Procedure. To 10.0 mmol of **4** in 20 mL of DMF at −30 °C was added dropwise a solution of NBS (10.0 mmol) in 10 mL of DMF. After addition was complete, the reaction mixture was slowly warmed to 0 °C and poured into ice-cooled water (80 mL). The mixture was extracted with ether (3 × 50 mL), and the organic layers were collected, washed with water (4 × 30 mL), and dried over $MgSO_4$. The solvent was removed in vacuo, and the residue was separated by flash column chromatography on silica gel with *n*-hexane/ethyl acetate [19/1 (v/v)] to afford **8**. The trans/cis ratio was determined by ^1H NMR of the mixture before chromatography.

Reaction of 4a with *m*-Chloroperbenzoic Acid (MCPBA). A solution containing 1.8 mmol of **4a** in 7.0 mL of *n*-hexane was added dropwise to a precooled (−30 °C), stirred solution of 1.8 mmol of MCPBA in 7.0 mL of *n*-hexane. After addition was complete, the resulting slurry was stirred for 1 h at −30 °C and then warmed to room temperature for 1 h. After filtration of the mixture to remove the bulk of the *m*-chlorobenzoic acid formed in the reaction, the solvent was removed in vacuo to give 620 mg of crude product. Part of the crude product (203 mg) was separated by TLC (SiO_2, *n*-hexane/ethyl acetate = 9/1 as an eluent) to give **9** (67 mg, 33%) and **10** (26 mg, 19%).

Reaction of 4 with an Iminium Salt (13). General Procedure. To a suspension of 2.48 mmol of *N,N*-diethyl-*N*-methyleneammonium chloride (**13**) in 2.0 mL of THF was added 1.31 mmol of **4** in 2.0 mL of THF at room temperature. The reaction mixture was stirred for 9 h and then poured into 25 mL of ice-cooled 5% aqueous Na_2CO_3. The mixture was extracted with CH_2Cl_2. The organic layer was dried over $MgSO_4$ and evaporated to give the crude product, which was purified by TLC (*n*-hexane/ethyl acetate = 8/2 as an eluent).

4-*n*-Butyl-4,6-dimethyl-3-methylene-3,4-dihydro-2-pyrone (15i). The ^1H NMR spectrum of the crude product indicated that 4-*n*-butyl-3-[(*N,N*-diethylamino)methyl]-4,6-dimethyl-4*H*-pyran (**14i**) was mainly produced, but **14i** underwent deamination during purification by TLC (*n*-hexane/ethyl acetate = 9/1) to afford **15i** (34%).

Reaction of 4n with *n*-Butanal in the Presence of $TiCl_4$. To a suspension of *n*-butanal (0.15 mL, 1.65 mmol) and $TiCl_4$ (0.18 mL, 1.65 mmol) in 20 mL of CH_2Cl_2 was added 1.65 mmol (439 mg) of **4n** in 10 mL of CH_2Cl_2 at −78 °C. After the reaction mixture was stirred for 1 h at −78 °C, 2 mL of water was added to the mixture, which was then warmed to room temperature. The organic layer was washed with aqueous saturated NaCl solution, and the water layer was extracted with ether. The combined organic layer was dried over $MgSO_4$ and evaporated to give the crude product, which was purified by TLC (*n*-hexane/ethyl acetate = 8/2 as an eluent) to give 3-(1-hydroxybutyl)-6-methyl-4-(2-propenyl)-3,4-dihydro-2-pyrone (**16**) as a pale yellow oil (40%).

Acknowledgment. We are grateful to Dr. Takayuki Kawashima and Dr. Hiroshi Hirota of the University of Tokyo for the measurement of high-resolution mass spectra. We thank Chisso Co., Ltd., for the gift of silyl chlorides, and the Grant-in-Aid for Special Project Research (Nos. 60118004 and 61111004) administered by the Ministry of Education, Science, and Culture of the Japanese Government.

Supplementary Material Available: Table 4 listing ^1H NMR data for **4** and **5**, Table 5 listing IR data and elemental analyses or HR mass spectral data for **8**, Table 6 listing ^1H NMR and mass spectral data for **8**, Table 7 listing IR data and elemental analyses or HR mass spectral data for **9**, **15**, and **16**, and Table 8 listing ^1H NMR and mass spectral data for **9**, **10**, and **14–16** (7 pages). Ordering information is given on any current masthead page.

Silver Ion Promoted Rearrangement of 4-Aryl- and 4-Alkenyl-3-bromo-4,6-dimethyl-3,4-dihydro-2-pyrones

Takashi Kume and Kin-ya Akiba*

Department of Chemistry, Faculty of Science, Hiroshima University, Higashisenda-machi, Hiroshima 730, Japan

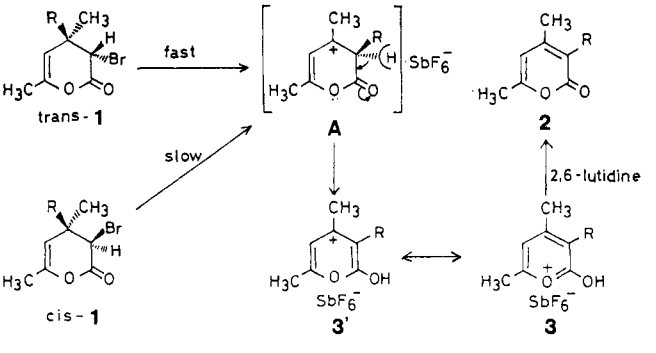
Received June 7, 1988

Debromination of 4-aryl- or 4-alkenyl-3-bromo-4,6-dimethyl-3,4-dihydro-2-pyrone **1** with $AgSbF_6$ in CH_2Cl_2 or $ClCH_2CH_2Cl$ induced migration of the aryl or alkenyl group, giving the corresponding 3-substituted 2-pyrones **2**. A 2-hydroxypyrylium salt **3** was detected in the reaction mixture by ^1H and ^{13}C NMR and was converted to **2** by treatment with 2,6-lutidine. Evidence that the rearrangement of **1** to **3** is concerted is provided by the complete retention of stereochemistry in the migrating alkenyl group and by trans specificity of the starting **1**. The 3-alkenyl group of **2** can be epoxidized with MCPBA.

Introduction

Although 2-pyrones are useful synthesis intermediates,[1] general methods for preparing 3-substituted 2-pyrones are lacking.[2] In particular, the 2-pyrone ring does not survive direct substitution at C-3 under basic conditions.[3]

Scheme I



α-Aryl and α-alkenyl carbonyl compounds can be synthesized by Favorskii,[4] pinacol,[5] or Wagner–Meerwein[6]

(1) (a) Shusherina, N. P. *Russ. Chem. Rev.* **1974**, *43*, 851. (b) Ireland, R. E.; Anderson, R. C.; Badoud, R.; Fitzsimmons, B. J.; McGarvey, G. J.; Thaisrivongs, S.; Wilcox, C. S. *J. Am. Chem. Soc.* **1983**, *105*, 1988. (c) Corey, E. J.; Watt, D. S. *J. Am. Chem. Soc.* **1973**, *95*, 2303. (d) Jung, M. E.; Hagenah, J. A. *J. Org. Chem.* **1987**, *52*, 1889. (e) Posner, G. H.; Wettlaufer, D. G. *Tetrahedron Lett.* **1986**, *27*, 667. (f) Posner, G. H.; Wettlaufer, D. G. *J. Am. Chem. Soc.* **1986**, *108*, 7373. (g) Boger, D. L.; Mullican, M. D. *J. Org. Chem.* **1984**, *49*, 4033; **1984**, *49*, 4045. (h) Dieter, R. K.; Fishpaugh, J. R. *J. Org. Chem.* **1987**, *52*, 923. (i) Poulton, G. A.; Cyr, T. D. *Can. J. Chem.* **1982**, *60*, 2821. (j) Carpenter, T. A.; Jenner, P. J.; Leeper, F. J.; Stauton, J. *J. Chem. Soc., Chem. Commun.* **1980**, 1227. (k) Posner, G. H.; Harrison, W.; Wettlaufer, D. G.; *J. Org. Chem.* **1985**, *50*, 5041.

(2) For a review of synthesis of 2-pyrone derivatives, see: Hepworth, J. D. *Compr. Heterocycl. Chem.* **1984**, *3*, 789.

(3) Harris, T. M.; Wachter, M. P.; Wiseman, G. A. *J. Chem. Soc., Chem. Commun.* **1969**, 177.

(4) Tsuchihashi, G.; Kitajima, K.; Mitamura, S. *Tetrahedron Lett.* **1981**, *22*, 4305.

0022-3263/89/1954-1935$01.50/0

Table I. Solvent and Counterion Effect on the Rearrangement of 1 to 2

entry	compound 1	compound R	AgX	solvent[a]	react. temp[c]	react. time	conv %	% yield of 2
1	1a	p-$CH_3C_6H_4$[b]	$AgSbF_6$	A	rt	15 min	100	100
2				B	rt	24 h	84	76
3			$AgBF_4$	A	rt	24 h	71	57
4				B	reflux	12 h	79	73
5	1d	(E,Z)-CH_3CH=CH	$AgSbF_6$	A	rt	15 min	100	84
6			$AgBF_4$	B	reflux	7 h	81	59

[a] A, CH_2Cl_2; B, CH_3CN. [b] *trans*-1/*cis*-1a = >97/3. [c] rt = room temperature.

Table II. Rearrangement of 1 to 2 with $AgSbF_6$

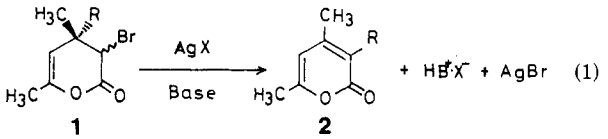
entry	compound 1	compound R	ratio *trans*-1/*cis*-1	solvent	react. time	conv %	% yield of 2
1	1a	p-$CH_3C_6H_4$	>97/3[a]	$ClCH_2CH_2Cl$	15 min	100	100
2	1b	p-$CH_3OC_6H_4$	85/15	CH_2Cl_2	15 min	88	80
3	1c	C_6H_5	80/20	CH_2Cl_2	15 min	57	47
4	1d	(E,Z)-CH_3CH=CH	>97/3[a]	CH_2Cl_2	15 min	100	84
5	1e	(E)-n-C_4H_9CH=CH	>97/3[a]	CH_2Cl_2	15 min	100	(>90)[b]
6	1e	(Z)-n-C_4H_9CH=CH	93/7	CH_2Cl_2	15 min	93	89
7	1f	CH_2=C(CH_3)	97/3	CH_2Cl_2	23 h	60	48
	1f	*c*	76/24	$ClCH_2CH_2Cl$	12 h	81	58
8	1g	CH_2=CH	>97/3[a]	CH_2Cl_2	12 h	*d*	–
	1g	*e*	88/12	CH_3CN	48 h	51	32

[a] >97/3 indicates that *cis*-1 was not detectable by ^1H NMR. [b] The product was not isolated, but none of the other product was detected in the ^1H NMR spectrum of the crude product. Thus, the yield was estimated >90%. [c] The reaction temperature was 50 °C. [d] A complex mixture of the products was obtained. [e] $AgBF_4$ was used as the silver salt.

1,2-migrations of an aryl or alkenyl group. These rearrangements can be promoted by Lewis acids[7] and by protic polar solvents to assist S_N1 solvolytic reactions.[8] These rearrangements depend on activation of a leaving group ("pull" effect) and stabilization of an emerging cationic intermediate ("push" effect).

On the basis of these findings, we have investigated the silver ion promoted rearrangement of 4-substituted 3-bromo-3,4-dihydro-2-pyrone derivatives 1, which can be prepared from 2-(silyloxy)-4*H*-pyrans.[9] Debromination of 1 should induce rearrangement of the C-4 substituent to C-3 while retaining the pyran ring and should be promoted by formation of the stabilized cationic species A (Scheme I).

Silver Ion Promoted Rearrangement of 4-Aryl- or 4-Alkenyl-3-bromo-3,4-dihydro-2-pyrones. Treatment of **1a** with $AgBF_4$ in the presence of 2,6-lutidine in refluxing acetonitrile for 12 h effected migration of the *p*-tolyl group to give **2a** in 75% yield (eq 1). Under the same



1 (1)

2

a: R=p-tolyl, b: R=p-anisyl, c: R=phenyl,
d: R=(E),(Z)-1-propenyl, e: R=(E),(Z)-hexenyl,
f: R=2-propenyl, g: R=vinyl

conditions, the 4-(1-propenyl) group (*E*, *Z* mixture) of **1d** migrated to C-3 to give **2d** (*E*, *Z* mixture) in 59% yield.[10]

To determine the effects of counterion and solvent on the rate of the rearrangement, we investigated $AgSbF_6$[11] and CH_2Cl_2 instead of $AgBF_4$ and CH_3CN and found that the rearrangements proceeded much faster and in higher yield. The results are summarized in Table I.

The 4-substituted 2-pyrones **1a–g** were treated with $AgSbF_6$ in CH_2Cl_2 or $ClCH_2CH_2Cl$ in the presence of 2,6-lutidine (Table II). The electron-donating *p*-methyl and *p*-methoxy groups substantially increased the rearrangement rate and yield compared with the phenyl group. The 1-alkenyl groups migrated much more rapidly and gave higher yields of rearranged products than the 2-propenyl or vinyl groups. The trans diastereomers of **1** rearranged much more rapidly than the cis isomers, and only the latter was recovered in the unchanged starting material.[12]

The 3-alkenyl derivatives **2d–g**, which are difficult to obtain by other methods, should be useful starting materials for the preparation of other 3-functionalized 2-pyrones. However, the *E* isomers of **2d**, **2e**, and **2g** polymerized completely on standing at room temperature for a few hours, and more slowly at −20 °C. The *Z* isomers of **2d** and **2e** also polymerized, but much less rapidly. On the other hand, **2f** did not polymerize even at room temperature. Accordingly, for subsequent reactions, these unstable 3-alkenyl-2-pyrones were not isolated but used as in solution in CH_2Cl_2. We suggest that the susceptibility of the *E* isomers to polymerization can be attributed to conjugation of the 3-alkenyl group with the pyrone ring (vide infra).

In order to investigate the mechanism of the rearrangement, we tried to detect the cationic intermediate in the reaction. Bromides **1a**, (*E*)-**1e**, and (*Z*)-**1e** were reacted

(5) Suzuki, K.; Katayama, E.; Tsuchihashi, G. *Tetrahedron Lett.* **1983**, *24*, 4997.
(6) (a) Castaldi, G.; Cavicchioli, S.; Giordano, C.; Uggeri, F. *J. Org. Chem.* **1987**, *52*, 3018. (b) Baudry, D.; Charpentier-Morize, M. *Nouv. J. Chem.* **1978**, *2*, 255.
(7) For a review, see: Giordano, C.; Castaldi, G.; Uggeri, F. *Angew. Chem., Int. Ed. Engl.* **1984**, *23*, 413.
(8) Castaldi, G.; Giordano, C.; Uggeri, F. *Synthesis* **1985**, 505.
(9) (a) Kume, T.; Iwasaki, H.; Yamamoto, Y.; Akiba, K.-y. *Tetrahedron Lett.* **1987**, *28*, 6305. (b) Kume, T.; Kojima, T.; Iwasaki, H.; Yamamoto, Y.; Akiba, K.-y. *J. Org. Chem.*, preceding paper in this issue.
(10) For references to vinyl rearrangements applied to synthesis of α-vinyl carbonyl compounds, see: (a) Holt, D. A. *Tetrahedron Lett.* **1981**, *22*, 2243. (b) Wender, P. A.; Holt, D. A.; Sieburth, S. M. *J. Am. Chem. Soc.* **1983**, *105*, 3348. (c) Suzuki, K.; Katayama, E.; Tsuchihashi, G. *Tetrahedron Lett.* **1984**, *25*, 1817.
(11) Begue, J.-P.; Charpentier-Morize, M. *Acc. Chem. Res.* **1980**, *13*, 207.
(12) Cis and trans refer to the migrating C-4 substituent (*R*) and the leaving C-3 bromine atom.

Table III. ^{1}H NMR Data of 2-Hydroxypyrylium Salt (3) and 2-Pyrone (2)

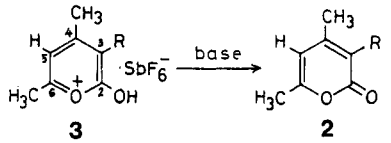
		chemical shift (δ, ppm)					
entry	compd	C(5)-H	C(4)-Me	C(6)-Me	H(α)	H(β)	C(2)-OH
1	**3a**	7.16	2.40	2.64			10.07
2	**2a**	5.94	1.99	2.22			
	Δ	1.22	0.41	0.42			
3	(*E*)-**3e**	7.15	2.58	2.65	6.20	6.51	10.75
4	(*E*)-**2e**	5.85	2.17	2.19	6.15	6.62	
	Δ	1.30	0.41	0.46	0.05	−0.11	
5	(*Z*)-**3e**	7.13	2.47	2.66	5.95	6.18	9.83
6	(*Z*)-**2e**	5.86	2.03	2.21	5.94	5.73	
	Δ	1.27	0.44	0.45	0.01	0.45	

Table IV. ^{13}C NMR Data of 2-Hydroxypyrylium Salt ((*Z*)-3e) and 2-Pyrone ((*Z*)-2e)

		chemical shift (δ, ppm)								
entry	compd	C(2)	C(3)	C(4)	C(5)	C(6)	C(α)	C(β)	C(4)-Me	C(6)-Me
1	(*Z*)-**3e**	171.4	117.1	166.2	114.6	168.0	117.4	142.5	19.6	22.2
2	(*Z*)-**2e**	162.2	119.2	151.3	107.1	158.9	121.3	136.5	19.8	20.2
	Δ	9.2	−2.1	14.9	7.5	9.1	−3.9	6.0	−0.2	2.0

with $AgSbF_6$ in CD_2Cl_2 at room temperature, and the solution was filtered from insoluble silver bromide. The ^{1}H NMR and ^{13}C NMR data for the filtrate are summarized in Tables III and IV. In the ^{1}H NMR spectra, there are large downfield shifts of the C-5 ring proton and of the methyl groups at C-4 and C-6 (Table III). In addition, a strongly deshielded singlet in the region δ 9.8–10.8 ppm was assigned to the hydroxy proton at C-2.

The ^{13}C NMR spectra of (*Z*)-**2e** and (*Z*)-**3e** also support the formation of the hydroxypyrylium salt **3e** (Table IV). The values of Δ are positive for all ring carbons and the β carbon of the olefinic substituent, excepting only C-3 and the α carbon of the olefinic substituent. The latter two of (*Z*)-**3e** were more shielded than those of (*Z*)-**2e**. The largest downfield shift was observed for C-4 (Δ 14.9 δ), indicating a substantial contribution from resonance form **3′** (Scheme I), in which C-4 bears the positive charge.[13] The resonance structure **3′** is the enolized form of A, which indicates that the cationic intermediate A was significantly stabilized by enolization. The large upfield and downfield shifts of the α and β carbons on the C-3 alkenyl group are caused by conjugation with the pyrylium ring. These experiments establish that 2-hydroxypyrylium salt **3** is generated in the reaction and is converted to **2** by base during workup. In fact, **2** was regenerated from **3** by addition of 2,6-lutidine (eq 2).



(2)

a ; R=p-tolyl

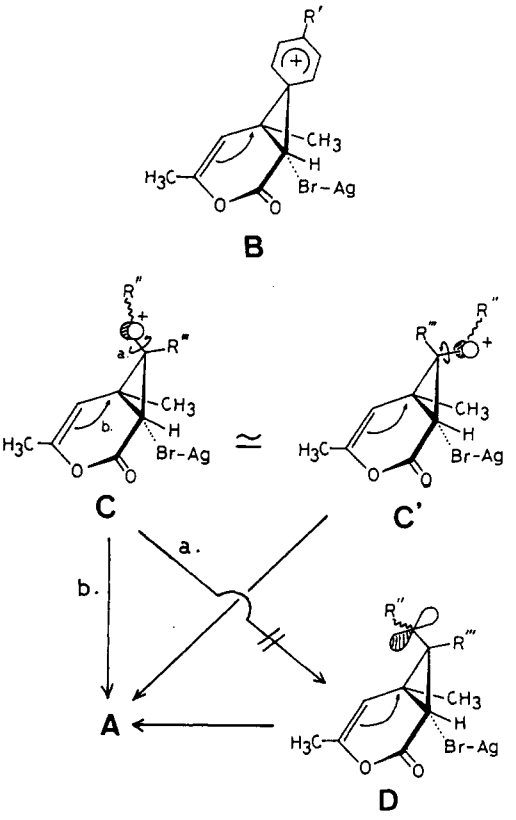
(E)-e ; R= Hβ Hα CH3

(Z)-e ; R= Hα Hβ CH3

These 2-hydroxypyrylium salts are stable at room temperature in CD_2Cl_2. The stereochemistry of the hexenyl groups in (*E*)-**1e** and (*Z*)-**1e** was essentially 100% retained during the migration. However, a small amount of (*E*)-**3e** was formed from (*Z*)-**1e** when the reaction mixture was allowed to stand for 1 day.

A plausible mechanism which accounts for these observations is shown in Scheme II. The solvent and the silver counterion may affect the ionization of the silver salt.

Scheme II



Coordination of a donor solvent such as acetonitrile to silver cation should lower the activity of the cation for fission of the C–Br bond. Thus the more separated ion pair of $AgSbF_6$ in CH_2Cl_2 or $ClCH_2CH_2Cl$ cleaves the C–Br bond more readily than the less separated ion pair of $AgBF_4$.[14]

The enhanced rate of debromination of the major isomer of **1** should be due to the stereoelectronic neighboring group participation of the trans aryl or alkenyl group in the ionization of the C–Br bond by the silver cation. Hence it is clear that the relative stereochemistry at C-3 and C-4 of the major isomer of **1** is trans.[15,16]

(13) Sojka, S. A. *J. Org. Chem.* **1975**, *40*, 1175.

(14) Alexander, R.; Parker, A. J.; Sharp, J. H.; Waghorne, W. E. *J. Am. Chem. Soc.* **1972**, *94*, 1148.

(15) For references to stereoelectronic effect on the Wagner–Meerwein rearrangement, see: (a) Nickon, A.; Weglein, R. C. *J. Am. Chem. Soc.* **1973**, *97*, 1271. (b) Kocovsky, P.; Turecek, F.; Langer, V.; Podlahova, J.; Podlaha, J. *J. Org. Chem.* **1986**, *51*, 4888 and references cited therein.

Table V. Epoxidation of 2 with MCPBA

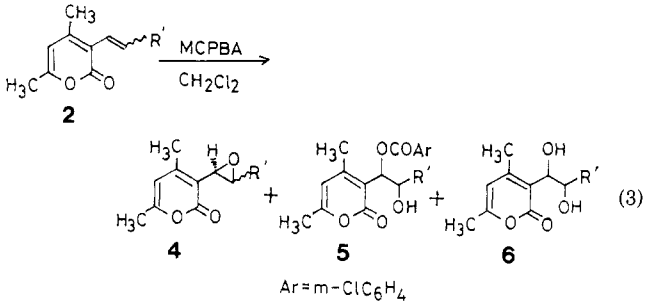
entry	compd 2	additive	react. time, h	conv %	yield, % 4	5	6
1	(*Z*)-**2d**	$NaHCO_3$	48	100	80		
2	(*E*)- and (*Z*)-**2d**[a]	none	12	47[b]	23[b]	(18)[c]	
3	(*Z*)-**2e**	$NaHCO_3$	54	100	78		
4	(*E*)-**2e**	$NaHCO_3$	8.5	100		32	35
5	(*E*)-**2e**	none	7.0	100	28	24	

[a] *E*/*Z* = 46/52. [b] Based on (*Z*)-**2d**. The conversion of (*E*)-**2d** was 100%. [c] Based on (*E*)-**2d** + (*Z*)-**2d**.

The trans specificity and the complete retention of stereochemistry in the migrating alkenyl group suggest a fully concerted mechanism for the rearrangement of **1** to **3**. The effect of substituents indicates that stabilization of the formal cationic intermediates (Scheme II, B for aryl, C, C′, the geometrical isomers about the cyclopropyl plane, for alkenyl) affects the rate of migration.[17] At first sight, these cyclopropyl carbinyl cations C and C′ seem to contradict the fact that the geometry of the migrating alkenyl group is completely retained. However, if the rearrangement is sufficiently faster than the σ-bond rotation in C → D (rotational isomers about the cyclopropyl–carbocation single bond),[18] the geometrical isomerization of the double bond cannot compete with the rearrangement. Thus the structure of the transition state can be quite similar to B and C (C′). These cationic intermediates are subsequently opened to form A by participation of the C-5–C-6 π-bond[17c] assisted by the lone pair of the oxygen, and fast enolization would give **3**.

The driving force for this facile rearrangement is the formation of a thermodynamically stable cationic species from an unstable α-carbonyl cation.

Epoxidation of 3-(1-Alkenyl)-2-pyrones 2. The availability of **2** suggested study of the functionalization of the C-3 1-alkenyl group, and we have explored the regioselective epoxidation of this group with MCPBA. Pyrones **2d** and **2e** were reacted with MCPBA in CH_2Cl_2 at 0 °C in the presence or absence of anhydrous $NaHCO_3$, which was added to avoid acid-catalyzed ring opening of the epoxide. The products were separated by flash chromatography on silica gel (Table V). The reaction of **2** with MCPBA occurred only at the C-3 1-alkenyl group (eq 3).



(3)

Although the *Z* isomers required relatively long reaction times in the presence of $NaHCO_3$, the corresponding *cis*-epoxides were obtained in ~80% yield with no ring-opened products of epoxides. In contrast, the reaction of (*E*)-**2e** proceeded faster in the presence of $NaHCO_3$, but the isolated products were monoester **5e** (32%) and diol **6e** (35%). Compounds **5e** and **6e** arise from ring opening of *trans*-**4e** by *m*-chlorobenzoic acid and water, respectively. However, when the reaction was carried out without $NaHCO_3$, the *trans*-epoxide **4e** was obtained in 28% yield together with monoester **5e** (26%). Thus the *trans*-epoxide **4e** is more susceptible to nucleophilic attack than the *cis*-epoxide.

The β-hydroxy group in **5d** was confirmed by conversion to its acetate, whose ^1H NMR spectrum showed a 1.1 ppm downfield shift of the C-β proton (H_β) in comparison with **5d** as a consequence of the acetylation. Ring opening of epoxide **4** occurred regioselectively at the sterically hindered α-carbon, indicating that the 2-pyrone ring can stabilize a developing carbocation at the α carbon.

The different reactivities of *cis*- and *trans*-**4** toward nucleophiles can also be rationalized by noting that conjugative interaction[19] between the 2-pyrone and epoxide rings is allowed in *trans*-**4** but prohibited in the cis isomer. Steric repulsion between the *cis*-β-alkyl group on the *cis*-epoxide and the 4-methyl group or the carbonyl oxygen on the pyrone ring forces the *cis*-epoxide ring into an unfavorable conformation for conjugative interaction with the pyrone ring. As a result, the *cis*-epoxide is stable and inert to nucleophilic attack. The differences between *E* and *Z* isomers of **2** in tendency to polymerize or epoxidize may be explained in the same way.

Experimental Section

Melting points were taken on a Yanagimoto micro melting point apparatus and are uncorrected. IR, ^1H and ^{13}C NMR, and mass spectra were obtained on Hitachi 215, Hitachi R-90H, and Hitachi RMU-6L spectrometers, respectively. High resolution mass spectra were recorded on a JEOL D-300 spectrometer. Commercial $AgSbF_6$, $AgBF_4$, and 4-(*N*,*N*-dimethylamino)pyridine were used. Dichloromethane, 1,2-dichloroethane, 2,6-lutidine, acetonitrile, and triethylamine were purified by distillation from CaH_2. Acetic anhydride was purified by a standard method[20] and stored over K_2CO_3.

General Procedure for the Rearrangement of 1 with $AgSbF_6$ (Table II). A solution of **1** (0.70 mmol) in CH_2Cl_2 or $ClCH_2CH_2Cl$ (6.0 mL) was added at 0 °C to a stirred solution of $AgSbF_6$ (0.288 g, 0.84 mmol) in CH_2Cl_2 or $ClCH_2CH_2Cl$ (5.0 mL). The reaction mixture was warmed to room temperature, and 2,6-lutidine (0.10 mL, ~0.84 mmol) was added dropwise via syringe. The resulting mixture was stirred for 15 min, and 20 mL of CH_2Cl_2 was added. The mixture was filtered on Celite, and the Celite was washed with 20 mL of CH_2Cl_2. The filtrate was washed with 20 mL of deionized water and 20 mL of dilute aqueous NaCl and dried over $MgSO_4$. The solvent was removed under reduced pressure to give **2**. The crude **2** was chromatographed, if necessary, on silica gel (*n*-hexane/ethyl acetate = 7/3) to give **2** in pure form and recovered **1**.

4,6-Dimethyl-3-*p*-tolyl-2-pyrone (2a) (100% from *trans*-**1a**/*cis*-**1a** = 97/3). Mp: 85–86 °C (*n*-hexane/ether). IR (KBr, cm^{-1}): 1696, 1650, 1570, 1180. ^1H NMR ($CDCl_3$): δ 1.99 (s, 3 H),

(16) A similar stereoelectronic effect was observed in 2,3-aryl migration in 3-bromoflavanones: Pelter, A.; Ward, R. S.; Balasubramanian, *J. Chem. Soc., Chem. Commun.* **1976**, 151.

(17) Raber, D. J.; Harris, J. M.; Schleyer, P. v. R. *J. Am. Chem. Soc.* **1971**, *93*, 4829.

(18) (a) Pittman, C. U., Jr.; Olah, G. A. *J. Am. Chem. Soc.* **1965**, *87*, 5123. (b) Kabakoff, D. S.; Namanworth, E. *J. Am. Chem. Soc.* **1970**, *92*, 3234. (c) Hanack, M.; Schneider, H.-J. *Angew. Chem., Int. Ed. Engl.* **1967**, *6*, 666.

(19) Buchanan, J. G.; Sable, H. Z. In *Selective Organic Transformation*; Thyagarajan, B. S., Ed.; Wiley: New York, 1972; Vol. 2, pp 2–8.

(20) Perrin, D. D.; Armarego, W. L. F.; Perrin, D. R. *Purification of Laboratory Chemicals*; Pergamon Press: Oxford, 1980; p 77.

2.22 (d, J = 0.7 Hz, 3 H), 2.36 (s, 3 H), 5.94 (br s, 1 H), 7.17 (br s, 4 H). Mass: m/z 214 (M^+), 186 (base peak). Anal. Calcd for $C_{14}H_{14}O_2$: C, 78.48; H, 6.59. Found: C, 78.19; H, 6.73.

3-*p*-Anisyl-4,6-dimethyl-2-pyrone (2b) (80% from *trans*-**1b**/*cis*-**1b** = 85/15, recovered *cis*-**1b** 12%). Mp: 100–101 °C (*n*-hexane/ether). IR (KBr, cm^{-1}): 1690, 1646, 1607, 1561, 1506, 1289, 1250, 1244, 1176, 1031. ^1H NMR ($CDCl_3$): δ 2.01 (s, 3 H), 2.24 (d, J = 0.9 Hz, 3 H), 3.82 (s, 3 H), 5.94 (br s, 1 H), 6.75–6.97 (m, 2 H), 6.97–7.24 (m, 2 H). Mass: m/z 230 (M^+), 202 (base peak), 187, 159, 116, 115. Anal. Calcd for $C_{14}H_{14}O_3$: C, 73.02; H, 6.13. Found: C, 72.77; H, 6.18.

4,6-Dimethyl-3-phenyl-2-pyrone (2c) (47% from *trans*-**1c**/*cis*-**1c** = 80/20, recovered **1c** 43% (trans/cis = 23/20)). Mp: 97–100 °C (*n*-hexane/ether). IR (KBr, cm^{-1}): 1693, 1646, 1611, 1562, 1506, 1289, 1244, 1176, 1031. ^1H NMR ($CDCl_3$) δ 2.00 (s, 3 H), 2.25 (d, J = 0.9 Hz, 3 H), 5.95 (br s, 1 H), 7.05–7.43 (m, 5 H). Mass: m/z 200 (M^+), 172 (base peak). HRMS: m/z 200.0818 (calcd for $C_{13}H_{12}O_2$ 200.0836).

4,6-Dimethyl-3-[(*E*)- and (*Z*)-1-propenyl]-2-pyrone (2d) (84%, (*E*)-**2d** (44%) and (*Z*)-**2d** (40%) from (*E*)-**1d**/(*Z*)-**1d** = 52/48, *trans*-**1d**/*cis*-**1d** = >97/3). Although both (*E*)- and (*Z*)-**2d** solidified on standing, (*E*)-**2d** completely polymerized within several hours. Therefore, they were used as a mixture of *E* and *Z* isomers in CH_2Cl_2; the solution can be stored at −20 °C for several days. (*E*)-**2d** ^1H NMR ($CDCl_3$): δ 1.89 (d, J = 6.3 Hz, 3 H), 2.17 (s, 3 H), 2.19 (br s, 3 H), 5.86 (br s, 1 H), 6.23 (d, J = 15.7 Hz, 1 H), 6.72 (dq, J = 15.7, 6.3 Hz, 1 H). Mass: m/z 164 (M^+, base peak), 149, 136, 121, 109, 93. (*Z*)-**2d** mp: ca. 53 °C. ^1H NMR ($CDCl_3$): δ 1.57 (d, J = 5.3 Hz, 3 H), 2.04 (s, 3 H), 2.21 (s, 3 H), 5.89 (br s, 1 H), 5.70–6.20 (m, 2 H). Mass: m/z 164 (M^+, base peak), 149, 136, 121, 109, 93.

3-[(*E*)-1-Hexenyl]-4,6-dimethyl-2-pyrone [(*E*)-2e]: yield >90% (only (*E*)-**2e**, from *trans*-(*E*)-**1e**/*cis*-(*E*)-**1e** = >97/3); the yield was estimated from the cation trap experiment (vide infra). The reaction was monitored by TLC (*n*-hexane/ethyl acetate = 7/3). (*E*)-**2e**: pale yellow oil. IR (neat, cm^{-1}): 2950 (m), 2920 (m), 1715 (s), 1643 (s), 1535 (m), 1443 (m), 1378 (m), 1342 (m), 1033 (m), 970 (m). ^1H NMR ($CDCl_3$): δ 0.77–1.02 (m, 3 H), 1.15–1.56 (m, 4 H), 2.05–2.45 (m, 2 H), 2.17 (s, 3 H), 2.19 (d, J = 0.9 Hz, 3 H), 5.85 (br s, 1 H), 6.15 (d, J = 15.2 Hz, 1 H), 6.62 (dt, J = 15.2, 6.6 Hz, 1 H).

3-[(*Z*)-1-Hexenyl]-4,6-dimethyl-2-pyrone [(*Z*)-2e]: yield 89% (only (*Z*)-**2e**, from *trans*-(*Z*)-**1e**/*cis*-(*Z*)-**1e** = 93/7, recovered *cis*-**1e** 7%). (*Z*)-**2e**: pale yellow oil. IR (neat, cm^{-1}): 2960 (m), 2920 (m), 1715 (s), 1643 (s), 1558 (s), 1442 (m), 1368 (m), 1317 (w), 1190 (w), 1038 (m), 1010 (w), 963 (m). ^1H NMR ($CDCl_3$): δ 0.69–1.03 (m, 3 H), 1.03–1.56 (m, 4 H), 1.71–2.06 (m, 2 H), 2.03 (d, J = 0.9 Hz, 3 H), 2.21 (s, 3 H), 5.60–6.08 (m, 3 H). ^{13}C NMR (CD_2Cl_2): δ 14.10 (q), 19.76 (q), 20.16 (q), 22.81 (t), 29.68 (t), 31.56 (t), 107.11 (d), 119.15 (s), 121.33 (d), 136.53 (d), 151.29 (s), 158.90 (s), 162.22 (s). Mass: m/z 206 (M^+), 191, 177, 163, 149, 137, 135 (base peak), 122, 91.

4,6-Dimethyl-3-(2-propenyl)-2-pyrone (2f): yield 48% (in CH_2Cl_2 at room temperature for 23 h from *trans*-**1f**/*cis*-**1f** = >97/3, recovered **1f** 40%) or 58% (in $ClCH_2CH_2Cl$ at 50 °C for 12 h from *trans*-**1f**/*cis*-**1f** = 76/24, recovered **1f** 19%). **2f** mp 55–56 °C (*n*-hexane/ether). IR (KBr, cm^{-1}): 2940 (w), 2915 (w), 1701 (s), 1642 (s), 1562 (s), 1430 (m), 1364 (w), 1334 (m), 1182 (m), 1046 (m), 1035 (m), 1014 (m), 961 (m), 913 (m), 852 (m), 784 (m). ^1H NMR ($CDCl_3$): δ 1.97 (br s, 3 H), 2.10 (s, 3 H), 2.20 (s, 3 H), 4.86 (q, J = 0.9 Hz, 1 H), 5.12–5.31 (m, 1 H), 5.88 (br s, 1 H). Mass: m/z 164 (M^+, base peak), 136, 121, 93, 77. HRMS: m/z 164.0841 (calcd for $C_{10}H_{12}O_2$ 164.0838).

4,6-Dimethyl-3-vinyl-2-pyrone (2g). (i) Reaction with $AgSbF_6$ in CH_2Cl_2. The rearrangement was performed as described above with 281 mg (1.20 mmol) of **1g** [*trans*-**1g**/*cis*-**1g** = >97/3], dissolved in 3 mL of CH_2Cl_2, and 410 mg (1.20 mmol) of $AgSbF_6$ (dissolved in 4 mL of CH_2Cl_2) and 0.14 mL (1.2 mmol) of 2,6-lutidine at room temperature. After 12 h TLC analysis indicated that the reaction was still far from complete and many products were formed. **(ii) Reaction with $AgBF_4$ in CH_3CN.** To a solution of silver tetrafluoroborate (219 mg, 1.13 mmol) in 4 mL of acetonitrile was added a solution of **1g** [174 mg, 0.75 mmol, *trans*-**1g**/*cis*-**1g** = 88/12] in 2 mL of acetonitrile, and 0.13 mL (1.1 mmol) of 2,6-lutidine was added dropwise to the mixture. The mixture was heated to reflux, stirred for 48 h [after 24 h, additional amounts of 2,6-lutidine (0.09 mL) and acetonitrile (2 mL) were added], and then cooled to room temperature. The mixture was filtered, and the filtrate was poured into 20 mL of ice–water. The mixture was extracted with ether (10 mL × 3), and the combined organic layers were dried over $MgSO_4$. Removal of the solvent gave a pale yellow oil, which was chromatographed on silica gel, eluted with *n*-hexane/ethyl acetate = 9/1, to give 36 mg (32%) of **2g** as pale yellow oil and 85 mg (49%) of **1g**. The **2g** readily polymerized and resinified on standing. **2g** ^1H NMR ($CDCl_3$): δ 2.19 (br s, 6 H), 5.46 (dd, J = 11.2, 2.6 Hz, 1 H), 5.88 (br s, 1 H), 6.17 (dd, J = 17.5, 2.6 Hz, 1 H), 6.50 (dd, J = 17.5, 11.2 Hz, 1 H). Mass: m/z 150 (M^+), 122, 86, 84 (base peak).

Detection of Cationic Intermediate of the Rearrangement by ^1H and ^{13}C NMR. General Procedure (Tables III and IV). A solution of 1 (0.76 mmol) in 1.0 mL of CD_2Cl_2 was added at 0 °C to a stirred solution of $AgSbF_6$ (263 mg, 0.76 mmol) in 1.0 mL of CD_2Cl_2. The reaction mixture was warmed to room temperature and stirred for 5 min, and the silver bromide was filtered off under N_2. ^1H NMR analysis indicated the conversion of 1 into **3**. No geometrical isomerization of the double bond was observed in (*Z*)-**1e** and (*E*)-**1e** during the reaction, but slight isomerization of (*Z*)-**3e** to (*E*)-**3e** was observed when the solution of (*Z*)-**3e** was allowed to stand for 1 day. **3a**: ^1H NMR (CD_2Cl_2) δ 2.35 (s, 3 H), 2.40 (s, 3 H), 2.64 (d, J = 0.7 Hz, 3 H), 7.16 (d, J = 8.6 Hz, 2 H), 7.16 (br s, 1 H), 7.34 (d, J = 8.6 Hz, 2 H), 10.07 (s, 1 H). (*Z*)-**3e** ^1H NMR (CD_2Cl_2): δ 0.70–1.03 (m, 3 H), 1.03–1.65 (m, 4 H), 1.76–2.05 (m, 2 H), 2.47 (s, 3 H), 2.66 (br s, 3 H), 5.95 (dd, J = 12, 1 Hz, 1 H), 6.18 (dt, J = 12, 7 Hz, 1 H), 7.13 (br s, 1 H), 9.83 (s, 1 H). ^{13}C NMR (CD_2Cl_2): δ 13.98 (q), 19.59 (q), 22.21 (q), 22.64 (t), 29.90 (t), 31.12 (t), 114.60 (d), 117.10 (s), 117.40 (d), 142.53 (d), 166.19 (s), 168.01 (s), 171.43 (s). (*E*)-**3e** ^1H NMR (CD_2Cl_2): δ 0.93 (br t, J = 5.6 Hz, 3 H), 1.14–1.71 (m, 4 H), 2.16–2.46 (m, 2 H), 2.58 (s, 3 H), 2.65 (d, J = 0.7 Hz, 3 H), 6.20 (d, J = 16.3 Hz, 1 H), 6.51 (dt, J = 16.3, 5.1 Hz, 1 H), 7.15 (br s, 1 H), 10.75 (s, 1 H).

Epoxidation of 3-(1-Alkenyl)-4,6-dimethyl-2-pyrone (2) with *m*-Chloroperbenzoic Acid (MCPBA) (Table V). **Procedure A** (reaction in the presence of $NaHCO_3$). To a stirred suspension of **2** (2.4 mmol) and anhydrous $NaHCO_3$ (500 mg, 6.0 mmol) in 7 mL of CH_2Cl_2 was added MCPBA (621 mg, 3.6 mmol) in 5 mL of CH_2Cl_2 at 0 °C. The mixture was stirred for the time given in Table V. The resulting mixture was diluted with 100 mL of CH_2Cl_2 and washed sequentially with 50 mL of saturated NaCl, 30 mL of 20% $NaHSO_3$, 50 mL of saturated $NaHCO_3$, and 50 mL of saturated NaCl. The organic layer was dried over $MgSO_4$ and concentrated in vacuo. The residue was purified by flash chromatography on silica gel (eluted with an appropriate ethyl acetate/*n*-hexane mixture).

Procedure B. All the procedures were the same as that of A, except that $NaHCO_3$ was not added.

3-(*cis*-1,2-Epoxypropyl)-4,6-dimethyl-2-pyrone (*cis*-4d): yield 80% (procedure A). Mp: 71–72 °C (*n*-hexane/ether). IR (KBr, cm^{-1}): 1708, 1648, 1576. ^1H NMR ($CDCl_3$): δ 1.15 (d, J = 5.3 Hz, 3 H), 2.21 (br s, 3 H), 2.26 (d, J = 1.1 Hz, 3 H), 3.31 (dq, J = 4.2, 5.3 Hz, 1 H), 3.79 (br d, J = 4.2 Hz, 1 H), 5.83 (br s, 1 H). Mass: m/z 180 (M^+, base peak), 165. Anal. Calcd for $C_{10}H_{12}O_3$: C, 66.65; H, 6.71. Found: C, 66.74; H, 6.71.

3-(*trans*-1,2-Epoxyhexyl)-4,6-dimethyl-2-pyrone (*trans*-4e): clear oil (28% (procedure B)). ^1H NMR ($CDCl_3$): δ 0.70–1.07 (m, 3 H), 1.07–2.03 (m, 6 H), 2.20 (s, 3 H), 2.26 (d, J = 0.7 Hz, 3 H), 3.00–3.20 (m, 1 H), 3.49 (d, J = 2 Hz, 1 H), 5.76 (br s, 1 H). Mass: m/z 222 (M^+), 207, 193, 179, 151, 108 (base peak). Since *trans*-**4e** easily decomposed under ambient temperature, HRMS or elemental analysis was not performed.

3-(*cis*-1,2-Epoxyhexyl)-4,6-dimethyl-2-pyrone (*cis*-4e): clear oil (78% (procedure A)). IR (neat, cm^{-1}): 1711, 1648, 1575. ^1H NMR ($CDCl_3$): δ 0.87 (br t, J = 6.2 Hz, 3 H), 1.00–1.72 (m, 6 H), 2.21 (br s, 3 H), 2.26 (d, J = 1.1 Hz, 3 H), 3.17 (dt, J = 4.2, 3.8 Hz, 1 H), 3.79 (br d, J = 4.2 Hz, 1 H), 5.81 (br s, 1 H). Mass: m/z 222 (M^+), 207, 193, 179, 151, 108 (base peak), 93. HRMS: m/z 222.1276 (calcd for $C_{13}H_{18}O_3$ 222.1256).

3-[1-(*m*-Chlorobenzoxy)-2-hydroxypropyl]-4,6-dimethyl-2-pyrone (5d): yellow oil (18% (procedure B)). IR (KBr, cm^{-1}): 3445, 1717, 1695 (sh), 1646, 1564, 1421, 1291, 1253, 1125, 1070, 749. ^1H NMR ($CDCl_3$): δ 1.21 (d, J = 6.4 Hz, 3 H), 2.19 (d, J = 0.9 Hz, 3 H), 2.37 (s, 3 H), 4.75 (dq, J = 7.5, 6.4 Hz, 1 H),

5.74-5.92 (m, 1 H), 5.84 (d, J = 7.5 Hz, 1 H), 7.17-7.57 (m, 2 H), 7.79-8.07 (m, 2 H).

3-[1-(*m*-Chlorobenzoxy)-2-hydroxyhexyl]-4,6-dimethyl-2-pyrone (5e): white solid (32% (procedure A) and 26% (procedure B)). IR (KBr, cm^{-1}): 3520, 1716, 1688, 1641, 1552, 1285, 1260, 1249, 1139, 1075. ^1H NMR ($CDCl_3$): δ 0.70-1.06 (m, 3 H), 1.11-1.87 (m, 6 H), 2.19 (d, J = 0.7 Hz, 3 H), 2.36 (s, 3 H), 2.82 (br s, 1 H), 4.32-4.60 (m, 1 H), 5.85 (s, 1 H), 5.87 (d, J = 7.0 Hz, 1 H), 7.18-7.56 (m, 2 H), 7.80-8.02 (m, 2 H). Mass: m/z 380, 378 (M^+), 294, 292, 222, 153 (base peak). HRMS: m/z 380.1221 (calcd for $C_{20}H_{23}{}^{37}ClO_5$ 380.1205), 378.1232 (calcd for $C_{20}H_{23}{}^{35}ClO_5$ 378.1233).

3-[1,2-Bis(hydroxyhexyl)]-4,6-dimethyl-2-pyrone (6e): pale yellow viscous oil (35% (procedure A)). IR (neat, cm^{-1}): 3430, 1690, 1645, 1566. ^1H NMR ($CDCl_3$): δ 0.69-1.00 (m, 3 H), 1.00-1.78 (m, 6 H), 2.18 (s, 3 H), 2.24 (d, J = 0.7 Hz, 3 H), 3.70-3.98 (m, 1 H), 4.21-4.53 (m, 1 H), 5.92 (br s, 1 H). HRMS: m/z 223.1337 (calcd for $C_{13}H_{19}O_3$, M^+ - OH, 223.1334), 222.1252 (calcd for $C_{13}H_{18}O_3$, M^+ - H_2O, 222.1255).

Acylation of 5d with Acetic Anhydride and 4-(*N*,*N*-Dimethylamino)pyridine (DMAP) in Triethylamine. To a mixture of **5d** (303 mg, 0.9 mmol), DMAP (33 mg, 0.27 mmol) and triethylamine (0.2 mL, ca. 2.0 mmol) was added dropwise 0.14 mL (1.5 mmol) of acetic anhydride at room temperature. The reaction mixture was stirred for 30 min and diluted with 20 mL of ether. The resulting mixture was poured into 30 mL of 1 N HCl, and the organic layer was separated. After the aqueous layer was extracted with ether (2 × 10 mL), the combined organic layers were washed with 5% $NaHCO_3$ and saturated NaCl and then dried over $MgSO_4$. The removal of the solvent gave a crude product. Purification by TLC (*n*-hexane/ethyl acetate = 6/4) afforded 187 mg (55%) of **7d**. **7d**: yellow oil. IR (KBr, cm^{-1}): 1770, 1723, 1690 (sh), 1641, 1573, 1374, 1284, 1251, 1242, 1234, 1124, 1069. ^1H NMR ($CDCl_3$): δ 1.25 (d, J = 5.4 Hz, 3 H), 1.99 (s, 3 H), 2.20 (d, J = 0.9 Hz, 3 H), 2.38 (s, 3 H), 5.76-5.89 (m, 1 H), 5.85 (dq, J = 8.4, 5.4 Hz, 1 H), 6.10 (d, J = 8.4 Hz, 1 H), 7.17-7.57 (m, 2 H), 7.77-7.97 (m, 2 H). Mass: m/z 380, 378 (M^+), 139 (base peak). HRMS: m/z 380.0801 (calcd for $C_{19}H_{19}{}^{37}ClO_6$ 380.0839), 378.0870 (calcd for $C_{19}H_{19}{}^{35}ClO_6$ 378.0839).

Acknowledgment. We thank Dr. Yohsuke Yamamoto and Dr. Keisuke Suzuki for helpful discussions. We are grateful to Dr. Takayuki Kawashima and Dr. Hiroshi Hirota of the University of Tokyo for measurement of high-resolution mass spectra and to the Grant-in-Aid for Special Project Research (Nos. 61111004 and 62101004) administered by the Ministry of Education, Science, and Culture of the Japanese Government. The gift of silyl chlorides from Chisso Co., Ltd., is also acknowledged.

Registry No. *trans*-**1a**, 114144-01-3; *cis*-**1a**, 114144-05-7; *trans*-**1b**, 119274-33-8; *cis*-**1b**, 119274-34-9; *trans*-**1c**, 119274-35-0; *cis*-**1c**, 119274-36-1; *trans*-(*E*)-**1d**, 119363-81-4; *trans*-(*Z*)-**1d**, 119363-82-5; *cis*-(*E*)-**1d**, 119363-83-6; *cis*-(*Z*)-**1d**, 119363-84-7; *trans*-(*E*)-**1e**, 119274-37-2; *trans*-(*Z*)-**1e**, 119274-38-3; *cis*-(*E*)-**1e**, 119274-39-4; *cis*-(*Z*)-**1e**, 119296-10-5; *trans*-**1f**, 119274-40-7; *cis*-**1f**, 119274-41-8; *trans*-**1g**, 119274-42-9; *cis*-**1g**, 114144-06-8; **2a**, 119274-43-0; **2b**, 119274-44-1; **2c**, 119274-45-2; *E*-**2d**, 119274-46-3; *Z*-**2d**, 119274-47-4; *E*-**2e**, 119274-48-5; *Z*-**2e**, 119274-49-6; **2f**, 119274-50-9; **2g**, 119274-51-0; **3a**, 119274-53-2; *Z*-**3e**, 119274-55-4; *E*-**3e**, 119274-57-6; *cis*-**4d**, 119274-58-7; *trans*-**4d**, 119274-59-8; *trans*-**4e**, 119274-60-1; *cis*-**4e**, 119274-61-2; **5d**, 119274-62-3; **5e**, 119274-63-4; **6e**, 119274-64-5; **7d**, 119274-65-6; $AgSbF_6$, 26042-64-8; $AgBF_4$, 14104-20-2.

A Convenient Synthesis of Vicinal Diamines

David S. Jones,* Ananthachari Srinivasan, Sudhakar Kasina, Alan R. Fritzberg, and David W. Wilkening

NeoRx Corporation, 410 W. Harrison, Seattle, Washington 98119

Received July 25, 1988

Various 3-substituted-1,2-diaminopropane compounds in which the amino groups are protected as bis(carbamates) or bis(sulfonamides) were prepared from the corresponding N,N'-bis-protected 2-(aminomethyl)aziridine derivatives by nucleophilic opening of the aziridine ring. The aziridine derivatives are ultimately derived from readily available 2-hydroxy-1,3-diaminopropane. A variety of nucleophiles can be added to incorporate various functionality (CN, O_2CCH_3, OH, Cl, CH_3, CH_2CO_2H) in the 3-position of the resulting 1,2-diaminopropane derivatives.

The vicinal diamino group plays an important role in medicinal chemistry, particularly in metal chelation.[1,2] In particular, vicinal diamines are key intermediates in the synthesis of bis thioacetamido (N_2S_2) chelating agents for ^{99m}Tc and $^{186}Re/^{188}Re$. The ^{99m}Tc N_2S_2 complexes have been of interest as renal tubular function imaging agents[1] and more recently have been applied as bifunctional chelating agents for labeling monoclonal antibody fragments for tumor imaging.[3] Rhenium radioisotopes, ^{186}Re and ^{188}Re, have appropriate physical properties for β emitter radiotherapy, and N_2S_2 ligands have demonstrated bifunctional chelating ability for antibodies for radioimmunotherapy.[4] The methods for preparing vicinal diamines are unfortunately rather limited, particularly with respect to including other functionalized groups on the molecule. Olefins react with azide anion oxidatively to form vicinal diazides.[5] The reduction of diazides to diamines is prone to alternative reactions and requires careful selection of reductants. Another drawback to the use of azides is their possible explosiveness. Olefinic hy-

(1) Kasina, S.; Fritzberg, A. R.; Johnson, D. L.; Eshima, D. *J. Med. Chem.* **1986**, *29*, 1933-1940.
(2) (a) Gutsche, C. D.; Mei, G. C. *J. Am. Chem. Soc.* **1985**, *107*, 7964-7967. (b) DeRiemer, L. H.; Meares, C. F.; Goodwin, D. A.; Diamanti, C. I. *J. Lab. Comp. Radiopharm.* **1981**, *18*, 1517-1534.
(3) Fritzberg, A. R.; Abrams, P. G.; Beaumier, P. L.; Kasina, S.; Morgan, A. C.; Rao, T. N.; Reno, J. M.; Sanderson, J. A.; Srinivasan, A.; Wilbur, D. S.; Vanderheyden, J.-L. *Proc. Natl. Acad. Sci. U.S.A.*, in press.
(4) Vanderheyden, J.-L.; Fritzberg, A. R.; Rao, T. N.; Kasina, S.; Srinivasan, A.; Reno, J. M.; Morgan, A. C. *J. Nucl. Med.* **1987**, *28*, Abstract Number 415.
(5) (a) Fristad, W. E.; Brandvold, T. A.; Peterson, J. R.; Thompson, S. R. *J. Org. Chem.* **1985**, *50*, 3647-3649, and references therein. (b) Moriarity, R. M.; Khosrewshahi, J. S. *Tetrahedron Lett.* **1986**, *27*, 2809-2812. (c) Becker, P. N.; White, M. H.; Bergman, R. G. *J. Am. Chem. Soc.* **1980**, *102*, 5676-5677.

0022-3263/89/1954-1940$01.50/0