Both rings of the spiro dihydrofuran group are in the envelope conformation. The atom C12 is 0.54 Å out of the plane C11-C9-O18-C13 (average deviation 0.013 Å) and C17 is 0.28 Å out of the plane C13-C14-C15-O16 (average deviation 0.014 Å). Except for C13-O18, all the bonds are normal. In particular the bond C14-C15, 1.321 Å, is a normal double bond, the bond C15-O16, 1.381 Å, is typical for a C-O next to a double bond, and all other bonds are normal single bonds.

The apparent bond lengths in the acetate at C6 are seriously affected by the considerable thermal motion of that group. After application of riding corrections to these bonds and C4b-O4d, both the group of C6 and the δ-lactone, which bridges C4 and C19, display bonding geometries typical of acetate esters. In particular, the corrected bond lengths for O6a-C6b, 1.342(4) Å, and C6b-C6d, 1.518(5) Å, are identical with their counterparts in the δ-lactone group, O4c-C4b and C4-C4b, respectively. The corrected carbonyl bond C4b-O4d, 1.240(4) Å, is typical but the large riding correction obtained for the C6b-O6c bond, 1.255(4) Å, is probably not valid because of the extreme thermal motion of atom O6c.

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Supplementary Material Available. A table of observed and calculated structure amplitudes from the final refinement will appear following these pages in the microfilm edition of this volume of the journal. Photocopies of the supplementary material from this paper only or microfiche (105 × 148 mm, 24× reduction, negatives) containing all of the supplementary material for the papers in this issue may be obtained from the Business Office, Books and Journals Division, American Chemical Society, 1155 16th St., N.W., Washington, D.C. 20036. Remit check or money order for \$4.50 for photocopy or \$2.50 for microfiche, referring to code number JACS-75-6236.

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Uracil and Its Interaction with Silver Ion in Aqueous Alkaline Media[1]

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Abstract: Carbon-13 nuclear magnetic resonance (^{13}C NMR) and uv spectrophotometric data show that uracil is a weak dibasic acid (H_2L) in aqueous alkaline medium: $pK_{a_1} = 9.7$; $pK_{a_2} = 14.2$. ^{13}C NMR data of uracil in neutral media show that the compound exists in the lactam form and ionizes first at the N^3 position and then at N^1. The lactam structure is retained in the monoanion (HL^-). Potentiometric and solubility measurements have shown that four complexes having the formulas AgHL, $Ag(HL)_2^-$, AgL^-, and AgL_2^{3-} can exist depending upon the pH and ratio of silver ion to uracil in the system. Stability constants for these ions were found to be $\beta_{11} = 10^6$, $\beta_{12} = 6 \times 10^8$, $\beta_{21} = 1.5 \times 10^8$, and $\beta_{22} = 1.8 \times 10^{11}$. ^{13}C NMR data show that the site of binding of silver for uracil in species AgL^- and AgL_2^{3-} is N^1-C^2-O.

The interaction of silver (Ag^+) and cyclic imides such as uracil to give alkali-soluble Ag^+ complexes has been known in photographic chemistry and in the patent literature for years.[2] The exact nature of this solubilization process remains largely unexplored in terms of structure and bonding.[3]

In addition, for uracil, a major constituent of ribonucleic acid, the study of model nucleic acid metal compounds assists in the understanding of the complex behavior of nucleic acids.[4]

Recent carbon-13 NMR (^{13}C NMR) studies of nitrogen heterocycles have demonstrated the value of this technique

Table I. ^{13}C NMR Spectroscopic Data for Uracil and Model Compounds[a]

Carbon atom (n)	^{13}C NMR shifts: Uracil[b]	Acrylamide[c]	Urea[c]	Nucleosides[d]	*N,N'*-Dimethyl-uracil[e]	2,4-Dimethoxy-pyrimidine[f]	Predicted lactim[g]	Predicted lactam[h]	Uracil $\Delta\delta C_n$, ppm: Lactim	Lactam
C^2	152.9 *40.8*		160.3 *33.4*	152.0 *41.7*	151.6 *42.1*	165.7 *28.0*	171.6 *22.1*	151.6 *42.1*	+18.7	−1.3
C^4	165.4 *28.3*	167.5 *26.2*		164.3 *29.4*	162.8 *30.9*	171.6 *22.1*	175.7 *18.0*	162.8 *30.9*	+10.3	−2.6
C^5	101.1 *92.6*			103.0 *90.7*	99.7 *94.0*	102.1 *91.6*	102.1 *91.6*	99.7 *94.0*	+1.0	−1.4
C^6	143.2 *50.5*			140.0 *53.7*	144.6 *49.1*	158.4 *35.3*	158.4 *35.3*	144.6 *49.1*	+15.2	+1.4

[a] ^{13}C NMR shifts are reported in parts per million relative to external Me_4Si (chemical shifts relative to CS_2 are shown in italics). Shifts to lower field are positive (+). Spectra were recorded on a Varian CFT-20 spectrometer. All spectra were run in Me_2SO-d_6 at 10% (w/v). [b] See ref 5. [c] It is known that going from acyclic to cyclic carbonyl compounds does not affect substantially the ^{13}C NMR shift of the carbonyl carbon (G. C. Levy and G. L. Nelson, "Carbon-13 NMR for Organic Chemists", Wiley, New York, N.Y., 1972, p 67). It is expected, therefore, that these carbonyl ^{13}C NMR shifts are models for the ^{13}C NMR shifts of C^2 and C^4 in the *lactam* form of uracil. [d] Nucleosides, where the site of attachment of ribose is known to be nitrogen, are models for the lactam form of uracil. The ^{13}C NMR shifts shown in this column are selected from those tabulated for nucleosides in J. B. Stothers, "Carbon-13 NMR Spectroscopy", Academic Press, New York, N.Y., 1972, p 471. [e] Obtained as a crystalline solid from HET-CHEM-CO., Harrisonville, Mo. [f] Obtained as a colorless liquid from Aldrich Chemical Co., Milwaukee, Wis. [g] Corrected values of C^2 and C^4 for dimethoxypyrimidine: $\Delta\delta = \delta^{PhOCH_3} - \delta^{PhOH}$ (see ref 12). [h] The model *N,N'*-dimethyluracil is best for predicted lactam and C^2, C^6, and C^4 have not been corrected for the changes from $N-CH_3$ to $N-H$. Such changes are usually very small compared to the large $\Delta\delta$'s observed for different tautomers.

Table II. ^{13}C NMR Spectroscopic Data of Uracil, Uracil in Alkali, and Soluble Silver Salts of Uracil[a]

Concn, % w/v	Substance	pD (±0.1)[c]	C_2	C_4	C_5	C_6
2.0	Uracil (U)	7.0	152.9 *40.8*	165.4 *28.3*	101.1 *92.6*	143.2 *50.5*
2.2	K^+U^- (>90%)[b]	11.1	162.3 *31.4* (9.4)[d]	174.5 *19.2* (9.1)	101.3 *92.4*	151.7 *42.0* (8.6)
2.2	$K_2^+U^{2-}$ (99%)[b]	15.3	173.3 *20.4* (20.4) [11.0][e]	180.1 *13.6* (14.7) [5.6]	100.7 *93.0*	159.2 *34.5* (16.0) [7.4]
2.0	$K^+U^- + K_2^+U^{2-}$	14.0	166.8 *26.9*	177.0 *16.7*	101.1 *92.6*	154.5 *39.2*
	U + $AgNO_3$ (1:1 *M/M*)	14.0	168.8 *24.9* (2.0)	176.4 *17.3* (−0.6)	101.0 *92.7* (−0.1)	158.4 *35.3* (3.9)
2.0					100.9 *92.8* (−0.23)	158.3 *35.4* (3.8)
2.0	U + $AgNO_3$ (2:1 *M/M*)	14.0	169.3 *24.4* (2.5) [0.5]	177.3 *16.4* (0.3) [0.9]	100.4 [0.67] *93.3* (0.5) [0.6]	157.7 [0.7] *36.0* (3.2) [0.6]

[a] ^{13}C NMR shifts are reported in parts per million relative to external Me_4Si (chemical shifts relative to CS_2 are shown in italics) and were recorded on a Varian CFT-20 spectrometer. [b] The pK_a's of uracil were determined by B. Belinky in our laboratories by uv spectrophotometry (pK_{a_1} = 9.72; pK_{a_2} = 14.16) and by ^{13}C NMR spectroscopy [pK_{a_1} = 9.7 and pK_{a_2} = 14.2 (see Figure 1)]. [c] pD ∝ [OD] and calculated from pD = 14 + log[OD]. [d] Parenthetic value is a $\Delta\delta$ from uracil. [e] Bracketed value is a $\Delta\delta$ from substance immediately above in this table.

as a probe for chemical structure, electron charge densities, and their relation to chemical and biological activity.[5]

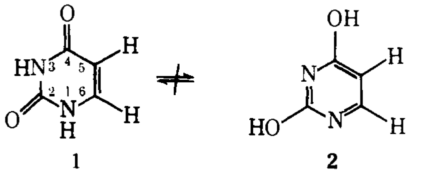
Although a great number of heteroorgano- and organosilver complexes have been isolated and studied, only a few definitive studies in solution have been reported.[6,7] To our knowledge, there have been no reports on the characterization of the complexation of Ag^+ with heteroorganic anions in solution.

We now wish to report the study of uracil and the characterization of the interaction of Ag^+ with uracil in alkaline aqueous media by ^{13}C NMR spectroscopic and solubility-stability studies.

Results and Discussion

A. Structure of Uracil in Neutral Media. Table I shows the ^{13}C NMR spectroscopic data for uracil and model compounds in dimethyl sulfoxide-d_6. The ^{13}C NMR spectrum of uracil in a solution buffered at pH 7.0 is virtually identical with that in Me_2SO-d_6. The ^{13}C NMR spectrum of uracil in Me_2SO-d_6 has been reported previously by Tarpley and Goldstein.[5]

Tautomerism of uracil is shown by structures **1** and **2** in eq 1 (mixed tautomers are not considered). The crystal



(1)

1 (amido form, lactam)

2 (2,4-dihydroxypyrimidine, lactim)

structure of uracil has been determined to be structure **1**.[8] No conclusive determination of structure for uracil in neutral solution has been reported. ^{1}H NMR and ir data are ambiguous but support the lactam form.[9] Conflicting uv data on uracil have been reported.[10] Table I shows the ^{13}C NMR chemical shifts of the carbons of uracil and of model compounds. Similarity of the ^{13}C NMR shifts of the carbonyl carbon of urea and acrylamide to those of C^2 and C^4, respectively, in uracil and the other lactam models is evident. The large deviation in the ^{13}C NMR shifts of uracil compared ($\Delta\delta_{C_n}$) with those of the lactim and the relatively close correlation with those of the lactam model is evident from Table I. This shows that in neutral solution the structure of uracil is **1**.

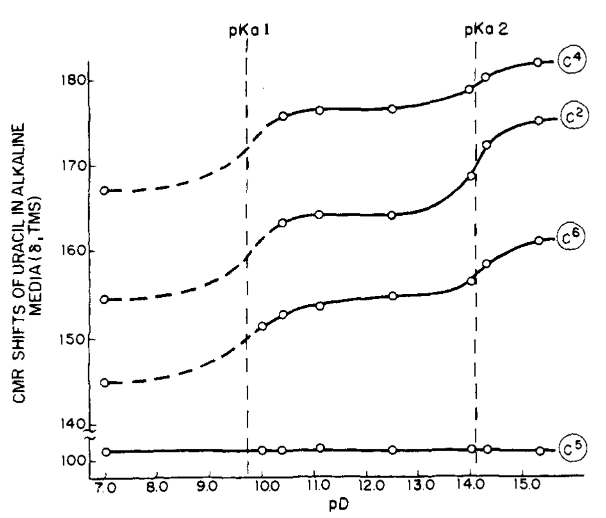


Figure 1. The effect of pD upon the ^{13}C NMR chemical shifts of uracil.

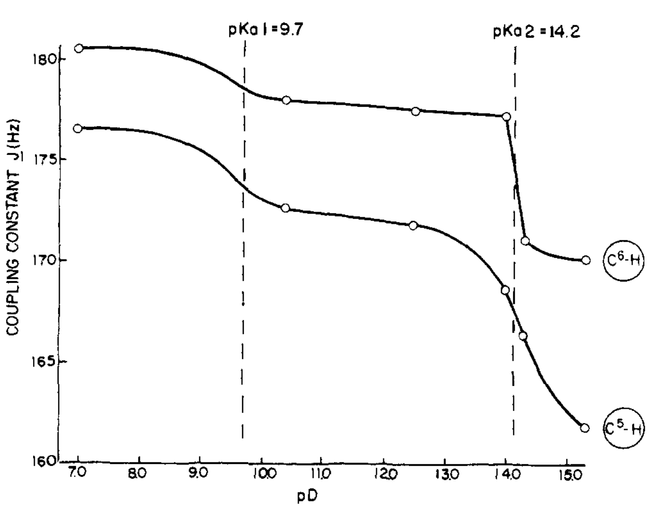
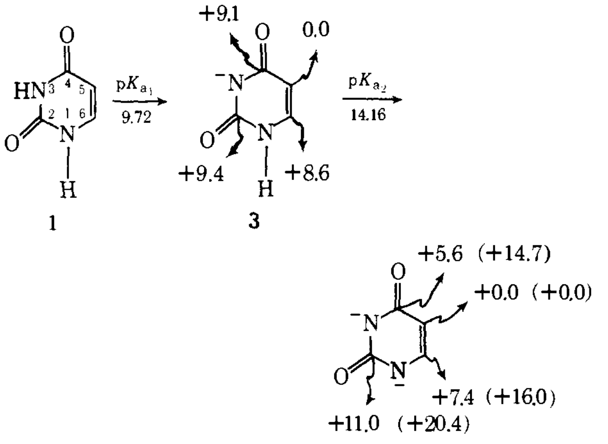


Figure 2. The effect of pD upon the C-H coupling constants of uracil.

B. Structure of Uracil in Alkaline Media. ^{13}C NMR spectroscopic data of uracil in KOD-D_2O solution are shown in Table II and Figure 1. The curves for ^{13}C NMR spectra of C^2, C^4, and C^6 appear in Figure 1 as titration curves with $pK_{a_1} = 9.7$ and $pK_{a_2} = 14.2$. By uv spectrophotometry these were determined to be $pK_{a_1} = 9.72 \pm 0.05$ and $pK_{a_2} = 14.16 \pm 0.05$. The Δδ's determined from Figure 1 are shown below in eq 2. C^2 and C^4 are deshielded by approximately the same magnitude in monoanion **3**. On the other hand, the deshielding of C^2 is twice that of C^4 in the dianion **4**. C^6 is deshielded by 1.2 ppm more in ion **3** than in dianion **4**. C^5 is unaffected by ionization. The differences observed in the Δδ's of C^2 and C^4 in the mono- and dianions suggest strongly that pK_{a_1} occurs at N^3 to give anion **3**.

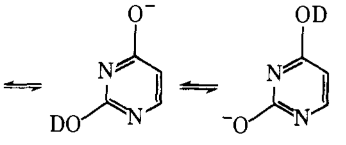


1 3 4 (2)

Unexpectedly, ionization at N^3-H affects the ^{13}C NMR signal of C^6 significantly. It is evident from the orbital symmetry in ion **3** that these Δδ's are indeed consistent with the changes in structure associated with ionization of uracil. X-Ray analysis of uracil has shown that the lactam tautomer is planar.[8] ^{13}C NMR data support a lactam structure in aqueous solution. Thus, the N-H bonds of uracil are sp^2 hybridized with a lone electron pair on each nitrogen in a $p\pi$ orbital. Ionization of N^3-H leaves a pair of electrons on nitrogen in an sp^2 orbital that is in the plane of the molecule. This orbital of atom N^3 is spatially oriented directly toward the C^6-H orbital of C^6. Hence, significant transannular anisotropy at C^6 is consistent with ionization of N^3-H. Similar effects have been noted in the study of carbenium ions in the adamantyl and norbornyl series.[11]

Tautomerism of ion **3** as shown in eq 3 to give ion **5** and/or **6** is possible. However, ionization of O-H(D) such as those in structures **5** and **6** is normally accompanied by shielding (~5 ppm) of the carbon that is para and no effect at the meta carbon (i.e., the C^5 and C^6).[12] Alternatively, the ^{13}C NMR spectra for the ionization of the lactam monoanion **3** should parallel those observed for the ionization of **1**, which is known to be in the lactam form. The relatively substantial deshielding of C^2, C^4, and C^6 through pK_{a_2} (eq 2) is most consistent with ionization of a lactam **3**.

3 ⇌

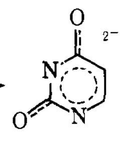


5 6 (3)

Since C^5 is the only carbon atom onto which charge density can be delocalized by resonance in uracil, shielding of C^5 is expected. Significant relative shielding of C^5 is observed. On the other hand, there is no change in the ^{13}C NMR shift of C^5 with pD (Figure 1). The basis for C^5's insensitivity to ionization is probably related to the following. Lactam uracil is a 10π electron system in the neutral, monoanion, and dianion forms.[5] The only changes expected for the π system upon ionization are an increase in the mobility of these π electrons due to ionization and inhomogenous polarization of the charge density due to the differing electronegativity of nitrogen and oxygen. For C^5, these effects are apparently equally in opposition and the charge density at C^5 remains relatively constant.

The ^{13}C NMR spectrum of the dianion **4** (Table II) is very similar to that of the lactim model **2** (Table I): Δδ $C^2 = +1.7$; $C^4 = +4.4$; $C^5 = -1.4$; and $C^6 = +0.8$. Whereas the tautomers of the monoanion of uracil **3**, **5**, and **6** are nondegenerate, the dianions formed by their ionization are equivalent (eq 4). The ^{13}C NMR spectrum of the dianion **4** is, therefore, expected to be similar to that of the lactim model **2**.[5,12]

$3 \xrightarrow{OD^-}$



$\xleftarrow{OD^-}$ 5 and/or 6 (4)

The ^{13}C-H coupling constants of C^5-H and C^6-H vs. pD are shown in Figure 2. The decrease in $J_{C^5\text{-}H}$ is greater in

Table III. Thermodynamic Constants for Uracil and Silver Complexes of Uracil at 25°

Constant		Coordination no.[a]
pK_{a_1}	9.7	
pK_{a_2}	14.2	
K_{11}	~10^6 (est.)	1
K_{12}		2
β_{12}	6.0×10^8	2
K_{21}	1.5×10^8	1
K_{22}	3.1×10^3	2
β_{22}	4.8×10^{11}	2

[a] The possible participation of hydroxide ion in these complexes cannot be ruled out on the basis of these experiments since emf measurements were made in a large excess of alkali.

the first ionization at N^3 than that of C^6-H. Both $J_{C^5\text{-}H}$ and $J_{C^6\text{-}H}$ show more substantial decreases in the second ionization at N^1 than in the first. $J_{C^6\text{-}H}$ shows a discontinuity that may be related to the interaction with the alkali cation upon ionization at N^1.

C. Formation Constants and Stoichiometry of Silver–Uracil Complexes. A complete consideration of all equilibria possible in the uracil-Ag^+-water-alkali system would be too extensive to be presented here. Therefore, we limit our discussion to dominant equilibria which are necessary to an interpretation of the ^{13}C NMR data.

Further, the potential for the formation of polynuclear species will not be considered. Since formation constants and ^{13}C NMR spectra are determined for dilute solutions ($\lesssim 10^{-3}$ *M*) of uracil-Ag^+, the importance of equilibria involving polynuclear species is minimized.

Representing uracil, its monoanion, and its dianion schematically as H_2L, HL^-, and L^{2-}, the following equilibria are dominant under the conditions studied.

acid–base

$$H_2L \rightleftharpoons HL^- + H^+ \qquad K_{a_1} = \frac{[H^+][HL^-]}{[H_2L]} \tag{5}$$

$$HL^- \rightleftharpoons H^+ + L^{2-} \qquad K_{a_2} = \frac{[H^+][L^{2-}]}{[HL^-]} \tag{6}$$

silver complex formation

$$Ag^+ + HL^- \rightleftharpoons AgLH \qquad K_{11} = \frac{[AgHL]}{[Ag^+][HL^-]} \tag{7}$$

$$AgHL + HL^- \rightleftharpoons [Ag(HL)_2^-] \qquad K_{12} = \frac{[Ag(HL)_2^-]}{[AgHL][HL^-]} \tag{8}$$

$$\beta_{12} = K_{11}K_{12} = \frac{[Ag(HL)_2^-]}{[Ag^+][HL^-]^2} \tag{9}$$

simple mononuclear complex

$$Ag^+ + L^{2-} \rightleftharpoons AgL^- \qquad K_{21} = \frac{[AgL^-]}{[Ag^+][L^{2-}]} \tag{10}$$

$$AgL^- + L^{2-} \rightleftharpoons AgL_2^{3-} \qquad K_{22} = \frac{[AgL_2^{3-}]}{[AgL^-][L^{2-}]} \tag{11}$$

$$\beta_{22} = K_{21}K_{22} = \frac{[AgL_2^{3-}]}{[Ag^+][L^{2-}]^2} \tag{12}$$

mixed mononuclear complex

$$AgHL + L^{2-} \rightleftharpoons [AgL \cdot HL^{2-}] \tag{13}$$

$$K^* = \frac{[AgL \cdot HL^{2-}]}{[AgHL][L^{2-}]} \tag{14}$$

Equilibrium 13 involves ligand monoanion and dianion and therefore can be dominant only in a narrow pH range where both species coexist in approximately equal quantity (i.e., at a pH ≈ pK_{a_2}). The formation constants and coordination numbers as determined by emf measurements are presented in Table III.

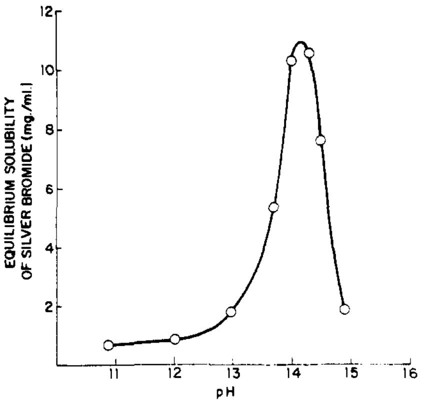


Figure 3. The effect of pH upon the solubility of the silver–uracil complex.

Figure 3 shows the amount of silver bromide solubilized by a 0.355 *M* solution of uracil as a function of pH. These data confirm the measured stability constant data in that the actual amount of silver bromide dissolved at both pH 12.0 and at 14.2 is in excellent agreement with computed values using the thermodynamic constants obtained above. A dramatic maximum in the solubility curve is seen at pH 14.2 (1.5 *M* NaOH), precisely the second pK_a of uracil.

The occurrence of the maximum in solubility at pH 14.2, corresponding to the pK_{a_2} of uracil, is coincidental. It might be argued that equilibrium 13 is involved, since at this pH, the concentrations of HL^- and L^{2-} are equal. However, a careful consideration of the relative magnitudes of the formation constants vs. the acid dissociation constants shows that AgL_2^{3-} is the thermodynamically favored species at this pH. It is apparent, therefore, that the dianion of uracil is the predominant silver binding species. At pH >14.2 a white microcrystalline solid slowly precipitates from solution. The same solubility behavior is observed when equimolar aqueous silver nitrate and uracil-alkali solutions are combined to pH 14.5. The precipitate formed gives an elemental analysis consistent with the formula $NaAg \cdot C_4H_2N_2O_2 \cdot 1.5H_2O$.

Previous investigations of organo complexes of silver in neutral solution[13] show that it bonds very strongly with ligands having $d\pi$ bonding potential (sulfur and phosphorus ligands being notable examples), whereas nitrogen and oxygen ligands typically are bonded much more weakly. Hence, the observed formation constants (Table III) are totally unexpected a priori. ^{13}C NMR spectroscopy has provided a probe to investigate the site of binding and the structure of the Ag^+-uracil complex.

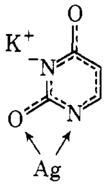
D. ^{13}C NMR Spectroscopic Study of Silver–Uracil Complex in Alkali. Association of uracil (2% w/v) with Ag^+ (1 *M*/1 *M*) in aqueous solution at pD 14 leads to a substantial deshielding of C^2 ($\Delta\delta = \delta_{C_2}{}^{pD\ 14}\ K^+Ag^+U^{2-} - \delta_{C_2}{}^{pD\ 14}\ K_2{}^+U^{2-} = +2.0$ ppm) and C^6 ($\Delta\delta = \delta_{C_6}{}^{pD\ 14}\ K^+Ag^+U^{2-} - \delta_{C_6}{}^{pD\ 14}\ K_2{}^+U^- = +3.8$ ppm). For uracil (2% w/v) and Ag^+ (2 *M*/1 *M*) at pD 14 the ^{13}C NMR shifts of C^2 and C^6 are affected similarly (Table II) ($\Delta\delta_{C_2}{}^{pD\ 14} = +2.5$ ppm, $\Delta\delta_{C_6}{}^{pD\ 14} = +3.2$ ppm). *These data are consistent with the complexing of Ag^+ by uracil in these solutions as shown in structure* **7**. The Δδ's of **7** are shown in Table IV along with those recently reported by Crist and coworkers[7d] for other oxygen and nitrogen ligands. Similarity in the values for $\Delta\delta_{C^2}$ in **7** and that of the α-carbon in $(Et)_2O$–Ag, and $\Delta\delta_{C^6}$ in **7** and those of the α-carbon in $(Et)_3N$–Ag and oxaziridines, is striking. Crist also reported ESCA data on the

Table IV. Deshielding by Ag^+ of the α-Carbon of Nitrogen and Oxygen Ligands

Silver–Uracil 7 (8)[b]	$(CH_3\overset{*}{C}H_2)_3$-N–Ag[a]	$(CH_3\overset{*}{C}H_2)_2$-O–Ag[a]	Oxaziridines[a] ($\overset{*}{R}$N–Ag)
C^2, +2.0 (+2.5)		+2.1	
C^6, +3.8 (+3.2)	+3.6		+3.5[c]

[a] Data reported by Crist et al.[7d] The starred carbons are those measured by ^{13}C NMR for $\Delta\delta$ in methylene chloride solution of the silver complexes and the corresponding ligand. [b] Parenthetic values are those obtained for a 2:1 M/M U–Ag^+ ratio. $\Delta\delta = \delta C^*_{\text{ligand-Ag}} - \delta C^*_{\text{ligand}}$. [c] For a number of R groups the value of $\Delta\delta$ in oxaziridine–silver complexes was ca. 3.5.

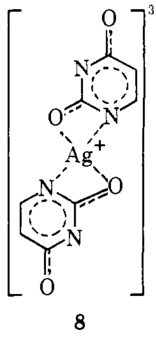
solid amine-, ether-, and oxaziridine-silver complexes which suggest that back donation of electrons from the filled 3d orbitals predominates over electron-withdrawal bonding of the empty 5s orbital of silver.



7

That N^1 in uracil is bonded to both C^2 and C^6 and that oxygen is bonded only to C^2 suggest that the numerical correlation in Table IV may be coincidental. Nevertheless, the overall correlation of deshielding shown in Table IV combined with the ESCA data of Crist[7d] suggests that the net effect of silver complexing in **7** and **8** is dominated by electron back-donation to the uracil ligand. This indicates that the changes in electron density associated with silver complexation of ligands with nitrogen and oxygen heteroatoms is relatively independent of the initial hybridization of and charge density on those heteroatoms. This in turn suggests that the effectiveness with which silver is solubilized in aqueous alkaline media by such a ligand is related strongly to the solubility of the complex itself and not only to the strength of silver-ligand bonding interactions.

For uracil (2% w/v) and Ag^+ in the equimolar mixture at pD 14 a pair of ^{13}C NMR signals of equal intensity for C^5 ($\Delta\delta$ = 0.1 ppm) and one for C^6 ($\Delta\delta$ = 0.1 ppm) are observed (see Table II). Labeling experiments with $^{109}Ag^+$-enriched $AgNO_3$ show that $J_{^{109}Ag^+-^{13}C}$ coupling is not observable for these complexes. Only one ^{13}C NMR signal is observed for C^5 and one for C^6 with a 1-mol excess of uracil. These ^{13}C NMR observations and those for C^2 and C^4 are consistent with the formation of a dimer of the monouracil-Ag^+ complex for the 1 M/1 M mixture and a symmetrical bisuracil-Ag^+ complex for the 2 M/1M mixture (see structure **8**).



8

Although the multiplicity of different olefinic C^5 and C^6 carbons for the two uracil moieties in the dimeric (1 M/1 M) complex shows a dissymmetry overall, we do not have enough data at present to unambiguously propose an overall structure for this species. It can be concluded, however, that the primary mode of bonding with Ag^+ in the dimeric (1 M/1 M) complex is that shown in structure **7**.

Experimental Section

A. **General.** Uracil was obtained from Eastman Kodak Co. and was used without further purification. Uv spectrophotometric measurements were made with a Cary 15 uv spectrophotometer. ^{13}C NMR spectra were recorded on a Varian CFT-20 spectrometer at ambient temperature except for those at near neutral pD. For near neutral pD a temperature of 90° and a calibrated pD electrode gave a solution of ~1% uracil. Uracil was not soluble in water at room temperature below pD 9.5. Emf measurements were made with an Orion 801 meter using an Orion specific ion electrode and a calomel double junction reference electrode. All emf measurements were performed in the dark and constant ionic strength at 25.0°. All pD values are computed from $[OD^-]$ (titration) with the relationship pD = 14 + log [OD]. All decoupled ^{13}C NMR spectra were measured in a 10-mm tube with a flip angle of ca. 20° and an accumulation of 250,000 transients. Coupled ^{13}C NMR spectra were measured for the same solutions with a flip angle of ca. 45° and an accumulation of 400,000 transients. A sensitivity enhancement of −0.1 and an apodization parameter of 0.187 were used in all cases.

B. **Preparation of Solutions of the Soluble Silver-Uracil Complex for ^{13}C NMR Analyses. I. Equimolar.** To 5 cc of 1.01 N KOD-D_2O in a dark 10-cc polyethylene tube was added 0.1 g (0.83 mmol) of uracil. To this solution 0.14 g (0.83 mmol) of $AgNO_3$ in a saturated D_2O solution was added slowly with gentle magnetic stirring. The mixture was stirred until all of the Ag_2O formed dissolved and a clear colorless solution was obtained. The sample was kept in the dark to prevent silver photolysis by placing aluminum foil over the ^{13}C NMR probe.

II. Excess Uracil. The preparation of the 2 M/1 M uracil-Ag^+ complex was accomplished according to procedure I above but in this case 0.07 g (0.41 mmol) of $AgNO_3$ was used. This sample was also kept in the dark to prevent silver photolysis as mentioned above.

C. **pK_a Measurements.** Accurately weighed samples of uracil were placed in volumetric flasks, dissolved, and diluted to the mark with uv transparent buffers containing varying amounts of potassium chloride to maintain ionic strength at a fixed value of 3.0. Absorbance values were then recorded from 320 to 240 nm at 2.5-nm intervals for each solution. Data for six such solutions, ranging in pH from 8.3 to 14.5 were thus obtained yielding 192 data points. The pK_a's were extracted from these data by means of a standard computer program (method of Sillen).

D. **Stability Constant Measurements.** Often, potentiometric measurement of stability constants is achieved by making incremental additions of the ligand (in the form of a titrant) to a series of solutions of varying concentrations of the metal ion of interest. The coordination numbers and stability constants are then extracted from the resulting family of curves (see ref 13) by either graphical or computer methods. In the present work, in alkaline medium, the precipitation of silver hydroxide interferes with this approach. The difficulty was overcome, however, by a simple modification, in which the role of metal ion and ligand solutions was reversed, i.e., silver ion solution was added incrementally to a series of solutions of varying concentrations of the ligand dissolved in alkaline aqueous solution of constant ionic strength. Hence the level of free silver ion remained very low throughout the additions, and the solubility product of silver hydroxide was not exceeded until more than 1 equiv of silver ion had been added.

Accurately weighed samples of uracil were dissolved in 100-ml portions of 1 M KOH or other solvent, adjusted to 1.0 ionic strength with KNO_3 or a similar inert salt. Uracil amounts ranged from 5 × 10^{-5} to 10^{-3} mol. These solutions were maintained at 25.0° and blanketed with nitrogen. They were then titrated incrementally with 5 × 10^{-2} M silver nitrate solution in the dark. The emf values and titrant volume were recorded at regular intervals up to the point of silver hydroxide precipitation (or a maximum of 5 ml of titrant added). Data for six such titrations were thus obtained yielding 80 data points. The maximum coordinations and β values were then extracted by graphical methods analogous to those of ref 13, modified in keeping with the experimental modifications.

E. Solubility Measurements. Solutions of uracil of known concentration (0.355 *M*) and pH were prepared. pH's were checked with the electrode in the range 10–13. pH's above 13 are "nominal" pH's based on the known molarity of alkali present; i.e., a 3 *M* KOH solution was assigned a nominal pH of 14.48.

Each such solution (20 ml) was placed in a 40-ml centrifuge tube. To this an excess of 200 mesh silver bromide was added in the dark. The mixture was capped and shaken for 3 hr. At the end of this time, the mixture was centrifuged and an aliquot of the supernatant removed and diluted to a known volume in ammoniacal medium. These solutions were then analyzed by atomic absorption.

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