Exploratory Investigations Probing a Preparatively Versatile, Pyridinium Salt Photoelectrocyclization−Solvolytic Aziridine Ring Opening Sequence

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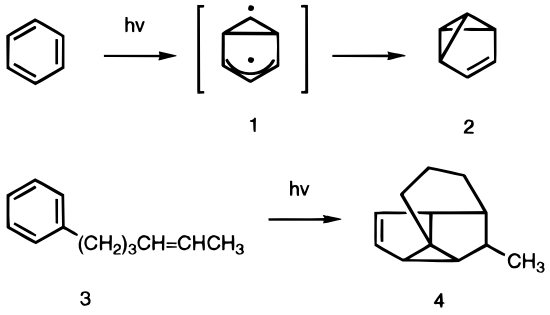
A novel pyridinium salt photoelectrocyclization−nucleophilic bicyclic aziridine ring opening reaction sequence has been investigated in order to determine its preparative potential. *N*-Alkylpyridinium perchlorates were found to undergo photoinduced electrocyclization upon irradiation in nucleophilic solvents, such as H_2O and MeOH, to efficiently produce 6-alkyl-6-azabicyclo[3.1.0]hex-2-en-4-yl alcohols and ethers. The bicyclic aziridine photoproducts react with a number of different nucleophiles (*e.g.*, H_2O, MeOH, AcOH, AcSH) under acid-catalyzed conditions to produce 5-(nucleophile-substituted)-4-(alkylamino)cyclopenten-3-yl alcohols and ethers. The aziridine ring opening processes are both regioselective and stereoselective, yielding *trans,trans*-trisubstituted cyclopentenes exclusively, apparently as a consequence of the operation of an SN_2 mechanism. The effects of C-alkyl substitution on the regiochemistry of the pyridinium cation photocyclization reaction were briefly probed, and a method was developed to produce *trans,cis*-trisubstituted cyclopentenes by use of this tandem preparative sequence.

Introduction

Photochemistry continues to be a source of unusual organic transformations, some of which have preparative potential. Owing to numerous, thorough photophysical and photochemical studies conducted in the past, it is now easy to understand and often predict the electronic and redox properties of photoexcited organic substances. The special properties of electronic excited states are responsible for the unique and interesting chemistry found in photochemical transformations which, for the most part, have no counterparts in electronic ground states. Photochemical [2 + 2]-cycloadditions,[1] dienone type A rearrangements[2] and single electron transfer (SET) induced amine−enone β-additions[3] are but a few of the large number of examples of interesting chemical processes which occur when organic substances are irradiated with light in the UV−vis regions.[4,5]

Among the most fascinating organic photochemical reaction are those that generate small-ring compounds. As a consequence of the ring strain present in these photoproducts, secondary reactions involving ring cleavage often occur with great facility. Tandem photochemical−ground state reaction sequences of this type can be preparatively useful. A popular example of this is the deMayo reaction in which [2 + 2]-photocycloaddition between an olefin and enolizable β-diketone generates a 2-hydroxycyclobutyl ketone. Facile retro-aldol cleavage then occurs to yield a 1,5-diketone.[6]

Another group of interesting strained ring forming photochemical reactions consists of the benzene valence bond isomerization processes. A flurry of research activity in the 1960−70 era uncovered a number of interesting photoreactions of benzene and its alkyl-substituted and condensed ring derivatives. An interesting example of these valence bond isomerization processes is the photochemical conversion of benzene to benzvalene (**2**) by a pathway involving formation and collapse of the intermediate diradical **1**. An intriguing observation by Morrison and Ferree[8] that trapping of this diradical by a tethered olefin grouping leads to formation of a meta intramolecular adduct (**3** → **4**) spawned a flurry of activity which resulted in a wide variety of synthetic applications of this excited state chemistry.[9]



Two intriguing observations made early in this area which have garnered far less attention in recent years are found in the independent efforts of Berson and Wilzbach and Kaplan. In 1966, Kaplan and Wilzbach[10] described the photochemical 1,3-addition of alcohols to

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(1) Weedon, A. C. In *Synthetic Organic Photochemistry*; Horspool, W. M., Ed.; Plenum Press: New York, 1984; Chapter 2.

(2) Schaffner, K.; Demuth, M. In *Rearrangements in Ground and Excited States*; deMayo, P., Ed.; Academic Press: New York, 1980; Vol. 3, Essay 18.

(3) Yoon, U. C.; Mariano, P. S.; Givens R. S.; Atwater, B. W. In *Advances in Electron Transfer Chemistry*; Mariano, P. S., Ed.; JAI Press: Greenwich, 1994; Vol. 4, Chapter 4.

(4) See, for example: *Organic Photochemistry and Photobiology*; Horspool, W. M., Song, P. S., Eds.; CRC Press: New York, 1994.

(5) See, for example: *Photoinduced Electron Transfer*; Fox, M. A., Chanon, M., Eds.; Elsevier: Amsterdam, 1988.

(6) Weedon, A. C. In *Organic Photochemistry and Photobiology*; Horspool, W. M., Song, P. S., Eds.; CRC Press: New York, 1994; pp 670−684.

(7) Gilbert, A. In *Organic Photochemistry and Photobiology*; Horspool, W. M., Song, P. S., Eds.; CRC Press: New York, 1994; pp 229−236.

(8) Morrison, H.; Ferree, W. L. *J. Chem. Soc., Chem. Commun.* **1969**, 268.

(9) DeKeukeleire, D. *Aldrichchimica Acta* **1994**, *27*, 59. Wender, P. A.; Siggel, L.; Nuss, J. M. *Organic Photochemistry*; Padwa, A., Ed.; Marcel-Dekker: New York, 1989; Vol. 10, Chapter 4.

(10) Kaplan, L.; Ritscher, J. S.; Wilzbach, K. E. *J. Am. Chem. Soc.* **1966**, *88*, 2881.

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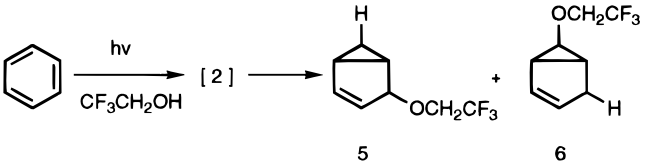
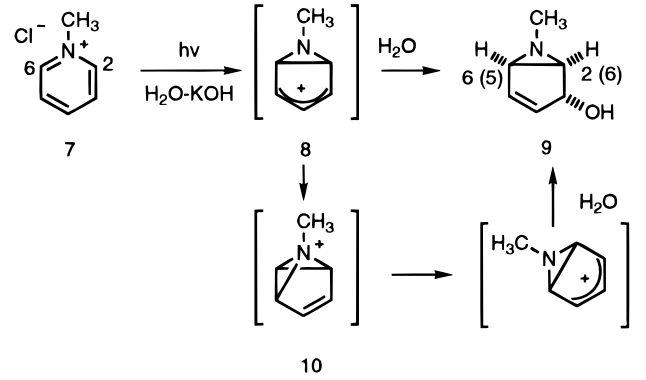
benzenes. One example is found in the formation of the bicyclic ether adducts **5** and **6** when a benzene in trifluoroethanol solution is irradiated. A mechanism involving formation and alcoholysis of benzvalene was proposed by Kaplan and Wilzbach, later challenged by Bryce-Smith and his co-workers,[11] and finally proven by Berson and Hasty[12] through an elegant use of D-labeling techniques. Clearly, this is yet another example of a preparatively useful tandem photochemical−ground state reaction sequence, involving formation and ring opening of a strained ring intermediate.



5 6

Of greater relevance to the studies described below is another early (1972) report by Wilzbach and Kaplan[13] describing the photochemistry of *N*-methylpyridinium chloride (**7**) and its simple ring methyl-substituted derivatives. These workers observed that irradiation of **7** in 0.05 M aqueous KOH solution leads to production (no yields given) of the bicyclic aziridinyl alcohol **9** as a single exo-stereoisomer. The mechanism proposed for this transformation (supported by ring alkyl labeling experiments) involves initial photoproduction of the bicyclic cation **8** followed by competitive capture of this cation by water and rearrangement *via* the aza benzvalene cation **10** (Scheme 1).

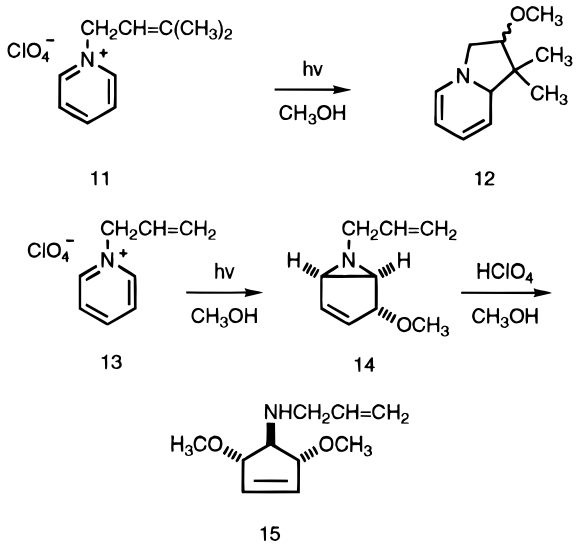
Scheme 1



7 8 9

10

This remarkable photochemical process has gone relatively unnoticed since the time of its discovery in the 1970s. We became acquainted with this area of photochemistry in the 1980s during the course of studies which pointed out the divergent photochemical behaviors of *N*-allylpyridinium perchlorates.[14] For example, we observed that irradiation of *N*-prenylpyridinium perchlorate (**11**) in methanol solution leads to production of the unstable bicyclic dihydropyridine **12**. This process occurs by a well-documented pathway involving SET from the olefinic π-system to the excited pyridinium chromophore followed by methanol addition to the olefin cation radical and diradical coupling. In contrast, we observed that irradiation of *N*-allylpyridinium perchlorate (**13**) under identical conditions does not produce a related indolizidine product. Rather **13** is efficiently (86%) transformed upon irradiation in methanol (followed by basic workup) to the stereochemically pure *trans*,*trans*-aminodimethoxycyclopentene **15**. A careful investigation of this process showed that **14** is produced initially and that **15** (and its *N*-methyl analog) originates by stereo- and regiocontrolled methanolysis of this intermediate bicyclic aziridine (and its *N*-methyl analog) under the acidic methanol condition attending its formations.



11 12

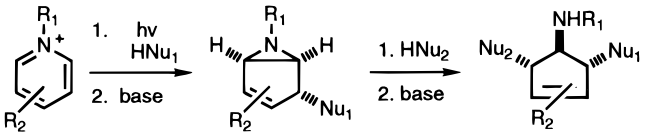
13 14

15

A comparison of these processes shows that pyridinium cation excited states react by SET pathways when linked to a good (low $E_{1/2}(+)$) electron donor (*e.g.*, trisubstituted alkene) but that the Wilzbach−Kaplan-like, electrocyclization pathway dominates in the absence of a strong SET-driving force (*e.g.*, poor monosubstituted alkene donor).

In the period since these initial observations were made, no attention has been given to the pyridinium salt photocyclization process. Recently, our interests returned to this area when we recognized the potential synthetic power of tandem sequences involving (1) photoinduced cyclization of pyridinium cations, (2) stereocontrolled nucleophile addition to produce bicyclic aziridines, and (3) stereocontrolled nucleophilic cleavage of bicyclic aziridine to produce highly functionalized aminocyclopentenes (Scheme 2). We believed that, when

Scheme 2

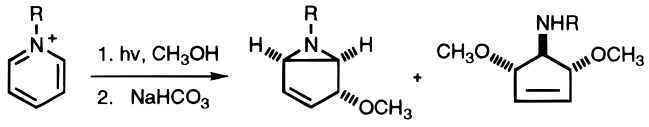


conducted in a proper manner, these sequences could be employed to prepare functionally rich cyclopentenes with high degrees of regiochemical and stereochemical control (Scheme 2). With this view in mind, we recently embarked on an exploratory study to probe the pyridinium salt photocyclization process as well as the ring cleavage chemistry of the bicyclic aziridine photoproducts. The results of this effort which demonstrate the synthetic versatility of this chemistry are described below.

(11) Bryce-Smith, D.; Gilbert, A.; Longuett-Higgins, H. C. *J. Chem. Soc., Chem. Commun.* **1967**, 240.
(12) Berson, J. A.; Hasty, N. M. *J. Am. Chem. Soc.* **1971**, *93*, 1549.
(13) Kaplan, L.; Pavlik, J. W.; Wilzbach, K. E. *J. Am. Chem. Soc.* **1972**, *94*, 3283.
(14) Yoon, U. C.; Quillen, S. L.; Mariano, P. S.; Swanson, R.; Stavinoha, J. L.; Bay, E. *J. Am. Chem. Soc.* **1983**, *105*, 1204.
(15) Mariano, P. S. *Acc. Chem. Res.* **1983**, *16*, 130.

Results and Discussion

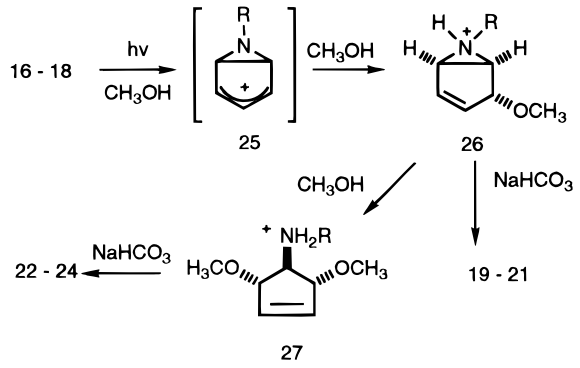
Pyridinium Salt Photoelectrocyclization Reactions. One of the first aims of this exploratory investigation was to assess the scope and possible limitations of the pyridinium salt photoelectrocyclization reaction discovered in the early work of Wilzbach and Kaplan.[13,14] For this purpose, the pyridinium perchlorates **16**−**18** were prepared by use of standard methods (see Experimental Section) and subjected to photochemical study. As anticipated,[13,14] irradiation (λ > 220 nm, 20 °C, N_2) of the N-propyl substrate **16** (9 mM) in methanol, followed by a workup procedure involving addition of solid $NaHCO_3$ to the photolysate, concentration *in vacuo*, and chromatographic separation on Fluorisil, led to isolation of two major products identified as the bicyclic aziridine **19** (33%) and 4-aminocyclopentene **22** (22%). Structural and stereochemical assignments to these substances were made on the basis of characteristic spectroscopic data and comparisons of the data to the *N*-methyl and *N*-allyl analogs reported earlier.[14] Photoreactions of the related amide- and alcohol-containing substrates **17** and **18** followed by workup under the conditions described above and silica gel chromatography provided the respective bicyclic aziridines **20** (22%) and **21** (47%) and the aminocyclopentenes **23** (58%) and **24** (22%).



16 (R = nC_3H_7)	19 (33%)	22 (22%)
17 (R = CH_2CONH_2)	20 (22%)	23 (58%)
18 (R = CH_2CH_2OH)	21 (47%)	24 (22%)

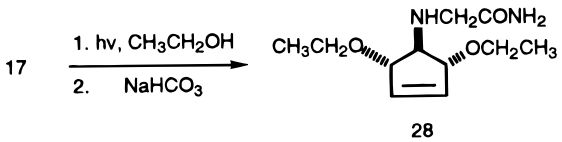
Product formation in these processes is a consequence of the mechanistic pathways described earlier.[13,14] Accordingly, photolysis of the pyridinium salts induces electrocyclization to generate the bicyclic cations **25** (Scheme 3) which are then trapped by the nucleophilic

Scheme 3



solvent in an exo-stereocontrolled manner to produce the bicyclic aziridinium salts **26.** Under the acidic conditions of their formation, the salts **26** partially undergo regiocontrolled (SN_2 and not SN'_2) methanol promoted ring opening to produce the protonated aminocyclopentenes **27**. Addition of base prior to concentration of the photolysate allows partial survival of the bicyclic aziridine primary photoproducts. In accord with our earlier observation,[14] when the photolysates are first concentrated and then treated with base, the aminocyclopentenes are the exclusive (55−80%) products isolated.

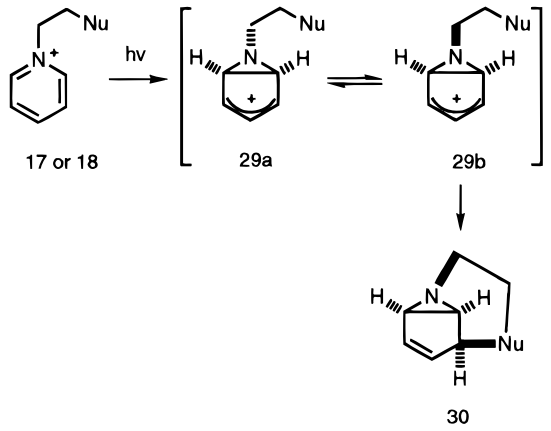
An interesting aspect of the photochemistry of pyridinium perchlorates **17** and **18** is that products arising by internal capture of the bicyclic cation **25** with the tethered amide and alcohol nucleophilic groups are not formed. An attempt to enhance the probability of internal nucleophile attack has uncovered another intriguing feature of this photoprocess. We reasoned that the use of less nucleophilic solvents for these photoreactions would provide a better opportunity for internal trapping of the allyl cation moiety in intermediates **25**. However, the results suggest that this cannot be accomplished and that the efficiency of the photoreactions are highly sensitive to the solvent system used. Thus, while irradiation of the (carbamoylmethyl)pyridinium perchlorate **17** in ethanol (no base added before concentration of the photolysate) leads to successful production of the diethoxyaminocyclopentene **28**, photoelectrocyclization reactions of this substrate do not occur in isopropyl alcohol or trifluoroethanol solvent systems. Moreover, the efficiency of bicyclic aziridine **19** production *via* irradiation of the *N*-propyl substrate **16** falls dramatically as the proportion of methanol in methanol−acetonitrile solvent systems is decreased (*e.g.*, 15% of **19** in 1:3 MeOH−MeCN).



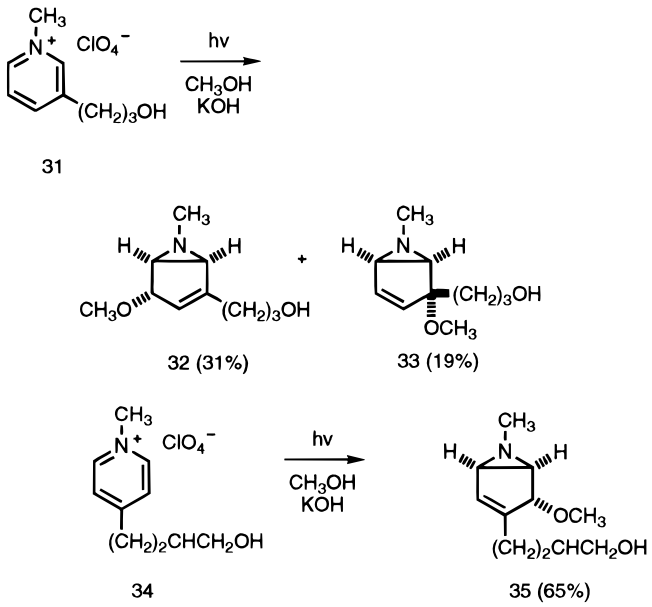
A number of factors may be responsible for these reactivity patterns. For example, a highly polar solvent (H_2O > MeOH > EtOH > iPrOH or MeCN) might be required in order for the rate of electrocyclization of the pyridinium salt excited state to be competitive with decay to ground state. Alternatively, the effect of solvent nucleophilicity may be an important factor since it is expected (see below) that a dark electrocyclic ring opening pathway could be available to return the photoproduced cation intermediate **25** to the pyridinium salt ground state. In this case, high concentration of good nucleophiles (*e.g.*, solvent MeOH or H_2O) may be needed to bring the efficiency of bicyclic aziridine formation into the detectable region.

In this light, the absence of products arising by internal capture by amide and alcohol nucleophiles in the photochemistry of **17** and **18** is still curious. One possible reason for this might lie in ring strain and nucleophile orientation effects in bicyclic allyl cations **29** arising from the N-nucleophile-tethered substrates **17** and **18**. Thus cyclizations in **29** would require endo-conformers **29b** and would generate somewhat strained tricyclic products **30** (Scheme 4). In order to evaluate the importance of these restrictions, the *N*-methylpyridinium salts **31** and **34**, both of which contain more favorably located nucleophilic alcohol functions, were prepared and subjected to photochemical study. Irradiation of **31** in methanol containing KOH (3.8 mM), followed by concentration, chloroform trituration (see below), and Fluorisil chromotographic separation, led to isolation of two products characterized as the bicyclic aziridines **32** (31%) and **33** (19%). The latter substance is a single diastereomer to which we have assigned the exo-methoxy stereochemistry on the basis of mechanistic reasoning alone. Finally, analysis of the crude photolysate by ^1H NMR spectroscopy and TLC shows that **32** and **33** are the exclusive major

Scheme 4

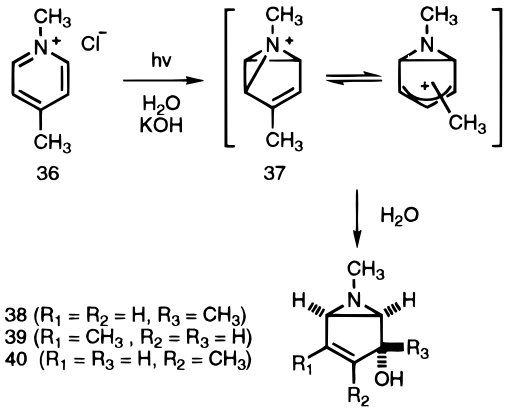


products formed upon irradiation of **31** in a 3:2 ratio which is unchanged by treatment with acidic methanol. In a similar manner, irradiation of the 4-substituted pyridinium salt **34** in KOH−MeOH (7.1 mM) followed by the same workup and separation procedures yields the bicyclic aziridine **35** (65%) exclusively as a 1:1 mixture of diastereomers. Clearly, internal capture of the intermediate bicyclic allyl cations produced in photoreactions of **31** and **34** does not compete with intermolecular addition of methanol. Thus, even in ideal cases (in terms of orientation and ring strain) such as these, photoelectrocyclization leads to formation of solvent−pyridinium salt adducts.

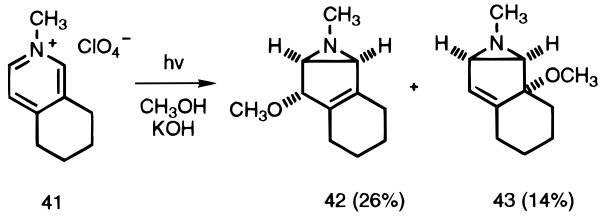


The high degrees of regioselectivity observed in the photoreactions of **31** and **34** are surprising. Kaplan and Wilzbach,[13] in their early photochemical studies with simple polymethylated pyridinium salts, observed significant degrees of ring scrambling. An example of this is found in the photoreaction of 1,4-dimethylpyridinium chloride (**36**) in aqueous base which is reported to yield a 1:1:2 mixture of the regioisomeric bicyclic aziridines **38**, **39**, and **40**. This was attributed to partial formation and ring opening of azabenvalene **37** (Scheme 5). The behavior of the hydroxypropyl derivative **34** is quite different; the exclusive formation of bicyclic aziridine **35** suggests that a benzvalene intermediate related to **37** does not intervene in this photoprocess. Finally, yet

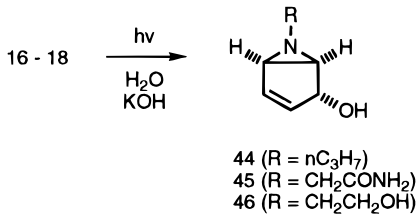
Scheme 5



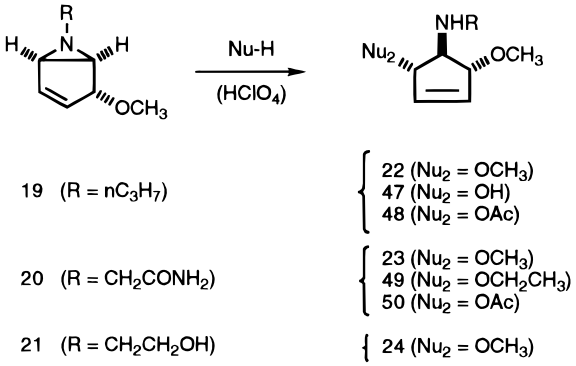
another example of regioselective photoelectrocyclization is seen in the transformation of the tetrahydroisoquinolinium perchlorate **41** upon irradiation in KOH−MeOH to the tricyclic aziridines **42** (26%) and **43** (14%).



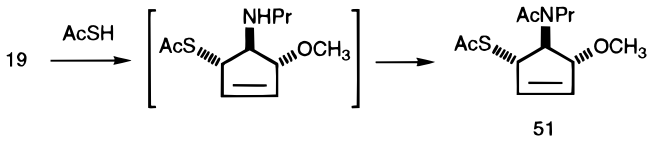
As shown above, preparatively useful conversions of pyridinium salts to bicyclic aziridine adducts can be accomplished by conducting the photoreactions under basic conditions. In these cases, acid-catalyzed opening of the aziridine photoproduct by solvent is prevented. Further examples, demonstrating the synthetic potential of this procedure, are found in the photoreactions of the pyridinium salts **16**−**18** in methanolic KOH solution (4−15 mM) in which the respective bicyclic aziridines **19**−**21** are efficiently produced in purified yields of 53%, 90%, and 98%, respectively. Also, the bicyclic aziridinyl alcohols **44**−**46** are produced selectively when the pyridinium salts **16**−**18** are irradiated in aqueous KOH (4−5 mM).



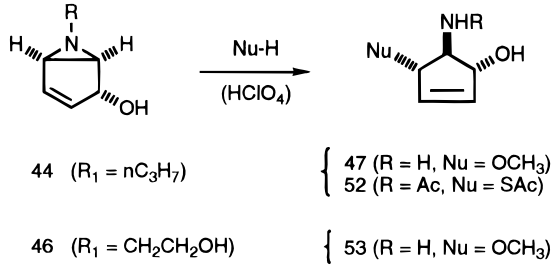
Bicyclic Aziridine Ring Opening Reactions. As demonstrated in our early work in this area[14] and again in the above discussion of our current studies, photoreactions of N-substituted pyridinium salts in neutral methanol or water solutions followed by concentration of the crude photolysate leads to direct generation of aminocyclopentene products (*e.g.*, conversions of **16**−**19** to **22**−**23**). These observations suggest that the initially formed bicyclic aziridines (*e.g.*, **19**−**21**) undergo ready, stereocontrolled acid-catalyzed ring-opening reactions by SN_2 (rather than SN_1 or SN'_2) pathways. On the basis of this proposal, we believed that sequential photoelectrocyclization−nucleophilic substitution sequences (Scheme 1) would serve as useful methods to prepare a variety of functionally diverse and stereochemically defined ami-



nocyclopentenes. To test the viability of this methodology, the bicyclic aziridinyl ethers **19**−**21** were subjected to acid-catalyzed ring-opening reactions with a number of nucleophilic solvents. Ideal conditions for alcoholysis and hydrolysis of these substances involve the use of millimolar concentrations of perchloric acid and ambient temperatures. For example, **19** is transformed to the cyclopentenes **22** (42%) and **47** (81%) by independent reactions in methanol and water under these conditions. Similarly, the amide analog **20** reacts in methanol or ethanol to form the respective aminocyclopentenes **23** (93%) and **49** (79%). The acetates **48** (36%) and **50** (54%) are likewise derived by reaction of the respective bicyclic aziridines **19** and **20** in acetic acid at 25 °C and the hydroxyethyl analog **21** yields **24** upon methanolysis. Finally, reaction of **19** in thioacetic acid yields the thioester amide **51** (74%) by a sequence involving aziridine ring opening followed by thioacid-induced amidation.

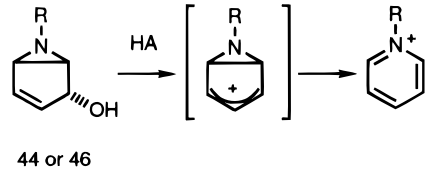


The bicyclic aziridinyl alcohols **44**−**46** undergo the same types of ring-opening reactions as exemplified by the formation of **47** (67%) and **52** (35%) from **44** and **53** (99%) from **46**.

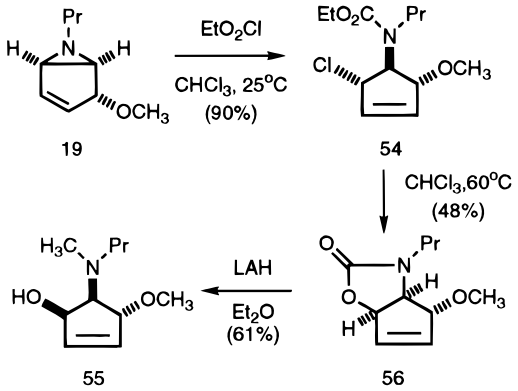


An interesting observation made in studying the aziridine ring opening reactions of **44** and **46** appears to have both a preparative (see below) and mechanistic significance. Specifically, the methanolysis reactions of **44** and **46** occur cleanly when low concentrations (<1 mm) of the perchloric acid catalyst are used. In contrast, when a methanolic solution of **46** containing ≫10 mM $HClO_4$ is stirred at 25 °C, efficient production of the pyridinium salt **18** occurs. This result suggests that at high acid concentrations acid-catalzyed dehydration−aziridine ring opening can occur *via* the intermediate allylic cation (Scheme 6) and, consequently, that this same intermediate formed in the photoelectrocyclization process can partition to bicyclic aziridine product or starting pyridinium cation depending on the nature and concentration of the trapping nucleophile.

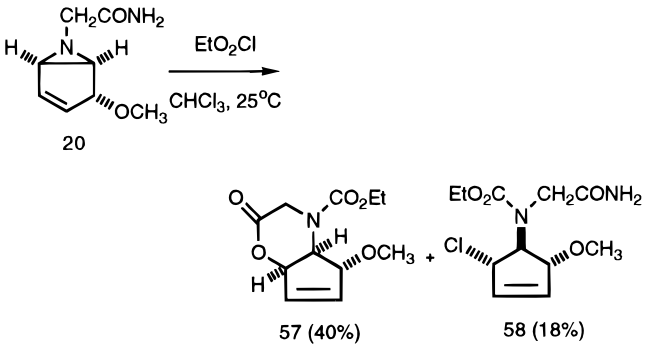
Scheme 6



In the aziridine ring opening reactions described above, high degrees of stereocontrol are observed for formation of the *trans,trans*-trisubstituted cyclopentenes as a consequence of the SN_2 nature of the processes. A procedure to alter the stereochemical course of aziridine ring opening and, thus, to allow potential access to *cis,trans*-stereoisomers of the aminocyclopentenes has been found. The protocol is exemplified by the reaction sequence employed to convert aziridinyl ether **19** to the *cis,trans*-aminocyclopentenyl alcohol **55**. Accordingly, reaction of



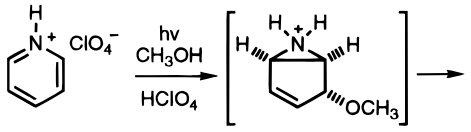
19 with ethyl chloroformate in chloroform at 25 °C leads to rapid generation of the chloro carbamate **54**. When stirred in a $CHCl_3$ solution at reflux, **54** undergoes azlactonization to yield cyclic carbamate **56** which upon LAH reduction furnishes the *cis,trans*-cyclopentenol **55**. Interestingly, when the amide derivative **20** is subjected to ethyl chloroformate ring opening the six-ring azlactone product **57** (40%) is produced along with the chlorocarbamate **58**. The exclusive formation of **57**, rather than a five-ring azlactone related to **56**, in this process is presumably the consequence of preferred displacement of chloride in **58** by the amide rather than carbamate nucleophilic carbonyl oxygen.



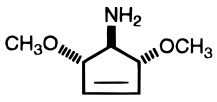
Preparative Aspects of the Aminocyclopentene Synthetic Process. As can be seen by viewing the examples presented above, the photoelectrocyclization−aziridine ring opening sequence serves as a concise method to transform readily available pyridinium salts

into highly functionalized aminocyclopentenes. Importantly, the process has great versatility in terms of the ability to introduce differentiated functionality into the five-membered ring and to control relative stereochemistry. One possible disadvantage of this chemistry concerns the potentially narrow range of N-substituents which can be present in the starting pyridinium salts and, thus, can be incorporated into the amino group of the cyclopentene products. In cases where a free (NH_2) or highly adorned amino function is required, it would be necessary to have a nitrogen protecting group in place in the starting pyridinium salt and then to remove this group at the aminocyclopentene stage. The range of nitrogen protecting groups that can be used for this purpose is quite narrow. For example, while *N*-alkylpyridinium salts undergo the photoelectrocyclization efficiently, their *N*-benzyl analogs are unreactive.[16] This is most probably due to quenching of the pyridinium singlet excited state by intramolecular SET from the electron rich arene ring.[17] In addition, *N*-acyl- or *N*-alkoxycarbonyl-protected pyridinium salts cannot be employed for this purpose, since these substances will not be stable in the nucleophilic solvent systems required for the photochemical step.

As a consequence of these considerations, we have briefly investigated the photochemical reactivity of pyridinium perchlorate (**59**) to determine if, like its *N*-alkyl analogs, this substance undergoes the photoelectrocyclization process. Interestingly, irradiation of **59** in methanol containing 0.5 mM $HClO_4$ (to insure full protonation of the pyridine nucleus) followed by workup and silica gel chromatography leads to isolation of the aminocyclopentene **61** in a 48% yield. Thus, the N-H pyridinium salt does indeed react to generate the bicyclic aziridine **60** which, under the acidic methanol reaction conditions, is transformed to **61**. Clearly, this result expands the applicability of this aminocyclopentene synthetic methodology.



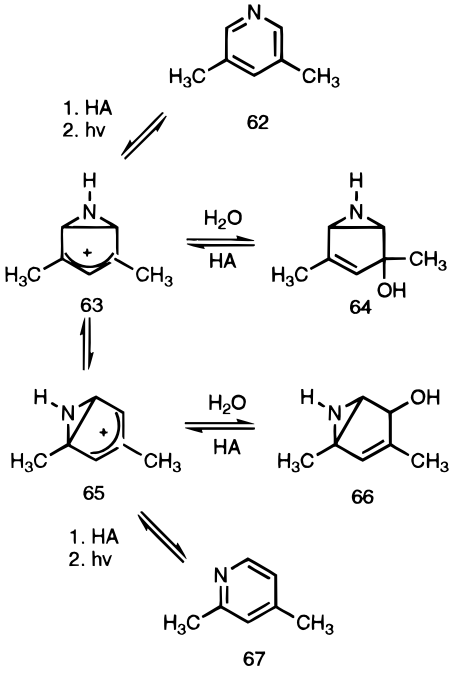
59 60



61

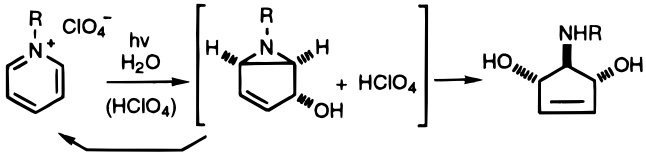
A hint that simple N-H pyridinium salts would be photoreactive is found in the early communication by Wilzbach and Kaplan.[13] These workers briefly stated that irradiation of 3,5-lutidine (**62**) in acidic D_2O results in its disappearance and concomitant formation of d_2-2,4-lutidine **67**. A pathway (Scheme 7) involving photogeneration, rearrangement, and water capture of the azabicyclic cation **63** appears reasonable to explain this transformation. In this case, the alcohol photoproducts

Scheme 7



62 63 64 65 66 67

Scheme 8



16 (R = nC_3H_7), **59** (R = H) **44** (R = nC_3H_7), **68** (R = H) **69** (R = nC_3H_7), **70** (R = H)

64 and **66** are formed in a highly acidic medium and, therefore, apparently reconvert to the starting pyridinium salts by the dehydrative ring opening chemistry described earlier in the current publication.

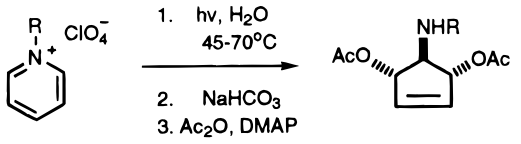
The problem associated with the pyridinium-forming, acid-catalyzed bicyclic aziridine alcohol (*e.g.*, **44**−**46**) ring opening process is also encountered in photoreactions of *N*-alkylpyridinium salts in water when base is not present. UV spectroscopic monitoring of the photoreaction of **16** at 25 °C in neutral water demonstrates that **16** is consumed efficiently. However, when the solution is allowed to stand in the dark at 25 °C, a large fraction of the pyridinium salt **16** re-forms. Thus, it appears that the bicyclic alcohol **44** under the acidic conditions of its formation is transformed competitively to **16** and the cyclopentendiol **69** (Scheme 8). As a result, **69** is formed in a low yield under these conditions even though UV monitoring of the photolysate suggested complete conversion of **16**.

A partial solution to this problem is found in the use of elevated temperature photochemical conditions. We reasoned that at elevated temperatures the reconversion of **44** to **16** as well as its transformation to **69** would occur rapidly during the irradiation process. Consequently, it should be possible to drive the reaction in the direction of aminocyclopentendiol formation by applying simultaneous thermal and photochemical activation. (*i.e.*, to enhance the rates of dark conversion of **44** to **16** and **69** while simultaneously allowing for photochemical reconversion of **16** to **44**). In the event, extended irradiation of **16** (1 g scale) in water at 45−70 °C, followed by aqueous base workup, acylation of the crude product

(16) Irradiation of *N*-benzylpyridinium perchlorate in a MeOH−KOH solution for an extended time period (as compared to the *N*-alkyl analogs) does not lead to generation of the corresponding *N*-benzyl bicyclic aziridine.

(17) For example, see: Borg, R. M.; Heuckeroth, R. D.; Lan, J. Y.; Quillen, S. L.; Mariano, P. S. *J. Am. Chem. Soc.* **1987**, *109*, 2728. Lan, J. Y.; Heuckeroth, R. O.; Mariano, P. S. *J. Am. Chem. Soc.* **1987**, *109*, 2738.

mixture, and chromatographic separation, led to isolation of the diacetoxyamidocyclopentene **71**. In a similar fashion, pyridinium perchlorate (**59**) (1 g scale) is converted to the triacetyl derivative **72** (25%) by extended irradiation in aqueous $HClO_4$ at 45−70 °C followed by acetylation and purification.



16 (R = nC_3H_7)
59 (R = H)

71 (R = nC_3H_7) (26%)
72 (R = H) (25%)

Summary

The results outlined above convincingly demonstrate that pyridinium salts which lack appended electron donor centers undergo efficient photoelectrocyclization to produce bicyclic aziridine ring containing, allylic cations. Capture of these intermediates by nucleophilic solvents, occurring in competition with dark conversion back to their pyridinium cation precursors, produces bicyclic aziridine products. The bicyclic aziridine photoproducts are themselves reactive with nucleophiles, undergoing acid-catalyzed ring opening to generate *trans,trans*-3,5-disubstituted-4-aminocyclopentenes in a highly regio- and stereocontrolled manner. The diversity of this methodology for functionalized aminocyclopentene synthesis is enhanced by the observation that the bicyclic aziridine intermediates can be converted to *trans,cis*-3,5-disubstituted-4-aminocyclopentenes by use of a chloroformate ring-opening−azlactonization sequence. Finally, the remarkable degree of functional and stereochemical complexity which can be assembled in a reasonably straightforward fashion by this photoelectrocyclization−aziridine ring opening protocol is well-exemplified by short syntheses of the *trans,trans*-diacetoxy-4-acetamidocyclopentenes described starting with pyridine. While more needs to be explored to elucidate the full preparative power of this chemistry, the results obtained thus far suggest that pyridinium salt photochemistry holds interesting synthetic potential.

Experimental Section

General. ^1H NMR and ^{13}C NMR spectra were recorded using $CDCl_3$ solutions unless specified otherwise, and chemical shifts are reported in ppm relative to $CHCl_3$ (δ 7.24 ppm for ^1H and δ 77.0 ppm for ^{13}C) which was used as a chemical shift internal standard for samples in $CDCl_3$, ^{13}C NMR resonance assignments were aided by the use of the DEPT technique to determine numbers of attached hydrogens. IR spectral vibrational frequencies are expressed in wave numbers (cm^{-1}). Column chromatography was performed with Merck-EM type 60 (230−400 mesh) silica gel, Alcoa type F-20 alumina (neutral, 80−200 mesh), or Fluorisil (100-200 mesh) absorbants. Preparative TLC was performed on 20 × 20 cm plates coated with Merck-EM type 60 GF-254 silica gel. Mass spectra were recorded by using electron impact ionization unless specified as chemical ionization by CI. All reactions were run under a dry N_2 atmosphere unless otherwise noted. Organic extracts obtained following workup of reaction mixtures were dried over anhydrous Na_2SO_4 or $MgSO_4$. All compounds prepared in this study were oils and were judged by NMR to be >90% pure unless otherwise noted.

Preparative photochemical reactions were conducted with an apparatus consisting of a 450 W Hanovia medium pressure mercury lamp surrounded by a Vycor glass filter immersed in the photolysis solution unless otherwise specified. The photolysis solutions were purged with N_2 both before and during irradiation. The progress of each preparative photochemical reaction was monitored by UV absorption spectrometry (to determine % conversions), TLC, and/or ^1H NMR spectroscopy. Large-scale preparative photoreactions were carried by use of a Rayonet reactor using a bank of 254 nm lamps.

1-Propylpyridinium Perchlorate (16). A solution of pyridine (20 g, 0.25 mol) and propyl iodide (43 g, 0.25mol) were stirred at 90 °C for 3 h under N_2 to yield a solid (55 g, 87%) identified as 1-propylpyridinium iodide. A mixture of the iodide salt (5 g, 0.02 mol), perchloric acid (2.9 g, 0.02 mol), and silver carbonate (2.8 g, 0.01 mol) in 50 mL of methanol was stirred at 25 °C for 1 h and filtered. Concentration in *vacuo* of the filtrate gave a residue which was subjected to column chromatography (alumina, acetone) to give 4.4 g (98.8%) of the perchlorate salt **16**: ^1H NMR (D_2O) 8.70 (d, J = 6.1 Hz, 2H, H_2, H_6), 8.41 (m, 1H, H_4), 7.93 (t, J = 6.7 Hz, 2H, H_3, H_5), 4.43 (t, J = 7.2 Hz, 2H, NCH_2), 1.90 (m, 2H, NCH_2CH_2), 0.81 (t, J = 7,4 Hz, 3H, $NCH_2CH_2CH_3$); ^{13}C NMR (D_2O) 147.3, 146.0, 130.0 (heteroaromatic), 65.1 (NCH_2), 25.9 (NCH_2CH_2), 11.5 ($NCH_2CH_2CH_3$).

1-(Carbamoylmethyl)pyridinium Perchlorate (17). A mixture of 2-chloroacetamide (5.5 g, 58 mmol) and pyridine (9.2 g, 116 mmol) was stirred at 80 °C for 30 min under N_2 to yield 9.1 g (91% yield) of a solid identified as 1-(carbamoylmethyl)pyridinium chloride. A solution of this chloride salt (3.1 g, 18 mmol) in MeOH (30 mL) was then added into a warm solution of silver carbonate (2.5 g, 9.0 mmol) and perchloric acid (70%, 2.6 g, 18 mmol) in acetone (30 mL) and MeOH (30 mL). The reaction mixture was stirred at 25 °C for 30 min, filtered, and concentrated in *vacuo* to give the crystalline perchlorate **17**, which was recrystallized from methanol to yield 3.9 g (90% yield) of **17** (mp 167−169 °C): ^1H NMR (D_2O) 8.66 (d, J = 6.2 Hz, 2H, H_2, H_6), 8.51 (t, J = 7.7 Hz, 1H, H_4), 7.99 (dd, J = 7.7, 6.2 Hz, 2H, H_3, H_5), 5.38 (s, 2H, CH_2); ^{13}C NMR (D_2O) 171.1 (C=O), 149.7, 148.7, 131.0 (heteroaromatic), 64.4 (CH_2); MS *m/z* (rel intensity) 138 (7), 137 (5), 79(100); HRMS calcd *m/z* for $C_7H_9NO_2$ 137.0715, found 137.0709.

1-(2-Hydroxyethyl)pyridinium Perchlorate (18). A mixture of 2-chloroethanol (5.0 g, 62 mmol) and pyridine (9.7 g, 123 mmol) was stirred at 120 °C for 5 h under N_2 to yield 9.9 g (100% yield) of a solid identified as 1-(2-hydroxyethyl)-pyridinium chloride. A solution of this chloride salt (1.4 g, 8.8 mmol) in MeOH (30 mL) was then added into a warm solution of silver carbonate (1.2 g, 4.4 mmol) and perchloric acid (70%, 1.2 g, 8.8 mmol) in acetone (30 mL) and MeOH (30 mL). The reaction mixture was stirred at 25 °C for 30 min, filtered, and concentrated in *vacuo* to give 1.9 g (95% yield) of perchlorate salt **18** as an oil: ^1H NMR (D_2O) 8.67 (d, J = 5.7 Hz, 2H, H_2, H_6), 8.40 (t, J = 7.8 Hz, 1H, H_4), 7.91 (dd, J = 7.8, 5.7 Hz, 2H, H_3, H_5), 4.54 (t, J = 5.0 Hz, 2H, CH_2OH), 3.89 (t, J = 5.0 Hz, 2H, CH_2CH_2OH); ^{13}C NMR (D_2O) 147.8, 146.5, 130.0 (heteroaromatic), 65.4 (CH_2OH), 62.3 (CH_2CH_2OH); MS *m/z* (rel intensity) 124 (2), 121 (2), 79 (100); HRMS calcd *m/z* for $C_7H_{10}NO$ 124.0762, found 124.0762.

1-Methyl-3-(hydroxypropyl)pyridinium Perchlorate (31). A mixture of 3-pyridyl-1-propanol (5.0 g, 36 mmol) and iodomethane (10 g, 72 mmol) was stirred at 0 °C for 30 min under N_2 to yield 9.4 g (94% yield) of a solid identified as 1-methyl-3-(hydroxypropyl)pyridinium iodide. A solution of this iodide salt (5.0 g, 18 mmol) in MeOH (30 mL) was then added into a solution of silver carbonate (2.5 g, 9.0 mmol) and perchloric acid (70%, 2.6 g, 18 mmol) in acetone (30 mL) and MeOH (30 mL). The reaction mixture was stirred at 25 °C for 30 min, filtered, and concentrated in *vacuo* to give 4.1 g (92% yield) of the perchlorate salt **31**: ^1H NMR (D_2O) 8.56 (s, 1H, H_2), 8.48 (d, J = 5.8 Hz, 1H, H_6), 8.28 (d, J = 7.9 Hz, 1H, H_4), 7.83 (dd, J = 7.9, 5.8 Hz, 1H, H_5), 4.23 (s, 3H, CH_3), 3.53 (t, J = 6.3 Hz, 2H, CH_2O), 2.80 (t, J = 7.5 Hz, 2H, CH_2CH_2-CH_2OH), 1.82 (m, 2H, $CH_2CH_2CH_2OH$); ^{13}C NMR (D_2O) 147.5, 146.8, 145.5, 144.9, 129.8 (heteroaromatic), 62.9 (CH_2OH), 50.3 (CH_3), 34.2, 30.8 ($CH_2CH_2CH_2OH$); MS *m/z* (rel intensity) 152 (13), 151 (45), 134 (11), 120 (100), 93 (53); HRMS calcd for *m/z* $C_9H_{14}NO$ 152.10075, found 152.1077.

1-Methyl-4-(3-hydroxybutyl)pyridinium Perchlorate

(34). To a solution of 4-picoline (2.5 g, 27 mmol) in anhydrous THF (20 mL) at −78 °C was added dropwise *n*-butyllithium (20 mL, 32 mmol). This resulting mixture was stirred for 2 h followed by warming gradually to 0 °C and adding dropwise propylene oxide (2.3 mL, 32 mmol). The reaction mixture was stirred at 25 °C for 4 h, then the reaction was quenched with ice−water, and the solution was extracted with $CHCl_3$. The organic extracts were dried and concentrated in *vacuo* to give 4.1 g (100%) of 4-(3-hydroxybutyl)pyridine: ^{1}H NMR ($CDCl_3$) 8.45 (d, J = 6.5 Hz, 2H, H_2, H_6), 7.11 (d, J = 6.5 Hz, 2H, H_3, H_5), 3.81 (m, 1H, C*H*(OH)CH_3), 2.85−2.60 (m, 2H, C*H*$_2$CH_2-CH(OH)CH_3), 1.72 (m, 2H, C*H*$_2$CH(OH)CH_3), 1.20 (d, J = 6.3 Hz, 3H, CH_3); ^{13}C NMR ($CDCl_3$) 151.3, 149.6, 123.9 (heteroaromatic), 67.0 (*C*H(OH)CH_3), 39.5 (*C*H_2CH_2CH(OH)CH_3), 31.4 (*C*H_2CH(OH)CH_3), 23.7 (CH_3).

A solution of 4-(3-hydroxybutyl)pyridine (2.4 g, 16 mmol) and iodomethane (2.9 g, 20 mmol) in $CHCl_3$ (15 mL) was stirred at 60 °C for 1 h under N_2 to yield 4.5 g (97% yield) of a solid identified as 1-methyl-4-(3-hydroxybutyl)pyridinium. A solution of the iodide salt (4.5 g, 15 mmol) in MeOH (30 mL) was then added to a solution of silver carbonate (2.1 g, 7.6 mmol) and perchloric acid (70%, 2.2 g, 15 mmol) in acetone (30 mL) and MeOH (30 mL). The reaction mixture was stirred at 25 °C for 30 min, filtered, and concentrated in *vacuo* to give 3.5 g (88% yield) of perchlorate salt **34**: ^{1}H NMR (D_2O) 8.46 (d, J = 6.5 Hz, 2H, H_2, H_6), 7.74 (d, J = 6.5 Hz, 2H, H_3, H_5), 4.18 (s, 3H, NCH_3), 3.80−3.68 (m, 1H, C*H*(OH)CH_3), 2.93−2.78 (m, 2H, C*H*$_2$CH_2CH(OH)CH_3), 1.82−1.68 (m, 2H, C*H*$_2$-CH(OH)CH_3), 1.08 (d, J = 6.3 Hz, 3H, CH(OH)C*H*$_3$); ^{13}C NMR (D_2O) 165.5, 146.7, 130.2 (heteroaromatic), 69.4 (*C*H(OH)CH_3), 49.8 (NCH_3), 40.1 (*C*H_2CH_2CH(OH)CH_3), 33.9 (*C*H_2CH(OH)-CH_3), 24.4 (CH(OH)*C*H_3); MS *m*/*z* (rel intensity) 166 (3), 165 (9), 120 (100); HRMS calcd *m*/*z* for $C_{10}H_{16}NO$ 166.1232, found 166.1247.

2-Methyl-5,6,7,8-tetrahydroisoquinolinium Perchlorate (41). A mixture of 5,6,7,8-tetrahydroisoquinoline (2.0 g, 14 mmol) and iodomethane (4.6 g, 32 mmol) was stirred at 0 °C for 15 min under N_2 to yield 3.6 g (92% yield) of a solid identified as 2-methyl-5,6,7,8-tetrahydroisoquinolinium iodide. A solution of this iodide salt (2.0 g, 7.2 mmol) in MeOH (30 mL) was then added to a solution of silver carbonate (1.0 g, 3.6 mmol) and perchloric acid (70%, 1.0 g, 7.2 mmol) in acetone (30 mL) and MeOH (30 mL). The reaction mixture was stirred at 25 °C for 30 min, filtered, and concentrated in *vacuo* to give the crystalline salt, which was recrystallized from methanol to yield 1.6 g (89% yield) of perchlorate salt **41** (mp 60−62 °C): ^{1}H NMR (D_2O) 8.29 (s, 1H, H_1), 8.18 (d, J = 6.3 Hz, 1H, H_3), 7.53 (d, J = 6.3 Hz, 1H, H_4), 4.11 (s, 3H, CH_3), 2.90−2.70 (m, 4H, H_5, H_8), 1.73 (p, J = 3.3 Hz, 4H, H_6, H_7); ^{13}C NMR (D_2O) 160.7, 146.3, 142.7, 141.0, 130.0 (heteroaromatic), 49.3 (CH_3), 31.3, 28.2, 23.0, 23.0 (C_5, C_6, C_7, C_8); MS *m*/*z* (rel intensity) 148 (8), 146 (100), 132 (13); HRMS calcd *m*/*z* for $C_{10}H_{14}N$ 148.1126, found 148.1120.

Pyridinium Perchlorate (59). Perchloric acid (70%, 3.7 g, 25 mmol) was added dropwise to a stirred solution of pyridine (2.0 g, 25 mmol) in $CHCl_3$ (5 mL). The formed crystalline pyridinium perchlorate was recrystallized from methanol to yield 4.2 g (93% yield) of perchlorate salt **59** (mp 287−289 °C); ^{1}H NMR (D_2O) 8.73 (d, J = 6.2 Hz, 2H, H_2, H_6), 8.55 (t, J = 7.7 Hz, 1H, H_4), 7.99 (dd, J = 7.7, 6.2 Hz, 2H, H_3, H_5); ^{13}C NMR (D_2O) 149.6, 143.4, 129.8 (heteroaromatic); MS *m*/*z* (rel intensity) 80 (9), 79 (100); HRMS calcd *m*/*z* for C_5H_6N 80.0500, found 80.0492.

Irradiation of 1-Propylpyridinium Perchlorate (16). An N_2-purged solution of **16** (200 mg, 0.90 mmol) in 100 mL of absolute methanol was irradiated for 1.75 h. The photolysate was subjected to the "normal workup procedure A" (neutralized with $NaHCO_3$ concentrated in *vacuo*, residue triturated with $CHCl_3$, triturate filtered, and filtrate concentrated in vacuo) to yield a residue which was subjected to column chromatography (Florisil, $CHCl_3$) to give 40 mg (33%) of 4-methoxy-6-propyl-6-azabicyclo[3.1.0]hex-2-ene (**19**) and 36 mg (22%) of 3,5-dimethoxy-4-(*N*-propylamino)cyclopentene (**22**).

19: ^{1}H NMR 6.31 (d, J = 5.8 Hz, 1H, vinyl), 5.88 (m, 1H, vinyl), 4.15 (s, 1H, H_4), 3.40 (s, 3H, OCH_3), 2.45 (brs, 2H, H_1, H_5), 2.20 (m, 2H, NCH_2), 1.60 (m, 2H, NCH_2CH_2), 0.95 (t, J = 7,4 Hz, 3H, $NCH_2CH_2CH_3$); ^{13}C NMR 136.5, 134.7 (CH=CH), 84.5 (C_4), 60.2 (NCH_2), 55.6 (OCH_3), 47.9 (C_5), 46.8 (C_1), 25.9 (NCH_2CH_2), 11.5 ($NCH_2CH_2CH_3$); MS *m*/*z* (rel intensity) 154-(1), 122(57), 80(100); HRMS calcd *m*/*z* for $C_9H_{15}NO$ 153.1154, found 153.1164.

22: ^{1}H NMR 6.20 (s, 2H, vinyl), 4.05 (d, 2H, H_3,H_5), 3.40 (s, 6H, OCH_3), 3.31 (t, 1H, H_1,H_4), 2.72 (t, 2H, NCH_2), 1.56 (m, 2H, NCH_2CH_2), 0.95 (t, J = 7,4 Hz, 3H, $NCH_2CH_2CH_3$); ^{13}C NMR 131.9 (CH=CH), 86.7 (C_3,C_5), 69.7 (C_4), 56.4 (OCH_3), 50.1 (NCH_2), 21.7 (NCH_2CH_2), 11.4 ($NCH_2CH_2CH_3$); MS *m*/*z* (rel intensity) 185(6), 154(100), 122(27), 99(19), 80(24); HRMS calcd *m*/*z* for $C_{10}H_{19}NO_2$ 1185.1416, found 1185.1410.

Irradiation of 16 in MeOH−KOH. An N_2-purged solution of **16** (300 mg, 1.35 mmol) and KOH (76 mg, 1.35 mmol) in 100 mL of absolute methanol was irradiated for 2.25 h. The photolysate was concentrated in *vacuo*, and the residue was subjected to the "normal workup procedure B" (triturated with $CHCl_3$, triturate filtered and concentrated in *vacuo*) to yield a residue which was subjected to column chromatography (Florisil, $CHCl_3$) to give 80 mg (53%) of **19**.

Irradiation of 1-(Carbamoylmethyl)pyridinium Perchlorate (17) in MeOH. An N_2-purged solution of **17** (96 mg, 0.40 mmol) in anhydrous MeOH (100 mL) was irradiated in a preparative apparatus for 90 min. The photolysate was subjected to the normal workup procedure A to give a residue which was subjected to column chromatography (silica gel, chloroform:acetone 90/10) to yield 12 mg (22% yield at 82% conversion) of 4-methoxy-6-(carbamoylamidomethyl)-6-azabicyclo[3.1.0]hex-2-ene (**20**) and 38 mg (58% yield at 82% conversion) of the 4-(carbamoylmethyl)amino-3,5-dimethoxycyclopentene (**23**).

20: ^{1}H NMR 6.29 (d, J = 6.0 Hz, 1H, vinyl), 5.92 (m, 1H, vinyl), 4.17 (s, 1H, H_4), 3.40 (s, 3H, OCH_3), 3.07 and 2.95 (ABq, J = 16.6 Hz, 2H, CH_2), 2.65 (brs, 2H, H_1, H_5); ^{13}C NMR 172.5 (C=O), 135.6, 135.3 (CH=CH), 83.4 (C_4), 60.2 (CH_2), 55.8 (OCH_3), 48.2, 47.7 (C_1, C_5); IR (neat) 2928, 1668, 1374, 1086; MS *m*/*z* (rel intensity) 168 (2), 137 (100), 93 (18), 80 (59); HRMS calcd *m*/*z* for $C_8H_{12}N_2O_2$ 168.0899, found 168.0906.

23: ^{1}H NMR 6.01 (s, 2H, vinyl), 4.01 (d, J = 5.1 Hz, 2H, H_3, H_5), 3.45 (s, 2H, CH_2), 3.37 (s, 6H, 2OCH_3), 3.15 (t, J = 5.1 Hz, 1H, H_4); ^{13}C NMR 174.5 (C=O), 132.0 (CH=CH), 88.1 (C_3, C_5), 70.5 (C_4), 56.4 (OCH_3), 50.4 (CH_2); IR (neat) 2928, 1667, 1371, 1083; MS *m*/*z* (rel intensity) 200 (1), 185 (3), 169 (40), 137 (100), 127 (25), 110 (54), 80 (29); HRMS calcd *m*/*z* for $C_9H_{16}N_2O_3$ 200.1161, found 200.1162.

Irradiation of 17 in MeOH−KOH. An N_2-purged solution of **17** (100 mg, 0.42 mmol) and potassium hydroxide (40 mg, 0.71 mmol) in anhydrous MeOH (100 mL) was irradiated in a preparative apparatus for 140 min. The photolysate was concentrated in *vacuo* to give a residue which was subjected to column chromatography (silica gel, chloroform:acetone 80/20) to yield 57 mg (90% yield at 98% conversion as indicated by UV) of 4-methoxy-6-(carbamoylmethyl)-6-azabicyclo[3.1.0]-hex-2-ene (**20**).

Irradiation of 1-(2-Hydroxyethyl)pyridinium Perchlorate (18) in MeOH. An N_2-purged solution of **18** (110 mg, 0.49 mmol) in anhydrous MeOH (90 mL) was irradiated in a preparative apparatus for 180 min. The photolysate was concentrated in *vacuo* and subjected to the normal workup procedure A to give a residue which was subjected to column chromatography (silica gel, first with chloroform:ether 50/50, chloroform:acetone 50/50) to yield 33 mg (47% yield at 93% conversion) of 4-methoxy-6-(hydroxyethyl)-6-azabicyclo[3.1.0]-hex-2-ene (**21**) and 19 mg (22% yield at 93% conversion) of 4-[*N*-(2-hydroxyethyl)amino]-3,5-dimethoxycyclopentene (**24**).

21: ^{1}H NMR 6.28 (d, J = 5.6 Hz, 1H, vinyl), 5.89 (m, 1H, vinyl), 4.16 (s, 1H, H_4), 3.69 (t, J = 5.4 Hz, 2H, C*H*$_2$OH), 3.38 (s, 3H, OCH_3), 2.57 (brs, 2H, H_1, H_5), 2.46 (m, 2H, C*H*$_2$CH$_2$-OH); ^{13}C NMR 136.1, 135.0 (CH=CH), 83.3 (C_4), 61.6 (CH_2-OH), 59.8 (*C*H_2CH$_2$OH), 55.7 (OCH_3), 47.7, 46.8 (C_1, C_5); IR (neat) 3418, 2931, 1667, 1645, 1455, 1372, 1115, 1084; MS *m*/*z* (rel intensity) 156 (4), 155 (5), 124 (100), 110 (7), 80 (88); HRMS calcd *m*/*z* for $C_8H_{13}NO_2$ 155.0946, found 155.0933.

24: ^{1}H NMR 6.09 (s, 2H, vinyl), 4.48 (d, J = 4.7 Hz, 2H, H_3, H_5), 3.85 (t, J = 5.3 Hz, 2H, C*H*$_2$OH), 3.40 (s, 3H, OCH_3), 3.29

(t, J = 4.7 Hz, 1H, H_4), 3.15 (t, J = 5.3 Hz, 2H, CH_2CH_2OH); ^{13}C NMR 131.2 (CH=CH), 83.6 (C_3, C_5), 69.4 (C_4), 57.4 (CH_2-OH), 56.5 (OCH_3), 50.0 (CH_2CH_2OH); IR (neat) 3427, 1654, 1455, 1372, 1089; MS *m/z* (rel intensity) 187 (2), 156 (100), 124 (46), 80 (30); HRMS calcd *m/z* for $C_9H_{17}NO_3$ 187.1209, found 187.1212.

Irradiation of 18 in MeOH−KOH. An N_2-purged solution of **18** (110 mg, 0.49 mmol) and potassium hydroxide (40 mg, 0.71 mmol) in anhydrous MeOH (100 mL) was irradiated in a preparative apparatus for 210 min. The photolysate was concentrated in *vacuo*, giving a residue which was subjected to column chromatography (silica gel, chloroform:acetone 80/20) to yield 71 mg (98% yield at 96% conversion) of 4-methoxy-6-(hydroxyethyl)-6-azabicyclo[3.1.0]hex-2-ene (**21**).

Irradiation of 17 in EtOH. An N_2-purged solution of **17** (100 mg, 0.42 mmol) in anhydrous EtOH (100 mL) was irradiated in a preparative apparatus for 80 min. The photolysate was subjected to the normal workup procedure A to give a residue which was subjected to column chromatography (silica gel, chloroform:acetone 80/20) to yield 61 mg (71% yield at 90% conversion) of 4-((carbamoylmethyl)amino)-3,5-diethoxycyclopentene (**28**): ^1H NMR 5.96 (s, 2H, vinyl), 4.09 (d, J = 5.3 Hz, 2H, H_3, H_5), 3.60 (m, 4H, $2OCH_2CH_3$), 3.48 (s, 2H, CH_2CONH_2), 3.18 (t, J = 5.3 Hz, 1H, H_4), 1.19 (t, J = 7.0 Hz, 6H, $2OCH_2CH_3$); ^{13}C NMR 174.4 (C=O), 132.3 (CH=CH), 86.4 (C_3, C_5), 71.3 (C_4), 64.4 (OCH_2CH_3), 50.4 (CH_2CONH_2), 15.6 (OCH_2CH_3); IR (neat) 2974, 2873, 1673, 1372, 1086; MS *m/z* (rel intensity) 229(1), 228(1),183 (32), 170 (9), 165(12), 155 (12), 137 (100), 124 (23); HRMS calcd *m/z* for $C_{11}H_{20}N_2O_3$ 228.1474, found 228.1482.

Irradiation of 1-Methyl-3-(hydroxypropyl)pyridinium Perchlorate (31) in MeOH−KOH. An N_2-purged solution of **31** (98 mg, 0.38 mmol) and potassium hydroxide (32 mg, 0.57 mmol) in anhydrous MeOH (90 mL) was irradiated in a preparative apparatus for 90 min. The photolysate was concentrated in *vacuo* to give a residue which was subjected to column chromatography (Florisil, hexanes:acetone 50/50) to yield 18 mg (31% yield at 84% conversion) of bicyclic aziridine **32** and 11 mg (19% yield at 84% conversion) of bicyclic aziridine **33**.

32: ^1H NMR 5.49 (s, 1H, vinyl), 4.10 (s, 1H, H_4), 3.64 (m, 2H, CH_2OH), 3.38 (s, 3H, OCH_3), 2.43 (s, 1H, H_1 or H_5), 2.32 (s, 3H, NCH_3), 2.31 (s, 1H, H_5 or H_1), 2.30 (m, 2H, CH_2CH_2-OH), 1.78 (m, 2H, $CH_2CH_2CH_2OH$); ^{13}C NMR 151.2 (CH=*C*), 127.3 (*C*H=C), 83.3 (C_4), 62.2 (CH_2OH), 55.6 (OCH_3), 49.6 (NCH_3), 49.7, 44.6 (C_1, C_5), 31.0, 27.7 ($CH_2CH_2CH_2OH$); IR (neat) 3369, 2938, 2868, 1630, 1452, 1093; MS *m/z* (rel intensity) 184 (M + 1, 4), 182 (6), 152 (100), 107 (27); HRMS (CI) calcd *m/z* for $C_{10}H_{18}NO_2$ 184.1338, found 184.1336.

33: ^1H NMR 6.24 (m, 1H, vinyl), 5.53 (m, 1H, vinyl), 3.55 (m, 2H, CH_2OH), 3.18 (s, 3H, OCH_3), 2.41 (s, 1H, H_1 or H_5), 2.30 (s, 3H, NCH_3), 2.23 (s, 1H, H_5 or H_1), 1.80 (m, 4H, CH_2CH_2-CH_2OH); ^{13}C NMR 137.3, 135.1 (CH=CH), 87.6 (C_4), 63.2 (CH_2-OH), 50.6, 50.1 (OCH_3, NCH_3), 48.3, 45.0 (C_1, C_5), 32.2, 28.8 ($CH_2CH_2CH_2OH$); IR (neat) 3393, 3056, 2939, 2869, 1648, 1454, 1065; MS *m/z* (rel intensity) 184 (M + 1, 7), 183 (6), 182 (9), 152 (100), 124 (52); HRMS (CI) calcd *m/z* for $C_{10}H_{18}NO_2$ 184.1338, found 184.1338.

Irradiation 1-Methyl-4-(3-hydroxybutyl)pyridinium Perchlorate (34) in MeOH−KOH. An N_2-purged solution of **34** (188 mg, 0.71 mmol) and potassium hydroxide (44 mg, 0.78 mmol) in anhydrous MeOH (100 mL) was irradiated in a preparative apparatus for 6 h. The photolysate was concentrated in *vacuo* to give a residue which was subjected to column chromatography (Florisil, hexanes:acetone 50/50) to yield 43 mg (65% yield at 47% conversion) of the bicyclic aziride **35** as a 1:1 mixture of diastereomers: ^1H NMR 5.91, 5.89 (s, 1H, vinyl), 4.09, 4.00 (s, 1H, H_4), 3.75 (m, 1H, $CH(OH)CH_3$), 3.41, 3.40 (s, 3H, OCH_3), 2.36 (brs, 1H, H_5), 2.33 (brs, 1H, H_1), 2.30, 2.29 (s, 3H, NCH_3), 2.16 (m, 2H, $CH_2CH(OH)CH_3$), 1.55 (m, 2H, $CH_2CH_2CH(OH)CH_3$), 1.12 (m, 3H, $CH(OH)CH_3$); ^{13}C NMR 149.5, 149.4 (*C*=CH), 128.9, 128.6 (C=*C*H), 85.2, 84.5 (C_4), 67.8, 67.1 ($CH(OH)CH_3$), 55.8, 55.7 (OCH_3), 48.2, 48.1 (C_5), 47.8 47.7 (C_1), 44.7, 44.6 (NCH_3), 37.2, 37.1 ($CH_2CH(OH)CH_3$), 25.2, 24.3 ($CH_2CH_2CH(OH)CH_3$), 23.4, 23.3 ($CH(OH)CH_3$); IR (neat) 3382, 2965, 2928, 1601, 1454, 1370, 1101; MS *m/z* (rel intensity) 198 (M + 1, 20), 197 (5), 196 (11), 166 (100), 150 (14), 134 (20), 120 (74); HRMS(CI) calcd *m/z* for $C_{11}H_{20}NO_2$ 198.1494, found 198.1493.

Irradiation of 2-Methyl-5,6,7,8-tetrahydroisoquinolinium Perchlorate (41) in MeOH−KOH. An N_2-purged solution of **41** (109 mg, 0.44 mmol) and potassium hydroxide (40 mg, 0.71 mmol) in anhydrous MeOH (90 mL) was irradiated in a preparative apparatus for 120 min. The photolysate was concentrated in *vacuo* to give a residue which was subjected to column chromatography (silica gel, hexanes: acetone 60/40) to yield 15 mg (26% yield at 74% conversion) of **42** and 12 mg (21% yield at 74% conversion) of a mixture of **42** and **43** (NMR 1:2 ratio). This mixture was subjected to preparative TLC (silica gel, hexanes:acetone 50/50) to give 3 mg of pure **43.** Spectroscopic data for **43** were obtained on pure material (^1H NMR, IR, and MS) or on a mixture of **42** and **43** (^{13}C NMR).

42: ^1H NMR 3.97 (s, 1H, H_4), 3.39 (s, 3H, OCH_3), 2.30 (s, 3H, NCH_3), 2.27 (s, 1H, H_5), 2.26 (s, 1H, H_1), 2.19−2.10 (m, 4H, $CH_2CH_2CH_2CH_2$), 1.60 (m, 4H, $CH_2CH_2CH_2CH_2$); ^{13}C NMR 141.3, 139.2 (C=C), 85.6 (C_4), 55.6 (OCH_3), 50.1 (NCH_3), 47.3, 44.9 (C_1, C_5), 24.7, 23.3, 22.7, 22.1 ($CH_2CH_2CH_2CH_2$); IR (neat) 3015, 2930, 2836, 1660, 1449, 1320, 1082; MS *m/z* (rel intensity) 180 (M + 1, 4), 179 (2), 164 (3), 148 (100), 120 (18); HRMS(CI) calcd *m/z* for $C_{11}H_{18}NO$ 180.1388, found 180.1390.

43: ^1H NMR 5.83 (s, 1H, vinyl), 3.18 (s, 3H, OCH_3), 2.28 (s, 3H, NCH_3), 2.13 (s, 1H, H_5), 2.12 (s, 1H, H_1), 2.00 (m, 4H, CH_2-$CH_2CH_2CH_2$), 1.69 (m, 4H, $CH_2CH_2CH_2CH_2$); ^{13}C NMR 147.9 (*C*=CH), 125.6 (C=*C*H), 83.8 (C_4), 50.9 (OCH_3), 50.0 (NCH_3), 46.8, 44.9 (C_1, C_5), 34.2, 26.6, 26.0, 21.1 ($CH_2CH_2CH_2CH_2$); IR (neat) 2931, 2861, 1705, 1453, 1096; MS *m/z* (rel intensity) 180 (M + 1, 31), 179 (11), 164 (23), 148 (100), 120 (17); HRMS(CI) calcd *m/z* for $C_{11}H_{18}NO$180.1388, found 180.1384.

Irradiation of 16 in H_2O−KOH. An N_2-purged solution of **16** (200 mg, 0.90 mmol) and KOH (51 mg, 0.90 mmol) in 100 mL of water was irradiated for 1.5 h. The photolysate was subjected to the normal workup procedure B to yield 71 mg (57%) of 6-propyl-6-azabicyclo[3.1.0]hex-3-en-2-ol (**44**): ^1H NMR 6.25 (d, 1H, vinyl), 5.83 (m, 1H, vinyl), 4.43 (s, 1H, H_2), 2.45, 2.41 (brs, 2H, H_1, H_5), 2.24 (t, 2H, NCH_2), 1.56 (m, 2H, NCH_2CH_2), 0.90 (t, J = 7,4 Hz, 3H, $NCH_2CH_2CH_3$); ^{13}C NMR 137.2, 135.5 (CH=CH), 74.8 (C2), 60.0 (NCH_2CH_2), 0.90 (NCH_2-CH_2CH_3); 55.5, 46.8 (C_1, C_5), 22.6 (NCH_2CH_2), 11.7 (NCH_2-CH_2CH_3); MS *m/z* (rel intensity) 139(7), 122(68), 96(17), 80(100); HRMS calcd *m/z* for $C_8H_{13}NO$ 139.0997, found 139.0989.

Irradiation of 17 in H_2O−KOH. An N_2-purged solution of **17** (100 mg, 0.42 mmol) and potassium hydroxide (40 mg, 0.71 mmol) in H_2O (100 mL) was irradiated in a preparative apparatus for 180 min. The photolysate was concentrated under reduced pressure to give a residue, which was subjected to column chromatography (silica gel, chloroform:acetone 90/10) to yield 24 mg (41% yield at 90% conversion) of the 6-(carbamoylmethyl)-6-azabicyclo[3.1.0]hex-3-en-2-ol (**45**): ^1H NMR 6.27 (d, J = 5.6 Hz, 1H, vinyl), 5.92 (d, J = 5.6 Hz, 1H, vinyl), 4.49 (s, 1H, H_2), 3.01 (s, 3H, OCH_3), 3.07 and 2.94 (ABq, J = 16.7 Hz, 2H, CH_2), 2.64 (brs, 2H, H_1, H_5); ^{13}C NMR 172.5 (C=O), 137.8, 135.0 (CH=CH), 75.2 (C_2), 60.1 (CH_2), 50.7, 47.6 (C_1, C_5); IR (neat) 3382, 1683, 1418, 1318, 1126, 1037; MS *m/z* (rel intensity) 154 (2), 137 (100), 120 (5), 93 (15); HRMS calcd *m/z* for $C_7H_{10}N_2O_2$ 154.0742, found 154.0742.

Irradiation of 18 in H_2O−KOH. An N_2-purged solution of **18** (100 mg, 0.45 mmol) and potassium hydroxide (40 mg, 0.71 mmol) in H_2O (100 mL) was irradiated in a preparative apparatus for 135 min. After the normal workup procedure B and column chromatography (silica gel, chloroform:acetone 50/50), 57 mg (100% yield at 90% conversion) of 6-(2-hydroxyethyl)-6-azabicyclo[3.1.0]hex-3-en-2-ol (**46**) was obtained: ^1H NMR 6.35 (d, J = 5.8 Hz, 1H, vinyl), 5.82 (m, 1H, vinyl), 4.50 (s, 1H, H_2), 3.71 (t, J = 5.2 Hz, 2H, CH_2OH), 2.55 (brs, 2H, H_1, H_5), 2.41 (t, J = 5.2 Hz, 2H, CH_2CH_2OH); ^{13}C NMR 137.4, 135.3 (CH=CH), 74.7 (C_2), 61.5 (CH_2OH), 59.7 (CH_2CH_2OH), 50.5, 46.6 (C_1, C_5); IR (neat) 3389, 2930, 1660, 1642, 1349, 1114, 1038; MS *m/z* (rel intensity) 142 (4), 141 (2), 140 (6), 124 (100), 96 (14), 80 (84); HRMS calcd *m/z* for $C_7H_{11}NO_2$ 141.0790, found 141.0794.

Methanolysis of 3-Methoxy-6-propyl-6-azabicyclo[3.1.0]-hex-2-ene (19). A solution of **19** (20 mg, 0.13 mmol) and perchloric acid (0.13 mmol) in 2 mL of absolute methanol was stirred at 25 °C for 4.5 h. The normal workup procedure A and column chromatography (silica gel, ether−acetone) gave 10 mg (42%) of **22**.

Hydrolysis of 19. A solution of **19** (20 mg, 0.13 mmol) and perchloric acid (0.13 mmol) in 1 mL of 1:9 H_2O−THF was stirred at 25 °C for 5.5 h. The reaction mixture was subjected to the normal workup procedure A to yield 18 mg (81%) of crude product 4-(*N*-propylamino)-5-methoxycyclopenten-3-ol (**47**): ^{1}H NMR 6.00 (d, 1H, vinyl), 5.92 (d, 1H, vinyl), 4.46 (d, 1H, H_3), 4.05 (d, 1H, H_5), 3.39 (s, 3H, OCH_3), 3.08 (t,1H, H_4), 2.79 (t, 2H, NCH_2), 1.58 (m, 2H, NCH_2CH_2), 0.93 (t, J = 7.4 Hz, 3H, $NCH_2CH_2CH_3$); ^{13}C NMR 135.4, 131.2 (CH=CH), 88.2 (C_3), 79.5 (C_5), 73.7 (OCH_3), 56.3 (C_4), 50.1 (NCH_2), 22.7 ($NCH2CH_2$), 11.6 ($NCH_2CH_2CH_3$); MS *m*/*z* (rel intensity) 171-(6), 154(37), 140(56), 122(40), 82(100); HRMS calcd *m*/*z* for $C_9H_{15}NO$ 171.1259, found 171.1248.

Reaction of 19 with Acetic Acid. A solution of **19** (20 mg, 0.13 mmol) in 1 mL of acetic acid was stirred at 25 °C for 72 h. The normal workup procedure A and column chromatography (silica gel, ether−$CHCl_3$) gave 10 mg (36%) of 3-acetoxy-4-(*N*-propylamino)-5-methoxycyclopentene (**48**): ^{1}H NMR 6.10 (d, 1H, vinyl), 5.85 (d, 1H, vinyl), 5.31 (s, 1H, H_3), 4.16 (s, 1H, H_5), 3.40 (s, 3H, OCH_3), 3.18 (t, 1H, H_4), 2.69 (m, 2H,NCH_2), 2.09 (s, 3H, $OCOCH_3$), 1.55 (m, 2H, NCH_2CH_2), 0.95 (t, J = 7,4 Hz, 3H, $NCH_2CH_2CH_3$); ^{13}C NMR 171.7 (C=O), 134.0, 131.4 (CH=CH), 88.5 (C_3), 82.6 (C_5), 70.6 (OCH_3), 56.5 (C_4), 49.8 (NCH_2), 30.3 ($OCOCH_3$), 22.8 (NCH_2CH_2), 11.6 ($NCH_2CH_2CH_3$); MS *m*/*z* (rel intensity) 214(12), 154(100), 122-(44), 80(24); HRMS calcd *m*/*z* for $C_{11}H_{20}NO_3$ 214.1443, found 214.1452.

Methanolysis of 4-Methoxy-6-(carbamoylmethyl)-6-azabicyclo[3.1.0]hex-2-ene (20). A solution of **20** (8 mg, 0.048 mmol) and perchloric acid (0.2 mL, 0.02 mmol) in MeOH (10 mL) was stirred at 25 °C for 5 h. The normal workup procedure A and column chromatography (silica gel, chloroform:ether 50/50) gave 9 mg (93%) of 4-((carbamoylmethyl)-amino)-3,5-dimethoxycyclopentene (**23**).

Ethanolysis of 20. A solution of **20** (25 mg, 0.15 mmol) and perchlorate acid (1.0 mL, 0.10 mmol) in EtOH (20 mL) was stirred at 25 °C for 72 h. The normal workup procedure A and column chromatography (silica gel, chloroform:acetone 80/20) gave 25 mg (79%) of 4-((carbamoylmethyl)amino)-3-methoxy-5-ethoxycyclopentene (**49**): ^{1}H NMR 6.01 (s, 2H, vinyl), 4.20 (d, J = 5.2 Hz, 1H, H_3 or H_5), 4.13 (d, J = 5.2 Hz, 1H, H_3 or H_5), 3.56 (s, 2H, CH_2CONH_2), 3.56 (q, J = 7.0 Hz, 2H, OCH_2CH_3), 3.37 (s, 3H, OCH_3), 3.23 (t, J = 5.2 Hz, 1H, H_4), 1.10 (t, J = 7.0 Hz, 3H, OCH_2CH_3); ^{13}C NMR 173.5 (C=O), 132.6, 131.5 (CH=CH), 87.3, 86.0 (C_3, C_5), 70.6 (C_4), 64.5 (OCH_2CH_3), 56.3 (OCH_3), 50.0 (CH_2CONH_2), 15.6 (OCH_2CH_3); IR (neat) 2977, 2884, 1653, 1374, 1087; MS *m*/*z* (rel intensity) 215 (2), 214 (1), 183 (21), 169 (10), 156 (9), 141 (12), 137 (100), 124 (19), 110 (25), 80 (23); HRMS calcd *m*/*z* for $C_{10}H_{18}N_2O_3$ 214.1317, found 214.1322.

Reaction of 20 with Acetic Acid. A solution of **20** (23 mg, 0.14 mmol) and acetic acid (0.3 mL, 5.2 mmol) in MeCN (20 mL) was stirred at reflux for 48 h. The normal workup procedure A and column chromatography (silica gel, chloroform:acetone 80/20) afforded 11 mg (34%) of 4-((carbamoylmethyl)amino)-3-acetoxy-5-methoxycyclopentene (**50**): ^{1}H NMR 6.12 (d, J = 6.1 Hz, 1H, vinyl), 5.86 (d, J = 6.1 Hz, 1H, vinyl), 5.35 (d, J = 4.2 Hz, 1H, H_3), 4.17 (d, J = 4.2 Hz, 1H, H_5), 3.50 (s, 2H, CH_2), 3.39 (s, 3H, OCH_3), 3.26 (t, J = 4.2 Hz, 1H, H_4), 2.08 (s, 3H, $OCOCH_3$); ^{13}C NMR 174.6, 171.5 (C=O), 133.7, 131.3 (CH=CH), 87.7 (C_3), 81.5 (C_5), 70.7 (C_4), 56.6 (OCH_3), 49.9 (CH_2), 21.0 ($OCOCH_3$); IR (neat) 2933, 1733, 1652, 1368, 1256, 1078, 1025, 968; MS *m*/*z* (rel intensity) 229 (M + 1, 4), 184 (6), 137 (100), 110 (27), 94 (20), 80 (30); HRMS(CI) calcd *m*/*z* for $C_{10}H_{17}N_2O_4$ 229.1188, found 229.1182.

Methanolysis of 4-Methoxy-6-(hydroxyethyl)-6-azabicyclo[3.1.0]hex-2-ene (21). A solution of **21** (10 mg, 0.064 mmol) and perchloric acid (0.5 mL, 0.05 mmol) in anhydrous MeOH (10 mL) was stirred at 25 °C for 6 h. The residue was subjected to the normal workup procedure A to yield 12 mg (99%) of **24**.

Reaction of 19 with Thioacetic Acid. A solution of **19** (20 mg, 0.13 mmol) in 0.5 mL of thioacetic acid was stirred at 25 °C for 4.5 h. The normal workup procedure A and column chromatography (silica gel, hexane−$CHCl_3$) yielded 26 mg (74%) of 3-(thioacetoxy)-4-(*N*-propylamino)-5-methoxycyclopentene (**51**): ^{1}H NMR 5.96 (m, 1H, vinyl), 5.78 (m, 1H, vinyl), 4.92 (d, 1H, H_3), 4.75 (d, 1H, H_5), 3.61 (t, 1H, H_4), 3.35 (s, 3H, OCH_3), 3.20 (m, 2H,NCH_2), 2.28 (s, 3H, $SCOCH_3$), 2.11 (s, 3H, $NCOCH_3$), 1.62 (m, 2H, NCH2CH_2), 0.90 (t, J = 7,4 Hz, 3H, $NCH_2CH_2CH_3$); ^{13}C NMR 194.9 (S*C*OCH3), 170.9 (N*C*OCH3), 133.3, 131.4 (CH=CH), 87.5 (C_3), 72.9 (C_5), 56.8 (OCH_3), 53.2 (NCH_2), 48.7 (C_4), 30.3 (SCOCH_3), 22.9 (NCH2CH_2), 22.5 (NCO*C*H3), 11.0 ($NCH_2CH_2CH_3$); MS *m*/*z* (rel intensity) 272 (1), 196 (100), 154 (57), 128 (14), 84 (17); HRMS calcd *m*/*z* for $C_{13}H_{22}NO_3S$ 272.1321, found 272.1322.

Methanolysis of 6-Propyl-6-azabicyclo[3.1.0]hex-2-en-3-ol (44). A solution of **44** (85 mg, 0.61 mmol) and perchloric acid (0.61 mmol) in 2 mL of absolute methanol was stirred at 25 °C for 18 h. The normal workup procedure A and column chromatography (silica gel, ether−acetone) gave 70 mg (67%) of **47**.

Reaction of 44 with Thioacetic Acid. A solution of **44** (25 mg, 0.18 mmol) in 0.5 mL of thioacetic acid was stirred at 25 °C for 16 h. The normal workup procedure A and column chromatography (silica gel, ether−$CHCl_3$) gave 16 mg (34%) of 3-(thioacetoxy)-4-(*N*-propyl-*N*-acetylamino)cyclopenten-5-ol (**52**): ^{1}H NMR 5.88 (m, 1H, vinyl), 5.70 (m, 1H, vinyl), 4.99 (d, 1H, H_3), 4.79 (m, 1H, H_5), 3.86 (t, 1H, H_4), 3.23 (m, 2H, NCH_2), 2.31 (s, 3H, $SCOCH_3$), 2.13 (s, 3H, $NCOCH_3$), 1.60 (m, 2H, NCH_2CH_2), 0.90 (t, 3H, $NCH_2CH_2CH_3$); ^{13}C NMR 195.3 (S*C*OCH$_3$), 171.8 (N*C*OCH$_3$), 134.5, 132.3 (CH=CH), 79.7 (C_3), 74.4 (C_5), 52.1 (NCH_2), 48.5 (C_4), 30.5 (SCOCH_3), 23.2 (NCH_2CH_2), 22.4 (NCOCH_3), 11.1 ($NCH_2CH_2CH_3$); MS *m*/*z* (rel intensity) 257 (1), 182 (100), 140 (81); HRMS calcd *m*/*z* for $C_{12}H_{19}NO_3S$ 257.1085, found 257.1108.

Methanolysis of 6-(2-Hydroxyethyl)-6-azabicyclo[3.1.0]-hex-3-en-2-ol (46). A solution of **46** (25 mg, 0.18 mmol) and perchloric acid (0.3 mL, 0.03 mmol) in anhydrous MeOH (10 mL) was stirred at 60 °C for 48 h. The normal workup procedure A gave 31 mg (99%) of 4-[*N*-(2-hydroxyethyl)amino]-3-hydroxy-5-methoxycyclopentene (**53**): ^{1}H NMR 5.96 (d, J = 5.9 Hz, 1H, vinyl), 5.88 (d, J = 5.9 Hz, 1H, vinyl), 4.39 (d, J = 4.7 Hz, 1H, H_3), 4.01 (d, J = 4.7 Hz, 1H, H_5), 3.71 (t, J = 5.3 Hz, 2H, CH_2OH), 3.38 (s, 3H, OCH_3), 3.07 (t, J = 4.7 Hz, 1H, H_4), 2.94 (t, J = 5.3 Hz, 2H, CH_2CH_2OH); ^{13}C NMR 135.5, 130.9 (CH=CH), 88.9 (C_5), 79.6 (C_3), 73.7 (C_4), 61.2 (CH_2OH), 56.3 (OCH_3), 49.7 (CH_2CH_2OH); IR (neat) 3361, 2980, 1651, 1548, 1361, 1057; MS *m*/*z* (rel intensity) 174 (4), 173 (3), 156 (61), 142 (100), 124 (69), 110 (62), 97 (18), 81 (58); HRMS calcd *m*/*z* for $C_8H_{15}NO_3$ 173.1052, found 173.1057.

Reaction of 19 with Ethyl Chloroformate. A solution of **19** (70 mg, 0.46 mmol) and ethyl chloroformate (0.2 mL, 2.09 mmol) in 3mL of $CHCl_3$ was stirred at 25 °C for 1 h and concentrated in *vacuo* to yield 110 mg (92%) of 3-chloro-4-(*N*-propylamino)-5-methoxycyclopentene (**54**) which was not subjected to further purification: ^{1}H NMR 6.01 (d, 1H, vinyl), 5.87 (m, 1H,vinyl), 5.16 (bs, 1H, H_3), 4.68 (m, 1H, H_5), 4.11(q, 2H, $NCO_2CH_2CH_3$ and t, 1H, H_4), 3.36 (s, H, OCH_3), 3.24 (t, 2H, NCH_2), 1.61 (m, 2H, NCH_2CH_2), 1.23 (t, 3H, $NCO_2CH_2CH_3$), 0.83 (t, 3H, $NCH_2CH_2CH_3$); ^{13}C NMR 155.6 (C=O), 134.0, 132.5 (CH=CH), 95.5 (C_3), 86.5 (C_5), 65.3 (C_4), 61.2 ($NCO_2CH_2CH_3$), 56.9 (OCH_3), 52.2 (NCH_2) 22.8 (NCH_2CH_2), 14.5 ($NCOCH_2CH_3$), 10.9 ($NCH_2CH_2CH_3$); MS *m*/*z* (rel intensity) 264 (2), 262 (4), 226 (100), 198 (11), 181 (11), 164 (15), 154 (8); HRMS calcd *m*/*z* for $C_{12}H_{20}NO_3{}^{35}Cl$ 261.11361, found 261.11434, HRMS calcd *m*/*z* for $C_{12}H_{20}NO_3{}^{37}Cl$ 263.1102, found 263.1106.

Preparation of Azlactone 56 by Cyclization of 54. A solution of carbamate **54** (110 mg, 0.42 mmol) in 3 mL of $CHCl_3$ was stirred at 65 °C for 17 h and then concentrated in *vacuo* to yield a residue which was subjected to column chromatography (silica gel, hexane−ether) to give 40 mg (48%) of azlactone **56**: ^{1}H NMR 6.18 (m, 1H, vinyl), 6.10 (m, 1H, vinyl), 5.44 (m, 1H, H_3), 4.32 (m, 1H, H_5), 4.02 (d, 1H, H_4), 3.38 (s, 3H, OCH_3), 3.47, 3.06 (m, 2H, NCH_2,), 1.67 (m, 2H, NCH_2CH_2),

0.93 (t, 3H, $NCH_2CH_2CH_3$); ^{13}C NMR 156.7 (C=O), 135.1,133.6 (CH=CH), 87.5 (C_3), 80.8 (C_5), 62.7 (C_4), 56.9 (OCH_3), 44.6 (NCH_2), 20.5 (NCH_2CH_2),11.1 ($NCH_2CH_2CH_3$); MS *m/z* (rel intensity) 197(1), 153(13), 122(100), 110(31); HRMS calcd *m/z* for $C_{10}H_{15}NO_3$ 197.1052, found 197.1705.

Preparation of 5-Methoxy-4-(*N*-methyl-*N*-propylamino)cyclopenten-3-ol (55) by Reduction of 56. A solution of **56** (32 mg, 0.16 mmol) and $LiAlH_4$ (20 mg, 0.56 mmol) in 3 mL of anhydrous ether was stirred at 25 °C for 3 h under N_2, diluted with H_2O, and then extracted with ether. The ethereal extracts were concentrated in *vacuo* to yield 17 mg (62%) of cyclopentenol **55**: ^1H NMR 6.10 (d, 2H, vinyl), 4.45 (m, 1H, H_5), 4.38 (m, 1H, H_3), 3.34 (s, 3H, OCH_3), 2.69 (t, 1H, H_4), 2.45 (m, 2H, NCH_2), 2.32 (s, 3H, NCH_3), 1.52 (m, 2H, NCH_2CH_2), 0.86 (t, 3H, $NCH_2CH_2CH_3$); ^{13}C NMR 135.0, 133.7 (CH=CH), 85.7 (C_5), 71.9 (C_3), 71.7 (OCH_3), 57.6 (NCH_2), 56.3 (C_4), 39.7 (NCH_3), 20.3 (NCH_2CH_2), 11.6 ($NCH_2CH_2CH_3$); MS *m/z* (rel intensity) 171 (2), 154 (100), 142 (12), 128 (18), 122 (11); HRMS calcd *m/z* for $C_9H_{17}NO_2$ 171.1259, found 171.1261.

Reaction of 20 with Ethyl Chloroformate. A solution of **20** (20 mg, 0.12 mmol) and ethyl chloroformate (0.4 mL, 4.2 mmol) in $CHCl_3$ (10 mL) was stirred at reflux for 12 h. The reaction mixture was concentrated *in vacuo*, and the residue was subjected to column chromatography (silica gel, acetone: hexanes 80/20) to afford 12 mg (41%) of 5-(ethoxycarbonyl)-7-methoxy-6-aza-2-oxabicyclo[4.3.0]non-8-en-3-one (**57**) and 6 mg (18%) of 4-(*N*-(carbamoylmethyl)-N-(ethoxycarbonyl)amino)-3-chloro-5-methoxycyclopentene (**58**).

57: ^1H NMR 6.26 (d, J = 6.0 Hz, 1H, vinyl), 6.09 (d, J = 6.0 Hz, 1H, vinyl), 5.66 (d, J = 6.8 Hz, 1H, H_1), 4.37 (s, 1H, H_7), 4.20 (q, J = 6.9 Hz, 2H, OCH_2CH_3), 3.45 (s, 3H, OCH_3), 3.36 (m, 1H, H_6), 1.28 (t, J = 6.9 Hz, 3H, OCH_2CH_3); ^{13}C NMR 166.7, 155.0 (C=O), 136.8, 133.9 (CH=CH), 88.0 (C_1), 81.8 (C_7), 62.6 (OCH_2CH_3), 57.7 (OCH_3), 54.4 (C_6), 42.9 (CH_2), 14.5 (OCH_2CH_3); MS *m/z* (rel intensity) 242 (7), 241 (10), 196 (43), 182 (32), 168 (100), 152 (35), 138 (35), 124 (40), 94 (41), 84 (58); HRMS calcd *m/z* for $C_{11}H_{15}NO_5$ 241.0950, found 241.0955.

58: ^1H NMR 5.90 (d, J = 5.8 Hz, 1H, vinyl), 5.79 (d, J = 5.8 Hz, 1H, vinyl), 4.69 (s, 1H, H_3), 4.19 (q, J = 7.0 Hz, 2H, OCH_2CH_3), 4.04 (s, 1H, H_5), 3.80 (s, 2H, NCH_2), 3.52 (s, 3H, OCH_3), 3.38 (t, J = 4.0 Hz, 1H, H_4), 1.26 (t, J =7.0 Hz, 3H, OCH_2CH_3); ^{13}C NMR 171.5, 157.0 (C=O), 134.4, 132.5 (CH=CH), 94.0 (C_5), 67.2 (C_3), 64.6 (OCH_2CH_3), 62.4 (OCH_3), 58.3 (C_4), 53.9 (NCH_2), 14.5 (OCH_2CH_3); MS *m/z* (rel intensity) 277 (1), 241 (100), 137 (28); HRMS calcd *m/z* for $C_{11}H_{17}ClN_2O_4$ 276.0877, found 276.0894.

Irradiation of Pyridinium Perchlorate (59) in MeOH−$HClO_4$. An N_2-purged solution of **59** (202 mg, 1.12 mmol) and perchloric acid (70%, 0.5 mL) in anhydrous MeOH (100 mL) was irradiated in a preparative apparatus for 9 h. The photolysate was concentrated in *vacuo* and the residue subjected to the normal workup procedure A to yield 48 mg (48% yield at 62% conversion) of 4-amino-3,5-dimethoxycyclopentene (**61**): ^1H NMR 6.04 (s, 2H, vinyl), 5.72 (brs, 2H, NH_2), 4.33 (d, J = 4.8 Hz, 2H, H_3, H_5), 3.47 (t, J = 4.8 Hz, 1H, H_4), 3.42 (s, 6H, $2OCH_3$); ^{13}C NMR 132.0, (CH=CH), 86.1 (C_3, C_5), 62.4 (C_4), 56.4 (OCH_3); IR (neat) 3072, 2939, 2832, 1556, 1095; MS *m/z* (rel intensity) 143 (2), 142 (3), 128 (17), 112 (75), 80 (100); HRMS calcd *m/z* for $C_7H_{13}NO_2$ 143.0946, found 143.0943.

Irradiation of *N*-Propylpyridinium Perchlorate (16) in H_2O. Small Scale. An N_2-purged solution of **16** (200 mg, 0.90 mmol) in 100 mL of water was irradiated for 2 h and then heated in the dark at 70 °C for 5 h. The reaction mixture was subjected to the normal workup procedure A to yield 142 mg (99%) of the aminocyclopentendiol **69**. The purity of **69** was determined to be ca. 40% by ^1H NMR. This material was not subjected to further purification. **69**: ^1H NMR (d_6-acetone) 5.70 (s, 2H, vinyl), 4.37 (d, 2H, H_3,H_5), 2.93 (t, 1H, H_4), 2.70 (t, 2H, $NCH_2CH_2CH_3$), 1.48 (m, 2H, $NCH_2CH_2CH_3$), 0.83 (t, 3H, $NCH_2CH_2CH_3$); ^{13}C NMR (d_6-acetone) 134.7 (CH=CH), 79.6 (C_3,C_5), 68.9 (C_4), 50.1 ($NCH_2CH_2CH_3$), 23.2 ($NCH_2CH_2CH_3$), 11.8 ($NCH_2CH_2CH_3$); MS *m/z* (rel intensity) 157 (12), 140 (100), 122 (56), 110 (43), 96 (30); HRMS calcd *m/z* for $C_8H_{15}NO_2$ 157.1102, found 157.1090.

Large Scale. An N_2-purged solution of **16** (1.0 g, 4.5 mmol) in 500 mL of water was irradiated at 45−70 °C for 25 h. The reaction mixture was subjected to the normal workup procedure A to yield 700 mg of **69**. The purity of **69** was determined to be ca. 60% by ^1H NMR. A solution of this material (490 mg, 3.12 mmol), diisopropylethylamine (3.7 mL, 21 mmol), acetic anhydride (2 mL, 21 mmol), and 4-(dimethylamino)-pyridine (60 mg) in 2 mL of CH_3CN was stirred at 25 °C for 17 h. The reaction mixture was poured into ice−water, neutralized with $NaHCO_3$, trituated with $CHCl_3$, filtered, and concentrated to yield the crude product, which was subjected to column chromatography (silica gel, $CHCl_3$−ether) to give 230 mg (26% from pyridinium salt **16**) of the diacetoxy amide **71**: ^1H NMR 5.90 (s, 2H, vinyl), 5.86 (d, 2H, H_3, H_5), 3.48 (t, 1H, H_4), 3.14 (t, 2H, $NCH_2CH_2CH_3$), 2.00 (s, 3H, $NCOCH_3$), 1.97 (s, 6H, $2OCOCH_3$), 1.49 (m, 2H, $NCH_2CH_2CH_3$), 0.82 (t, 3H, $NCH_2CH_2CH_3$); ^{13}C NMR 170.8 ($OCOCH_3$), 170.2 ($NCOCH_3$), 132.8 (CH=CH), 78.9 (C_3, C_5), 71.3 (C_4), 53.0 (NCH_2), 22.6 (NCH_2CH_2), 22.1 ($OCOCH_3$), 20.8 ($NCOCH_3$), 10.7 ($NCH_2CH_2CH_3$); MS *m/z* (rel intensity) 283 (11), 224 (38), 181 (75), 140 (100), 122 (23); HRMS calcd *m/z* for $C_{14}H_{21}NO_5$ 283.1419, found 283.1406.

Irradiation of 59 in H_2O−$HClO_4$. Small Scale. An N_2-purged solution of **59** (211 mg, 1.17 mmol) and perchloric acid (70%, 0.5 mL) in H_2O (120 mL) was irradiated in a preparative apparatus for 24 h. The photolysate was concentrated in *vacuo* and the residue subjected to the normal workup procedure A to yield 4-amino-3,5-dihydroxycyclopentene (**70**) (96% conversion): ^1H NMR (d_6-acetone) 5.76 (s, 2H, vinyl), 4.43 (d, J = 5.4 Hz, 2H, H_3, H_5), 2.82 (t, J = 5.4 Hz, 1H, H_4); ^{13}C NMR (d_6-acetone) 136.0, (CH=CH), 81.5 (C_3, C_5), 76.0 (C_4).

Without purification, a solution of **70** in anhydrous pyridine (10 mL) was stirred at 0 °C, and acetyl chloride (440 mg, 5.61 mmol) was then added dropwise. The solution was stirred at 0 °C under N_2 for an additional 1 h. The reaction mixture was poured into ice−water, neutralized with $NaHCO_3$, and extracted with $CHCl_3$. The extracts were concentrated in *vacuo* to give a residue (98 mg), which was subjected to column chromatography (silica gel, chloroform and acetone−hexanes 60/40) to yield 72 mg (30%) of 4-acetamido-3,5-diacetoxycyclopentene (**72**) as a crystalline material (mp 167−171 °C): ^1H NMR 5.93 (s, 2H, vinyl), 5.56 (d, J = 5.2 Hz, 2H, H_3, H_5), 4.22 (dt, J = 5.2 Hz, J = 7.6 Hz, 1H, H_4), 2.05 (s, 6H, $2CO_2CH_3$), 1.95 (s, 3H, $NHCOCH_3$); ^{13}C NMR 170.8, 170.7 (C=O), 132.9 (CH=CH), 80.1 (C_3, C_5), 62.6 (C_4), 23.2, 20.9 (CO_2CH_3, $NHCOCH_3$); IR (neat) 3301, 3072, 2950, 1738, 1656, 1547, 1228, 1020; MS *m/z* (rel intensity) 242 (M + 1, 5), 241 (1), 198 (5), 182 (13), 139 (100), 97 (81); HRMS(CI) calcd *m/z* for $C_{11}H_{16}NO_5$ 242.1028, found 242.1040.

Large Scale. An N_2-purged solution of **59** (1.60 g, 8.91 mmol) and perchloric acid (70%, 5.0 mL) in H_2O (1000 mL) was irradiated for 48 h. The photolysate was concentrated in *vacuo* and the residue subjected to the normal workup procedure A to yield **70** (74% conversion as indicated by UV). Without further purification, a solution of **70** in anhydrous pyridine (60 mL) was stirred at 0 °C, and acetyl chloride (6.62 g, 84.4 mmol) was then added dropwise. The solution was stirred at 0 °C under N_2 for 24 h. The reaction mixture was poured into ice−water, neutralized with $NaHCO_3$, and extracted with $CHCl_3$. The extracts were concentrated in *vacuo* to give a residue which was subjected to column chromatography (silica gel, chloroform and acetone:hexanes 60/40) to yield 346 mg (22%) of 4-acetamido-3,5-acetoxycyclopentene (**72**).

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Supporting Information Available: ^1H and ^{13}C NMR spectra are provided for all new compounds characterized in this work (77 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal, and can be ordered from the ACS; see any current masthead page for ordering information.

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