure (**15**) previously suggested;[4] similarly, structure **16** is proposed for the ion of *m/e* 137 derived from O^2,5′-cyclouridine (**17**). The preference for structures **7** over **12**, and of **13** over **15**, is based on a fourfold argument. First, these structures do not require extensive skeletal rearrange-



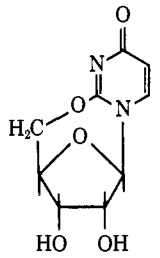
13 (*m/e* 137)

14

15 (*m/e* 137)



16 (*m/e* 137)



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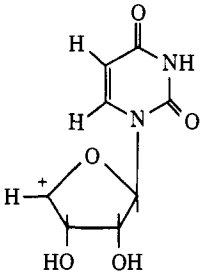
ment. Second, trimethylsilyl (Tms) substituted **13**, *m/e* 209 (*vide infra*), is the most abundant peak in the spectrum of **14**-Tms_2; *m/e* 209 is absent from the spectrum of **17**-Tms_2. Third, the preferred structures are consistent with the overall degradation pattern given in Scheme I. For example, **1g** yields ions **6g** and **7g** at *m/e* 168 and 167, respectively, and **1h** yields the corresponding ions of *m/e* 195 (**6h**) and 194 (**7h**). Finally, a structure analogous to those proposed here (**7**, **13**, and **16**) fits an ion (*m/e* 153) observed in the spectrum of O^6,2′-cyclouridine.[4] It is further suggested that **9**, derived from **1a** and **1b**, is a preferable alternative to **18**, proposed by Tsuboyama and McCloskey[4] for the

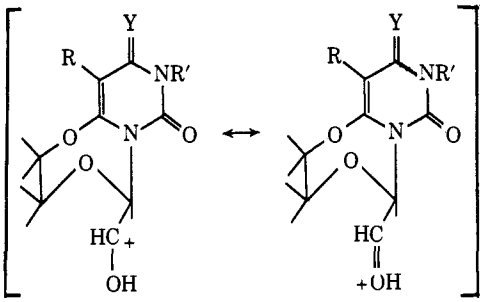


18 (M−29)

ion resulting from the loss of *m/e* 29 (CHO) from the molecular ion. The latter structure is an unlikely one because it probably should be accompanied by reasonably abundant B + H (112) and B + 2H (113) peaks, just as is the case with ordinary nucleosides.[12] In **1a** the relative intensities of these are only 5 and 3%, respectively, whereas in uridine the corresponding percentages are 19 and 86. Structure **9** (M − 29) also seems more plausible than **18** because it is consistent with the proposed pathway by which it gives rise through further decompositions to **10**, **11**, **7**, and **8** (Scheme I).

(12) K. Biemann and J. A. McCloskey, *ibid.*, 84, 2005 (1962).

Furthermore, this ion is found in the ribose derivatives and not in the deoxyribose derivatives, consistent with a stability suggested by the resonance structures A and B.

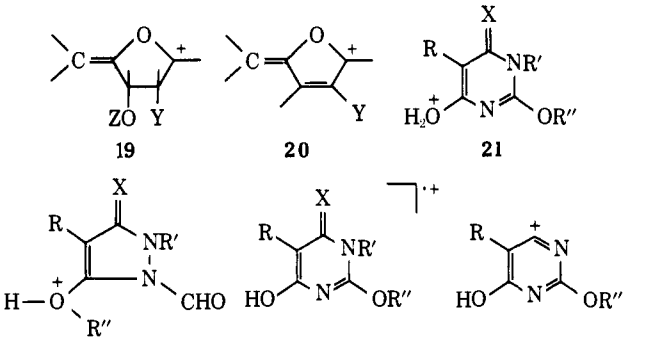


A B

Were **18** to be an appropriate assignment, then this type of ion should be found in both ribose- and deoxyribose-based O^6,5′-cyclonucleosides, as well as in **1g**. An ion of *m/e* 255 (M − 29) occurs with an abundance of only 1% in the spectrum of the latter. Not surprisingly, furthermore, **1g** gives rise to an ion of *m/e* 241 (M − 43), *i.e.*, parent minus $COCH_3$, with an abundance of only 1%.

The *m/e* values and relative abundances of base- and sugar-derived ions resulting from type 2 fragmentation are shown in Table III, and the corresponding structures are depicted in Table IV. The most striking

Table IV. Type 2 Ions[a] from O^6,5′-Cyclonucleosides



19 20 21

21′ 22 23

[a] R″ = H or Tms.

feature of the data is the contrast between the relative abundances found for the base fragments, **21** (R″ = H) and **22** (R″ = H), from the uracil-derived ribose cyclonucleosides as contrasted with the deoxyribosides. The data imply the necessity of a 2′-hydroxyl to provide for proton transfer to the base to facilitate production of these ions.[11b] This implication is further supported by the absence of these ions in **1g**.[13] On the other hand, the cytosine cyclonucleosides (**1e**, **1f**, and **1h**), regardless of the sugar, give rise to abundant amounts of ions of *m/e* 128, **21** (R″ = H), and 127, **22** (R″ = H). This presumably is due to the greater aromaticity of the

(13) An ion is found at *m/e* 142 (10) which could be attributed to 22 (R″ = H), but is more likely

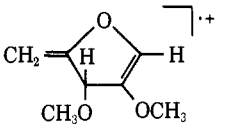


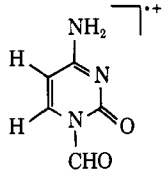
Table V. Mass Spectral Data for O^2,2′- and O^2,5′-Cyclouridine

	Spectrometer	Probe temp, °C	Relative intensities *m/e* 85	112	113	115	137	226
			O^2,2′-Cyclouridine					
Tsuboyama and McCloskey data[4]	LKB 9000	150–250	35	34	41	100	83	53
Direct insertion of sample	MS 902	200	26	15	24	72	100	60
Direct insertion of sample	M-66	200	0	66	16	0	100	34
Sublimation[a] followed by direct insertion of sample	M-66	<200	27	100	25	9		
		200	29	29	19	15	100	69
		240	31	100	84	22	91	41
		275	53	98	90	87	100	69
			O^2,5′-Cyclouridine					
Direct insertion of sample	MS 902	200	6	20	100	2	15	28
Direct insertion of sample	M-66	200	12	100	55	6	50	49

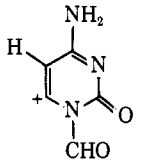
[a] A sample of cyclonucleoside was placed in the tip of a melting point capillary. While this was being continually evacuated at a pressure of 10^{-3}–10^{-5} mm, the samples were heated by means of an oil bath at a number of different temperatures for varying periods of time. A sublimate formed in the capillary just above the heated zone. Afterward, the portion of the capillary containing the sublimate was cut out and introduced into the mass spectrometer. This particular sample was heated at 193–200° for about 1 hr. Samples pyrolyzed under other conditions (*e.g.*, 300° for 1 min) gave similar results.

cytosine derivatives compared with the dioxopyrimidines. As a consequence, the former are better able to stabilize a positive charge. This property of charge stabilization is further exemplified by the fact that **1e**, **1f**, and **1h** produce a unique ion, **23** (R″ = H), with the positive charge on the ring, corresponding to one of the largest peaks in their spectra. Another marked difference between the underivatized ribo- and deoxyribonucleosides (**1a–f**, inclusive) is found in the relative abundances of the sugar-derived ions **19** and **20**; the deoxyribose cyclonucleosides afford intense ions compared to the ribose compounds.

Structures with a formyl group on N-1[12] are appropriate for a number of ions which occur throughout the spectra. Thus, **1e** produces ions at *m/e* 155 (11) and *m/e* 138 (38) which are assigned structures **24** and **25**,

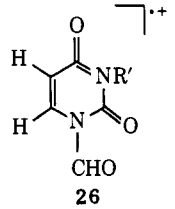


24 (*m/e* 155)



25 (*m/e* 138)

respectively. An ion of *m/e* 156 (2) from **1a** can be represented by a structure, **26** (R′ = H), analogous to **24**.



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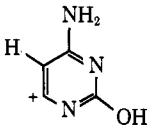
Furthermore, the three O^6,5′-cycloribonucleosides (**1a**, **1b**, and **1e**) exhibit ions at *m/e* 157 (2) (R′ = H) and 171 (1) (R′ = CH_3) corresponding to **26** + H, and an ion of *m/e* 156 (8) corresponding to **24** + H.

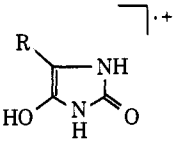
Illustrative of type 3 cleavage, which is rarely observed, is **27** from **1e** (15%) and **1f** (19%). Actually, ions corresponding to the aforementioned **24**, **25**, **26**, **24** + H, and **26** + H also represent type 3 cleavages in the sense that their formation requires the breaking of the bond between C-6 of the heterocyclic ring and



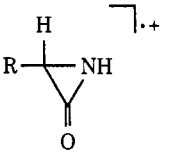
27 (*m/e* 110)

oxygen. Other such ions are found in the spectra, but in relatively low abundance (*e.g.*, **1a** yields *m/e* 112 (5)).

Further evidence for structures with contracted heterocyclic rings is provided by an examination of some of the smaller fragments. An ion of *m/e* 100 is found in the spectra of **1a** (12%) and **1c** (3%) and a homologous one of *m/e* 114 (2) occurs in the spectrum of **1d**. Furthermore, an ion of *m/e* 57 is present in the spectra of **1a** (46%) and **1c** (19%) and the homologous one of *m/e* 71 is found in the spectrum of **1d** (26%). No ions analogous to these are found in the mass spectra of the simple pyrimidines.



R = H, *m/e* 100
R = CH_3, *m/e* 114



R = H, *m/e* 57
R = CH_3, *m/e* 71

Tsuboyama and McCloskey refer to the fact that thermal decomposition of underivatized cyclonucleosides may take place during the process of obtaining their mass spectra.[4] Throughout this work, mass spectra obtained on the M-66 spectrometer were in general agreement with those provided by the MS 902 spectrometer,[14] but the mass spectra of **14** and **17** do not support this statement. A comparison of the mass spectra of these two cyclonucleosides obtained in various ways is given in Table V.

During the recording of the M-66 spectra of **14**, the pressure remained constant, the abundance of *m/e* 112 at 70 eV was relatively constant, and the uv of the material recovered from the spectrometer retained a λ_{max}

(14) Although **1e** and **1f** readily decompose, it was possible to obtain spectra of these compounds with the MS 902 before they lost even a molecule of water.

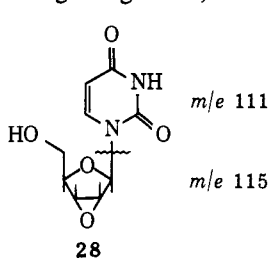
Table VI. Additional Silicon-Containing Ions[a] from Tms Derivatives of Cyclonucleosides

m/e	Compd									
	1a-Tms$_2$	1a-Tms$_3$	1b-Tms$_2$	1c-Tms	1d-Tms	1e-Tms$_2$	1e-Tms$_3$	1f-Tms$_2$	14-Tms$_2$	17-Tms$_2$
M	5[b]	13	28	14	26	6	18	23	9	1
(M − 15)	57	48	87	4	9	36	40	8	12	11
73	100	100	100	100	77	91	100	79	57	100
103	8					12			56	
129	54	30	64	18	18	37	30	11	8	53
147[c]	61	84	64	26		68	85	8	13	38
169	6	6	7	25	4	13	36	16	8	7
204	8	4	5			13	14			6
217	8	6	14			13	20	4	59	4
230	6	4	13			34	28			
231	7	3	13			18	17			
243	29	38	54			15	22	5	11	8
245	44	24	65			5				
258	8	11	11			10	10			

[a] Ions containing ^{29}Si and ^{30}Si are omitted from this compilation. [b] These numbers represent relative intensities of ions in the spectrum of a given compound. [c] The occurrence of the ion m/e 147 in abundance is characteristic of the spectra of ribose-derived O^6,5′-cyclonucleosides. It does occur, however, in relatively small amounts in the spectra of almost all Tms derivatives. In these cases, it presumably is an artifact arising during the preparation of the Tms derivative.

at 250 mμ. Despite these observations, and in an attempt to determine whether or not m/e 112 was thermal in origin, M-66 spectra were run at different electron energies. At high electron energy m/e 137 was the base peak in the spectrum. As the electron energy decreased, this ion decreased and m/e 112 became the base peak. The abundance of m/e 112 decreased to approximately equal to the parent peak at the threshold for ionization. This implies that either it is formed as readily as the molecular ion or it is thermal in origin. Since the formation of m/e 112 requires breaking of two bonds, a higher energy process than formation of the molecular ion, it is probably thermal in origin.

Concerning the differences in abundance of m/e 115 in the spectra of **14**, M-66 spectra obtained under a variety of source and probe temperatures afforded an ion of m/e 115 with a maximum intensity of 20%. Spectra recorded over a period of time on the MS 902 showed decreasing abundances for m/e 115. A significant increase in the abundance of m/e 115 in spectra obtained with the M-66 spectrometer was achieved with samples which were sublimed prior to introduction into the instrument. Mass spectra obtained from these samples indicate involvement of two thermal processes. Below 200°, **14** presumably tends to decompose to uracil and to rearrange to give **28**, with the same m/e as



28

M. Thus, in the M-66 spectrometer one observes a distillation of uracil and **14**, the former being responsible for the enhanced abundance of the m/e 112 ion; the further supposition is that in the MS 902 one observes a distillation of **14** and the rearrangement product, **28**, the latter being the source of m/e 113, 115, and 85 (115 − CH_2O).[15] The question of why two different thermal processes occur in different spectrometers has not been resolved but probably is related to their design. O^2,5′-Cyclouridine (**17**) also appears to decompose thermally to give uracil at or near the temperature required for volatilization.[16]

(15) The relative abundances of m/e 115 and 85 run roughly parallel to each other throughout a series of spectra.

Mass Spectra of Trimethylsilyl Derivatives of Cyclonucleosides

Low resolution mass spectral data for Tms derivatives of the cyclonucleosides (**1a**-Tms$_2$[17] to **1f**-Tms$_2$, inclusive) are summarized in Tables III and VI.[8] The various conclusions regarding these spectra were arrived at by a comparative study of the spectra and by a further comparison of the mass spectra of **1a**-Tms$_2$ and **1e**-Tms$_2$[18] with the spectra of the corresponding 5-deuterio compounds.

The spectra of the Tms derivatives of all the cyclonucleosides have fairly abundant molecular ions and ions corresponding to (M − 15)[19] (Table VI). The relative intensities of these pairs vary, with the deoxy compounds having molecular ions of greater abundance than (M − 15) and the ribosides generally exhibiting the opposite behavior.

It was pointed out in the previous section (Scheme I) that one of the characteristic features of the mass spectra of O^6,5′-cyclonucleosides, compared with those of ordinary nucleosides, is the widespread occurrence of ions containing sugar fragments attached to base fragments by both the glycosidic and cyclonucleoside bonds. Although this is not the predominant type of ion found in the spectra of the Tms derivatives, the important ions of this class which are present are appropriately substituted derivatives of **3** [**3a**-Tms, m/e 268 (6); **3b**-Tms, m/e 282 (11); **3d**, m/e 194 (2); **3e**-Tms, m/e 267 (5)], **29**, and **30**. Ions, in Scheme I, analogous to **2**, **4**, **5**, and **7**, are no longer of significance.[20]

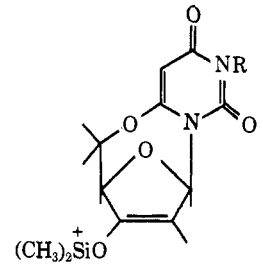
(16) This conclusion is based on experiments at different electron energies and instability of sample pressure.

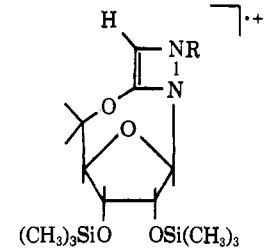
(17) See footnote *b* in Table I.

(18) **1e**-Tms$_2$ is assumed to have the structure given in Table I, rather than the isomeric structure, N^6-(trimethylsilyl)-2′(or 3′)-*O*-trimethylsilyl-O^6,5′-cyclocytidine. This assumption is based on the occurrence of three ions in the spectrum of the compound: (1) m/e 204 (13), TmsOCH=CHOTms]·$^+$; (2) m/e 147 (68), TmsOSi(CH$_3$)$_2$]$^+$; and (3) m/e 111 (100), **23** (R′′ = H), in abundance.

(19) J. A. McCloskey, A. M. Lawson, K. Tsuboyama, P. M. Krueger, and R. N. Stillwell, *J. Amer. Chem. Soc.*, **90**, 4182 (1968).

(20) The spectrum of **1d**-Tms has an ion (**6d**) of m/e 168 (7); **1c**-Tms has an ion (**11c**) of m/e 155 (15); and **1a**-Tms$_2$ and **1b**-Tms$_2$ have ions (**8**) of m/e 110 with abundances of 8 and 5%, respectively.





29, R = H, *m/e* 281 (17)
R = CH_3, *m/e* 295 (7)

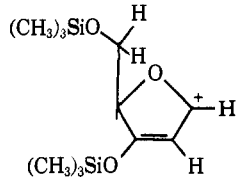
30, R = H, *m/e* 330 (30)
R = CH_3, *m/e* 344 (11)

Heterocyclic base fragments[21] of importance, resulting from type 2 fragmentation, are observed in the mass spectra (Table III) of **1a**-Tms_3, **1b**-Tms_2, and the cytosine cyclonucleosides (**1e**-Tms_2, **1e**-Tms_3, and **1f**-Tms_2). Two features of these fragments which are worthy of note are the marked differences in the abundances found for ions **21**, **22**, and **23** derived from the last three compounds and the occurrence of trimethylsilyl transfer from the sugar to the base.[22] Illustrative of the first of these features is the fact that the ribose-based cytosine derivatives (**1e**-Tms_2 and **1e**-Tms_3) are characterized by abundant ions with structures corresponding to **23**, while the deoxyribose-based compound (**1f**-Tms_2), on the contrary, is characterized by an abundant ion with a structure corresponding to **22** (R'' = H). As for the second feature, ions involving the transfer of trimethylsilyl groups are quantitatively more significant for the ribose compounds (**1a**-Tms_3, **1e**-Tms_2, and **1e**-Tms_3) than for the deoxyribose derivatives (*e.g.*, **1f**-Tms_2). This may be attributed to the proximity of the Tms group on C-2′ to the base and to the relief of C-2′–C-3′ steric strain by Tms transfer in the ribose-derived cyclonucleosides.

The ability of the base to carry the positive charge in type 2 fragmentations is illustrated by the occurrence of the ion *m/e* 111, **23** (R'' = H), in the spectra of **1e**-Tms_2, **1e**-Tms_3, and **1f**-Tms_2, the same as in the parent compounds themselves, and of *m/e* 183, **23** (R'' = Tms), in the spectrum of **1e**-Tms_3. Furthermore, it can be seen (Table III) that the sugar-derived ion, **20** (*m/e* 81),[19] characteristic of the deoxyribosides, is less abundant in **1f**-Tms_2 than in the uracil-derived compounds **1c**-Tms and **1d**-Tms. This fact lends further support to the supposition stated earlier that the relatively aromatic, cytosine-derived ion bears the positive charge more readily than does the sugar.

It was pointed out in the previous section that the spectra of the free cyclonucleosides contain peaks corresponding to heterocyclic bases with formyl groups on N-1.[12] Two such ions are obtained from Tms derivatives: **1e**-Tms_2 gives rise to **25**, *m/e* 138 (61), and **1e**-Tms_3 yields **25** with a Tms group on N-4, *m/e* 210 (18).

Other ions which are characteristic of the mass spectra of Tms derivatives of the cyclonucleosides are Tms-substituted sugar fragments (Table VI). These are principally *m/e* 103,[19] 129,[23] 169,[24] 204,[23] 217,[23] 230,[24] 231 (*m/e* 230 + H), 243,[24] 245,[24] and 258.[24] Three other ions which are commonly found, but which do not fall in this class, are $(CH_3)_3Si^+$ (*m/e* 73);[23] **20**, Y = H (*m/e* 81); and $TmsOSi(CH_3)_2]^+$ (*m/e* 147)[25] (Tables III and VI). Of this entire group of ions, *m/e* 73, 129, and 169 are common to all of the compounds studied, while *m/e* 81 is common to only the three deoxyribose derivatives and *m/e* 243 is common to all of the ribosides.[26] The pairs of ions, 243–258 and 230–231, on the other hand, are characteristic of only the O^6,5′-cycloribonucleosides. Finally, the ions CH_2O-Tms^+ (*m/e* 103) and *m/e* 259[4] are found in abundance



m/e 259

only in the spectrum of the one cyclonucleoside discussed in this paper which is not 5′-linked (**14**-Tms_2).

Experimental Section

Both the low and high resolution mass spectra of **1a**–f, inclusive, and of **1i**, **14** and **17** were obtained on a GEC-AEI MS 902 mass spectrometer at an accelerating voltage of 8 kV and a beam current of 100 μA. The direct insertion probe was used. The low resolution mass spectra of all compounds, except **1e** and **1f**, were determined using the direct sample introduction, controlled-temperature probe of a Varian M-66 mass spectrometer at an ionizing potential of 70 eV, an ionizing current of 30 μA, and a resolution of approximately 2200. The analyzer was maintained at 110°. Perfluorokerosene was used throughout as a standard for mass determinations. A comparison of the probe temperatures used for both free and derivatized cyclonucleosides is given in Table VII.

Table VII. Comparison of Probe Temperatures for Free and Derivatized Cyclonucleosides[a]

Compd	Temp, °C (free (nucleoside)	Temp, °C (deriv)
O^6,5′-Cyclouridine	190 (**1a**)	125 (**1a**-Tms_2) 110 (**1a**-Tms_3) 65 (**1g**)
N^3-Methyl-O^6,5′-cyclouridine	150 (**1b**)	80 (**1b**-Tms_2)
O^2,2′-Cyclouridine	190 (**14**)	80 (**14**-Tms_2)
O^2,5′-Cyclouridine	190 (**17**)	120 (**17**-Tms_2)
O^6,5′-Cyclo-2′-deoxyuridine	160 (**1c**)	130 (**1c**-Tms)
O^6,5′-Cyclothymidine	120 (**1d**)	70 (**1d**-Tms)
O^6,5′-Cyclocytidine	230 (**1e**)[b]	175 (**1e**-Tms_2) 150 (**1e**-Tms_3) 125 (**1h**)
O^6,5′-Cyclo-2′-deoxycytidine	130 (**1f**)[b]	75 (**1f**-Tms_2)

[a] All of these data were obtained with the M-66 spectrometer. [b] Thermal decomposition set in before spectra could be obtained.

Pmr spectra were obtained on a Varian A-60 spectrometer at room temperature using tetramethylsilane as an internal standard.

Vapor Phase Chromatography.[27] Tms derivatives of cyclonu-

(21) It is of interest to note that these fragmentation patterns resemble those of O^8- and S^8-cycloadenosines in that these latter also give rise to type 2 base fragments in abundance. On the other hand, fragmentation of **14**-Tms_2 or **17**-Tms_2 does not give rise to heterocyclic base fragments of any significance.

(22) E. White and J. A. McCloskey, *J. Org. Chem.*, **35**, 4241 (1970).

(23) D. C. DeJongh, T. Radford, J. D. Hribar, S. Hanessian, M. Bieber, G. Dawson, and C. C. Sweeley, *J. Amer. Chem. Soc.*, **91**, 1728 (1969).

(24) A. M. Lawson, R. N. Stillwell, M. M. Tacker, K. Tsuboyama, and J. A. McCloskey, *ibid.*, **93**, 1014 (1971).

(25) M. Katoh and C. Djerassi, *ibid.*, **92**, 731 (1970).

(26) The one exception to this statement is **1f**-Tms_2, which also has an ion of *m/e* 243 (5).

(27) Y. Sasaki and T. Hashizume, *Anal. Biochem.*, **16**, 1 (1966).

cleosides were collected in open-ended melting point capillaries from 24–41 × 0.25 in. o.d. aluminum columns packed with 1–3% SE-30 (Applied Science Laboratories, State College, Pa.) on Anakrom AS, 40–50 mesh [Analabs, North Haven, Conn.). Column temperatures ranged from 185 to 200°. Helium flow rates were 85–100 ml/min. Retention times were 5 min or less with such helium flow rates. In general, compounds with longer retention times decomposed on the column.

Thin Layer Chromatography. Chromatography was performed on Analtech silica gel G thin layer plates containing fluorescent indicator (Analtech, Inc., Newark, Del.). Three solvent systems were employed for developing the plates: (a) benzene–dioxane (1:1, v/v) was used for the cyclocytidines; (b) benzene–ethyl acetate (2:1, v/v) for **1a**-Tms_2, **1a**-Tms_3,[28] **1b**-Tms_2, **1c**-Tms, and **1d**-Tms; and (c) dioxane–ethyl acetate (2:5, v/v) for **14**-Tms_2 and **17**-Tms_2.

Trimethylsilylation Procedure.[29] The reagent of choice for the silylation of cyclonucleosides is bis(trimethylsilyl)trifluoroacetamide[30] (**31**) (Regis Chemical Co., Chicago, Ill.). One of the advantages of this reagent is that the by-product formed, trifluoroacetamide, is neutral and of high volatility. Another advantage is that it does not bring about ring opening reactions with cyclonucleosides, whereas the commonly used silylating agent, hexamethyldisilazane plus trimethylsilyl chloride in pyridine, does. The solvent of choice for trimethylsilylation is acetonitrile.[31]

In most cases the Tms derivatives could be purified by vpc,[27] but the derivatives of **17** and of the cyclocytidines decompose on the column. These derivatives were purified instead by crystallization from mixtures of 2,2,4-trimethylpentane–benzene. It is worth noting that the Tms derivatives of the cyclodeoxynucleosides are less stable toward hydrolysis by atmospheric moisture than derivatives of cyclonucleosides having two or more Tms groups.[32]

O^6,5′-Cyclouridine (20 mg, 8.3×10^{-2} mmol) (*vide infra*), acetonitrile (1 ml), and **31** (100 μl, 0.4 mmol) were combined in a glass-stoppered flask. The flask and its contents were heated (5–10 min) until all of the suspended solid dissolved. Since thin layer chromatography indicated that the reaction was complete, a 20-μl portion of the reaction mixture was subjected to vpc. The product, **1a**-Tms_2, was collected in a capillary tube for insertion in the mass spectrometer.

5-Deuterio-O^6,5′-cyclocytidine (3.1×10^{-2} mmol) (*vide infra*), acetonitrile (0.3 ml), and **31** (50 μl, 0.2 mmol) were combined in a glass-stoppered flask. The reaction mixture was heated (5–10 min) until the suspended solid dissolved, and then it was evaporated *in vacuo*. The residue was recrystallized from a mixture of benzene and 2,2,4-trimethylpentane.

Cyclonucleosides. Compounds **14** and **17** were obtained from Dr. J. J. Fox of the Sloan-Kettering Institute. Compounds **1a**,[1] **1c**,[1] **1d**,[2] **1e**,[1] and **1f**[1] were prepared by methods which already have been described.

N^3-Methyl-O^6,5′-cyclouridine (1b). A sample of **1a** (260 mg, 1.07 mmol) was dissolved in a mixture of 75 ml of water plus 5 ml of methanol. A solution of diazomethane[33] in ether (*ca.* 150 ml, 30 mmol) was added while the reaction mixture was shaken vigorously. The aqueous layer was then concentrated *in vacuo*. Crystallization of the residue from methanol afforded 142 mg (55%) of **1b**: mp (from ethanol) 181–182°; pmr (3% CF_3CO_2H in DMSO-d_6) δ 3.18 (s, 3, NCH_3), 3.95 (q, 1, $J_{4',5'} = 1$ Hz, $J_{5'a,5'b} = 13$ Hz, H-5′a), 4.32–4.47 (m, 3, H-2′, H-3′, H-4′), 4.62 (q, 1, $J_{4',5'} = 1$ Hz, $J_{5'a,5'b} = 13$ Hz, H-5′b), 5.42 (s, 1, H-5), and 6.31 ppm (s, 1, H-1′). *Anal.*[34] Calcd for $C_{10}H_{12}N_2O_6$: C, 46.88; H, 4.72; N, 10.93. Found: C, 47.07; H, 4.72; N, 11.08.

3′-*O*-Acetyl-O^6,5′-cyclothymidine (1i).[35] Compound **1d** (0.26 g, 1.1 mmol) was dissolved in anhydrous pyridine (5 ml), and 0.5 ml (*ca.* 5.3 mmol) of acetic anhydride was added. After 20 hr at room temperature, the mixture was concentrated *in vacuo* to a syrup. The syrup was dissolved in ethanol and the solution then was concentrated *in vacuo;* this operation was repeated once more. Finally the product was recrystallized from ethanol to give 0.265 g (87%) of **1i**: mp 241–242°; pmr (DMSO-d_6) δ 1.72 (s, 3, 5-CH_3), 2.05 (s, 3, 3′-CH_3CO), ~2.52 (m, 2, H-2′, partly hidden under solvent pentuplet), 4.55 (broad s, 1, H-4′), 3.98 and 4.70 (pair d, 2, $J_{5'a,5'b} = 12.5$ Hz, $J_{4',5'a} = 1$ Hz, $J_{4',5'b} = 0$ Hz, H-5′), 5.42 (m, 1, H-3′), 6.81 (m, 1, H-1′) and 11.22 ppm (broad s, 1-NH). *Anal.* Calcd for $C_{12}H_{14}N_2O_6$: C, 51.06; H, 4.96; N, 9.93. Found: C, 51.28; H, 5.07; N, 9.96.

***N*-Acetyl-2′,3′-*O*-diacetyl-O^6,5′-cyclocytidine (1h).** A 15.6-mg sample of **1e** (6.5×10^{-2} mmol), 50 μl of acetic anhydride (0.49 mmol), and 1 ml of pyridine were combined and heated at 55° for 20 hr. The resulting reaction mixture was evaporated *in vacuo* and the residual oil was recrystallized from acetonitrile. The product, **1h** (mp 198–205°), was not purified further.

N^3-Methyl-2′,3′-*O*-dimethyl-O^6,5′-cyclouridine (1g). 5-Iodouridine (129 mg, 0.35 mmol) and 400 mg (2.21 mmol) of tetramethylammonium hydroxide pentahydrate were dissolved in DMSO and the solution was diluted to a volume of 4 ml. After standing at room temperature for 14 days, the solution was found to contain 6.14×10^{-2} mmol of **1a** (73%) and 1.08×10^{-2} mmol of 6-hydroxyuridine (13%). A 1-ml aliquot of this solution was cooled in an ice bath, and then 50 μl (0.54 mmol) of methyl sulfate was added. After 3 days, the reaction mixture was chromatographed on paper (Whatman 3MM) using butanol-1–acetic acid–water (4:1:1, v/v) as the developing solvent. The band with an R_f of 2.60, relative to **1a**, was eluted with water (λ_{max} 262 nm). The aqueous eluate was evaporated *in vacuo*. The residue, which was unchanged on attempting to convert it to a Tms derivative, was purified by vpc. The resulting sample of **1g** was used to obtain the mass spectrum reported above.

5-Deuterio-O^6,5′-cyclouridine. A sample of **1a** (280 mg, 1.15 mmol) and 280 mg (1.36 mmol) of 1,3-diiodo-5,5-dimethylhydantoin (Arapahoe Chemicals, Inc., Boulder, Colo.) were dissolved in 3 ml of DMSO. The solution was allowed to stand in the dark at room temperature for 24 hr. The resulting mixture was diluted with cold water, and then it was neutralized to pH 7 with dilute sodium hydroxide. The crystalline product, 5-iodo-O^6,5′-cyclouridine (360 mg, 85% yield, mp 228° dec), was used without further purification. It (200 mg, 0.54 mmol) was dissolved in 3 ml of 3% potassium hydroxide in methanol, and 400 mg of 10% palladium on charcoal was added to the solution. After reduction[36] of the iodo compound with deuterium gas at atmospheric pressure, the catalyst was removed by filtration. The filtrate was neutralized with acetic acid and evaporated to dryness *in vacuo*. Recrystallization of the residue from water gave 100 mg (76%) of 5-deuterio-O^6,5′-cyclouridine: mp 278–278.5° dec, undepressed by **1a**; pmr (3% CF_3CO_2H in DMSO-d_6) δ 3.92 (q, 1, $J_{4',5'} = 1$ Hz, $J_{5'a,5'b} = 13$ Hz, H-5′a), 4.27–4.44 (m, 3, H-2′, H-3′, H-4′), 4.55 (q, 1, $J_{4',5'} = 1$ Hz, $J_{5'a,5'b} = 13$ Hz, H-5′b), and 6.20 ppm (s, 1, H-1′). The deuterium content of the sample was found to be *ca.* 85% by mass spectrometry.

5-Deuterio-O^6,5′-cyclocytidine. 5-Iodocytidine (225 mg, 0.60 mmol) was treated with a 1-ml portion of D_2O and the resulting solution evaporated *in vacuo*. This operation was repeated two more times. The replaceable hydrogens in a sample of tetramethylammonium hydroxide pentahydrate were exchanged for deuterium by the same procedure. The deuterated nucleoside was then dissolved in 6.5 ml of a 0.28 *N* solution (1.82 mmol) of the resulting tetramethylammonium hydroxide pentadeuterate in DMSO-d_6. The reaction mixture was assayed at appropriate intervals by paper chromatography, using 1-propanol–water (7:3, v/v) as the developing solvent. After approximately 50% of the 5-iodocytidine was consumed (10 days), the reaction mixture was poured into 100 ml of cold water and this solution then was neutralized to pH 7. It was poured into a chromatographic column containing a mixture of 1.5 g of acid-washed charcoal and 1.5 g of cellulose powder. The product was eluted with a linear gradient of water–50% aqueous propanol-1. The fractions containing the 5-deuterio-O^6,5′-cyclocytidine are the first cytosine-containing fractions to come off of the column. These were combined and evaporated *in vacuo* to give a 32% yield of product containing 78% D at C-5.

Acknowledgments. Partial support for this investigation was provided by National Science Foundation Grant No. GM-23358. Additional support was made

(28) Tlc with this solvent system did not distinguish **1a**-Tms_2 from **1a**-Tms_3.

(29) A. E. Pierce, "Silylation of Organic Compounds," Pierce Chemical Co., Rockford, Ill., 1968.

(30) R. W. Zumwalt, D. L. Stalling, and C. W. Gehrke, Abstracts, 154th National Meeting of the American Chemical Society, Chicago, Ill., Sept 1967, p 159C.

(31) Attempts to trimethylsilylate reaction mixtures containing DMSO with **31** led to unidentified products.

(32) Vpc led to loss of the Tms group from **1c**-Tms.

(33) J. A. Moore and D. E. Reed, *Org. Syn.*, **41**, 16 (1961).

(34) Microanalyses were performed by Galbraith Laboratories, Knoxville, Tenn.

(35) We wish to thank Mr. Jaime A. Rabi for the preparation of **1i**.

(36) P. K. Chang, *J. Org. Chem.*, **30**, 3913 (1965).

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Solid State Ultraviolet Irradiation of 1,1′-Trimethylenebisthymine and Photosensitized Irradiation of 1,1′-Polymethylenebisthymines[1,2]

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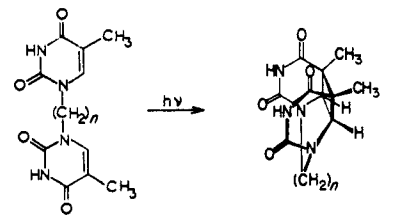
Abstract: Solid state ultraviolet irradiation of 1,1′-trimethylenebisthymine (**1**) at 300 nm yielded, by topochemical control, a polymer made up of trans–syn thymine cyclobutane dimer units, each joined to the next by a trimethylene chain. Photosensitized irradiation of **1** in acetone (10%)–water solution and also of the di- and tetramethylene homologs yielded practically exclusively the cis–syn internal cyclobutane dimers. The relative rate of internal photodimerization was dependent upon the chain length ($C_3 > C_4 > C_2 > C_6$) and was maximal for the trimethylene chain. As a group, the rates were faster than those for the unsensitized internal photodimerizations in aqueous solution, reflecting the longer lifetime of the triplet state. Only in the case of **1** was the unsensitized photoreaction practical. The photosensitized irradiation of 1,1′-trimethylenebisuracil also gave a cis–syn internal dimer, the structure of which was established by spectroscopic and chemical means.

We have utilized a ribofuranose backbone[3] and a trimethylene bridge[4,5] as spacers for examining the interactions and photoreactions between two thymine rings held in close proximity. For example, 1,1′-trimethylenebisthymine (**1**), Thy-C_3-Thy or Thy-(1(CH_2)$_3$1)Thy,[6] rapidly undergoes photoreaction when irradiated at 300 nm in dilute aqueous solution to form the intramolecular cis–syn photodimer **2**, Thy[1(CH_2)$_3$-1]Thy(c,s).[4,6] This finding has led to further questions as to the influence of chain length on the intramolecular reaction, the effect of photosensitization for both the thymine and the uracil series, and possible topochemical control[7] of the photoreaction in the solid state. To all of these questions we are now able to provide reasonable answers.



1, $n = 3$ **4**, $n = 2$ **6**, $n = 4$ **8**, $n = 6$

2, $n = 3$ **5**, $n = 2$ **7**, $n = 4$ **9**, $n = 6$

Solid State Irradiation of Thy-C_3-Thy. From the time we first utilized the trimethylene-bridged heterocycles, B–(CH_2)$_3$–B,[5] to serve as spectroscopic models of stacked base pairs in aqueous solution, we assumed that the chain length was particularly advantageous in permitting nearly plane-parallel stacking of the rings. We were somewhat gratified, therefore, that the X-ray structure analysis of crystals of Thy-C_3-Thy(**1**) as obtained from aqueous solution showed the thymine rings to be lying over each other with the exact geometry indicated in the accompanying paper by

(1) The present paper is no. XI in the series on Synthetic Spectroscopic Models Related to Coenzymes and Base Pairs.

(2) For the preceding paper (X) in this series, see J. H. Craig, P. C. Huang, T. G. Scott, and N. J. Leonard, *J. Amer. Chem. Soc.*, **94**, 5872 (1972), and references therein.

(3) M. W. Logue and N. J. Leonard, *ibid.*, **94**, 2842 (1972).

(4) N. J. Leonard, K. Golankiewicz, R. S. McCredie, S. M. Johnson, and I. C. Paul, *ibid.*, **91**, 5855 (1969).

(5) D. T. Browne, J. Eisinger, and N. J. Leonard, *ibid.*, **90**, 7302 (1968), and references therein.

(6) In keeping with the symbolism of pyrimidine photoproducts suggested by Dr. Waldo E. Cohn, Director of the NAS-NRC Office of Biochemical Nomenclature, using the IUPAC–IUB symbols (*Biochemistry*, **9**, 4072 (1970)), the following shortened forms are employed: for **1**, Thy-C_3-Thy (the three-letter abbreviation is preferred over Th[6]) or, more explicitly, Thy(1(CH_2)$_3$1)Thy, which indicates the position of attachment to each thymine ring and the nature and length of the chain between these; for **2**, Thy[1(CH_2)$_3$1]Thy(c,s), where the *brackets* indicate cyclobutane dimer formation and (c,s) indicates its cis–syn geometry; for the simple cyclobutane photodimers of thymine: Thy[ ]Thy(c,s), Thy[ ]Thy(t,s), Thy[ ]Thy(c,a), and Thy[ ]Thy(t,a), where t = trans and a = anti. Instead of brackets, the symbols 〈 〉 may also be used, *e.g.*, Thy〈1(CH_2)$_3$1〉Thy(c,s) for **2**.

(7) (a) M. D. Cohen and G. M. J. Schmidt, *J. Chem. Soc.*, 1996 (1964); (b) G. M. J. Schmidt, *ibid.*, 2014 (1964).