Conclusion

AM1 and ab inito STO 3G MO calculations on bicyclo[2.2.2]oct-1-yl cation and 2- and 3-substituted derivatives suggest that the carbonyl and imine functions in 3-oxo- (**13**) and 3-(*E*)-iminobicyclo[2.2.2]oct-1-yl (**15**) cations are less electron withdrawing than expected on the basis of their inductive (through-space) effect because of the intervention of an electron-releasing effect due to favorable through bond n(CO) ↔ σ(C,C) ↔ p(C^+) and n(C=NH) ↔ σ(C,C) ↔ p(C^+) interactions, respectively.[25] This phenomenon is predicted to be less important in 3-(*Z*)-iminobicyclo[2.2.2]cation (**17**).

Acknowledgment. We are grateful to the Swiss National Science Foundation, the Fonds Herbette (Lausanne), and Hoffmann-La Roche and Co., AG (Basel) for financial support. We thank the Ecole Polytechnique Fédérale of Lausanne (EPFL, CRAY 2 computer), the Swiss Institute of Technology in Zürich (ETHZ, CRAY XMP computer), and Prof. G. Bodenhausen, University of Lausanne (SUN 4), for generous gifts of computing time.

Registry No. **11**, 22907-76-2; **12**, 129314-99-4; **13**, 129315-04-4; **14**, 129315-00-0; **15**, 129315-05-5; **16**, 129315-01-1; **17**, 129315-06-6; **18**, 129315-02-2; **19**, 129315-07-7; **20**, 129315-03-3; **21**, 129315-08-8; **22**, 129315-09-9; **23**, 129447-11-6; **24**, 129315-10-2; **25**, 129447-12-7; **26**, 280-33-1; **27**, 2716-23-6; **28**, 129315-11-3; **29**, 129315-12-4; **30**, 2972-20-5; **31**, 129315-13-5; **32**, 6962-74-9; **33**, 5437-58-1; H^-, 12184-88-2.

Supplementary Material Available: Atomic coordinates, bond lengths, and bond angles calculated (completely optimized geometries) by the AM1 method for **11–36** and by the STO 3G techniques for **11–19**, **26–30** (81 pages). Ordering information is given on any current masthead page.

(25) For α-acylcarbenium ions, see: Bégué, J. P.; Charpentier-Morize, M.; Pardo, C.; Sansoulet, J. *Tetrahedron* **1978**, *34*, 293–298. Bégué, J. P.; Charpentier-Morize, M. *Acc. Chem. Res.* **1980**, *13*, 207–212. Paddon-Row, M. N.; Houk, K. N.; Tidwell, T. T. *Tetrahedron Lett.* **1982**, *23*, 383–386. See also: Hojo, M.; Masuda, R.; Ichi, T.; Yoshinaga, K.; Yanada, M. *Tetrahedron Lett.* **1982**, *23*, 4963–4964. Endo, Y.; Shudo, K.; Okamoto, T. *J. Am. Chem. Soc.* **1982**, *104*, 6393–6397. Olah, G. A.; Prakash, G. K. S.; Arvanaghi, M.; Krishnamurthy, V. V.; Narang, S. C. *Ibid.* **1984**, *106*, 2378–2380. Gassman, P. G.; Tidwell, T. T. *Acc. Chem. Res.* **1983**, *16*, 279–285. Creary, X.; McDonald, S. R.; Eggers, M. D. *Tetrahedron Lett.* **1985**, *26*, 811–814. Creary, X. *J. Am. Chem. Soc.* **1981**, *103*, 2463–2465. Creary, X.; Geiger, C. C. *Ibid.* **1982**, *104*, 4151–4162; **1983**, *105*, 7123–7129. Kulkarni, G. C.; Karmarkar, S. N.; Kelkon, S. L.; Wadia, M. S. *Tetrahedron* **1988**, *44*, 5189–5198.

Amino Alcohol and Amino Sugar Synthesis by Benzoylcarbamate Cyclization

Spencer Knapp,* Paivi J. Kukkola, Shashi Sharma, T. G. Murali Dhar, and Andrew B. J. Naughton

Department of Chemistry, Rutgers–The State University of New Jersey, New Brunswick, New Jersey 08903

Received April 10, 1990

The sodium anion (**3**) of an alcohol-derived benzoylcarbamate (**2**) may be used to deliver an amino nitrogen intramolecularly to electrophilic carbon centers such as bromides, epoxides, and triflates, giving rise to amino alcohol and amino diol derivatives of general form **4–6**. A procedure for selective monotriflation of carbohydrate diols is described that exploits the enhanced reactivity of carbohydrate hydroxyls flanked by a cis, vicinal ether oxygen. Subsequent benzoylcarbamate formation and cyclization allows the conversion of several sugars to amino sugars (**47**, **54**, **74**, **80**). However, the cyclization occurs on the carbonyl oxygen if the triflate site is hindered (**63** and **67**).

For the synthesis of amino compounds, intramolecular delivery of a nitrogen nucleophile sometimes offers advantages over the intermolecular variant. An extensive family of cyclization methods has been developed that allows the synthesis of amino compounds with excellent control over the position and the stereochemistry of the amino group, while minimizing the extent of competing elimination or rearrangement side reactions.[1,2] We recently introduced,[3] coincidentally with McCombie's group,[4] the benzoylcarbamate cyclization method for the synthesis of amino alcohol and amino diol derivatives from precursors bearing a hydroxy group and a nearby electrophilic carbon center. In this paper we present the full description and experimental details for these transformations and also describe their further application to the preparation of amino sugars.

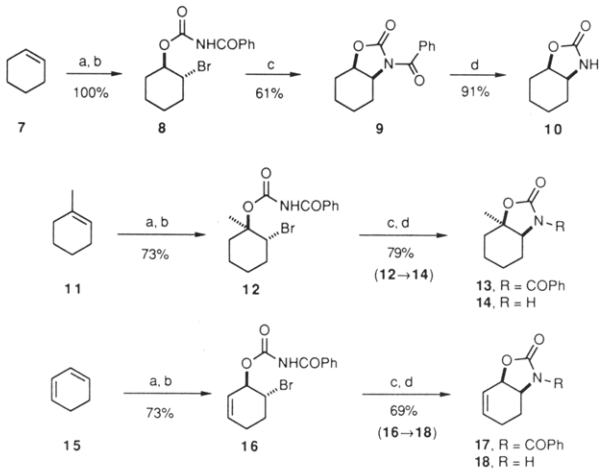
The concept of an alcohol-derived benzoylcarbamate **2** as a likely intramolecular source of nucleophilic nitrogen arose because [1] such derivatives should readily form under neutral conditions (**1** → **2**),[5] [2] the anion **3** of a benzoylcarbamate should be easily generated and stable toward reversion to the original alcohol,[6,7] but still possess sufficient negative charge at nitrogen to undergo *N*-

(1) Harding, K. E. In *Comprehensive Organic Synthesis*; Trost, B. M., Fleming, I., Eds.; Pergamon Press: Oxford, in press; Vol. 4, Part 1, Chapter 9.
(2) Cardillo, G.; Orena, M. *Tetrahedron* **1990**, *46*, 3321.
(3) Knapp, S.; Kukkola, P. J.; Sharma, S.; Pietranico, S. *Tetrahedron Lett.* **1987**, *28*, 5399.
(4) McCombie, S. W.; Nagabhushan, T. L. *Tetrahedron Lett.* **1987**, *28*, 5395.

(5) (a) Speziale, A. J.; Smith, L. R. *J. Org. Chem.* **1961**, *27*, 3742. (b) Ulrich, H. *Chem. Rev.* **1965**, *65*, 369.
(6) The difference in acidity between a secondary alcohol ($pK_a \approx 16.5$) and the alcohol-derived benzoylcarbamate (**2**) in water may be estimated at about 7 pK_a units, based on the pK_a's of ethyl acetoacetate (11) and phthalimide (9.9), and the roughly hundredfold greater acidity of amide N–H relative to ketone C–H. *Lange's Handbook of Chemistry*; Dean, J. A., Ed.; McGraw-Hill: New York, 1972. March, J. *Advanced Organic Chemistry*, 3rd ed.; Wiley-Interscience: New York, 1985; p 221.
(7) For a review of the properties and chemistry of imidic compounds, see: Wheeler, O. H., Rosado, O. In *The Chemistry of Amides*; Zabicky, J., Ed.; Wiley Interscience: New York, 1970; pp 335–382.

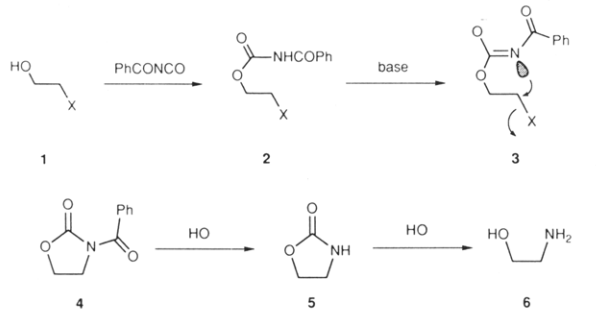
0022-3263/90/1955-5700$02.50/0

Scheme I[a]



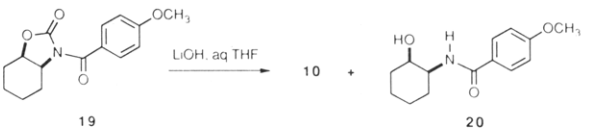
[a] Reagents: (a) NBS, H_2O, 0 to 25 °C; (b) PhCONCO, CCl_4, 25 °C; (c) NaH (1.25 equiv), THF, reflux; (d) LiOH, H_2O, THF, 25 °C.

cyclization,[8] and [3] one[9] or both[10] carbonyl groups of the cyclized product **4** should be removable from the amino nitrogen by a basic hydrolysis step (**4** → **5** → **6**). These expectations have been generally fulfilled in practice, and for certain classes of amino alcohol derivatives, the benzoylcarbamate cyclization serves as an efficient synthetic method.[3,4,11]



Cis-oxyamination of Alkenes. Bromohydrins[12] derived from alkenes such as **7**, **11**, and **15** (Scheme I) are useful substrates for intramolecular nitrogen delivery. Each was converted to a benzoylcarbamate derivative (**8**, **12**, and **16**, respectively) in high yield by treatment with benzoyl isocyanate. Because this reaction occurs without the necessity for a basic catalyst, neither epoxide formation from the bromohydrins nor base-promoted destruction of the products interferes. Even the tertiary alcohol from **11** reacts rapidly at room temperature. Diagnostic for the formation of the benzoylcarbamate are infrared stretches at about 3260 cm^{-1} for the N–H and about 1760 and 1690 cm^{-1} for the two carbonyl groups. Cyclization of the benzoylcarbamates was carried out by using sodium hydride in refluxing tetrahydrofuran solution. For best yields and to minimize premature hydrolysis of the cyclized products, it is important to use freshly opened sodium hydride and to carefully exclude moisture from the reaction. Benzoylcarbamate derivatives of cyclohexene *chloro*hydrin and *iodo*hydrin gave much lower yields of cyclized product compared with bromohydrin derivative **8**.

Selective removal of the benzoyl groups of the cyclized products (e.g., **9** → **10**) was accomplished by treatment with lithium hydroxide in aqueous tetrahydrofuran.[9] For all the *N*-benzoyloxazolidinones examined, lithium hydroxide promoted hydrolysis occurred preferentially at the benzoyl carbonyl group. However, the balance is shifted by substitution on the phenyl ring. For example, the *p*-(methoxybenzoyl)oxazolidinone **19**, formed in 65% yield



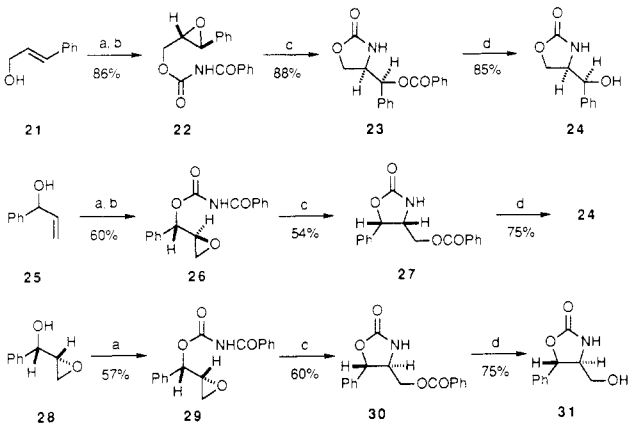
by analogous use of *p*-methoxybenzoyl isocyanate, underwent nonselective hydrolysis to give a 2:1 mixture of oxazolidinone **10** and the hydroxy amide **20**. Thus electron-donating substituents on the benzoyl group are probably to be avoided (we have also eschewed electron-*withdrawing* groups on the phenyl ring so as not to reduce the reactivity of the benzoylcarbamate anion). For convenience of isolation and characterization, the hydrolysis of the cyclized products was only taken as far as the oxazolidinones **10**, **14**, and **18**, respectively, although more vigorous conditions, described below, convert the oxazolidinone to the free amino alcohol when this is desired.

The conversion of cyclic alkenes to oxazolidinones such as **10**, **14**, and **18** amounts to an overall cis-oxyamination and as such compares favorably with other alkene cis-oxyamination procedures[13,14] such as osmium-based methods[15] and the iodine isocyanate method.[16] A useful aspect of the benzoylcarbamate cyclization method is that the face selectivity and site selectivity follow from those of bromohydrin formation, and bromohydrins may be formed in several ways[17] with complementary selectivities, including water attack on a bromonium ion (Markovnikov addition, hydroxyl on more hindered face), epoxide cleavage by bromide anion by trans-diaxial attack (hydroxyl on less hindered face), and epoxide cleavage by bromide anion at less substituted side (formal Markovnikov addition, hydroxyl on less hindered face).

Synthesis of Amino Diol Derivatives. The use of epoxy alcohols as substrates for benzoylcarbamate cyclization should lead to amino diol derivatives, wherein the original epoxide stereochemistry dictates the stereochemistry of the product.[3,4,11] Many epoxy alcohols are available as nearly pure enantiomers when prepared by Sharpless epoxidation[18] of the corresponding allylic alcohols. Additionally, many allylic alcohols can be kinetically resolved by selective epoxidation of one enantiomer[19] or obtained in homochiral form in other ways.[20] Methods for the

(8) Barton, D. H. R.; Motherwell, W. B. *J. Chem. Soc., Perkin Trans. I* **1980**, 1124. See: Sammes, P. G.; Thetford, D. *Chem. Soc., Perkin Trans. I* **1989**, 655.
(9) Evans, D. A.; Chapman, K. T.; Bisaha, J. *J. Am. Chem. Soc.* **1987**, *109*, 6881.
(10) Knapp, S.; Patel, D. V. *J. Am. Chem. Soc.* **1983**, *105*, 6985.
(11) Jung, M. E.; Jung, Y. H. *Tetrahedron Lett.* **1989**, *30*, 6637.
(12) (a) Dalton, D. R.; Dutta, V. P.; Jones, D. C. *J. Am. Chem. Soc.* **1968**, *90*, 5498. (b) Sisti, A. J. *J. Org. Chem.* **1970**, *35*, 2670.
(13) Review of alkene oxyamination: Gasc, M. B.; Lattes, A.; Perie, J. J. *Tetrahedron* **1983**, *39*, 703.
(14) For a related method using benzylcarbamates, see: Das, J. *Synth. Commun.* **1988**, *18*, 907.
(15) Harranz, E.; Sharpless, K. B. *Org. Synth.* **1983**, *61*, 85 and 93, and references therein.
(16) Hassner, A.; Lorber, M. E.; Heathcock, C. *J. Org. Chem.* **1966**, *31*, 540 and references therein.
(17) For a compilation of references on bromohydrin formation, see: Larock, R. C. *Comprehensive Organic Transformations*; VHC Publishers: New York; 1989; p 326.
(18) Gao, Y.; Hanson, R. M.; Klunder, J. M.; Ko, S. Y.; Masamune, H.; Sharpless, K. B. *J. Am. Chem. Soc.* **1987**, *109*, 5765 and references therein.
(19) Martin, V. S.; Woodward, S. S.; Katsuki, T.; Yamada, Y.; Ikeda, M.; Sharpless, K. B. *J. Am. Chem. Soc.* **1981**, *103*, 6327.
(20) See, for example: Satoh, T.; Oohara, T.; Ueda, Y.; Yamakawa, K. *J. Org. Chem.* **1989**, *54*, 3130 and references therein.

Scheme II[a]



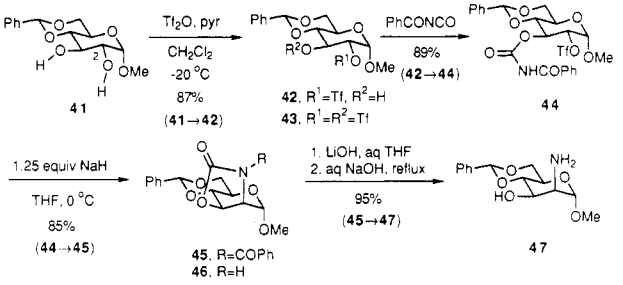
[a] Reagents: (a) PhCONCO, CCl_4, 25 °C; (b) MCPBA, CH_2Cl_2, 25 °C; (c) NaH (0.25 equiv), THF, reflux; (d) LiOH, H_2O, THF, 25 °C.

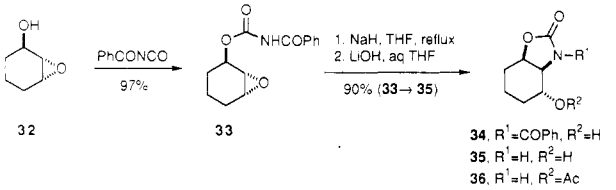
synthesis of 2-amino 1,3-diols are of continuing interest because this (or a closely related) functional array appears in sphingolipids, amino sugars, amino cyclitols, antibiotics, alkaloids, and amino acids.[21,22]

Three (racemic) isomeric epoxy carbamates **22**, **26**, and **29** were prepared from cinnamyl alcohol (**21**) and phenylvinylcarbinol (**25**), and treated with 0.25 equiv of sodium hydride in refluxing tetrahydrofuran to effect cyclization (Scheme II). The major products[23] produced (**23**, **27**, and **30**) are isomeric oxazolidinone esters, wherein cyclization has taken place with the expected inversion in stereochemistry at the epoxide carbon closer to the carbamate nitrogen. In all three products, the benzoyl group has migrated from the nitrogen of the oxazolidinone to the newly formed hydroxyl, as evidenced by the carbonyl stretches at about 1750 and 1725 cm^{-1} (compare **9** at 1780 and 1675 cm^{-1}) and the oxazolidinone N–H resonance at about 6.6 ppm in the ^1H NMR spectrum. The cis-disubstituted oxazolidinone **27** shows a larger H-4/H-5 coupling constant (8 Hz) than the corresponding trans-disubstituted isomer **30** (6 Hz), corroborating the structure assignment.[24] Hydrolysis of the ester group in **23** and **27** led to the same monosubstituted oxazolidinone **22**, whereas hydrolysis of **28** led to an isomeric product, the trans-disubstituted oxazolidinone **31**. The benzylic methine at 5.39 ppm (d, J = 6) of **31** is diagnostic, whereas **24** lacks a doublet in this region. Evidently the cis-disubstituted isomer, which would have been expected as the initial hydrolysis product from **27** and which might experience steric repulsion between the 4- and 5-substituents, rearranged to **24** under the basic reaction conditions.

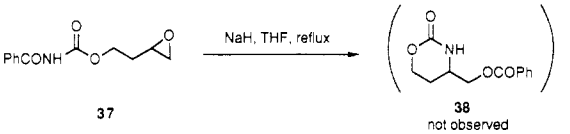
An example relevent to aminocyclitol synthesis[25] is the efficient conversion of epoxycyclohexanol **32** to its carbamate **33** and then cyclization of **33** to **34** and partial hydrolysis. The oxazolidinone product as its *O*-acetate **36** matches the known compound.[26]

Scheme III

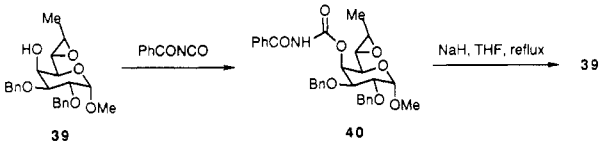




In comparison to benzoylcarbamate cyclizations that afford oxazolidinone products, the homologous six-membered cyclizations are much more difficult to achieve. Epoxy benzoylcarbamate **37** was prepared in the usual way from 3-buten-1-ol. However, under reaction conditions that were successful for cyclizations of epoxy benzoylcarbamates such as **22**, **37** gave starting material and benzamide but no cyclized product corresponding to **38** or an isomer. It is possible that reversion of **37** to 3,4-epoxbuten-1-ol and benzoyl isocyanate (a source of benzamide) occurred instead.



A situation where the reversion to starting epoxy alcohol could be documented arose during our recently completed synthesis of lincomycin.[27] The galactose-derived epoxy alcohol **39** formed benzoylcarbamate derivative **40** despite the congested environment of the C-4 hydroxy group. Sodium hydride treatment of **40**, however, returned **39** without the formation of any detectable cyclization product. Three factors may contribute to this failure to cyclize: delivery of a nucleophile to C-6 of this hindered octose is known[27] to be difficult, six-membered ring cyclizations of the sort desired are rare,[21] and steric repulsions may be relieved upon loss of benzoyl isocyanate from the anion of **40**. Successful intramolecular delivery of nitrogen to C-6 of **39** was later accomplished in a different manner, by employing the isourea anion generated from **39**, sodium hydride, and *N*,*N*-dimethylcyanamide.[27] Whether this latter method enjoys the generality of the benzoylcarbamate cyclization for other substrates has not yet been established.



Amino Sugar Synthesis. Many amino sugars are synthesized by displacement reactions of carbohydrate derivatives such as *p*-toluenesulfonates,[28] or, better, tri-

(21) Jacobsen, S. *Acta Chem. Scand.* **1988**, *B42*, 605.

(22) Some recent examples: (a) Roush, W. R.; Brown, R. J. *J. Org. Chem.* **1982**, *47*, 1371. (b) Roush, W. R.; Adam, M. A. *J. Org. Chem.* **1985**, *50*, 3752. (c) Minami, N.; Ko, S. S.; Kishi, Y. *J. Am. Chem. Soc.* **1982**, *104*, 1109. (d) Bernet, B.; Vasella, A. *Tetrahedron Lett.* **1983**, *24*, 5491. (e) Julina, R.; Herzig, T.; Bernet, B.; Vasella, A. *Helv. Chim. Acta* **1986**, *69*, 368. (f) Knapp, S.; Lal, G. S.; Sahai, D. *J. Org. Chem.* **1986**, *51*, 380. For additional examples, see refs 3, 4, 8, 11, 25, 26, and 28b.

(23) Small amounts of non-oxazolidinone (by IR analysis) byproducts were formed in these cyclizations, but were not further characterized.

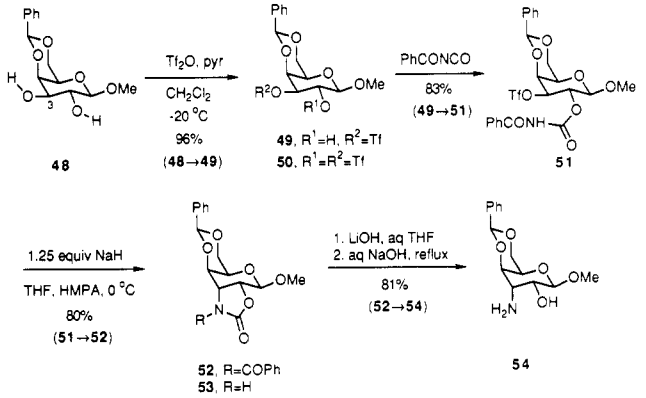
(24) (a) Spassov, S. L.; Stefanovsky, J. N.; Kurtev, B. J.; Fodor, G. *Chem. Ber.* **1972**, *105*, 2462. (b) Futagawa, S.; Inui, T.; Shiba, T. *Bull. Chem. Soc. Jpn.* **1973**, *46*, 3308.

(25) For example, see: Kuhlmeyer, R.; Seitz, B.; Weller, T.; Fritz, H.; Schwesinger, R.; Prinzbach, H. *Chem. Ber.* **1989**, *122*, 1729 and references therein.

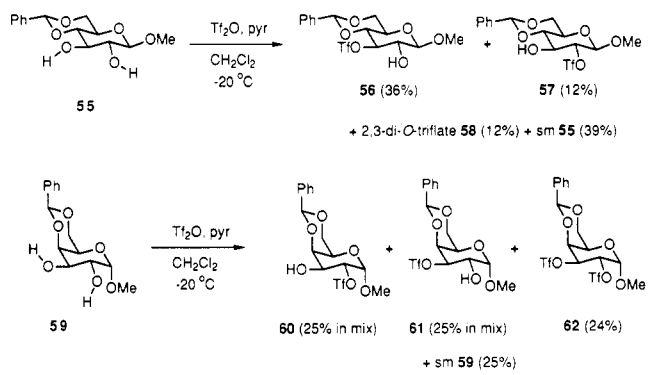
(26) Knapp, S.; Patel, D. V. *J. Org. Chem.* **1984**, *49*, 5072.

(27) Knapp, S.; Kukkola, P. J. *J. Org. Chem.* **1990**, *55*, 1632.

Scheme IV



Scheme V



fluoromethanesulfonates (triflates).[29] Thus for application of the benzoylcarbamate cyclization method to amino sugar synthesis, a series of carbohydrate diol monotriflates would be useful. These could in principle be prepared by selective triflation of the corresponding diol. We therefore investigated the preparation and cyclization of some carbohydrate substrates akin to **2**, where "X" is an alcohol derived triflate.

Procedures exist for the selective tosylation and acylation of carbohydrate diols such as methyl 4,6-*O*-(phenylmethylene)-α-D-glucopyranoside (**41**, Scheme III),[30,31] but there is little information on selective triflation.[32] We find that under carefully defined conditions (1.15 equiv of triflic anhydride, 2.0 equiv of pyridine, 0.05 M substrate in dichloromethane, −20 °C), triflic anhydride exhibits even better selectivity for the C-2 hydroxyl of **41** than other electrophiles [the actual electrophile is probably *N*-((trifluoromethyl)sulfonyl)pyridinium[30]]. Thus **41** was converted to a single diol monotriflate (**42**) (Scheme III). The only detectable byproduct was a small amount of the 2,3-di-*O*-triflate **43**,[33] whose structure was confirmed by independent and quantitative synthesis from **41** using excess triflic anhydride in pyridine solution. The position(s) of triflation in pyranosides is clearly indicated in the ^{1}H NMR spectrum by the downfield shift (typically about 1.1 ppm to $\delta \sim 4.9$) of the appropriate ring methine proton(s). Purified **42** was then converted to benzoylcarbamate derivative **44** in the usual way (the stability of the carbohydrate triflate group to the acylation conditions is noteworthy). Cyclization of **44** was carried out under the previously defined protocol, but at 0 °C, and the *N*-benzoyloxazolidinone **45** was isolated in good yield. Hydrolysis of **45**, carried out in two steps to characterize the intermediate oxazolidinone **46**, gave the methyl 2-amino-2-deoxymannopyranoside **47**,[34] completing the sugar to amino sugar transformation.

Methyl 4,6-*O*-(phenylmethylene)-β-D-galactopyranoside (**48**, Scheme IV) has shown modest to good selectivity for reaction with electrophiles at the C-3 hydroxyl.[30] With triflic anhydride under the conditions described above, **48** gave the 3-*O*-triflate **49** in excellent yield accompanied by a trace of the 2,3-di-*O*-triflate **50** (confirmed by independent synthesis). Purified **49** was converted to the benzoylcarbamate **51** and cyclized as before. The resulting *N*-benzoyloxazolidinone **52** was then hydrolyzed in two steps to the 3-aminogulose derivative **54**.

The site selectively exhibited toward triflic anhydride by **41** and **48** is lost upon switching to the alternate anomers. Thus methyl 4,6-*O*-(phenylmethylene)-β-D-glucopyranoside (**55**) (Scheme V) gave a mixture consisting of 3-*O*-triflate **56**, 2-*O*-triflate **57**, 2,3-di-*O*-triflate **58** (confirmed by independent synthesis), and recovered starting material. Likewise, methyl 4,6-*O*-(phenylmethylene)-α-D-galactopyranoside (**59**) gave a mixture of **59**–**62**. What is the cause of these remarkable changes in relative reactivity?

Previous workers studying other electrophiles have suggested[30,35] that hydrogen bonding of the proton on the reacting hydroxyl to a cis, vicinal ether oxygen can enhance its reactivity relative to another hydroxy group (which is presumably less electron rich). Examination of the ^{1}H NMR spectra of **41**, **48**, **55**, and **59** at 400 MHz in deuteriochloroform solution reveals that hydroxyl protons that can (possibly) hydrogen bond to nearby cis, vicinal ether oxygens show a larger splitting than those that are not cis and vicinal to an ether oxygen. There is an apparent three bond coupling of about 9 Hz between the hydroxyl proton and the ring methine proton at C-2 of **41**, C-3 of **48**, and both C-2 and C-3 of **59**, even in the presence of water. The remaining hydroxyl protons appear as narrow doublets (apparent $J \approx 2$ Hz). Decoupling experiments indicate which signals are due to C-2 hydroxyl protons and which are due to C-3 hydroxyl protons. Figure 1 shows the hydroxyl region for all four diols. Addition of 1 mol % of pyridine to the NMR solution of **41** broadens slightly *both* C-2 and C-3 hydroxyl resonances relative to reference.

Selectivity is therefore *correlated* with structure and NMR spectra in these four examples (strongly coupled hydroxyl groups, cis and vicinal to an ether oxygen, react in preference to weakly coupled ones, not cis and vicinal to an ether oxygen), although hydrogen bonding is not thereby indicated to be *causal*.[30] Rapid "trapping" of the product of initial sulfonylation by intramolecular removal of the hydroxyl proton by the cis, vicinal ether oxygen[30,36] would also explain the observed selectivities. Another view[37] is that lone-pair repulsion between the ether oxygen and the hydroxyl oxygen might enhance the reactivity of

(28) (a) Horton, D.; Wander, J. D. In *The Carbohydrates: Chemistry and Biochemistry*, 2nd ed.; Pigman, W., Horton, D., Eds.; Academic Press: New York, 1980; Vol IB, pp 644–760. (b) Cerny, I.; Trnka, T.; Cerny, M. *Collect. Czech. Chem. Commun.* **1983**, *48*, 2386.
(29) Karpiesiuk, W.; Banaszek, A.; Zamojski, A. *Carbohydr. Res.* **1989**, *186*, 156.
(30) Haines, A. H. *Adv. Carbohydr. Chem. Biochem.* **1976**, *33*, 11.
(31) (a) Garegg, P. J.; Iverson, T.; Oscarson, S. *Carbohydr. Res.* **1977**, *53*, C5. (b) Box, L. L.; Box, V. G. S.; Roberts, E. V. E. *Carbohydr. Res.* **1979**, *69*, C1.
(32) (a) Binkley, R. W.; Ambrose, M. G. *J. Carbohydr. Chem.* **1984**, *3*, 1. (b) Binkley, R. W.; Abdulaziz, M. A. *J. Org. Chem.* **1987**, *52*, 4713. (c) Kunz, H.; Gunther, W. *Angew. Chem., Int. Ed. Engl.* **1988**, *27*, 1086.
(33) Englebrecht, G. J.; Holzapfel, C. W.; Verdoorn, G. H. *S. Afr. J. Chem.* **1989**, *42*, 123.
(34) Bukhari, S. T. K.; Guthrie, R. D.; Scott, A. I.; Wrixon, A. D. *Tetrahedron* **1970**, *26*, 3653.
(35) Kondo, Y. *Carbohydr. Res.* **1987**, *162*, 159.
(36) Jencks, W. P. *Acc. Chem. Res.* **1976**, *9*, 425.
(37) Box, V. G. S. *Heterocycles* **1983**, *20*, 677 and references therein.

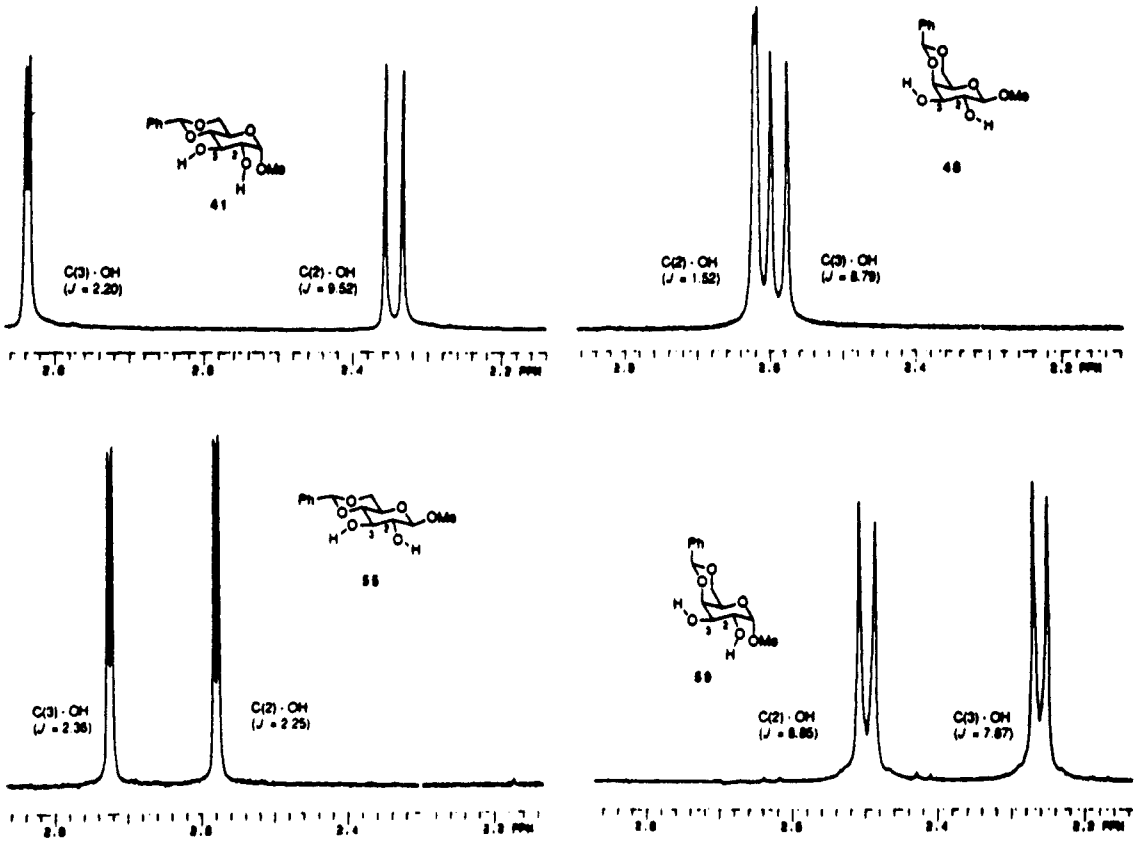
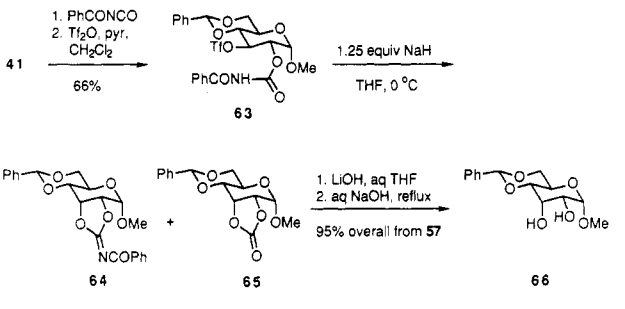


Figure 1. ^1H NMR spectra showing the hydroxyl region for the four carbohydrate diols **41**, **48**, **55**, and **59**, each ~0.05 M in $CDCl_3$. Assignments and apparent coupling constants J are listed near the respective absorbances.

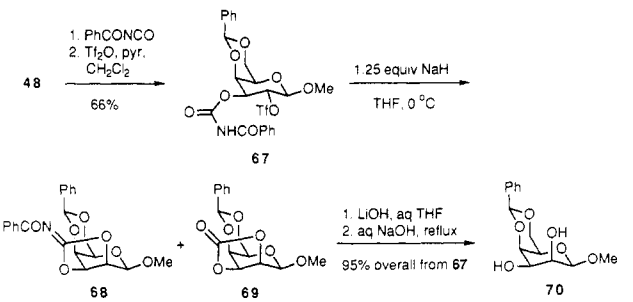
the latter. Explanations based on steric hindrance[30] or on the electronic withdrawing effect of the anomeric center,[38] may be declared unlikely, since relative reactivity does not correlate with either property. Migration or equilibration of the (trifluoromethyl)sulfonyl group[32] probably does not occur, since (for example) **42** and **49** are observed to be stable to the triflation, workup, and chromatography conditions. "Delivery" of the electrophile by the neighboring ether oxygen[39] might be possible for a positively charged electrophile in certain cases but seems unlikely for a neutral electrophile like benzoyl isocyanate (see below). We have also found that for furanosides and other carbohydrate substrates there is correlation of enhanced hydroxyl reactivity with the presence of a cis, vicinal heteroatom, although the other carbohydrate diols do not show quite the pronounced changes in relative hydroxyl reactivity exhibited by the pyranose substrates **41**, **48**, **55**, and **59**.[40] Further investigation into this aspect of hydroxyl reactivity is currently underway.

The greater reactivity of the 2-hydroxyl of **41** is retained with benzoyl isocyanate as the electrophile (suggesting that the selectivity may be an intrinsic property of the substrate and not depend strongly on the nature of the electrophile[30]). Thus condensation of **41** with benzoyl isocyanate under the usual conditions (Scheme VI) gave a 2:1 mixture of the 2-*O*-carbamate and the 2,3-di-*O*-carbamate (no 3-*O*-carbamate was observed), and this mixture was treated with triflic anhydride to give the cyclization substrate **63**. However, **63** underwent O-cyclization, not N-cyclization, upon treatment with sodium hydride, giving a mixture of the benzoyl-iminocarbonate **64** and the allopyranoside cyclic carbonate **65**.[41] Lithium hydroxide converted the mixture entirely to **65**, and more vigorous basic hydrolysis gave the allopyranoside **66**.[42] This reveals another avenue of reactivity available to benzoylcarbamates, the most

Scheme VI



Scheme VII



(38) Dejter-Juszynski, M.; Flowers, H. M. *Carbohydr. Res.* **1973**, *28*, 61.

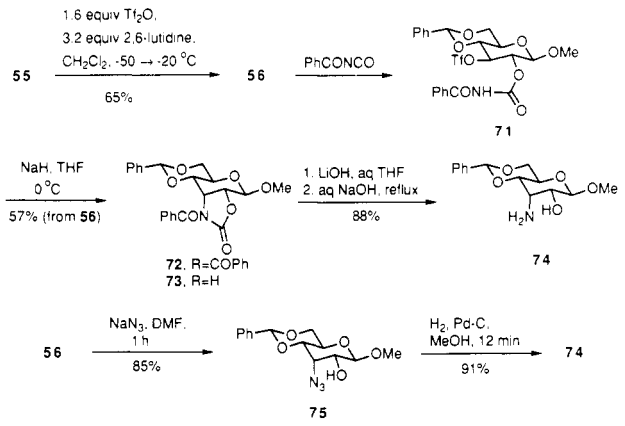
(39) (a) Knoblich, J. M.; Sugihara, J. M.; Yamazaki, T. *J. Org. Chem.* **1971**, *36*, 3407. (b) Chamberlin, A. R.; Mulholland, R. L.; Kahn, S. D.; Hehre, W. J. *J. Am. Chem. Soc.* **1987**, *109*, 672.

(40) Knapp, S.; Naughton, A. B. J.; Kukkola, P. J.; Shieh, W.-C. Unpublished results. For a mechanistic study of the reaction of an intramolecularly hydrogen-bonded primary carbohydrate alcohol with phenyl isocyanate, see: Knapp, S.; Schreck, R. P.; Carignan, Y. P. *Carbohydr. Res.* In press.

(41) Copeland, C.; Stick, R. V. *Aust. J. Chem.* **1982**, *35*, 581.

(42) Kondo, Y. *Carbohydr. Res.* **1973**, *30*, 386.

Scheme VIII



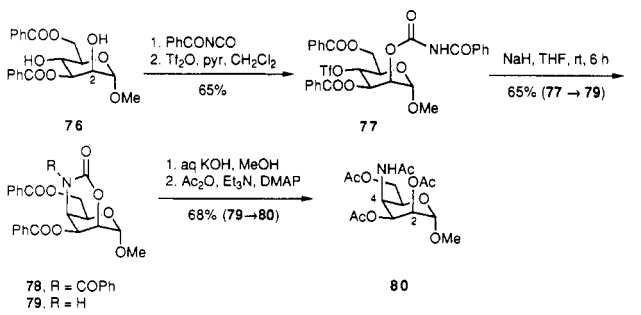
likely cause of which is the presence of the axially situated anomeric methoxy group. Apparently this amount of steric hindrance is sufficient to overcome the usual tendency of benzoylcarbamate anions to react at nitrogen rather than at the smaller carbonyl oxygen.

Another example of the same effect is provided by the β-galactopyranoside **48**. Selective carbamylation followed by triflation led very efficiently to the substrate **67**, but cyclization gave the analogous mixture of O-cyclized talopyranoside products (**68** and **69**), and subsequent basic hydrolysis delivered methyl 4,6-*O*-(phenylmethylene)-β-D-talopyranoside (**70**) (Scheme VII). The controlling structural feature here is probably the axial ether oxygen at C-4, which might be expected to block N-cyclization. Clearly, as with intermolecular displacements on carbohydrate triflates,[29,32] the success of benzoylcarbamate cyclizations is highly substrate dependent.

Two additional carbohydrate examples have been investigated to illustrate ways to get around the steric hindrance problem. A solution where there is an interfering anomeric methoxy group is to use the other anomer, provided the desired hydroxyl can be converted to its triflate. By adjusting the conditions for the conversion of **55** to **56**, we have been able to raise the yield of the 3-*O*-triflate to 65%, as shown in Scheme VIII. Conversion to **56** to its benzoylcarbamate derivative gave **71**, which was cyclized to the benzoyloxazolidinone **72**. Hydrolysis of **72** gave the 3-aminoallopyranoside **74**, whose α-anomer had proved unreachable from **63**. With the availability of the less hindered triflate **56**, direct intermolecular displacement with azide anion (**56** → **75**) also became feasible, and this route led efficiently to **74** even though the C-2 hydroxyl remains unprotected throughout. Carbohydrate diol monotriflates are rarely seen in the literature,[32] but their accessibility through selective triflation should open up a variety of possibilities for further transformation. This may include, for triflates comparable to **56**, conversion to amino sugars by a more direct route than that offered by cyclization.

Another solution to the problem of a sterically interfering group is to use that very group to deliver the nucleophile. This is achievable in the case of the 3,5-di-*O*-benzoylmannopyranoside **76**,[43] Scheme IX. Selective carbamylation of **76** at the C-2 hydroxyl followed by triflation at C-4 led to **77**, which was cyclized to give either the *N*-benzoylperhydrooxazinone **78** or its parent **79** (depending on the reaction temperature and probably also on the condition of the sodium hydride). Separate lithium

Scheme IX



hydroxide treatment of **78** also gave **79**. The perhydrooxazinone structures follow from their respective infrared spectra (**78**, 1720 and 1690 cm^{-1}; **79**, 3250 and 1700 cm^{-1}). Hydrolysis of all the acyl groups gave the new amino sugar, methyl 4-amino-4-deoxy-α-D-talopyranoside, which was characterized as its peracetate **80**. From the NMR spectrum of **80**, coupling of the N–H with H-4 (J = 9.8 Hz) places the acetamido group at C-4. A four-bond "W" coupling[44] (J = 1 Hz) between H-4 and H-2 and the small H-1/H-2 coupling (J = 1 Hz) suggest that in solution the pyranose ring adopts a $^4C_1$ conformation,[45] with axial acetamido and C-2 acetoxy groups as shown. The axial group at C-2 of mannopyranoses would be expected to render intermolecular displacements at C-4 very difficult, but the benzoylcarbamate group of **77** is apparently well situated for six-membered ring closure.

Summary. The benzoylcarbamate formation/cyclization/hydrolysis sequence described here allows the conversion of three bromohydrins to oxazolidinones, four epoxy alcohols to 2-amino-1,3-diol derivatives, and four carbohydrate diol monotriflates to amino sugars. Useful features of this chemistry for possible future application include (1) the control of the site and stereochemistry of the newly formed C–N bond, (2) the availability of a variety of starting substrates, including some enantiomerically pure ones, and (3) the flexibility in the level of protection of the amino alcohol product. Possibilities are also raised for predicting (based on structure and NMR spectrum), and exploiting, the relative reactivities of carbohydrate hydroxy groups.

Experimental Section

Apparatus and Reagents. Melting points were determined on an Electrothermal apparatus and are uncorrected. Infrared spectra (IR) were recorded by using a Perkin-Elmer Model 727B spectrophotometer or Mattson Instruments Expert-FT-IR instrument (selected absorption maxima are reported in cm^{-1}). Proton nuclear magnetic resonance (NMR) spectra were obtained with a Varian Associates VXR-200 or XL-400 instrument on deuteriochloroform solutions unless otherwise specified. Chemical shifts are reported in parts per million downfield from tetramethylsilane and coupling constants are in hertz. Elemental analyses were obtained from Galbraith Laboratories (Knoxville, TN), MicAnal Laboratories (Tuscon, AZ), and Robertson Laboratories (Madison, NJ). Desorption chemical ionization mass spectra (CI-MS) were obtained on a Finnegan Model MAT 8230 spectrometer using isobutane as the reagent gas. Fast atom bombardment mass spectra (FAB-MS) were recorded on a VG 7070 EQ spectrometer with dithiothreitol/dithioerythritol matrix. Specific rotations [α] were determined on a Perkin-Elmer Model 141 polarimeter at the sodium D line at 23 °C in chloroform solution.

(43) Compound **76** is prepared by selective di-benzoylation of methyl α-D-mannopyranoside. Williams, J. M.; Richardson, A. C. *Tetrahedron* **1967**, *23*, 1369.

(44) (a) Horton, D.; Jewell, J. S. *Carbohydr. Res.* **1967**, *5*, 149. (b) Hall, L. D.; Manville, J. F. *Carbohydr. Res.* **1968**, *8*, 295.

(45) For a recent discussion of pyranoside conformations, see: El Khadem, H. S. *Carbohydrate Chemistry, Monosaccharides and Their Oligomers*; Academic Press: New York, 1988; pp 47–55.

Precoated silica gel plates (Baker Si250F) were used for analytical thin-layer chromatography (TLC). Macherey Nagel silica gel 60 (230–400 mesh) was employed for column chromatography. Tetrahydrofuran (THF) was distilled from benzophenone ketyl, dichloromethane, pyridine, lutidine, dimethylformamide, hexamethylphosphoric triamide (HMPA), and pentane from calcium hydride, and carbon tetrachloride from phosphorus pentoxide. Other reagents were obtained commercially and used as received unless otherwise specified. Organic solutions were dried over anhydrous magnesium sulfate. All reactions were run under an argon atmosphere. Carbohydrate derivatives were recrystallized from dichloromethane–hexane mixtures unless otherwise specified.

General Procedure for the Preparation of Benzoylcarbamates. For the reaction using 2.5 mmol of an alcohol, a mixture of 531 mg (3.55 mmol) of silver cyanate and 392 μL (3.38 mmol) of benzoyl chloride in 10 mL of carbon tetrachloride was heated at reflux for 12 h, cooled, and filtered under an argon atmosphere. The filtrate was added to a solution of the alcohol in 5 mL of carbon tetrachloride, and the reaction was stirred at room temperature or the temperature indicated until TLC analysis showed no more starting alcohol (1–3 h). The reaction mixture was concentrated and chromatographed or crystallized to give the benzoylcarbamate. All the benzoylcarbamates showed an N–H stretch at 3250–3280 cm^{-1} and two carbonyl stretches at 1750–1770 and 1660–1700 cm^{-1} in the IR spectrum (thin film). Although NMR and TLC analysis indicated that the benzoylcarbamates *derived from bromohydrins* **8**, **12**, and **16** were pure, we were unable to obtain accurate elemental analysis for these compounds.

General Procedure for Cyclization of Bromo and Epoxy Benzoylcarbamates and Carbohydrate Benzoylcarbamates. For 1 mmol of substrate, a solution of the epoxy benzoylcarbamate or bromo benzoylcarbamate or carbohydrate benzoylcarbamate in 16 mL of THF was added to a suspension of pentane-washed sodium hydride (0.25 mmol for epoxides, 1.25 mmol for bromides and carbohydrate benzoylcarbamates) in 4 mL of THF, and the mixture was heated at reflux (bromides and epoxides) or stirred at the temperature indicated (carbohydrate benzoylcarbamates) until TLC analysis indicated no more starting material (1–6 h). The reaction was cooled and quenched with saturated aqueous sodium bicarbonate. The solvent was evaporated, and the residue was partitioned between ether and brine. The organic layer was dried, concentrated and chromatographed to afford the *N*-benzoyloxazolidinone product.

General Procedures for Trifluoromethanesulfonylation of Carbohydrates. A mixture of the carbohydrate substrate (3 mmol) and 485 μL (6 mmol) of pyridine in 10 mL of dichloromethane was treated with 512 μL (3.45 mmol) of trifluoromethanesulfonic anhydride at −20 °C. The reaction was stirred for 2 h, then allowed to warm to room temperature, and quenched with water. The mixture was concentrated, extracted with dichloromethane, and chromatographed to afford the trifluoromethanesulfonate ("triflate") derivative. The carbohydrate triflates are generally sensitive toward prolonged handling and were stored in the freezer and used as promptly as was practical. We were unable to obtain satisfactory elemental analysis for several of the triflates because of their instability.

For quantitative preparation of di-*O*-triflates from carbohydrate diols, a stirred solution of the substrate (0.25 mmol) in 10 equiv of pyridine was treated with 5 equiv of triflic anhydride at −20 °C. The reaction was allowed to warm to room temperature over 3 h and then stirred until TLC analysis indicated complete conversion to the di-*O*-triflate (3–12 h). The product was then isolated as described above.

General Procedure for De-benzoylation of *N*-Benzoyloxazolidinones with Lithium Hydroxide. A mixture of the *N*-benzoyloxazolinone (0.5 mmol) and 275 μL of 2.27 M aqueous lithium hydroxide in 3 mL of THF was stirred at room temperature for 12 h, concentrated, extracted with dichloromethane, and chromatographed to give the pure de-benzoylated product.

General Procedure for Hydrolysis of Carbohydrate Oxazolidinones and Carbonates Using Sodium Hydroxide. A mixture of the carbonate or the oxazolidinone (0.15 mmol) and 83 μL (0.165 mmol) of 2 M aqueous sodium hydroxide in 2 mL of water was heated at reflux until TLC analysis showed no more starting material (1–6 h). The reaction was cooled and extracted with dichloromethane. The organic solution was dried and concentrated to afford the sugar or aminosugar derivative.

***trans*-2-Bromocyclohexyl Benzoylcarbamate (8).** Cyclohexene (**7**) was transformed to its bromohydrin by using the literature procedure.[12] The latter formed its benzoylcarbamate derivative essentially quantitatively upon treatment with benzoyl isocyanate. Crystallization of the crude product from dichloromethane–petroleum ether gave 815 mg of **8**, mp 127–128 °C: NMR 1.29–2.37 (m, 8 H), 3.94–4.00 (m, 1 H), 4.89–4.95 (m, 1 H), 7.46–7.50 (m, 2 H), 7.57–7.60 (m, 1, H), 7.86–7.88 (m, 2 H), 8.45 (s, 1 H).

3aα,4,5,6,7,7aα-Hexahydrobenzoxazolin-2-one (10). Cyclization of **8** according to the general procedure and chromatography using 1:4 ethyl acetate–hexane as eluant gave 149 mg (61%) of **9**, mp 115–116 °C (from ether–petroleum ether): NMR 1.26–2.47 (m, 8 H), 4.41–4.46 (m, 1 H), 4.68–4.71 (m, 1 H), 7.41–7.45 (m, 2 H), 7.52–7.56 (m, 1 H), 7.63–7.65 (m, 2 H); IR 1776, 1680; CI-MS 246 $(M + 1)^+$. Anal. Calcd for $C_{14}H_{15}NO_3$: C, 68.55; H, 6.16; N, 5.71. Found: C, 68.75; H, 6.35; N, 5.70.

Hydrolysis of **9** by using the general procedure and chromatography using 1:1 ethyl acetate–hexane as eluant gave 64 mg (91%) of **10**, mp 57–58 °C (from dichloromethane–petroleum ether): NMR 1.23–2.07 (m, 8 H), 3.73–3.78 (m, 1 H), 4.59–4.65 (m, 1 H), 5.28 (br s, 1 H); IR 3275, 1740. Anal. Calcd for $C_7H_{11}NO_2$: C, 59.56; H, 7.86; N, 9.92. Found: C, 59.99; H, 7.72; N, 9.81.

2(*R)-Bromo-1(*R**)-methylcyclohexyl Benzoylcarbamate (12).** 1-Methylcyclohexene (**11**) was converted to **12** by following the procedure for **8**. Purified **12**, 678 mg (80% overall yield), was isolated by chromatography using 1:7 ethyl acetate–hexane as eluant. A sample crystallized from dichloromethane–petroleum ether had mp 103–105 °C: NMR 1.70 (s, 3 H), 1.42–2.39 (m, 8 H), 4.72–7.75 (m, 1 H), 7.47–7.50 (m, 2 H), 7.57–7.61 (m, 1 H), 7.82–7.84 (m, 2 H), 8.15 (s, 1 H).

7aα-Methyl-3aα,4,5,6,7,7aα-hexahydrobenzoxazolin-2-one (14). Cyclization of **12** according to the general procedure and chromatography using 1:7 ethyl acetate–hexane as eluant gave 207 mg (80%) of the *N*-benzoyloxazolidinone **13**, mp 85–87 °C (from ether–petroleum ether): NMR 1.53 (s, 3 H), 1.42–2.08 (m, 8 H), 4.20 (app t, 1 H, J = 6), 7.41–7.45 (m, 2 H), 7.53–7.56 (m, 1 H), 7.66–7.68 (m, 2 H); IR 1780, 1680. Anal. Calcd for $C_{15}H_{17}NO_3$: C, 69.21; H, 6.58; N, 5.38. Found: C, 69.59; H, 6.68; N, 5.27.

Hydrolysis of **13** by using the general procedure and chromatography using 3:4 ethyl acetate–hexane as eluant gave 77 mg (99%) of **14**, mp 50–51 °C (from dichloromethane–hexane): NMR 1.31–1.87 (m, 8 H), 1.45 (s, 3 H), 3.60 (app t, 1 H, J = 4), 6.23 (br s, 1 H); IR 3275, 1750. Anal. Calcd for $C_8H_{13}NO_2$: C, 61.91; H, 8.44; N, 9.03. Found: C, 61.85; H, 8.50; N, 8.83.

(1R*)-6(R*)-Bromocyclohex-2-enyl Benzoylcarbamate (16). Cyclohexa-1,3-diene (**15**) was converted to **16** by following the procedure for **8**. Chromatography using 1:3 ethyl acetate–hexane as eluant afforded 648 mg (80% overall yield) of product, mp 121–123 °C: NMR 2.16–2.35 (m, 4 H), 4.28–4.35 (m, 1 H), 5.53 (br s, 1 H), 5.70–5.75 (m, 1 H), 6.04 (d, 1 H, J = 10), 7.53 (dd, 2 H, J = 8, 2), 7.64 (app t, 1 H, J = 7), 7.88 (dd, 2 H, J = 7, 2), 8.23 (s, 1 H); CI-MS 244 $(M^+ - 79)$.

3aα,4,5,7aα-Tetrahydrobenzoxazolin-2-one (18). Cyclization of **16** following the general procedure and chromatography using 2:5 ethyl acetate–hexane as eluant afforded 187 mg (77%) of the *N*-benzoyloxazolidinone **17**, mp 124–125 °C (from ether–petroleum ether): NMR 2.05–2.18 (m, 2 H), 2.24–2.32 (m, 2 H), 4.70–4.75 (m, 1 H), 5.03 (br s, 1 H), 5.94 (app dd, 1 H, J = 7, 1), 6.33 (app dd, 1 H, J = 7,1), 7.48 (app t, 2 H, J = 8), 7.60 (dd, 1 H, J = 7, 1), 7.70 (dd, 2 H, J = 7, 2); IR 1760, 1680; CI-MS 244 $(M + 1)^+$. Anal. Calcd for $C_{14}H_{13}NO_3$: C, 69.12; H, 5.39; N, 5.76. Found: C, 68.75; H, 5.35; N, 5.60.

Hydrolysis of **17** by using the general procedure and chromatography using 2:3 ethyl acetate–hexane as eluant gave 63 mg (90%) of **18**, mp 86–88 °C (fom dichloromethane–petroleum ether): NMR 1.70–1.78 (m, 1 H), 1.88–2.03 (m, 1 H), 2.26–2.32 (m, 1 H), 4.01–4.06 (m, 1 H), 4.96 (br s, 1 H), 5.81–5.89 (m, 2 H), 6.20–6.24 (m, 1 H); IR 3225, 1740. Anal. Calcd for $C_7H_9NO_2$: C, 60.42; H, 6.52; N, 10.07. Found: C, 60.94; H, 6.56; N, 9.56.

3-Phenyl-2(R*),3(R*)-epoxypropyl Benzoylcarbamate (22). Cinnamyl alcohol (**21**) formed a benzoylcarbamate derivative when treated with benzoyl isocyanate as described above. The crude product was purified by chromatography using 1:1 ether–

petroleum ether as eluant to afford 675 mg (96%) of the benzoylcarbamate. A sample crystallized from dichloromethane–petroleum ether had mp 94–96 °C: NMR 4.83 (app d, 2 H, J = 8), 6.26–6.31 (m, 1 H), 6.67 (d, 1 H, J = 16), 7.27–7.37 (m, 5 H), 7.44 (app t, 2 H, J = 8), 7.55 (app t, 1 H, J = 8), 7.88 (dd, 2 H, J = 8, 2), 8.74 (s, 1 H). Anal. Calcd for $C_{17}H_{15}NO_3$: C, 72.59; H, 5.37; N, 4.98. Found: C, 72.79; H, 5.48; N, 4.88.

A solution of 562 mg (2 mmol) of the benzoylcarbamate in 5 mL of dichloromethane was treated with a solution of 647 mg (3 mmol) of *m*-chloroperoxybenzoic acid in 10 mL of dichloromethane. The mixture was stirred at room temperature for 12 h, quenched with saturated aqueous sodium sulfite, and extracted with ether. The organic layer was washed with saturated aqueous sodium carbonate and brine, dried, and concentrated. Chromatography using 1:2 ethyl acetate–hexane as the eluant gave 535 mg (90%) of **22**, mp 110–111 °C (from dichloromethane–petroleum ether): NMR 3.26 (br s, 1 H), 3.81 (s, 1 H), 4.08–4.13 (m, 1 H), 4.63 (d, 1 H, J = 12), 7.18–7.91 (m, 10 H), 9.03 (s, 1 H); CI-MS 298 $(M + 1)^+$. Anal. Calcd for $C_{17}H_{15}NO_4$: C, 68.68; H, 5.09; N, 4.71. Found: C, 68.50; H, 5.37; N, 4.56.

4(*R)-[(*S**)-Hydroxy(phenyl)methyl]-1,3-oxazolin-2-one (24).** Cyclization of **22** according to the general procedure and chromatography using ether as eluant gave 261 mg (88%) of **23**, mp 54–56 °C (from dichloromethane–petroleum ether): NMR 4.22–4.27 (m, 1 H), 4.35 (t, 1 H, J = 8), 4.40–4.44 (m, 1 H), 6.05 (d, 1 H, J = 3), 6.60 (s, 1 H), 7.20–7.38 (m, 5 H), 7.44 (t, 2 H, J = 8), 7.56 (t, 1 H, J = 8), 8.07 (app d, 2 H, J = 9); IR 3260, 1750, 1730; CI-MS 298 $(M + 1)^+$.

Hydrolysis of **23** by using the general procedure and chromatography using 2:3 ethyl acetate–hexane as eluant gave 82 mg (85%) of **24**, mp 140–142 °C (from dichloromethane–petroleum ether): NMR 2.47 (br s, 1 H), 3.98–4.03 (m, 1 H), 4.44–4.52 (m, 2 H), 4.69 (d, 1 H, J = 6), 4.97 (br s, 1 H), 7.28–7.54 (m, 5 H); IR 3370, 1795, 1715; CI-MS 194 $(M + 1)^+$. Anal. Calcd for $C_{10}H_{11}NO_3$: C, 62.17; H, 5.74; N, 7.25. Found: C, 62.49; H, 5.78; N, 7.15.

Compound **24** was also the product of an alternative cyclization–hydrolysis sequence. Cyclization of **26** according to the general procedure and chromatography using 1:2 ethyl acetate–hexane as eluant afforded 160 mg (54%) of **27**, mp 158–160 °C (from dichloromethane–petroleum ether): NMR 3.78–3.82 (m, 1 H), 4.01–4.05 (m, 1 H), 4.34–4.39 (m, 1 H), 5.80 (d, 1 H, J = 8), 6.67 (s, 1 H), 7.34 (br s, 5 H), 7.41 (t, 2 H, J = 8), 7.54 (t, 1 H, J = 7), 7.93 (d, 2 H, J = 8); IR 3200, 1745, 1720; CI-MS 298 $(M + 1)^+$. Anal. Calcd for $C_{17}H_{15}NO_4$: C, 68.68; H, 5.09; N, 4.71. Found: C, 68.32; H, 5.16; N, 4.64.

Hydrolysis of **27** following the general procedure and chromatography as described above gave 72 mg (75%) of the rearranged oxazolidinone **24**.

2(*R),3-Epoxy-1(*R**)-phenylpropyl Benzoylcarbamate (26).** By using the general procedure, phenylvinylcarbinol (**25**) was converted to its benzoylcarbamate derivative, which was isolated by chromatography using 1:1 ether–petroleum ether as eluant in 70% yield (492 mg): NMR 5.13–5.57 (m, 2 H), 5.80–6.43 (m, 2 H), 7.20–7.47 (m, 7 H), 7.50 (app t, 1 H, J = 8), 7.83 (dd, 2 H, J = 8.2), 8.43 (s, 1 H). Anal. Calcd for $C_{17}H_{15}NO_3$: C, 72.59; H, 5.37; N, 4.98. Found: C, 72.36; H, 5.61; N, 4.84.

Epoxidation of the benzoylcarbamate as above and chromatography using 1:1 ether–petroleum ether as eluant afforded 511 mg (86%) of a 2:1 mixture of **26** and its *erythro* isomer. Further chromatographic purification (same eluant) gave 225 mg of the *threo* isomer **26**, mp 123–124 °C (from dichloromethane–petroleum ether): NMR 2.69–2.76 (m, 2 H), 3.29–3.33 (m, 1 H), 5.55 (d, 1 H, J = 7), 7.28–7.87 (m, 10, H), 9.20 (s, 1 H).

2(*R),3-Epoxy-1(*S**)-phenylpropyl Benzoylcarbamate (29).** Phenylvinylcarbinol (**25**) was epoxidized to 2(*R**),3-epoxy-1(*S**)-phenylpropan-1-ol (**28**) by using anhydrous *tert*-butyl hydroperoxide and vanadyl acetylacetonate.[46] Compound **28** was converted to its benzoylcarbamate derivative by following the general procedure. Chromatography using 1:1 ether–petroleum ether as eluant gave **29** in 57% yield (423 mg): NMR 2.69–2.76 (m, 2 H), 3.24–3.26 (m, 1 H), 5.87 (d, 1 H, J = 3), 7.28–7.87 (m, 10 H), 9.26 (s, 1 H).

4(*R)-(Hydroxymethyl)-5(*R**)-phenyl-1,3-oxazolin-2-one (31).** Cyclization of **29** by using the general procedure and chromatography using 1:1 ether–petroleum ether as eluant gave 178 mg (60%) of the benzoyloxy oxazolidinone **30**, mp 108–110 °C (from dichloromethane–petroleum ether): NMR 4.12 (app q, 1 H, J = 5), 4.39–4.43 (m, 1 H), 4.54–4.58 (m, 1 H), 5.37 (d, 1 H, J = 6), 6.88 (s, 1 H), 7.39 (br s, 5 H), 7.43 (t, 2 H, J = 8), 7.57 (t, 1 H, J = 7), 8.02 (d, 2 H, J = 7); IR 3260, 1760, 1720; CI-MS 298 $(M + 1)^+$. Anal. Calcd for $C_{17}H_{15}NO_4$: C, 68.68; H, 5.09; N, 4.71. Found: C, 68.35; H, 5.27; N, 4.89.

Hydrolysis of **30** according to the general procedure and chromatography using 2:5 ethyl acetate–petroleum ether as eluant afforded 72 mg (75%) of **31**, mp 109–110 °C (from dichloromethane–petroleum ether): NMR 3.13 (br s, 1 H), 3.71–3.75 (m, 1 H), 3.86–3.88 (m, 2 H), 5.39 (d, 1 H, J = 6), 6.29 (br s, 1 H), 7.33–7.43 (m, 5 H); IR 3450, 3220, 1720; CI-MS 194 $(M + 1)^+$. Anal. Calcd for $C_{10}H_{11}NO_3$: C, 62.17; H, 5.74; N, 7.25. Found: C, 61.79; H, 5.81; N, 7.41.

(1*R)-2(*S**),3(*R**)-Epoxycyclohexanol Benzoylcarbamate (33).** Cyclohex-2-en-1-ol was converted to epoxide **32** by following the literature procedure.[47] **32** formed its benozylcarbamate derivative when treated with benzoyl isocyanate. Crystallization of the crude product from dichloromethane–petroleum ether afforded 600 mg (97%) of **33**, mp 119–121 °C: NMR 1.34–1.48 (m, 3 H), 1.82–2.00 (m, 3 H), 3.17 (app d, 1 H, J = 3), 3.23 (s, 1 H), 5.13 (t, 1 H, J = 6), 7.47 (app t, 2 H, J = 7), 7.55 (app t, 1 H, J = 7), 7.83 (d, 2 H, J = 7), 8.26 (s, 1 H); CI-MS 262 $(M + 1)^+$. Anal. Calcd for $C_{14}H_{15}NO_4$: C, 64.37; H, 5.75; N, 5.36. Found: C, 64.29; H, 5.70; N, 5.84.

4-Hydroxy-3aα,4b,5,6,7,7aα-hexahydrobenzoxazolin-2-one (35). Cyclization of **33** according to the general procedure and crystallization from ether–petroleum ether gave 235 mg (95%) of **34**, mp 161–164 °C: NMR 1.40–1.80 (m, 4 H), 2.10–2.30 (m, 2 H), 3.70 (app t, 1 H, J = 7), 4.80–4.83 (m, 1 H), 4.92–4.97 (m, 1 H), 5.81 (s, 1 H), 7.45 (app t, 2 H, J = 7), 7.59 (app t, 1 H, J = 7), 8.00 (d, 2 H, J = 7); IR 3225, 1750, 1715; CI-MS 262 $(M + 1)^+$. Anal. Calcd for $C_{14}H_{15}NO_4$: C, 64.37; H, 5.75; N, 5.36. Found: C, 64.02; H, 5.62; N, 5.47.

Hydrolysis of **34** by using the general procedure and chromatography using 3% methanol in ethyl acetate as the eluant gave 68 mg (95%) of the hydroxyoxazolidinone **35**, mp 104–106 °C (from dichloromethane): NMR 1.24 (app q, 1 H, J = 8), 1.51–1.69 (m, 3 H), 1.86 (d, 1 H, J = 10), 2.14 (d, 1 H, J = 13), 2.42 (s, 1 H), 3.34 (t, 1 H, J = 7), 3.59–3.63 (m, 1 H), 4.71 (s, 1 H), 5.88 (s, 1 H); IR 3325, 1710; CI-MS 158 $(M + 1)^+$. Anal. Calcd for $C_7H_{11}NO_3$: C, 53.59; H, 7.01; N, 8.92. Found: C, 53.21; H, 6.96; N, 8.55. This compound was also characterized as its acetate **36**, mp 156–158 °C (from ether–petroleum ether, lit.[26] mp 149–151 °C), which was identical with an authentic sample[26] by TLC and ^1H NMR.

Methyl 4,6-*O*-(Phenylmethylene)-2-*O*-[(trifluoromethyl)sulfonyl]-α-D-glucopyranoside (42). Methyl 4,6-*O*-(phenylmethylene)-α-D-glucopyranoside (**41**) was converted to its trifluoromethanesulfonate derivative according to the general procedure. Chromatography using 1:3 ethyl acetate–hexane as eluant gave 1.06 g (85%) of **42**. A recrystallized sample had mp 114–116 °C dec: $[\alpha]$ +73.3° (c = 0.51); NMR 2.71 (s, 1 H), 3.49 (s, 3 H), 3.55 (t, 1 H, J = 10), 3.74 (t, 1 H, J = 10), 3.85–3.89 (m, 1 H), 4.28–4.35 (m, 2 H), 4.70 (dd, 1 H, J = 9, 4), 4.97 (d, 1 H, J = 4), 5.55 (s, 1 H), 7.38–7.40 (m, 3 H), 7.47–7.49 (m, 2 H); IR (KBr) 3450; CI-MS 415 $(M + 1)^+$. Anal. Calcd. for $C_{15}H_{17}F_3O_8S$: C, 43.48; H, 4.14. Found: C, 43.40; H, 4.04.

Methyl 2,3-Bis-*O*-[(trifluoromethyl)sulfonyl]-4,6-*O*-(phenylmethylene)-α-D-glucopyranoside (43). By using the general procedure and then chromatography with 1:9 ether–petroleum ether as the eluant, 0.25 mmol of **41** was quantitatively converted to its 2,3-di-*O*-triflate **43**: mp 73–75 °C; $[\alpha]$ +46.1° (c = 1.00); NMR 3.47 (s, 3 H), 3.76 (td, 1 H, J = 10.5, 2.9), 3.92 (td, 1 H, J = 10, 4.6), 4.35 (dd, 1 H, J = 10.5, 4.9), 4.84 (dd, 1 H, J = 9.3, 3.7), 5.12 (d, 1 H, J = 3.6), 5.29 (t, 1 H, J = 9.6), 5.57 (s, 1 H), 7.36–7.39 (m, 3 H), 7.48–7.50 (m, 2 H); FT-IR (CCl_4) 1420; CI-MS 547 $(M + 1)^+$. Anal. Calcd for $C_{16}H_{16}F_6O_{10}S_2$: C, 35.17; H, 2.95. Found: C, 35.17; H, 2.89.

(46) Sharpless, K. B.; Michaelson, R. C. *J. Am. Chem. Soc.* **1973**, *95*, 6136.

(47) Henbest, H. B. *Proc. Chem. Soc.* **1963**, 159.

Methyl 3-*O*-(Benzoylcarbamyl)-4,6-*O*-(phenylmethylene)-2-*O*-[(trifluoromethyl)sulfonyl]-α-D-glucopyranoside (44). A solution of 414 mg (1 mmol) of **42** in 10 mL of dichloromethane was treated with benzoyl isocyanate according to the general procedure for formation of the benzoylcarbamate derivative. Purification by chromatography using 1:2 ethyl acetate–hexane as eluant gave 448 mg (89%) of **44**. A recrystallized sample had mp 157–159 °C dec: NMR 3.52 (s, 3 H), 3.75 (t, 1 H, J = 10), 3.78 (t, 1 H, J = 10), 3.98–4.00 (m, 1 H), 4.35 (dd, 1 H, J = 10, 5), 4.88 (dd, 1 H, J = 10, 4), 5.04 (d, 1 H, J = 4), 5.52 (s, 1 H), 5.71 (t, 1 H, J = 10), 7.36–7.38 (m, 3 H), 7.44–7.49 (m, 4 H), 7.57–7.61 (m, 1 H), 7.79 (d, 2 H, J = 7), 8.01 (s, 1 H); IR (KBr) 3300, 1780, 1700.

Methyl 2-Amino-2-deoxy-4,6-*O*-(phenylmethylene)-α-D-mannopyranoside (47). Cyclization of **44** according to the general procedure at 0 °C for 12 h and chromatography using 1:1 ethyl acetate–hexane as eluant afforded 174 mg (85%) of **45**. A recrystallized sample had mp 111–113 °C: NMR 3.46 (s, 3 H), 3.84–3.89 (m, 1 H), 3.93–3.98 (m, 2 H), 4.42 (dd, 1 H, J = 10, 5), 4.73 (d, 1 H, J = 8), 4.89 (t, 1 H, J = 8), 5.18 (s, 1 H), 5.68 (s, 1 H), 7.40–7.44 (m, 3 H), 7.48–7.55 (m, 4 H), 7.61–7.66 (m, 1 H), 7.82 (d, 2 H, J = 7); IR (KBr) 1790, 1690; CI-MS 308 $(M + 1)^+$.

Hydrolysis of **45** by using the general procedure and chromatography using 2:1 ethyl acetate–hexane as the eluant gave 150 mg (98%) of the oxazolidinone **46**. A recrystallized sample had mp 261–263 °C: NMR 3.40 (s, 3 H), 3.80–3.83 (m, 2 H), 3.94 (t, 1 H, J = 8), 4.15 (d, 1 H, J = 8), 4.36 (d, 1 H, J = 5), 4.76–4.80 (m, 2 H), 5.23 (d, 1 H, J = 1), 5.60 (s, 1 H), 7.36–7.41 (m, 3 H), 7.49–7.57 (m, 2 H); IR (KBr) 3300, 1770, 1720; CI-MS 308 $(M + 1)^+$.

Hydrolysis of **46** by using the general procedure gave 42 mg (97%) of **47**. A recrystallized sample had mp 121–122 °C (lit.[34] mp 110 °C, recrystallized from water): [α] +42° (c = 0.40) (lit.[34] +43°); NMR 1.64 (br s, 1 H), 3.12 (br s, 1 H), 3.41 (s, 3 H), 3.71–3.73 (m, 1 H), 3.82–3.85 (m, 2 H), 4.04–4.07 (m, 1 H), 4.29 (d, 1 H, J = 6), 4.70 (s, 1 H), 5.33 (s, 1 H), 5.60 (s, 1 H), 7.38 (d, 3 H, J = 4), 7.53 (d, 2 H, J = 4); CI-MS 282 $(M + 1)^+$. Anal. Calcd for $C_{14}H_{19}NO_5 \cdot {}^1/_8H_2O$: C, 59.31; H, 6.80; N, 4.94. Found: C, 59.32; H, 6.66; N, 4.86.

Methyl 4,6-*O*-(Phenylmethylene)-3-*O*-[(trifluoromethyl)sulfonyl]-β-D-galactopyranoside (49). Methyl 4,6-*O*-(phenylmethylene)-β-D-galactopyranoside (**48**) was converted to its (trifluoromethyl)sulfonyl derivative by using the general procedure and chromatography using 1:3 ethyl acetate–hexane as eluant gave 1.2 g (96%) of **49**: NMR 2.56 (br s, 1 H), 3.49 (s, 1 H), 3.57 (s, 3 H), 4.04–4.11 (m, 2 H), 4.25 (d, 1 H, J = 8), 4.38 (d, 1 H, J = 13), 4.42 (d, 1 H, J = 3), 4.81 (dd, 1 H, J = 10, 4), 5.57 (s, 1 H), 7.38 (d, 3 H, J = 5), 7.48 (d, 2 H, J = 4); IR (KBr) 3400; CI-MS 414 $(M + 1)^+$.

Methyl 2,3-Bis-*O*-[(trifluoromethyl)sulfonyl]-4,6-*O*-(phenylmethylene)-β-D-galactopyranoside (50). By using the general procedure, 0.25 mmol of **48** was quantitatively converted to its 2,3-di-*O*-triflate **50**. Because **50** was unstable toward chromatography, the product was purified by crystallization from dichloromethane–petroleum ether to give white needles: mp 145.5–147 °C dec, [α] +37.5° (c = 0.56); NMR 3.57 (s, 1 H), 3.60 (s, 3 H), 4.11 (d, 1 H, J = 12.5), 4.41 (d, 1 H, J = 12.2), 4.50 (d, 1 H, J = 7.6), 4.59 (d, 1 H, J = 3.7), 4.96 (dd, 1 H, J = 9.8, 3.7), 5.05 (dd, 1 H, J = 9.8, 7.8), 5.57 (s, 1 H), 7.34–7.38 (m, 3 H), 7.46–7.48 (m, 2 H); FT-IR (CCl_4) 1420; CI-MS 547 $(M + 1)^+$.

Methyl 2-*O*-(Benzoylcarbamyl)-4,6-*O*-(phenylmethylene)-3-*O*-[(trifluoromethyl)sulfonyl]-β-D-galactopyranoside (51). Compound **49** (1.2 g, 2.9 mmol) was converted to its benzoylcarbamate derivative by following the general procedure. Chromatography using 1:2 ethyl acetate–hexane as the eluant afforded 1.4 g (83%) of **51**. A recrystallized sample had mp 143–145 °C dec: NMR 3.50 (s, 3 H), 3.51 (s, 1 H), 4.06 (d, 1 H, J = 12), 4.36 (d, 1 H, J = 12), 4.44 (d, 1 H, J = 3), 4.54 (d, 1 H, J = 8), 5.10 (dd, 1 H, J = 10, 3), 5.38 (t, 1 H, J = 10), 5.54 (s, 1 H), 7.32 (d, 3 H, J = 3), 7.40–7.44 (m, 4 H), 7.53 (t, 1 H, J = 7), 7.74 (d, 2 H, J = 8), 7.99 (s, 1 H); IR (KBr) 3300, 1780, 1690; FAB-MS 584 $(M + 23)^+$ and 562 $(M + 1)^+$. Anal. Calcd for $C_{23}H_{22}F_3NO_{10}S$: C, 49.20; H, 3.95; N, 2.49. Found: C, 49.19; H, 3.78; N, 2.49.

Methyl 3-Amino-3-deoxy-4,6-*O*-(phenylmethylene)-β-D-gulopyranoside (54). Cyclization of **51** at 0 °C following the general procedure in the presence of 174 μL (1 mmol) of HMPA and chromatography using 1:1 ethyl acetate–hexane gave 326 mg (80%) of **52**. A recrystallized sample had mp 224–226 °C: NMR 3.65 (s, 3 H), 3.68 (s, 1 H), 4.08 (d, 1 H, J = 11), 4.42 (d, 1 H, J = 13), 4.52 (s, 1 H), 4.63 (d, 1 H, J = 8), 4.67 (d, 1 H, J = 7), 4.82 (d, 1 H, J = 8), 5.61 (s, 1 H), 7.38–7.40 (m, 3 H), 7.49 (t, 3 H, J = 8), 7.54–7.56 (m, 1 H), 7.63 (t, 1 H, J = 7), 7.74 (d, 2 H, J = 8); IR (KBr) 1790, 1690; CI-MS 412 $(M + 1)^+$.

Hydrolysis of **52** by using the general procedure and chromatography using 2:1 ethyl acetate–hexane as eluant afforded 130 mg (85%) of the oxazolidinone **53**. A recrystallized sample dried in a vacuum desiccator for 7 days had mp 218–220 °C: NMR 3.59 (s, 3 H), 3.73 (s, 1 H), 4.02 (s, 1 H), 4.10 (d, 1 H, J = 13), 4.23 (d, 1 H, J = 7) 4.44 (d, 1 H, J = 13), 4.49 (t, 1 H, J = 7), 4.59 (d, 1 H, J = 7), 5.54 (s, 1 H), 5.79 (s, 1 H), 7.37 (d, 3 H, J = 4), 7.49 (d, 2 H, J = 4); IR (KBr) 3400, 1780; CI-MS 308 $(M + 1)^+$. Anal. Calcd for $C_{15}H_{17}NO_6 \cdot {}^1/_4H_2O$: C, 57.78; H, 5.66; N, 4.49. Found: C, 57.95; H, 5.51; N, 4.35.

Hydrolysis of **53** according to the general procedure afforded 40 mg (95%) of the amino alcohol **54**. A recrystallized sample had mp 208–211 °C: [α] −101° (c = 0.400); NMR 1.76 (br s, 3 H), 3.58 (s, 3 H), 3.63 (s, 1 H), 3.85–3.89 (m, 2 H), 3.93 (s, 1 H), 4.07 (d, 1 H, J = 13), 4.36 (d, 1 H, J = 13), 4.71 (d, 1 H, J = 8), 5.52 (s, 1 H), 7.35 (d, 3 H, J = 5), 7.50 (d, 2 H, J = 5); IR (KBr) 3375, 3320, 3300; CI-MS 282 $(M + 1)^+$. Anal. Calcd for $C_{14}H_{19}NO_5 \cdot {}^2/_5H_2O$: C, 58.29; H, 6.74; N, 4.86. Found: C, 58.21; H, 6.55; N, 4.71.

Triflation of Methyl 4,6-*O*-(Phenylmethylene)-β-D-glucopyranoside (55). (A) By the General Procedure. Treatment of 70.5 mg (0.25 mmol) of **55** with triflic anhydride according to the general procedure and chromatography using 1:5 ether–petroleum ether as the eluant gave in order of elution 28.8 mg (24%) of a 1:1 mixture (according to NMR analysis) of the 2-*O*-triflate **57** and the 2,3-di-*O*-triflate **58**, 37.3 mg (36%) of the 3-*O*-triflate **56**, and 27 mg (39%) of starting diol **55**.

(B) For Selective Synthesis of Methyl 4,6-*O*-(Phenylmethylene)-3-*O*-[(trifluoromethyl)sulfonyl]-β-D-glucopyranoside (56). A solution of 665 mg (2.36 mmol) of **55** in 47.1 mL of dichloromethane and 879 μL (7.54 mmol) of lutidine was stirred at −50 °C. Trifluoromethanesulfonic anhydride (634 μL, 3.75 mmol) was added in one portion, and the mixture was allowed to warm slowly to −20 °C over a 6-h period, after which time TLC analysis showed complete consumption of **55**. The reaction mixture was quenched with 500 μL of water and then concentrated to a residue, which was chromatographed by using 1:5 ether–petroleum ether as the eluant to give, in order of elution, 214 mg (22%) of the 2-*O*-triflate **57**, 185 mg (14%) of the 2,3-di-*O*-triflate **58**, and 619.9 mg (64%) of the 3-*O*-triflate **56**. The 2,3-di-*O*-triflate **58** was also independently prepared from **55** (see general procedures).

3-*O*-Triflate 56: mp 95–96 °C dec; [α] −43.3° (c = 1.00); NMR 2.62 (d, 1 H, J = 3.3), 3.47 (td, 1 H, J = 9.8, 5.1), 3.58 (s, 3 H), 3.70 (ddd, 1 H, J = 10.9, 7.6, 3.2), 3.79 (app t, 1 H, J = 9.5), 3.81 (app t, 1 H, J = 10), 4.35 (d, 1 H, J = 7.6), 4.40 (dd, 1 H, J = 10.7, 5.1), 4.92 (app t, 1 H, J = 9.5), 5.57 (s, 1 H), 7.34–7.37 (m, 3 H), 7.45–7.47 (m, 2 H); IR ($CHCl_3$) 3600, 3340, 1412, 1387; CI-MS 415 $(M + 1)^+$. Anal. Calcd for $C_{15}H_{17}F_3O_8S$: C, 43.48; H, 4.14. Found: C, 43.51; H, 3.88.

2-*O*-Triflate 57: mp 106–108 °C; [α] −39.4° (c = 1); NMR 2.81 (d, 1 H, J = 3.2), 3.46 (td, 1 H, J = 9.8, 5.0), 3.56 (app t, 1 H, J = 9.6), 3.59 (s, 3 H), 3.79 (app t, 1 H, J = 10), 4.01 (td, 1 H, J = 9.1, 3), 4.40 (dd, 1 H, J = 10.5, 5.0), 4.52 (d, 1 H, J = 7.8), 4.58 (app t, 1 H, J = 7.8), 5.54 (s, 1 H), 7.37–7.42 (m, 3 H), 7.46–7.49 (m, 2 H); IR (CCl_4) 3580, 3290, 1415, 1395; CI-MS 415 $(M + 1)^+$. Anal. Calcd for $C_{15}H_{17}F_3O_8S$: C, 43.48; H, 4.14. Found: C, 43.40; H, 4.04.

2,3-Di-*O*-triflate 58: mp 122–123 °C; [α] −49.8° (c = 1); NMR 3.50 (td, 1 H, J = 9.7, 5.1), 3.58 (s, 3 H), 3.78 (t, 1 H, J = 9.6), 3.81 (dd, 1 H, J = 9.5, 7.6), 4.43 (dd, 1 H, J = 10.7, 5.1), 4.53 (d, 1 H, J = 7.6), 4.73 (dd, 1 H, J = 9.2, 7.6), 5.05 (t, 1 H, J = 9.5), 5.57 (s, 1 H), 7.36–7.39 (m, 3 H), 7.46–7.48 (m, 2 H); IR (CCl_4) 1415; CI-MS 547 $(M + 1)^+$. Anal. Calcd for $C_{16}H_{16}F_6O_{10}S_2$: C, 35.17; H, 2.95. Found: C, 35.23; H, 2.99.

Triflation of Methyl 4,6-*O*-(Phenylmethylene)-α-D-galactopyranoside (59). Treatment of 70.5 mg (0.25 mmol) of **59** with triflic anhydride according to the general procedure and

chromatography using 2:5 ether–petroleum ether as the eluant gave in order of elution 23 mg (24%) of the 2,3-di-*O*-triflate **62**, 52 mg (50%) of a 1:1 mixture of the 2-*O*-triflate **60** and the 3-*O*-triflate **61**, and 18 mg (25%) of starting diol **59**. The 2,3-di-*O*-triflate **62** was also independently synthesized from **59** according to the general procedure for di-*O*-triflates.

Mixture of 60 and 61: mp 100–102 °C dec; NMR (resonances due to **61** are marked with an asterisk; coincidental resonances are underlined) 2.13* (d, 1 H, J = 11), 2.53 (d, 1 H, J = 11.2), 3.49 (s, 6 H), 3.74* (s, 1 H), 3.80 (s, 1 H), 4.11 (d, 2 H, J = 11), 4.22 (partially obscured dd, 1 H, J = 10.6, 3.9), 4.26* (app dd, 1 H, J = 10, 3.7), 4.32 (app dd, 1 H, J = 11.2, 1.5), 4.34* (app dd, 1 H, J = 10, 1.5), 4.39 (d, 1 H, J = 3.6), 4.48* (d, 1 H, J = 3.2), 4.95 (dd, 1 H, J = 9.8, 3.0), 5.00 (d, 1 H, J = 3.9), 5.02* (dd, 1 H, J = 10.3, 3.5), 5.05* (d, 1 H, J = 3.7), 5.58 (s, 1 H), 5.60* (s, 1 H), 7.35–7.39 (m, 6 H), 7.46–7.49 (m, 4 H); IR ($CHCl_3$) 3560, 3400, 1416; CI-MS 415 $(M + 1)^+$.

2,3-Di-*O*-triflate 62: mp 136–138 °C; $[\alpha]$ +145.8° (c = 0.51); NMR 3.52 (s, 3 H), 3.82 (s, 1 H), 4.13 (dd, 1 H, J = 12.8, 1.52), 4.36 (dd, 1 H, J = 12.8, 1.5), 4.65 (d, 1 H, J = 2.9), 5.19 (d, 1 H, J = 3.4), 5.26 (dd, 1 H, J = 10, 3.4), 5.34 (dd, 1 H, J = 10, 3.4), 5.62 (s, 1 H), 7.39–7.43 (m, 3 H), 7.48–7.50 (m, 2 H); IR (CCl_4) 1417; CI-MS 547 $(M + 1)^+$. Anal. Calcd for $C_{16}H_{16}F_6O_{10}S_2$: C, 35.17; H, 2.95. Found: C, 35.53; H, 2.95.

Methyl 2-*O*-(Benzoylcarbamyl)-4,6-*O*-(phenylmethylene)-3-*O*-[(trifluoromethyl)sulfonyl]-α-D-glucopyranoside (63). Methyl 4,6-*O*-(phenylmethylene)-α-D-glucopyranoside (**41**) (846 mg, 3 mmol) was converted to its benzoylcarbamate derivative by using the general procedure. Chromatography using 1:2 ethyl acetate–hexane as eluant afforded 1.6 g of a 2:1 mixture of methyl 2-*O*-(benzoylcarbamyl)-4,6-*O*-(phenylmethylene)-α-D-glucopyranoside and methyl 2,3-bis-*O*-(benzoylcarbamyl)-4,6-*O*-(phenylmethylene)-α-D-glucopyranoside. Methyl 2-*O*-(benzoylcarbamyl)-4,6-*O*-(phenylmethylene)-α-D-glucopyranoside (in the mixture): NMR 2.80 (s, 1 H), 3.44 (s, 3 H), 3.61 (t, 1 H, J = 10), 3.78–3.88 (m, 2 H), 4.32 (t, 1 H, J = 5), 4.35 (dd, 1 H, J = 10, 5), 4.84 (dd, 1 H, J = 10, 4), 5.11 (d, 1 H, J = 3), 5.54 (s, 1 H), 7.35–7.37 (m, 3 H), 7.38–7.49 (m, 4 H), 7.54–7.76 (m, 1 H), 7.83 (d, 2 H, J = 3), 8.34 (s, 1 H); IR (KBr) 3450, 3250, 1770, 1690.

This mixture (1.6 g) was sulfonylated according to the general procedure. Purified **63** was isolated by chromatography using 1:2 ethyl acetate–hexane as eluant in 66% yield (1.05 g). A recrystallized sample had mp 125–126 °C dec: NMR 3.47 (s, 3 H), 3.84–3.96 (m, 3 H), 4.40 (dd, 1 H, J = 10, 4) 5.05 (dd, 1 H, J = 10, 4), 5.20 (d, 1 H, J = 4), 5.34 (t, 1 H, J = 10), 5.64 (s, 1 H), 7.39–7.40 (m, 3 H), 7.48–7.55 (m, 4 H), 7.63–7.64 (m, 1 H), 7.85 (d, 2 H, J = 7), 8.28 (s, 1 H); IR (KBr) 3250, 1780, 1700.

Methyl 2,3-*O*-(Internal carbonate)-4,6-*O*-(phenylmethylene)-α-D-allopyranoside (65). Cyclization of **63** according to the general procedure at room temperature for 12 h and chromatography using 1:1 ethyl acetate–hexane as eluant gave 380 mg of a mixture of **64** and **65**, according to ^{1}H NMR and IR analysis.

Hydrolysis of this mixture by using the general procedure and chromatography using 2:1 ethyl acetate–hexane as eluant afforded 280 mg (98%) of **65**. A recrystallized sample had mp 178–180 °C (lit.[41] mp 181–182 °C): NMR 3.50 (s, 3 H), 3.76–3.83 (m, 2 H), 4.23–4.24 (m, 1 H), 4.42 (dd, 1 H, J = 10, 5), 4.74 (t, 1 H, J = 5), 4.94 (d, 1 H, J = 5), 4.95 (d, 1 H, J = 3), 5.61 (s, 1 H), 7.38–7.40 (m, 3 H), 7.50–7.53 (m, 2 H); IR (KBr) 1800; CI-MS 309 $(M + 1)^+$.

Methyl 4,6-*O*-(Phenylmethylene)-α-D-allopyranoside (66). Hydrolysis of **65** according to the general procedure gave 41 mg (97%) of **66**. A recrystallized sample had mp 65–67 °C (lit.[42] mp 60 °C, dihydrate, recrystallized from water–ethanol): $[\alpha]$ +119° (c = 0.40) (lit.[42] +110° in DMF); NMR 2.59 (br s, 1 H), 2.85 (br s, 1 H), 3.42 (s, 3 H), 3.49 (dd, 1 H, J = 10, 2), 3.66 (d, 1 H, J = 7), 3.70 (d, 1 H, J = 10), 3.99–4.05 (m, 1 H), 4.23 (s, 1 H), 4.32 (dd, 1 H, J = 10, 5), 4.70 (d, 1 H, J = 4), 5.52 (s, 1 H), 7.30 (d, 3 H, J = 5), 7.43 (d, 2 H, J = 5); IR (KBr) 3450; CI-MS 283 $(M + 1)^+$.

Methyl 3-*O*-(Benzoylcarbamyl)-4,6-*O*-(phenylmethylene)-2-*O*-[(trifluoromethyl)sulfonyl]-β-D-galactopyranoside (67). Methyl 4,6-*O*-(phenylmethylene)-β-D-galactopyranoside (**48**) (423 mg, 1.5 mmol) formed its benzoylcarbamate derivative when treated with benzoyl isocyanate, following the general procedure at −30 °C. Chromatography using 1:2 ethyl acetate–hexane as eluant gave 546 mg (85%). A recrystallized sample had mp 158–160 °C: NMR 2.63 (s, 1 H), 3.55 (s, 1 H), 3.60 (s, 3 H), 4.01 (t, 1 H, J = 8), 4.08 (d, 1 H, J = 10), 4.31 (d, 1 H, J = 7), 4.35 (d, 1 H, J = 12), 4.52 (d, 1 H, J = 4), 4.90 (dd, 1 H, J = 7, 4), 5.52 (s, 1 H), 7.30–7.32 (m, 3 H), 7.42–7.52 (m, 4 H), 7.56 (t, 1 H, J = 7), 7.80 (d, 2 H, J = 9), 8.45 (s, 1 H); IR (KBr) 3400, 3250, 1770, 1690.

Sulfonylation of the benzoylcarbamate (60 mg, 0.14 mmol) according to the general procedure and chromatography using 1:3 ethyl acetate–hexane as eluant afforded 76 mg (96%) of **67**. A recrystalized sample had mp 138–140 °C dec: NMR 3.63 (s, 4 H), 4.10 (d, 1 H, J = 13), 4.38 (d, 1 H, J = 13), 4.59 (d, 2 H, J = 7), 5.07–5.11 (m, 2 H), 5.52 (s, 1 H), 7.36–7.38 (m, 3 H), 7.90 (d, 4 H, J = 7), 7.60 (t, 1 H, J = 7), 7.79 (d, 2 H, J = 7), 8.33 (s, 1 H); IR (KBr) 3350, 1770, 1690.

Methyl 2,3-*O*-(Internal carbonate)-4,6-*O*-(phenylmethylene)-β-D-talopyranoside (69). Cyclization of **67** (140 mg, 0.25 mmol) according to the general procedure at room temperature for 2 h afforded 140 mg of a mixture of **68** and **69**, according to ^{1}H NMR and IR analysis. Hydrolysis of the mixture by the general procedure and chromatography using 2:1 ethyl acetate–hexane as eluant gave 74 mg (96%) of **69**. A recrystallized sample had mp 221–222 °C: NMR 3.40 (s, 1 H), 3.65 (s, 3 H), 4.13 (d, 1 H, J = 13), 4.28 (d, 1 H, J = 6), 4.42 (d, 1 H, J = 13), 4.64 (d, 2 H, J = 5), 4.91 (t, 1 H, J = 6), 5.59 (s, 1 H), 7.32–7.37 (m, 3 H), 7.48 (d, 2 H, J = 8); IR (KBr) 1800.

Methyl 4,6-*O*-(Phenylmethylene)-β-D-talopyranoside (70). Hydrolysis of **69** by following the general procedure afforded 42 mg (99%) of **70**. A recrystallized sample had mp 185–186 °C: $[\alpha]$ −75° (c = 0.40); NMR 2.72 (d, 1 H, J = 12), 3.07 (d, 1 H, J = 11), 3.35 (s, 1 H), 3.55 (s, 3 H), 3.61–3.64 (m, 1 H), 3.80 (dd, 1 H, J = 12, 3), 4.05 (d, 1 H, J = 13), 4.15 (d, 1 H, J = 4), 4.28 (s, 1 H), 4.36 (d, 1 H, J = 12), 5.43 (s, 1 H), 7.29–7.30 (m, 3 H), 7.40 (d, 2 H, J = 3); IR (KBr) 3450; CI-MS 283 $(M + 1)^+$. Anal. Calcd for $C_{14}H_{18}O_6$: C, 59.57; H, 6.38. Found: C, 59.35; H, 6.22.

Methyl 2-*O*-(Benzoylcarbamyl)-4,6-*O*-(phenylmethylene)-3-*O*-[(trifluoromethyl)sulfonyl]-β-D-glucopyranoside (71). The 3-*O*-triflate **56** (162 mg, 0.392 mmol) was converted to its benzoylcarbamate derivative **71** by following the general procedure. Because **71** was difficult to recover in good yield following chromatography or crystallization, the crude product was normally subjected to the cyclization directly. A portion of the crude product, however, was purified by chromatography using 2:1 ether–petroleum ether as the eluant: mp 127–128.5 °C dec; NMR 3.52 (partially obscured app td, 1 H, J = 10, 5), 3.55 (s, 3 H), 3.86 (t, 1 H, J = 10.3), 3.90 (app t, 1 H, J = 9.3), 4.45 (dd, 1 H, J = 10.5, 5), 4.60 (d, 1 H, J = 7.5), 5.11 (t, 1 H, J = 9.1), 5.18 (dd, 1 H, J = 9.5, 7.5), 5.61 (s, 1 H), 7.37–7.40 (m, 3 H), 7.47–7.52 (m, 4 H), 7.61 (t, 1 H, J = 6.3), 7.81–7.84 (m, 2 H), 8.14 (s, 1 H); IR (film) 3304, 1782, 1695; CI-MS 562 $(M + 1)^+$.

Methyl 3-Amino-3-*N*-benzoyl-3-deoxy-2,3-(internal carbamate)-4,6-*O*-(phenylmethylene)-β-D-allopyranoside (72). Crude **71** (162 mg; see above) was cyclized according to the general procedure at 0 °C for 3 h. Chromatography using 1:5 ethyl acetate–petroleum ether as the eluant afforded 59 mg (37%) of the *N*-benzoyloxazolidinone **72** and 24 mg (20%) of the oxazolidinone **73** as white solids (combined yield 57%). Compound **72**: mp 185–187 °C; $[\alpha]$ −68.75° (c = 0.51); NMR 3.49 (s, 3 H), 3.73 (t, 1 H, J = 10.4), 4.20 (td, 1 H, J = 10.1, 4.9), 4.41 (dd, 1 H, J = 10.5, 4.9), 4.55 (dd, 1 H, J = 10.4, 4.9), 4.81 (dd, 1 H, J = 9.2, 2.2), 4.94 (d, 1 H, J = 2.1), 5.48 (dd, 1 H, J = 9, 4.9), 5.58 (s, 1 H), 7.09–7.19 (m, 4 H), 7.37–7.43 (m, 3 H), 7.55 (t, 1 H, J = 7.35), 7.75 (d, 2 H, J = 7.3); IR (film) 1800, 1695; CI-MS 412 $(M + 1)^+$. Anal. Calcd for $C_{22}H_{21}NO_7$: C, 64.34; H, 5.15; N, 3.40. Found: C, 64.68; H, 5.54; N, 3.50.

Hydrolysis of 15.4 mg (0.038 mmol) of **72** by using the general procedure and chromatography using 1:1 ether–petroleum ether as the eluant provided 11.2 mg (97%) of the oxazolidinone **73**: mp 74–75 °C; $[\alpha]$ +31.3° (c = 0.83); NMR 3.48 (s, 3 H), 3.70 (t, 1 H, J = 10.4), 4.01 (td, 1 H, J = 10, 5), 4.19 (dd, 1 H, J = 10, 4.4), 4.34 (dd, 1 H, J = 8.6, 4.4), 4.40 (dd, 1 H, J = 10.4, 4.9), 4.69 (dd, 1 H, J = 8.6, 3.2), 5.31 (br s, 1 H), 5.58 (s, 1 H), 7.37–7.39

(m, 3 H), 7.43–7.46 (m, 2 H); IR (film) 3307, 1765; CI-MS 308 (M + 1)$^+$. Anal. Calcd for $C_{15}H_{17}NO_6$: C, 58.63; H, 5.58; N, 4.55. Found: C, 59.02; H, 5.58; N, 4.15.

Methyl 3-Amino-3-deoxy-4,6-*O*-(phenylmethylene)-β-D-allopyranoside (74). (A) By Hydrolysis of 73. Hydrolysis of 40 mg (0.13 mmol) of oxazolidinone **73** according the general procedure and chromatography using 2:1 ether–petroleum ether as the eluant afforded 35 mg (96%) of the amino alcohol **74**: mp 162–163 °C; [α] −50.8° (*c* = 1.00); NMR 1.52 (br s, 3 H), 3.51 (dd, 1 H, *J* = 7.9, 4), 3.57 (s, 3 H), 3.64 (dd, 1 H, *J* = 9.5, 3.5), 3.75 (t, 1 H, *J* = 10.3), 3.78 (dd, 1 H, *J* = 5.2, 3.8), 4.10 (td, 1 H, *J* = 10, 5), 4.38 (dd, 1 H, *J* = 10.4, 4.5), 4.70 (d, 1 H, *J* = 7.9), 5.56 (s, 1 H), 7.38–7.40 (m, 3 H), 7.47–7.51 (m, 2 H); IR (film) 3363, 3306, 3194; CI-MS 282 (M + 1)$^+$. Anal. Calcd for $C_{14}H_{19}NO_5$: C, 59.78; H, 6.81; N, 4.98. Found: C, 59.78; H, 6.72; N, 4.77.

(B) By Reduction of 75. A mixture of 14.7 mg (0.48 mmol) of **75**, 1.5 mL of degassed methanol, and approximately 20 mg of 10% palladium-on-carbon was stirred at room temperature. Approximately 0.5 L of hydrogen gas was bubbled through the solution over a 12-min period, by which time TLC analysis indicated the disappearance of **75** and a single new product whose R_f matched that of **74**. The reaction mixture was flushed with argon and filtered through a medium fritted disk funnel. The solids were rinsed with two additional 10-mL portions of methanol, and the combined methanol extracts were concentrated to a solid product, 12.3 mg (91%): mp 160–163 °C, mmp with **74** from procedure A 160–163 °C. The product matched **74** from procedure A by TLC and 400-MHz ^{1}H NMR comparison.

Methyl 3-Azido-3-deoxy-4,6-*O*-(phenylmethylene)-β-D-allopyranoside (75). A solution of 100 mg (0.241 mmol) of the triflate **56** and 156 mg (2.41 mmol) of sodium azide in 4.8 mL of dimethylformamide was stirred at room temperature for 1 h, by which time TLC analysis of an aliquot showed no more starting material. The reaction mixture was concentrated to a residue at the vacuum pump and then extracted using dichloromethane (2 × 25 mL) and saturated aqueous sodium bicarbonate. The combined organic extracts were dried, concentrated, and chromatographed using 1:2 ether–petroleum ether as the eluant to afford 63.2 mg (85%) of the azide **75**: mp 137–138 °C; [α] −89.4° (*c* = 0.51); NMR 2.47 (d, 1 H, *J* = 5.1), 3.57 (s, 3 H), 3.60 (ddd, 1 H, *J* = 7.8, 5.1, 3.7), 3.71 (dd, 1 H, *J* = 8.1, 3), 3.74 (t, 1 H, *J* = 10.3), 3.94 (app td, 1 H, *J* = 9.7, 4.7), 4.35 (app t, 1 H, *J* = 2.8), 4.38 (dd, 1 H, *J* = 10.5, 5.1), 4.53 (d, 1 H, *J* = 7.8), 5.54 (s, 1 H), 7.36–7.41 (m, 3 H), 7.49–7.51 (m, 2 H); IR (film) 3345, 2109; CI-MS 308 (M + 1)$^+$. Anal. Calcd for $C_{14}H_{17}N_3O_3$: C, 54.72; H, 5.58; N, 13.67. Found: C, 54.66; H, 5.43; N, 13.44.

Methyl 3,6-Di-*O*-benzoyl-2-*O*-(benzoylcarbamyl)-4-*O*-[(trifluoromethyl)sulfonyl]-α-D-mannopyranoside (77). Methyl 3,6-di-*O*-benzoyl-α-D-mannopyranoside[43] (**76**, 200 mg, 0.5 mmol) formed its benzoylcarbamate derivative when treated with benzoyl isocyanate at −30 °C according to the general procedure. Chromatography using 1:2 ethyl acetate–hexane as eluate gave 176 mg (64%). A sample recrystallized from ether–petroleum had mp 106–108 °C: NMR 3.10 (s, 1 H), 3.45 (s, 3 H), 4.04–4.15 (m, 2 H), 4.63 (d, 1 H, *J* = 12), 4.78 (dd, 1 H, *J* = 12, 5), 4.88 (s, 1 H), 5.41 (s, 1 H), 5.53 (dd, 1 H, *J* = 9, 3), 7.37–7.46 (m, 6 H), 7.52–7.60 (m, 3 H), 7.74 (d, 2 H, *J* = 7), 8.04 (d, 2 H, *J* = 8), 8.09 (d, 2 H, *J* = 7), 8.18 (s, 1 H); IR (KBr) 3450, 3250, 1760, 1720.

Sulfonylation of the benzoylcarbamate (110 mg, 0.2 mmol) by using the general procedure and chromatography using 1:2 ethyl acetate–hexane as the eluant afforded 125 mg (94%) of **77**: NMR 3.50 (s, 3 H), 4.39 (dd, 1 H, *J* = 10, 3), 4.53 (dd, 1 H, *J* = 12, 4), 4.84 (d, 1 H, *J* = 12), 4.95 (s, 1 H), 5.52 (s, 1 H), 5.67 (t, 1 H, *J* = 10), 5.84 (dd, 1 H, *J* = 10, 3), 7.40–7.48 (m, 6 H), 7.50–7.63 (m, 3 H), 7.76 (d, 2 H, *J* = 8), 8.05 (s, 1 H), 8.07 (d, 2 H, *J* = 8), 8.16 (d, 2 H, *J* = 8), 8.16 (d, 2 H, *J* = 7), IR (KBr) 3250, 1740, 1700; CI-MS 682 (M + 1)$^+$.

Methyl 4-Amino-3,6-di-*O*-benzoyl-4-deoxy-2,4-*O*,*N*-(internal carbamate)-α-D-talopyranoside (79). Cyclization of **77** according to the general procedure at 0 °C for 6 h and chromatography using 1:2 ethyl acetate–hexane as the eluant gave 300 mg (55%) of the *N*-benzoyloxazolidinone derivative **78**: NMR 3.51 (s, 3 H), 4.52–4.57 (m, 2 H), 4.62 (dd, 1 H, *J* = 11, 5), 4.77 (s, 1 H), 5.01 (s, 1 H), 5.74 (d, 1 H, *J* = 4), 7.34 (t, 2 H, *J* = 8), 7.41–7.49 (m, 5 H), 7.55–7.64 (m, 4 H), 8.07 (d, 4 H, *J* = 8); IR (KBr) 1720, 1690; CI-MS 523 (M + 1)$^+$.

Hydrolysis of **78** (80 mg, 0.15 mmol) by using the general procedure at 0 °C for 6 h and chromatography using 1:1 ethyl acetate–hexane as the eluant afforded 35 mg (55%) of **79**: [α] +26.2° (*c* = 0.225); NMR 3.51 (s, 3 H), 3.75 (s, 1 H), 4.20–4.22 (m, 1 H), 4.31 (dd, 1 H, *J* = 11, 5), 4.57 (s, 1 H), 4.70 (t, 1 H, *J* = 9), 5.03 (s, 1 H), 5.52 (s, 1 H), 7.43–7.47 (m, 4 H), 7.60 (t, 2 H, *J* = 7), 8.03 (t, 4 H, *J* = 8); IR (KBr) 3250, 1700; CI-MS 428 (M + 1)$^+$.

Alternatively, cyclization of 140 mg (0.2 mmol) of **77** for 6 h at room temperature gave directly 57 mg (65% overall yield) of **79**.

Methyl 4-Amino-4-deoxy-2,3,4,6-*O*,*O*,*N*,*O*-tetraacetyl-α-D-talopyranoside (80). A solution of 57 mg (0.13 mmol) of **79** and 300 mL (.45 mmol) of 2 N aqueous potassium hydroxide in 2 mL of methanol was heated at reflux for 2 h. The reaction mixture was cooled and concentrated to a residue, which was dried by azeotropic evaporation of 5 mL of toluene. A mixture of this residue, 100 μL (1 mmol) of acetic anhydride, 1 mL of triethylamine, 1 mL of pyridine, and 2 mg of 4-(dimethylamino)pyridine was stirred at room temperature for 4 h. The reaction mixture was concentrated and then partitioned between 15 mL of ethyl acetate and 10 mL of water. The organic layer was washed sequentially with 5 mL of cold 1 N aqueous hydrochloric acid, 5 mL of water, 5 mL of saturated aqueous sodium bicarbonate, and 10 mL of brine, then dried, and concentrated. Chromatography of the crude product using 1:1 ethyl acetate–petroleum ether as the eluant afforded 32 mg (68% overall yield) of the tetraacetate **80** as a thick syrup: [α] +76.7° (*c* = 0.275); NMR 2.01 (s, 3 H), 2.04 (s, 3 H), 2.07 (s, 3 H), 2.18 (s, 3 H), 3.40 (s, 3 H, OCH_3), 4.07–4.22 (m, 3 H, H-5,6,6′), 4.54 (ddt, 1 H, *J* = 10, 4.4, 1, H-4), 4.65 (d, 1 H, *J* = 1.2, H-1), 5.12 (dt, 1 H, *J* = 4, 1, H-2), 5.24 (t, 1 H, *J* = 4, H-3), 6.14 (d, 1 H, *J* = 9.8, N—H); IR ($CHCl_3$) 3450, 3402, 1749, 1683; CI-MS 362 (M + 1)$^+$. Anal. Calcd for $C_{15}H_{23}NO_9$: C, 49.86; H, 6.37; N, 3.87. Found: C, 49.69; H, 6.19; N, 3.75.

Acknowledgment. We are grateful to the Charles and Johanna Busch Memorial Fund for financial support of this work and to Johnson and Johnson Co. for a graduate fellowship to P.J.K. The 400-MHz NMR spectrometer was purchased with partial support from NSF Grant CHEM-8300444 and the FT-IR spectrophotometer with support from NIH Instrumentation Grant 1510 RRO 1486 01A. We thank Sherrie Pietranico for experimental assistance in the early stages of this work, Prof. Kenn E. Harding, Texas A & M University, for an exchange of references and for a preprint of ref 1, Prof. Gaetano Montelione, Rutgers University, for helpful discussion, and Jeffrey Hale, Merck, Co., for measuring optical rotations.

Registry No. **7**, 110-83-8; **8**, 129217-10-3; **9**, 129217-11-4; **10**, 129263-13-4; **11**, 591-49-1; **12**, 129217-12-5; **13**, 129217-13-6; **14**, 129217-14-7; **15**, 592-57-4; **16**, 129217-15-8; **17**, 129217-16-9; **18**, 129263-14-5; **21**, 4407-36-7; **21** benzoylcarbamate derivative, 129217-44-3; **22**, 129217-17-0; **23**, 129217-18-1; **24**, 129217-19-2; **25**, 42273-76-7; **25** benzoylcarbamate derivative, 129217-45-4; **26**, 127870-52-4; *erythro*-**26**, 127870-51-3; **27**, 127870-54-6; **28**, 127913-26-2; **29**, 127870-51-3; **30**, 127870-53-5; **31**, 129263-15-6; **32**, 126059-76-5; **33**, 129217-20-5; **34**, 129217-21-6; **35**, 129217-22-7; **36**, 129217-23-8; **41**, 57701-27-6; **41** 2-benzoyl derivative, 80041-30-1; **41** dibenzoyl derivative, 120200-46-6; **43**, 126456-16-4; **44**, 129217-25-0; **45**, 116535-53-6; **46**, 129217-26-1; **47**, 116561-28-5; **48**, 71117-36-7; **48** 3-benzoylcarbamate derivative, 129217-47-6; **49**, 129217-27-2; **50**, 129263-16-7; **51**, 129217-28-3; **52**, 129217-29-4; **53**, 129217-30-7; **54**, 129263-17-8; **55**, 71117-37-8; **56**, 129217-31-8; **57**, 129217-32-9; **58**, 129263-18-9; **59**, 64552-06-3; **60**, 129217-33-0; **61**, 129217-34-1; **62**, 129311-75-7; **63**, 129217-35-2; **64**, 129217-36-3; **65**, 129263-19-0; **66**, 79549-74-9; **67**, 129217-37-4; **68**, 129217-38-5; **69**, 129263-20-3; **70**, 129263-21-4; **71**, 129217-39-6; **72**, 129263-22-5; **73**, 129263-23-6; **74**, 128657-56-7; **75**, 129311-76-8; **76**, 14315-85-6; **76** 2-benzoylcarbamate derivative, 129217-46-5; **77**, 129217-40-9; **78**, 129217-41-0; **79**, 129217-42-1; **80**, 129217-43-2; cyclohex-2-en-1-ol, 62860-38-2.