azeotroped three times with 30 ml of methanol and the orange residue obtained was extracted with chloroform. The chloroform extract was stripped *in vacuo* to afford 0.372 g (79%) of the product as a clear syrup. A sample of this material was further purified by molecular distillation at 130° (0.10 mm); a clear syrup identical with the above crude product was obtained: ir (neat) 2.95 (b), 6.10, 6.51, 7.07, and 13.2 μ; nmr ($CDCl_3$, 100 MHz) δ 6.62 (s, 1 H), 4.0–3.0 (m, 6 H), 2.96 (s, 3 H), 2.79 (s, 3 H), and 1.90 (m, 2 H); mass spectrum (70 eV) *m/e* 173.1167 (calcd, 173.1164) (P, 12), 155 (P − H_2O, 8), 142 (P − H, − $NHCH_3$, 7), 115 (P − $CONHCH_3$, 47), and 56 (CH_3NHCO, 100). This compound was characterized more fully as its acetate. The acetate prepared from the alcohol and acetic anhydride in 96% yield was a clear liquid: ir (neat) 2.93, 5.74, 6.02, 6.56, 8.07, and 9.65 μ; nmr ($CDCl_3$, 60 MHz) δ 6.23 (br s, 1 H), 4.14 (d, J = 2.5 Hz, 2 H), 4.14–3.20 (m, 3 H), 2.96 (s, 3 H), 2.78 (d, J = 5.0 Hz, 3 H), 2.06 (s, 3 H), and 2.1–1.7 (m, 2 H); mass spectrum (70 eV) *m/e* 215.1273 (calcd, 215.1269) (P, 17, 156 (P − OAc, 30), 128 (P − $N(CH_3)CONHCH_3$, 55), and 97 (100).

Anal. Calcd for $C_9H_{17}N_3O_3$: C, 50.22; H, 7.96; N, 19.52. Found: C, 50.23; H, 7.95; N, 19.62.

Photochemical Cycloadditions of Triplet 1,3-Dimethyluracil to Olefins. Structural Studies on the Adducts

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Abstract: The acetone-sensitized additions of 1,3-dimethyluracil (**1**) to ketene diethyl acetal (**2a**), *tert*-butyl vinyl ether (**2b**), and vinyl acetate (**2c**) have been studied. From excited **1** and **2a** an 85% yield of cis- and trans-fused 8,8-diethoxy-2,4-diazabicyclo[4.2.0]octane-3,5-diones in a ratio of 84:16 were produced. From cycloaddition of excited **1** to **2b** and **2c** good yields of cis-fused 8-substituted 2,4-diazabicyclo[4.2.0]octa-3,5-diones were formed. The orientation and stereochemistry of all these adducts were rigorously established by a combination of chemical, labeling, and X-ray crystallographic studies.

While the photochemistry of both uracil and thymine derivatives has been extensively studied, most of the emphasis has been placed on the hydration and dimerization reaction of these moieties.[2] In view of the considerable interest in relating chemical reactivity and excited state electron distribution in these systems,[3] we felt it would be valuable to develop reactions which could probe the electronic character of the excited state. A reasonable choice for such a study was cycloaddition reactions of these excited bases to olefins. Thus, the rates and efficiencies of these cycloadditions as a function of olefin structure would possibly contribute to a basic understanding of the electronic character of the nucleic acid excited states. Since at the time this work was begun little was known of the photochemical processes of excited uracil[4–6] or thymine[7] with olefins, by necessity detailed structural studies of the products from these systems were required. We wish to report here chemical, labeling, kinetic, and X-ray studies which establish the orientation and stereochemistry of the major cycloadducts from 1,3-dimethyluracil (**1**), with ketene diethyl acetal (**2a**), *tert*-butyl vinyl ether (**2b**), and vinyl acetate (**2c**).

Orientation of the Cycloadducts from 1. The importance of the triplet state of uracil in its dimerization reactions,[8] together with the possible complicating factor of products being derived from both singlet and triplet excited state on direct irradiation,[9] led us to investigate the triplet sensitized reactions of **1**. Photosensitized addition of **1** to **2a**, **2b**, and **2c** produced in each case two major products in good overall yield (Table I). There are numerous possible structures for these compounds. In addition to the two regioisomers i and ii, there are epimeric centers at either C_7 or C_8 and the possibility of either cis- or trans-ring fusions at C_1 and C_6. Thus, we first sought to establish the regiospecificity of these reactions.

The reaction of triplet 1,3-dimethyluracil (**1**) with ketene diethyl acetal, (**2a**) will be discussed first. Irradiation of a 4% solution of **1** and a fivefold molar excess of **2a** in acetonitrile–acetone with Corex-filtered light resulted in the formation of two products in a ratio of *ca.* 86:14 (vpc). Both compounds were obtained as crystalline solids after silica gel chromatography, and their combustion analyses and mass spectra

(1) (a) Alfred P. Sloan Fellow (1970–1972); Camille and Henry Dreyfus Teacher–Scholar (1971–1976); (b) Ohio State University Graduate Fellow (1970–1971 and 1972–1973); (c) For a preliminary report, see J. A. Hyatt and J. S. Swenton, *J. Amer. Chem. Soc.*, **94**, 7605 (1972); (d) Iowa State University; (e) Camille and Henry Dreyfus Teacher–Scholar (1972–1977); Alfred P. Sloan Fellow (1973–1975).

(2) For reviews in this area, see (a) J. R. Burr, *Advan. Photochem.*, **6**, 193 (1968); (b) A. D. McLaren and D. Shugar, "Photochemistry of Proteins and Nucleic Acids," Macmillan, New York, N. Y., 1961, pp 162–220; (c) E. Fahr, *Angew. Chem., Int. Ed. Engl.*, **8**, 578 (1969); (d) *Photochem. Photobiol.*, **7**, 511 (1968).

(3) For leading references, see (a) Z. Neiman, *Isr. J. Chem.*, **9**, 119 (1971); (b) V. I. Danelov, Y. A. Kruglyak, V. A. Kuprievich, and V. V. Ogloblin, *Theor. Chim. Acta*, **14**, 242 (1969); (c) B. Pullman, *Photochem. Photobiol.*, **7**, 525 (1968); (d) V. Klunwashter, J. Drobnik, and L. Augenstein, *ibid.*, **5**, 579 (1966); (e) A. Imamura, H. Fuyita, and C. Nagata, *Bull. Chem. Soc. Jap.*, **40**, 21 (1967).

(4) (a) E. Krajewska and D. Shugar, *Acta Biochim. Polon.*, **19**, 207 (1972); (b) R. Beugelmans, J. Fourney, S. Gero, M. LeGoff, D. Mereur, V. Ratovelomana, and M. Janot, *C. R. Acad. Sci.*, **274**, 882 (1972).

(5) C. Helene and F. Brun, *Photochem. Photobiol.*, **11**, 77 (1970).

(6) The orientation of the adduct between thymine and acrylonitrile, while not rigorously established, was proposed to be 7-cyano-6-methyl-2,4-diazabicyclo[4.2.0]octa-3,5-dione.[5] The orientation differs from that established here for adducts of 1,3-dimethyluracil with olefins.

(7) R. Malewski and H. Morrison, *Mol. Photochem.*, **4**, 507 (1972).

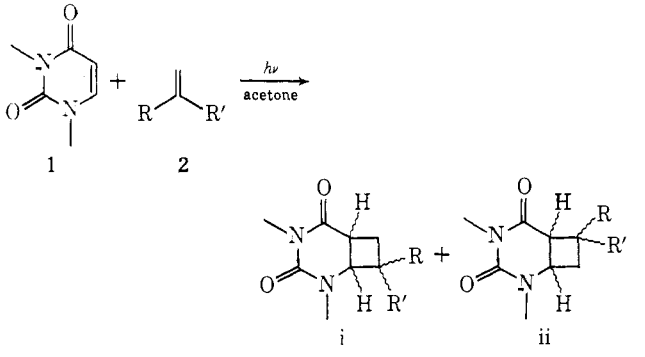
(8) For leading references, see E. Hayan, *J. Amer. Chem. Soc.*, **91**, 5397 (1969).

(9) (a) H. Morrison and R. Kleopfer, *J. Amer. Chem. Soc.*, **90**, 5037 (1968); (b) H. Morrison, A. Feeley, and R. Kleopfer, *J. Chem. Soc., Chem. Commun.*, 358 (1972); (c) R. Kleopfer and H. Morrison, *J. Amer. Chem. Soc.*, **94**, 255 (1972).

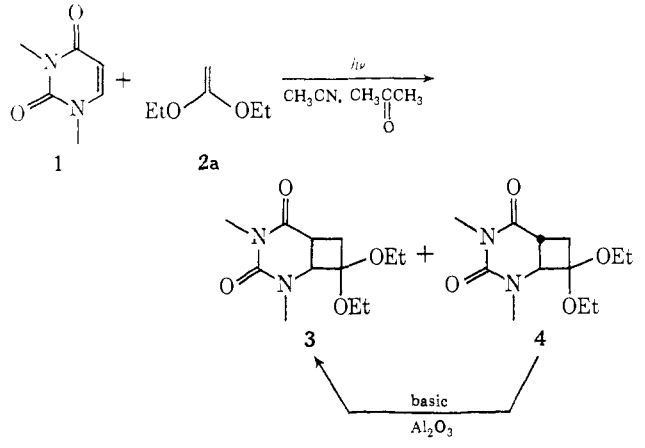
Table I. Acetone-Sensitized Cycloaddition of 1,3-Dimethyluracil (1) to Olefins 2a–c[a]

1, *M*	Olefin (*M*)	Irradiation time, hr	Product (% yield)	% unreacted 1
0.14	**2a** (0.66)	4	**3** (73), **4** (11)	~16
0.12	**2b** (0.40)	12	**5** (32), **6** (37)[b,c]	~10
0.04	**2c** (0.44)	20	9 (34), **10** (31)[b,c]	<0.5

[a] All irradiations were performed with a 450-W Hanovia high-pressure source using a Corex filter in acetonitrile 0.4 *M* in acetone. [b] The total yield of cycloadducts was 76% from **1** and **2b** and 70% from **1** and **2c** as column chromatography did not completely separate the products. [c] Minor products amounting to 3–4% of the major adducts were detected in the vpc traces of the crude reaction mixtures but were not characterized.

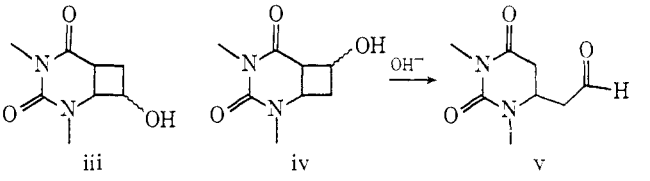


established that these were 1:1 adducts of **1** and **2a**. The absence of any olefinic absorption in their nmr spectra indicated the compounds were bicyclic. That **4** possessed a trans ring fusion was readily established



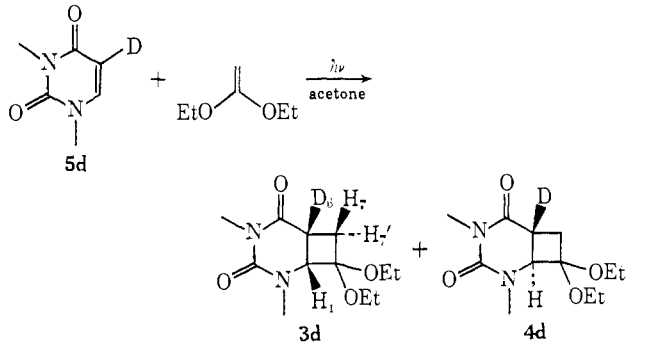
from its conversion to **3** by chromatography on basic alumina; **3** was stable under these same conditions. The facile base-catalyzed isomerization of **4** to **3** has close analogy to similar epimerization of trans-fused bicyclo[4.2.0]octan-5-ones to their cis isomers previously observed by Corey.[10] This base-catalyzed epimerization of **4** to **3** indicates that these compounds have a common orientation and differ only in the stereochemistry of the ring fusion. In a similar fashion triplet **1** was reacted with *tert*-butyl vinyl ether (**2b**) and vinyl acetate (**2c**). In each case the major products were isolated as crystalline solids after silica gel chromatography. The analytical and spectroscopic properties of these compounds (see Experimental Section) established them to be 1:1 adducts of **1** and the respective olefin. Since the major cycloadducts of **1** with *tert*-butyl vinyl ether (**2b**) and vinyl acetate (**2c**) were stable to dilute base, these compounds must possess the more stable cis ring fusion.

Having established the stereochemistry of the ring fusion, it seemed reasonable that all these cycloadducts were formed with similar regioselectivity. To confidently establish this point the various adducts were chemically interrelated as shown in Scheme I. At this point then, all the cycloadducts of triplet **1** and the three olefins have identical, yet unknown, orientations. To distinguish between the general orientations i and ii two approaches were utilized. First, alcohols of structure iii would be expected to have reasonable base sta-



bility while alcohols corresponding to orientation iv have available a mechanistically reasonable path for ring opening analogous to a reverse-aldol reaction. The isolation of the alcohols **7** and **8** in good yields from basic hydrolysis of the corresponding acetates strongly supports orientation iii. However, the lack of a direct analogy[11] for a facile reverse-aldol-like process in these systems and the decomposition of the alcohols in refluxing alkali solution indicated confirming evidence of the orientation advisable.

It is apparent that deuterium substitution at position 1 or 6 in the adducts will allow establishement of the orientation by simple nmr analysis. The photosensitized addition of 1,3-dimethyluracil-**5**-d_1, prepared in excellent isotopic purity (>98%) by catalytic reduction of 5-bromo-1,3-dimethyluracil, to **2a** afforded the cis- and trans-ring fused adducts in good yield. For **3**, H_1

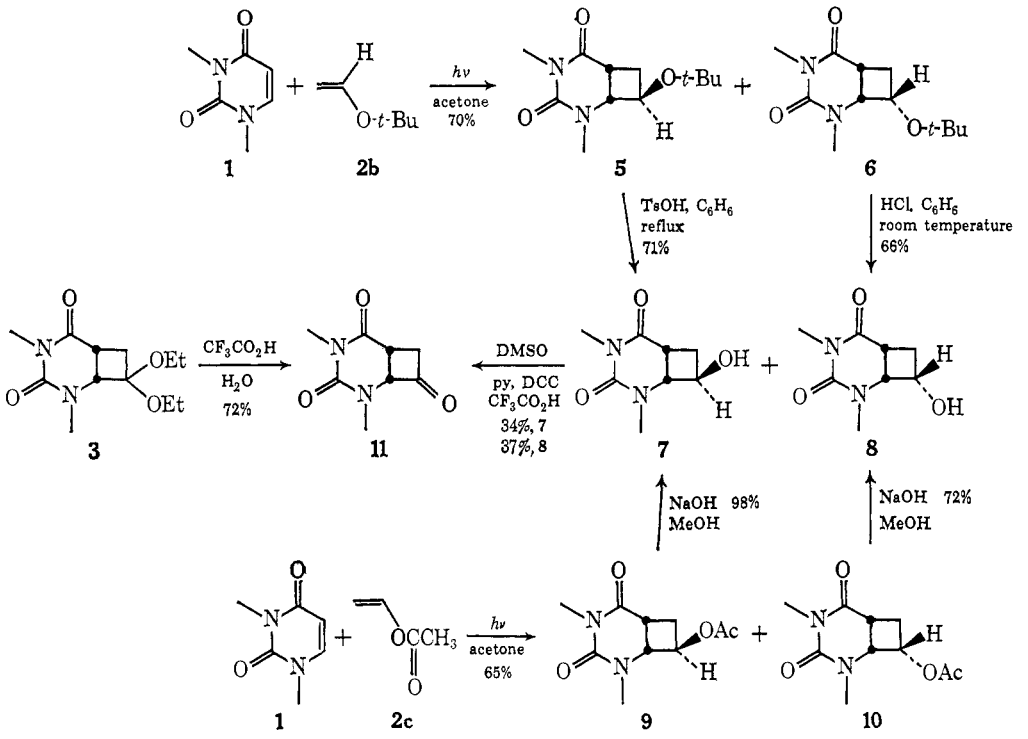


appears as a doublet at δ 3.79 (J = 9.6 Hz), while H_6 is partially obscured under the ether resonances at δ 3.1–3.6, and H_7, $H_{7'}$ appear as a multiplet at δ 2.25–2.60. In the deuterio compound **3d** the resonance of H_6 disappears, that of H_1 collapses to a singlet, and the multiplet for H_{7exo}, H_{7endo} is reduced to a AB system (J = 12.5 Hz). The results of deuteration on the nmr spectrum of the trans-fused adduct **4d** were similar: the doublet for H_1 at δ 3.32 ($J_{1,6}$ = 13.0 Hz) collapses to a singlet, the partially obscured multiplet at δ 3.1–3.4 for H_6 disappears, and the multiplet for the methylene

(10) E. J. Corey, J. Bass, R. LeMahiew, and R. Mitra, *J. Amer. Chem. Soc.*, **86**, 5570 (1964).

(11) Some analogy for an expected reverse-aldol-like reaction derives from the work of Wang: M. Khattak and S. Y. Wang, *Tetrahedron*, **28**, 945 (1972).

Scheme I. Chemical Transformations Interrelating Adducts of Uracil with Diethyl Ketene Acetal, *tert*-Butyl Vinyl Ether, and Vinyl Acetate



group becomes a clean AB system (J = 12.5 Hz). The nmr spectra of **3d** and **4d** are consistent only with compounds containing isolated 1- and 2-spin systems; thus, 8-substituted derivatives of the 2,4-diazabicyclo[4.2.0]-octane-3,5-dione are assigned as the isomers produced in these photochemical reactions.

Stereochemistry of the Adducts. Having established the orientation of the adducts, we next sought to assign the stereochemistry of the substituents at C_8. Our initial approach was derived from the observation in our chemical studies that the *tert*-butyl ether, **6**, cleaved more readily in acid than did its epimer, **5**. Since it seemed reasonable that more relief of steric strain in **6** *vs.* **5** accounted for this rate difference, competitive studies of the acid-catalyzed *tert*-butyl ether cleavage were examined. When a 1 : 1 mixture of **5** and **6** was heated in benzene containing *p*-toluenesulfonic acid and an internal standard, vpc analysis showed that **6** reacted at least three times faster than **5**.

To further substantiate this modest steric acceleration in the presumed endo isomer **6**, the competitive acetylation of the corresponding alcohols was studied. If indeed steric hindrance was responsible for the accelerated *tert*-butyl ether cleavage, then the relative rates of acetylation of the corresponding alcohols should be reversed. Indeed, competitive acetylation of a mixture of equal parts of **7** and **8** with a deficiency of acetic anhydride showed that the presumed exo alcohol, **7**, reacted at least five times faster than **8**.

In our preliminary work tentative evidence on the stereochemistry of the alcohols **7** and **8** was proposed based on the magnitude of the M − 18 peak in the mass spectrum of these compounds. It had been previously shown that loss of water from cyclic alcohols upon impact involves a cis-1,4 or a cis-1,3 elimination.[12] Examination of **7** and **8** indicates that only the presumed exo isomer **7** has a cis-1,3 relationship between the hydroxyl group and H_6. As was anticipated, the mass spectrum of one alcohol, **7**, showed an enhanced M − 18 peak relative to the second alcohol, **8**. However, when the mass spectrum of the 6-deuterio derivative of **7** was examined, it was found that loss of water did not exclusively involve a 1,3 elimination; P − 18 and P − 19 peaks were present in equal intensity. In addition, very small P − 18 and P − 19 peaks were observed in the mass spectrum of **8** (6-d_1). Thus, the mass spectral results on these alcohols do not provide any unequivocal stereochemical evidence.

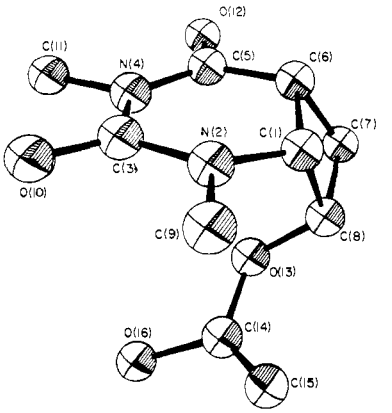


Figure 1. A computer generated drawing of the X-ray model of adduct **10**. All atoms are rendered the same size and hydrogens are not shown for clarity.

Even though we felt the relative reactivity of the epimeric ethers and alcohols in cleavage and esterification reactions strongly suggestive of the stereochemistry at C_8, the results were not conclusive. Having exhausted other means at our disposal, the structure of the endo acetate **10** was determined by X-ray crystallography (Figure 1). Gratifyingly, the

(12) (a) C. MacDonald, J. Shannon, and G. Sugowidz, *Tetrahedron Lett.*, 807, (1963); (b) S. Shrader, "Introductory Mass Spectroscopy," Allyn and Bacon, Boston, Mass., 1971, pp 52–57.

stereochemistry originally assigned on a chemical basis is now conclusively established by the X-ray determination.

Nmr Studies of Selected Cycloadducts. Having established both the orientation and stereochemistry of the cycloadducts, and having available a variety of 6-deuterio derivatives of the cycloadducts, we examined the coupling constants $J_{1,6}$ and $J_{1,8}$ in these compounds to see if correlations of coupling constants with stereochemistry would be apparent. For simple cyclobutane derivatives cis vicinal protons have coupling constants between 4.6 and 12.0 Hz and trans vicinal protons have J = 2.0–8.7 Hz; J_{cis} was generally found to be larger than J_{trans}.[13] Examination of the nmr spectra of the deuterated adducts, **3d**, **4d**, **7d**, **8d**, **9d**, and **10d**, allowed determination of the coupling constants given in Table II (spin decoupling was used to verify proton assignments where necessary). It is noted that the exo compounds **7** and **9** have $J_{1,8}$ = 6.0–6.2 Hz, whereas their epimers have $J_{1,8}$ = 4.5–4.7 Hz. In addition, the $J_{1,6}$ coupling for cis-fused adducts was in the range 9.0–10.3 Hz, while the one trans-fused compound **4** had $J_{1,6}$ = 13.0 Hz. Thus, in these systems it appears that J_{cis} is smaller than J_{trans}. However, in view of the small differences in these values, the assignment of stereochemistry of the basis of vicinal coupling constants would appear very hazardous unless there is exceedingly close similarity between the unknown system and those reported here.

Table II. Chemical Shifts and Coupling Constants for H_1, H_6, and H_8 of Selected Cycloadducts

Adduct	H_1	H_6	H_8
3	δ 3.76 (d, $J_{1,6}$ = 9.6 Hz)	δ 3.1–3.6 partially obscured multiplet	
4	δ 3.32 (d, $J_{1,6}$ = 13.0 Hz)	δ 3.1–3.4 partially obscured multiplet	
7	δ 3.68 (q, $J_{1,6}$ = 10.3 Hz, $J_{1,8}$ = 6.0 Hz)		δ 4.26 multiplet
8	δ 3.88 (broadened quartet, $J_{1,6}$ = 9.0 Hz, $J_{1,8}$ = 4.7 Hz)		δ 4.34 br. multiplet
9	δ 3.83 (q, $J_{1,6}$ = 10.2 Hz, $J_{1,8}$ = 6.2 Hz)	δ 3.35 two structured absorptions	δ 4.94 multiplet
10	δ 4.02 (quartet with additional coupling, $J_{1,6}$ = 9.0 Hz, $J_{1,8}$ = 4.5 Hz)	δ 3.27–3.47 partially obscured multiplet	δ 5.17 multiplet

Discussion

The facile, high yield cycloadditions of triplet 1,3-dimethyluracil to these three olefins of moderately different electronic character establishes the general reactivity of this nitrogen base in cycloaddition processes. These results affirm the feasibility of using such reactions as probes for the character of the uracil excited state, and the cleanliness of the reactions suggests they could prove an excellent utility in detailed studies of photochemical cycloaddition reactions themselves.

Although the discrete steps in the cycloaddition process are undoubtedly quite complicated and much kinetic work is needed to establish the relative reactivities of the olefins at each step in the reaction, the high regioselectivity observed is indicative of a rather polarized excited state or exiplex intermediate. This observed regioselectivity is reminiscent of that observed in 2-cyclohexenone photoadditions; thus, the use of the enone as a crude model for pyrimidine bases merits further consideration.[11,14] The lower yield of trans-fused products in this system relative to cyclohexenone may result from less geometric distortion of the more rigid uracil system than that of cyclohexenone. This smaller tendency toward geometric distortion may further account for the high reactivity toward cycloaddition as relaxation of the initially formed excited state to a twisted ground state would be much less favorable.

We plan to extend the study of these cycloaddition reactions to other nucleic acid systems and to elucidate the relative reactivity of the olefins at various stages of the reactions by detailed kinetic studies. Applications of these types of photoaddition processes to the synthesis of modified nucleoside derivatives is currently under investigation.

Experimental Section

General Procedures. Melting points were taken in a Thomas-Hoover "Unimelt" apparatus and are corrected. Infrared spectra were taken as neat films or KBr pellets with a Perkin-Elmer Model 137 spectrophotometer. Nuclear magnetic resonance spectra were recorded on a Varian A-60A, HA-100, or Jeolco MH-100 instrument in chloroform-d_1 and are reported in δ units relative to tetramethylsilane as internal standard. Mass spectra were obtained with an AEI MS-902 instrument with an ionizing potential of 70 eV. All irradiations were performed with Pyrex-filtered light from a 450-W medium-pressure source in a nitrogen atmosphere unless otherwise noted. Gas chromatographic analyses were effected using a 5 ft × 1/8 in. column of 3% SE-30 on 100–120 mesh Varaport 30 on a Varian Aerograph Model 1400 flame ionization gas chromatograph. Elemental analyses were performed by Scandinavian Microanalytical Laboratory, Herlev, Denmark, and Heterocyclic Chemical Co., Harrisonville, Mo., on sublimed samples. In the chromatographic elution E refers to ether, and H to hexane.

Cycloaddition of *tert*-Butyl Vinyl Ether to 1,3-Dimethyluracil. A solution of 4.0 g (0.0285 mol) of 1,3-dimethyluracil, 10.0 g (0.10 mol) of *tert*-butyl vinyl ether, and 5.8 g (0.10 mol) of purified acetone in 350 ml of acetonitrile was irradiated for 12 hr. Vpc inspection of the photolysis solution showed 90% loss of 1,3-dimethyluracil and the formation of four products in a ratio of 46:50:2:2. After removal of the solvent *in vacuo* the resulting light yellow oil was chromatographed on silica gel (80 × 5 cm, packed in 10% ether–hexane, E–H). Elution, which was followed by vpc, proceeded as follows: 700 ml each of 10, 20, 30, 40, and 50% E–H, nil; 60%, E–H, 1.2 l., nil; 60% E–H, 2 l., 2.2 g (32%) of **5** with trace amounts of the other cycloadducts. This material, which crystallized on standing, was recrystallized from ether–pentane to yield **5** was white crystals: mp 66–68°; ir (KBr) strong absorptions at 5.87, 6.01, 7.86, 8.41, 8.91, 11.24, 13.32, and 13.52 μ; nmr 1.18 (s, 9 H), 3.09 (s, 3 H), 3.27 (s, 3 H), and 2.0–4.3 (m, 5 H).

Anal. Calcd for $C_{12}H_{20}N_2O_3$: C, 59.98; H, 8.39; N, 11.66. Found: C, 59.95; H, 8.35; N, 11.34.

Continued elution with 60% E–H gave: 1 l., 0.5 g of a mixture of

(13) (a) I. Fleming and D. Williams, *Tetrahedron*, **23**, 2747 (1967); (b) H. Weitkampe and F. Forte, *Tetrahedron, Suppl.*, **No. 7**, 75 (1966); (c) L. Paolillo, H. Ziffer, and O. Buchardt, *J. Org. Chem.*, **35**, 38 (1970); (d) M. Servé, *Can. J. Chem.*, **50**, 3744 (1972).

(14) (a) A. Lamola, *Photochem. Photobiol.*, **7**, 619 (1968); (b) P. Wagner and D. Bucheck, *J. Amer. Chem. Soc.*, **92**, 181 (1970).

cycloadducts; 2 l., 2.5 g (37%) of **6** with a trace of **5**. The light yellow oil, which crystallized on standing, was recrystallized from ether–pentane to yield **6**; mp 76–77°; ir (KBr) strong absorptions 5.89, 6.02, 6.75, 7.75, 9.36, 10.70, and 13.32 μ; nmr 1.17 (s, 9 H), 3.04 (s, 3 H), 3.22 (s, 3 H), 2.0–4.5 (m, 5 H).

Anal. Calcd for $C_{12}H_{20}N_2O_3$: C, 59.98; H, 8.39; N, 11.66. Found: C, 59.96; H, 8.45; N, 11.71.

Cycloaddition of Vinyl Acetate to 1,3-Dimethyluracil. A solution of 2.0 g (0.014 mol) of 1,3-dimethyluracil, 10.0 g (0.115 mol) of vinyl acetate, and 5 g (0.086 mol) of acetone in 150 ml of acetonitrile was irradiated for 20 hr. Gas chromatographic analysis showed complete loss of 1,3-dimethyluracil and the formation of two major and two minor products, 46:41:7:6 in order of increasing retention time. Removal of the solvent *in vacuo* yielded a light yellow oil which was chromatographed on 150 g of silica gel (50 × 3.5 cm column). Elution proceeded as follows: 2 l. each of E–H from 40 to 100% by 10% increments, nil; 10% $CHCl_3$–E, 1.5 l., nil; 10% $CHCl_3$–E, 1 l., 1.1 g (34%) of **9** as an oil. Recrystallization of the oil from ether–pentane yielded a crystalline solid: mp 97–99°; ir (KBr) strong absorptions at 5.73, 5.85, 6.00, 7.07, 7.32, 7.82, 8.13, 9.35, and 9.60 μ; nmr 2.06 (s, 3 H), 2.99 (s, 3 H), 3.19 (s, 3 H), 4.85–5.14 (m, 1 H), 3.74–3.94 (m, 1 H), and 2.15–3.45 (m, 3 H).

Anal. Calcd for $C_{10}H_{14}N_2O_4$: C, 53.09; H, 6.24; N, 12.39. Found: C, 53.49; H, 6.19; N, 12.22.

Continued elution with 10% $CHCl_3$–E gave: 750 ml, 0.5 g of a *ca.* 1:1 mixture of **9** and **10**; 1.5 l., 1.0 g (31%) of **10** as light yellow oil. Recrystallization of the solidified oil gave crystalline **10**: mp 76–78°; ir (KBr) strong absorptions at 5.74, 5.86, 6.01, 7.32, 7.80, 8.19, and 9.50 μ; nmr 2.05 (s, 3 H), 2.97 (s, 3 H), 3.27 (s, 3 H), 5.47–5.05 (m, 1 H), 4.23–3.81 (m, 1 H), and 3.59–2.00 (m, 3 H).

Anal. Calcd for $C_{10}H_{14}N_2O_4$: C, 53.09; H, 6.24; N, 12.39. Found: C, 53.21; H, 6.23; N, 12.33.

Cycloaddition of Vinyl Acetate to 1,3-Dimethyluracil-*5-d*. A solution of 2.0 g (14.3 mmol) of 1,3-dimethyluracil-*5-d* greater than 98% isotopic purity, 10 g of vinyl acetate (115 mmol), and 10 g of purified acetone in 200 ml of acetonitrile was irradiated for 12 hr. Work-up and chromatographic separation of products as described in the synthesis of **9** and **10** (*vide supra*) gave the pure products **9d** and **10d**.

9d: 0.80 g (26%), mp 96–98°, after recrystallization from ether; ir (KBr) 5.72, 5.85, 6.00, 7.05, 7.81, 8.18, 10.19, 11.12, and 13.27 μ; nmr ($CDCl_3$, 100 MHz) 4.96 (q, X part of ABX system, 1 H), 3.78 (d, J = 6.0 Hz, 1 H), 3.18 (s, 3 H), 2.99 (s, 3 H), 2.40 (m, center of AB part of ABX system, J = 12.1 Hz, J' = 5.0 Hz, J'' = 2.0 Hz, 2 H), and 2.03 (s, 3 H). Double irradiation at δ 4.96 gave: 3.78 (s, 1 H), 3.18 (s, 3 H), 2.99 (s, 3 H), 2.40 (AB system, J = 12.1 Hz, 2 H), and 2.03 (s, 3 H).

10d: 0.54 g (19%), mp 72–75°, after ether recrystallization; ir (KBr) 5.75, 5.85, 6.00, 6.80, 7.30, 8.16, 9.09, 9.57, 10.66, 10.88, 11.13, 12.01, 13.28, and 14.45 μ; nmr ($CDCl_3$, 100 MHz) 5.18 (m, X part of ABX system, 1 H), 4.02 (d, J = 4.8 Hz, 1 H), 3.18 (s, 3 H), 2.87 (s, 3 H), 2.45 (center of AB part of ABX system, J = 13.1 Hz, J' = 6.2 Hz, J'' = 2.0 Hz, 2 H), and 1.99 (s, 3 H). Double irradiation at δ 5.18 gave: 4.02 (s, 1 H), 3.18 (s, 3 H), 2.87 (s, 3 H), 2.45 (center of AB system, J = 13.1 Hz, 2 H), and 1.99 (s, 3 H).

Cycloaddition of Ketene Diethyl Acetal to 1,3-Dimethyluracil. In an ammonium hydroxide washed apparatus 5.0 g (0.036 mol) of 1,3-dimethyluracil, 19.3 g (0.165 mol) of ketene diethyl acetal, 10 g (0.172 mol) of acetone, and 250 ml of acetonitrile were irradiated through Corex for 4 hr. Gas chromatographic analysis of the photolysis mixture showed 18% unreacted 1,3-dimethyluracil and two products in a ratio of 86:14. After removal of solvent *in vacuo* the resulting oil was chromatographed on 250 g of silica gel (4 × 60 cm column). Elution proceeded as follows: 60% E–H, 500 ml, nil; 75% E–H, 700 ml, 0.84 g (11%) of the trans adduct, **4**, which crystallized on standing. Recrystallization of this material from pentane at low temperature yielded the pure sample: mp 125–126°; ir (KBr) strong absorptions at 5.76, 5.95, 7.10, 7.65, 7.70, 8.17, 8.60, 9.03, 9.50, and 13.26 μ; nmr 1.25 (broadened t, 6 H), 3.09 (s, 3 H), 3.12 (s, 3 H), 3.45 (d, J = 13 Hz, 1 H), and 3.72–2.0 (m, 8 H).

Anal. Calcd for $C_{12}H_{10}N_2O_4$: C, 56.24; H, 7.87; N, 10.93. Found: C, 55.98; H, 7.68; N, 11.06.

Continued elution with 1.5 l. of 100% E gave 5.42 g (73%) of **3** as an oil which crystallized on standing. Low-temperature recrystallization of the solid from pentane yielded crystalline **3**: mp 54–55°; ir (KBr) 5.85, 6.01, 6.77, 7.77, 7.99, 8.37, 9.55 (all strong), and 10.55 (m) and 13.78 (m) μ; nmr 1.00–1.30 (overlapping triplets, 6 H), 2.25–2.60 (m, 2 H), 3.07 (s, 3 H), 3.22 (s, 3 H), 3.10–3.61 (m, 5 H), and 3.79 (d, 1 H, J = 9 Hz).

Anal. Calcd for $C_{12}H_{20}N_2O_4$: C, 56.24; H, 7.87; N, 10.93. Found: C, 56.25; H, 7.72; N, 10.81.

Finally, elution with 500 ml of 20% $CHCl_3$–ether yielded 0.75 g of recovered 1,3-dimethyluracil.

Cycloaddition of Ketene Diethyl Acetal to 1,3-Dimethyluracil-*5-d*. A solution of 0.75 g (5.3 mmol) of 1,3-dimethyluracil-*5-d*, 6.4 g (60 mmol) of ketene diethyl acetal, and 10 g of purified acetone in 200 ml of acetonitrile was irradiated 20 hr under N_2 purge in a base-washed apparatus. Work-up and chromatographic separation of products as described in the preparation of **3** and **4** (*vide supra*) gave 72 mg (5.30%) of the trans-fused adduct **4**: mp 122–125°; ir (KBr) 5.82, 5.98, 7.78, 8.19, 12.53, and 13.32 μ; nmr ($CDCl_3$, 100 MHz) 3.50 (m, 4 H), 3.30 (s, 1 H), 2.96 (s, 3 H), 2.20 (center of AB quartet, J = 11.9 Hz, 2 H), and 1.20 (m, 6 H). The major cis-fused product **3** (0.80 g, 59%) had mp 51–54° (pentane); ir (KBr) 5.88, 6.05, 6.80 (br), 7.80, 9.58 (br), 10.58, 12.18, and 13.30 μ; nmr ($CDCl_3$) 3.67 (s, 1 H), 3.35 (m, 4 H), 3.06 (s, 3 H), 2.94 (s, 3 H), 2.28 (center of AB quartet, J = 12.5 Hz, 2 H), and 1.64 (m, 6 H).

Base-Catalyzed Isomerization of the Trans Adduct 4 to 3. A solution of the 30.0 mg (1.7 mmol) of the trans adduct **4** in 1 ml of ether was placed on a column of 3 g of activity I basic alumina and the column eluted with 75% ether–hexane. Gas chromatographic analysis of the eluent showed a 95:5 mixture of **3** and **4**. The ir and nmr of the isomerization product were superimposable with that of **3**. Similar treatment of the cis-fused acetal led to no observable change as noted by ir, nmr, and glpc.

Acid-Catalyzed Cleavage of *tert*-Butyl Ether Adduct 5. To a solution of 200 mg of **5** in 25 ml of dry benzene was added 0.025 g of *p*-toluenesulfonic acid.[15] The mixture was refluxed for 4.5 hr, then cooled, slurried with 1 g of sodium bicarbonate and filtered, and finally the solvent was removed *in vacuo*. Chromatography of the light red oil on 25 g of silica gel (40 × 1.5 cm column) yielded the following results: $CHCl_3$, 100 ml, trace of starting ether; 2% CH_3OH–$CHCl_3$, 200 ml, nil; 5% CH_3OH–$CHCl_3$, 200 ml, 0.107 g (71%) of the alcohol which crystallized on standing. Recrystallization from ether gave white crystals of **7**: mp 86.5–88.0°; ir (KBr) strong absorptions at 2.89, 5.90, 6.08, 6.79, 7.89, 8.92, 9.20, 9.73, and 13.35 μ; nmr 2.8–2.0 (m, 2 H), 3.10 (s, 3 H), 3.71 (s, 3 H), 3.47 (s, 1 H), 3.2–3.4 (m, 2 H), 4.6–4.1 (m, 1 H).

Anal. Calcd for $C_8H_{12}N_2O_3$: C, 52.17; H, 6.57; N, 15.21. Found: C, 51.93; H, 6.56; N, 15.19.

Acid-Catalyzed Cleavage of *tert*-Butyl Ether 6. A stream of dry hydrogen chloride was passed through a solution of 0.25 g (0.0010 mol) of **6** in 25 ml of dry benzene for 8 hr.[16] Work-up and chromatography (5% CH_3OH–$CHCl_3$) as in the case of **5** yielded 0.125 g (66%) of crystalline alcohol **8**. Recrystallization of this material from ether–ethanol gave white crystals: mp 103–107°; ir (KBr) strong absorptions at 2.93, 5.90, 6.10, 6.75, 7.80, 8.85, 9.40, and 13.27 μ; nmr 3.5–2.0 (m, 3 H), 3.04 (s, 3 H), 3.22 (s, 3 H), 3.37 (s, 1 H), 4.1–3.6 (m, 1 H), 4.6–4.2 (m, 1 H).

Anal. Calcd for $C_8H_{12}N_2O_3$: C, 52.17; H, 6.57; N, 15.21. Found: C, 51.91; H, 6.61; N, 15.16.

Saponification of Acetates 9 and 9d′. A solution of 0.107 g (0.44 mmol) of acetate **9** in 5.0 ml of methanol was treated with 0.2 ml of 0.1 *M* methanolic sodium hydroxide at room temperature. After 10 min, tlc analysis indicated complete reaction. Removal of the solvent *in vacuo* below 40° yielded an oil which was chromatographed on 20 g of silica gel (5% MeOH–$CHCl_3$) to afford 0.080 g (98%) of crystalline alcohol identical with the product from acid-catalyzed hydrolysis of ether **5** (ir, nmr, and tlc).

Fifty milligrams (0.22 mmol) of exo acetate-*5-d*$_1$, **9d**, was taken up in 2 ml of CH_3OH, and 2 drops of 1 *N* NaOH in CH_3OH was added. After stirring at room temperature for 0.25 hr, tlc analysis showed only traces of acetate **9d** remaining, and the reaction was worked up as described in the saponification of **9** to afford 34.0 mg (83.5%) of alcohol **7d**: mp 86–88° (Et_2O); ir (KBr) 2.85, 5.84, 6.07, 7.85, 8.28, 8.50, 12.65, 13.28, and 13.62 μ; nmr ($CDCl_3$) 4.25 (m, 1 H), 3.65 (d, J = 5.2 Hz, 1 H), 3.54 (d, J = 5.0 Hz, 1 H), 3.16 (s, 3 H), 3.05 (s, 3 H), 2.53 (m, 1 H), and 2.15 (m, 1 H). Double irradiation at δ 4.25 gives 2.35 (center of AB quartet, J = 12.3 Hz, 2 H); mass spectrum *m/e* 185 (P, 0.15), 166 (P − HOD, 0.30), 167 (P − H_2O, 0.27), and 141 (100).

Saponification of Acetates 10. A solution of 0.106 g (0.44 mmol) of **10** in 5 ml of methanol was treated with 2 ml of 0.1 *M* methanolic sodium hydroxide. After the mixture was

(15) Attempted cleavage of this ether with dry hydrogen chloride in benzene led only to recovered starting material.

(16) This product could be obtained in comparable yield by refluxing the ether with 0.1 ml of *p*-toluenesulfonic acid in benzene for 0.5–1.0 hr.

Table III. Final Coordinates and Anisotropic Thermal Parameters for **10**[a]

Atom	x	y	z	β_{11}	β_{22}	β_{33}	β_{12}	β_{13}	β_{23}
C(1)	0.3377 (7)	0.2878 (5)	0.8282 (7)	0.01279 (94)	0.00566 (50)	0.01114 (96)	0.00086 (53)	0.00037 (77)	0.00012 (56)
N(2)	0.4277 (5)	0.2226 (4)	0.7418 (6)	0.01137 (74)	0.00642 (42)	0.01192 (84)	0.00028 (44)	0.00076 (62)	0.00045 (48)
C(3)	0.4725 (7)	0.2462 (6)	0.6003 (8)	0.01056 (90)	0.00791 (60)	0.01276 (92)	0.00081 (62)	0.00064 (80)	0.00096 (70)
N(4)	0.4185 (6)	0.3327 (5)	0.5314 (6)	0.01136 (73)	0.00719 (45)	0.01029 (78)	0.00119 (47)	0.00131 (61)	0.00047 (48)
C(5)	0.3121 (7)	0.3910 (6)	0.5868 (7)	0.01359 (97)	0.00740 (59)	0.01021 (99)	0.00100 (56)	0.00247 (80)	0.00066 (65)
C(6)	0.2506 (8)	0.3628 (6)	0.7371 (8)	0.01328 (94)	0.00627 (51)	0.01231 (100)	0.00050 (54)	0.00231 (77)	0.00034 (59)
C(7)	0.2837 (8)	0.4468 (6)	0.8589 (7)	0.01423 (102)	0.00817 (61)	0.01218 (104)	0.00148 (64)	0.00011 (82)	0.00210 (64)
C(8)	0.4006 (8)	0.3779 (6)	0.9169 (8)	0.01535 (106)	0.00753 (58)	0.01078 (98)	0.00138 (64)	0.00113 (83)	0.00032 (62)
C(9)	0.4827 (9)	0.1300 (6)	0.8126 (10)	0.01863 (128)	0.00614 (56)	0.02110 (145)	0.00042 (67)	0.00190 (106)	0.00373 (75)
O(10)	0.5571 (6)	0.1944 (4)	0.5348 (6)	0.01745 (80)	0.00801 (44)	0.01786 (91)	0.00382 (47)	0.00548 (68)	0.00119 (47)
C(11)	0.4730 (9)	0.3601 (8)	0.3812 (8)	0.02052 (128)	0.01239 (82)	0.01141 (111)	0.00036 (83)	0.00546 (99)	0.00149 (77)
O(12)	0.2676 (6)	0.4628 (4)	0.5169 (6)	0.02076 (90)	0.00912 (48)	0.01525 (82)	0.00329 (52)	0.00017 (67)	0.00186 (52)
O(13)	0.5274 (5)	0.4124 (4)	0.8492 (5)	0.01363 (66)	0.00719 (36)	0.01145 (67)	0.00131 (40)	0.00114 (54)	0.00107 (40)
C(14)	0.6456 (8)	0.3658 (6)	0.8945 (9)	0.01463 (112)	0.00731 (59)	0.01486 (120)	0.00111 (64)	0.00543 (94)	0.00033 (73)
C(15)	0.7668 (8)	0.3971 (7)	0.7964 (10)	0.01483 (118)	0.01106 (80)	0.02216 (161)	0.00201 (79)	0.00218 (109)	0.00250 (91)
O(16)	0.6471 (6)	0.3080 (4)	0.9992 (7)	0.01936 (91)	0.00972 (51)	0.01943 (96)	0.00106 (51)	0.00469 (74)	0.00501 (57)

[a] Standard deviations are given in parentheses for the least significant figure. Thermal motion is described by the relation $\exp[-(\beta_{11}h^2 + \beta_{22}k^2 + \beta_{33}l^2 + 2\beta_{12}hk + 2\beta_{13}hl + 2\beta_{23}kl)]$.

stirred at room temperature for 20 min, the solvent was removed *in vacuo* at 40° and the residue chromatographed on 20 g of silica gel to afford 0.062 g (72%) of an oil which crystallized upon seeding with alcohol from acid-catalyzed cleavage of *tert*-butyl ether **6**. The recrystallized material was identical with **8** (ir, nmr, tlc).

Saponification of Endo Acetate-*5-d*, 10d. Saponification of 50 mg (0.22 mmol) of acetate **10d** as described in the preceding experiment afforded 37.1 mg (91%) of endo deuterated alcohol **8**: mp 102–106°; ir (KBr) 2.88, 5.77, 6.08, 6.74, 7.78, 8.23, 8.48, 9.08, 13.28, and 14.39 μ; nmr ($CDCl_3$) 4.38 (m, 1 H), 3.95 (broad d, J = 5 Hz, 1 H), 3.84 (d, J = 5 Hz, 1 H), 3.14 (s, 3 H), 2.96 (s, 3 H), 2.72 (center of d of d, J = 12.8 Hz, J' = 6.1 Hz, 1 H), and 2.16 (center of d of d, J = 12.8 Hz, J' = 3.9 Hz, 1 H). Irradiation at δ 4.38 gave 2.40 (center of AB, J = 12.8 Hz, 2 H); mass spectrum *m/e* 185 (P, 1.6), 166 (P − HOD, 0.04), 167 (P − H_2O, 0.04), and 141 (100).

Hydrolysis of Diethyl Acetal (3). A solution of 0.50 g (1.95 mmol) of **3** was stirred at room temperature for 10 min with 5.0 ml of 9:1 trifluoroacetic acid–water. After removal of solvent *in vacuo*, the residue was dissolved in 20 ml of ether, treated with solid sodium bicarbonate and sodium sulfate, and finally filtered. Removal of the ether *in vacuo* gave an oil which was chromatographed on 30 g of Florisil (40 × 1.5 cm column). Elution proceeded as follows: 50% E–H, 200 ml, 0.10 g of recovered acetal; 100% E, 100 ml, 0.10 g of a mixture of acetal and cyclobutanone; 100% E, 300 ml, 0.205 g of cyclobutanone for a yield of 72% based on starting ketal consumed. Molecular distillation (100°, 0.01 mm) gave a colorless oil:[17] ir (KBr) strong absorptions at 5.57, 5.87, 6.00, 6.78, 7.07, 7.84, 10.23, and 13.38 μ; nmr 3.17 (s, 3 H), 3.23 (s, 3 H), 3.95–3.32 (m, 3 H), 4.75–4.53 (6 line multiplet, 1 H). The phenylhydrazone was formed in the standard fashion and recrystallized from ethanol–ethyl acetate, mp 208–210°.

Anal. Calcd for $C_{14}H_{14}N_6O_6$: C, 61.75; H, 5.92; N, 20.57. Found: C, 62.13; H, 5.91; N, 20.80.

Oxidation of Alcohol 7. A solution of 0.065 g (0.8 mmol) of trifluoroacetic acid in 1 ml of benzene was added to a mixture of 0.285 g (0.6 mmol) of **7**, 3.0 ml of dry dimethyl sulfoxide, 50 ml of benzene, 0.13 ml of pyrimidine, and 0.95 g (47 mm) of dicyclohexylcarbodiimide. The solution was stirred for 12 hr at room temperature while protected from moisture, then diluted with 25 ml of ethyl acetate, and the precipitate of dicyclohexylurea was filtered. The filtrate was concentrated *in vacuo* and the dimethyl sulfoxide removed at 40° under high vacuum. The orange-red, oily residue was chromatographed on 10 g of Florisil to yield 0.095 g (34%) of **11** as the only identifiable product. This material was identical by ir, nmr, tlc, and glpc with the cyclobutanone from hydrolysis of the acetal.

Oxidation of Alcohol 8. In a manner analogous to that above, 0.72 g (3.9 mmol) of **8** in a mixture of 5.0 ml of dry dimethyl sulfoxide, 8.0 ml of benzene, 0.33 ml (0.4 mmol) of pyridine, and 2.4 g (11.7 mmol) of dicyclohexylcarbodiimide was treated with 0.10 ml (0.2 mmol) of trifluoroacetic acid and the mixture stirred for 12 hr under anhydrous conditions. Work-up as previously described yielded 0.265 g (37%) of cyclobutane **11**, identical by ir, nmr, tlc, and glpc with material from acetal hydrolysis.

Comparison of Rates of Acid-Catalyzed Cleavage of *tert*-Butyl Ethers 5 and 6. A solution of *ca.* 10 mg each of *tert*-butyl ethers **5** and **6** and 10 mg of octadecane (internal concentration standard) in 5 ml of benzene was treated with 2 mg of *p*-toluenesulfonic acid and stirred at reflux. Aliquots of 0.25 ml were withdrawn at 0.25-hr intervals, washed with aqueous $NaHCO_3$, and dried over Na_2SO_4, and the composition of the ether mixture determined by glc analysis. The analytical method was proved by similar work-up and glc analysis of a mixture of known composition of **5** and **6** plus octadecane; analysis was judged reliable to within 3%. The ratio of **5** to **6** rose from 1.15 initially to 3.22 during the first 45 min; after 1 hr, 32.1% of the *exo*-**5** and 11.2% of the endo ether **6** remained.

In order to ascertain that the more rapid loss of endo ether **6** was not due to an epimerization process, the reaction mixture was quenched after 1 hr by addition of solid $NaHCO_3$ (43% of initial 20 mg of ethers remained at this time), and the filtered reaction mixture was stripped to 0.5 ml *in vacuo*. Preparative tlc allowed isolation of the product mixture of alcohols **7** and **8**. The alcoholic fraction was taken up in 1 ml of benzene–pyridine, 0.1 ml of acetic anhydride was added, and the mixture stirred at reflux until no alcohol remained (tlc analysis). The reaction mixture was washed with aqueous $NaHCO_3$, dried over Na_2SO_4, and analyzed by glc. The only products were exo acetate **9** (35%) and endo acetate **10** (65%), thus confirming the more rapid cleavage of the endo ether **5**.

Competitive Acetylation of Alcohols 7 and 8. To a solution of 25 mg each of alcohols **7** and **8** (0.272 mmol total alcohol) in 3.0 ml of 4:1 benzene–pyridine was added 0.5 ml of a solution of 0.65 ml of acetic anhydride in 25 ml of benzene (0.135 mmol of anhydride added). The mixture was stirred at 25°; at 15-min intervals, 0.25-ml aliquots were withdrawn, washed with 0.5 ml of water, and dried over Na_2SO_4, and the alcohol-free extract was analyzed by gas chromatography. The ratio of exo acetate **9** to endo acetate **10** was found to be 85:15 for the first hour; after 8 hr, the ratio was 79:21. Work-up of the remaining reaction mixture after the 8-hr sampling and preparative tlc separation of the reaction products, followed by ir analysis, confirmed the identity of the acetates **9** and **10**.

The analytical method was proven by preparation of a mixture of acetates **9** and **10** of known proportion in benzene–pyridine solution, addition of acetic anhydride, work-up as described above, and glc analysis. The analyzed ratio of the acetates was found to be constant to within 3%.

1,3-Dimethyluracil-*5-d*. A suspension of 3.0 g (13.6 mmol) of 5-bromo-1,3-dimethyluracil in 100 ml of 1:1 deuterium oxide–methanol-*O-d* containing 20 mg of 10% Pd C catalyst was placed under deuterium at 1 atm until deuterium uptake ceased (*ca.* 5 hr). The reaction mixture was filtered and concentrated to *ca.* 5 ml at 14 mm; the concentrate was diluted to 20 ml with ordinary water, rendered basic by the addition of 10 ml of 10% aqueous NaOH solution, and extracted with chloroform (3 × 25 ml). Removal of

(17) The cyclobutanone **11** was found to be hygroscopic as a crystalline hydrate formed upon standing in moist air or treatment with water. The hydrate which could be recrystallized from water had: mp 103–104°; ir (KBr) strong absorptions at 2.95, 3.08, 5.89, 6.06, 8.42, 8.71, 9.49, 9.97, and 13.31 μ; nmr (D_2O)-δ 2.91–2.10 (m, 2 H), 3.05 (s, 3 H), 3.15 (s, 3 H), 3.6–3.2 (m, 1 H), 4.05 (d, J = 9 Hz, 1 H).

Table IV. Bond Lengths (Å) for **10**[a]

C(1)–N(2)	1.441 (8)	C(5)–C(6)	1.502 (10)
C(1)–C(6)	1.530 (10)	C(5)–O(12)	1.212 (8)
C(1)–C(8)	1.551 (10)	C(6)–C(7)	1.581 (10)
N(2)–C(3)	1.361 (8)	C(7)–C(8)	1.537 (10)
N(2)–C(9)	1.474 (9)	C(8)–O(13)	1.435 (9)
C(3)–N(4)	1.396 (9)	O(13)–C(14)	1.357 (9)
C(3)–O(10)	1.212 (8)	C(14)–C(15)	1.512 (11)
N(4)–C(5)	1.373 (9)	C(14)–O(16)	1.201 (9)
N(4)–C(11)	1.473 (9)		

[a] Standard deviations are derived from the least-squares variance–covariance matrix and are given in parentheses for the least significant figure.

Table V. Bond Angles (deg) for **10**[a]

N(2)–C(1)–C(8)	119.5 (6)	C(6)–C(5)–O(12)	120.5 (7)
C(6)–C(1)–N(2)	116.2 (5)	N(4)–C(5)–O(12)	121.5 (7)
C(6)–C(1)–C(8)	89.2 (5)	C(5)–C(6)–C(1)	114.3 (6)
C(1)–N(2)–C(3)	122.6 (6)	C(5)–C(6)–C(7)	110.4 (6)
C(1)–N(2)–C(9)	199.3 (6)	C(1)–C(6)–C(7)	89.1 (5)
C(3)–N(2)–C(9)	117.9 (6)	C(6)–C(7)–C(8)	87.8 (5)
N(2)–C(3)–N(4)	118.1 (7)	C(1)–C(8)–C(7)	89.7 (5)
N(2)–C(3)–O(10)	121.5 (7)	C(1)–C(8)–O(13)	111.5 (6)
N(4)–C(3)–O(10)	120.4 (7)	C(7)–C(8)–O(13)	107.3 (6)
C(5)–N(4)–C(3)	125.7 (6)	C(8)–O(13)–C(14)	116.6 (6)
C(5)–N(4)–C(11)	116.7 (6)	O(13)–C(14)–C(15)	111.8 (7)
C(3)–N(4)–C(11)	117.5 (6)	O(13)–C(14)–O(16)	121.9 (8)
C(6)–C(5)–N(4)	118.0 (7)	C(15)–C(14)–O(16)	127.3 (8)

[a] Standard deviations are derived from the least-squares variance–covariance matrix and are given in parentheses for the least significant figure.

solvent from the dried extract left 1.60 g (84%) of chromatographically pure 1,3-dimethyluracil-*5-d*, mp 118–120°. The isotopic purity was judged to be greater than 98% by nmr analysis: ir (KBr) 5.88, 6.10, 7.51, 8.21, 8.82, 10.67, 12.90, and 13.17 μ; nmr ($CDCl_3$, 60 MHz) 7.18 (s, 1 H), 3.28 (s, 3 H), and 3.25 (s, 3 H).

Crystallographic and X-Ray Data. Crystals of the dimethyluracil–olefin adduct acetate (mp 75–77°) were obtained by slow crystallization from an ether–pentane solution. Photographic investigation revealed monoclinic diffraction symmetry and the systematic absences for $h0l$ (absent if $h + l = 2n + 1$) and $0k0$ (absent if $k = 2n + 1$) uniquely require space group $P2_1/n$ (C_{2h}^5, alternate setting). Precise lattice constants were obtained by a least-squares fit of 12 strong reflections measured at both $+\theta$ and $-\theta$ to eliminate problems of instrumental zeroing on a Hilger–Watts four-circle diffractometer using Cu $K\alpha_1$ radiation (1.54056 Å). They are: $a = 9.643$ (5), $b = 13.223$ (6), and $c = 8.848$ (6) Å and $\beta = 89.87$ (2)°. The measured density of 1.30 g/cm³ agreed well with a calculated density of 1.33 g/cm³ for $Z = 4$; hence there is one molecule of composition $C_{10}H_{14}N_2O_4$ per asymmetric unit.

X-Ray intensity data were collected using Ni-filtered Cu $K\alpha$ radiation with a takeoff angle of ~4° on a computer-controlled Hilger–Watts four-circle diffractometer. The crystal specimen was roughly cubical with an average dimension 0.3 mm. All independent reflections for which $\theta \leq 55°$ were collected with a θ–2θ scan technique. All scans were of variable increment to allow for spectral dispersion. A background of one-half the time of the scan was measured at the extremes of the scan. Three standard reflections were monitored every 100 reflections throughout data collection. These showed no appreciable decrease in intensity. No absorption corrections were deemed necessary. The intensity data were reduced to a set of relative squared amplitudes, $|F_o|^2$, by application of the standard Lorentz and polarization factors. Data were retained if $|F_o| \geq 3\sigma(F_o)$ where $\sigma(F_o)$ was computed from $\{[I + \sigma(I)]/\mathrm{Lp}\}^{1/2} - \{I/\mathrm{Lp}\}^{1/2}$ [18] and $\sigma(I)$ was computed from {total count + background count + 0.05 (total count)² + 0.05 (background count)²}$^{1/2}$. A total of 1226 reflections were judged observed by this procedure (65% of total).

Determination and Refinement of Structure. The observed structure factor amplitudes ($|F_o|^2$) were converted to normalized structure factors ($|E|$) by removing the angular dependence of the reflections. The normalized structure factors with magnitude greater than 1.4 were assigned phases by routine use of the program MULTAN.[19] The initial E synthesis revealed all C, N, and O atoms, save the four atoms of the acetate group. These were revealed in the subsequent F synthesis.[20] Full-matrix least-squares refinements with anisotropic temperature factors for all atoms smoothly converged to an unweighted residual of 10.7%.[21] A difference Fourier showed all non-methyl hydrogens but these were ill-behaved in subsequent refinement. Figure 1 is a computer generated drawing of the X-ray model.[22] Table III lists the fractional coordinates and thermal parameters of the nonhydrogen atoms. Tables IV and V give selected bond distances and angles with their associated errors. No abnormally short intermolecular distances were present.

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