Substitution and Elimination Reactions in Chloro Olefins. 3.[1] Reactions of Methyl β-Chlorocinnamates with Thiophenoxide Ion

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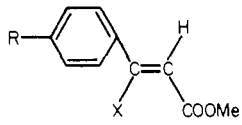
Received November 4, 1980

The reactions of a series of para-substituted (*Z*)-methyl β-chlorocinnamates with thiophenoxide ion in methanol have been studied and their rates measured. The products are the corresponding β-phenylthio esters with retention of configuration with the exception of the *p*-nitro-substituted derivative. Good Hammett correlations with ρ values of 1.73–2.28 were obtained which suggests a carbanionic character of the transition state. An addition–elimination mechanism proceeding via an intermediate carbanion has been postulated for this nucleophilic vinylic substitution reaction.

Nucleophilic vinylic substitution[2] reactions can theoretically proceed either via an elimination–addition or addition–elimination mechanism. Extensive work has been carried recently by Rappoport[3] and others[4,5] in this field.

In continuation to our studies on the reactions of chloro olefins[1] we report the reactions of para-substituted (*Z*)-methyl β-chlorocinnamates **1a–d** with thiophenoxide ion.



1, X = Cl
2, X = SC_6H_5

a, R = H; **b**, R = CH_3; **c**, R = Cl; **d**, R = NO_2

Results and Discussion

The starting materials **1a–d** were prepared as previously reported.[1b] The reactions of thiophenoxide ion and the corresponding β-chloro esters were conducted under conditions identical with those of the kinetic runs. Concurrent and consecutive methanolysis was avoided by adding about a tenfold excess of thiophenol with each run, thus displacing to the left to effective completion the equilibrium shown below. The presence of large excess of the thiophenol (up to a 50-fold excess) was found to have no effect on the rate constant. The products obtained from the reactions of thiophenoxide ion and the β-chloro esters **1a–d** are the corresponding para-substituted methyl β-(phenylthio)cinnamates **2a–d**. NMR spectra showed a single product for compounds **2a–c** and a mixture for **2d**. In order to explore the possibility of the formation of acetylenic intermediates in the reaction, we tried two approaches. In the first, samples were withdrawn every 10 min from the reaction of **1b** with thiophenoxide ion, worked up, and analyzed by IR for acetylenic intermediates. No evidence for the presence of such intermediates was obtained. This indicates that either the acetylenic intermediate was not formed at all or that, if formed, it undergoes very rapid addition and cannot be detected.

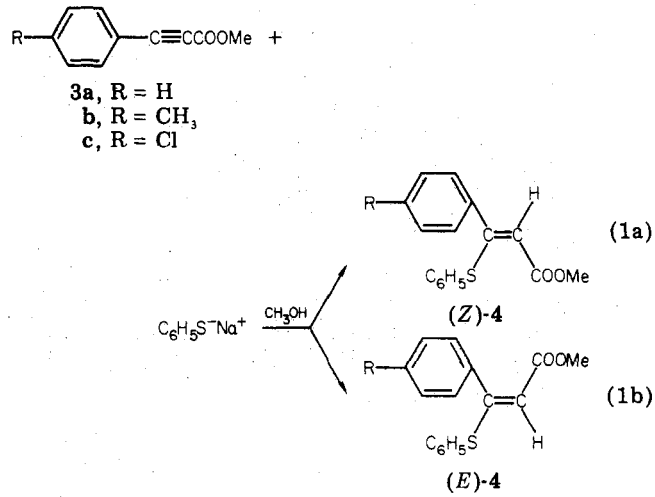
$$PhS^- + CH_3OH \rightleftharpoons PhSH + CH_3O^-$$

Table I. ^1H Chemical Shifts[a]

compd	aromatic	olefinic	OCH_3	CCH_3
1a	7.72	6.73	3.92	
1b	7.1-7.4	6.45	3.75	2.35
1c	7.8-8.1	7.13	3.88	
1d	8.3-8.7	7.22	3.97	
2a	7.12-7.22	6.08	3.78	
2b	6.83-7.23	6.10	3.77	2.17
2c	7.10-7.33	6.03	3.80	
2d	7.03-8.20	6.03 (*Z*)	3.76 (*Z*)	
		5.47 (*E*)	3.42 (*E*)	
4a	7.02-7.30	6.05 (*Z*)	3.75 (*Z*)	
		5.33 (*E*)	3.38 (*E*)	
4b	6.79-7.40	6.06 (*Z*)	3.69 (*Z*)	2.07
		5.40 (*E*)	3.36 (*E*)	
4c	7.05-7.43	6.00 (*Z*)	3.77 (*Z*)	
		5.33 (*E*)	3.42 (*E*)	
5	7.68-8.22	*b*	3.60	
6	7.20-8.08	*b*	3.68	

[a] Chemical shifts in δ units; solvent $CDCl_3$. [b] Within the aromatic region.

Second, para-substituted methyl phenylpropiolates **3a–c** were allowed to react with thiophenoxide ion under the same conditions and the isolated products compared with those obtained from the reaction of **1a–d**. NMR spectra showed that the products **4a–c** obtained from the addition reactions were mixtures of both *E* and *Z* isomers (eq 1) and



3a, R = H
b, R = CH_3
c, R = Cl

(1a)

(*Z*)-**4**

(1b)

(*E*)-**4**

differ from those obtained from the reaction of **1a–c** with thiophenoxide ion. Although the addition of nucleophiles to acetylenic compounds has been reported to be stereoselective in most cases,[5-8] Dolfini[9] pointed out that both

(1) (a) Part I: A. A. Youssef and A. G. Abdel-Reheim, *Indian J. Chem., Sect. B*, **14B**, 101 (1976); (b) Part II: A. A. Youssef and H. Abdel-Maksoud, *J. Org. Chem.*, **40**, 3227 (1975).
(2) W. H. Saunders and A. F. Cockerill, "Mechanisms of Elimination Reactions", Wiley, New York, 1973.
(3) Z. Rappoport and A. Topol, *J. Am. Chem. Soc.*, **102**, 406 (1980), and references cited in.
(4) J. C. Chalchat, F. Théron, *Bull. Soc. Chem. Fr.*, 953 (1974).
(5) D. E. Jones and C. A. Vernon, *Nature (London)*, **176**, 791 (1955).
(6) W. E. Truce, et al., *J. Am. Chem. Soc.*, **78**, 2743 (1956).

0022-3263/81/1946-3813$01.25/0

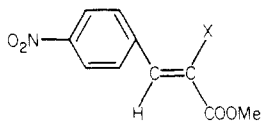
Table II. Specific Rate Constants and Activation Parameters[a,b]

compd	temp, °C	[RCl], M	$10^5 k_2$, s^{-1} mol^{-1}	$\Delta H^{\ddagger}$, kcal/mol	$\Delta S^{\ddagger}$, cal mol^{-1} deg^{-1}	r
1a	30	0.0025	33.1	22.1 ± 0.17	−8.9	0.990
	40	0.0025	98.8			
	50	0.0050	175.2			
1b	30	0.0050	6.4			
	40	0.0040	25.3	22.4 ± 0.17	−9.7	0.994
	50	0.0025	141.2			
1c	30	0.0050	53.4			
	40	0.0010	165.0	17.9 ± 0.3	−16.1	0.996
	50	0.0050	414.0			
1d	20	0.0050	53.4			
	30	0.0050	1230.0	17.1 ± 0.3	−16.6	0.992
	40	0.0050	3230.0			
	50	0.0009	5144.4			

[a] The solvent used was methanol. [b] $[C_6H_5S^-]/[RCl] = 10$.

cis and trans additions to acetylenic compounds are possible, depending upon the nature of the solvent. Thus, the reaction of aziridine and dimethyl acetylenedicarboxylate in methanol at room temperature gave a mixture of trans and cis isomers in the ratio 67:33, respectively. He further proved that this ratio is inherent in the addition and not a result of possible isomerization. Other workers[10] arrived at the same conclusion.

Configuration of the Products. The configurations of the products from the reactions of **1a–d** with thiophenoxide ion were arrived at by their spectral studies as compared to those for the products formed by addition of thiophenoxide ion to the appropriate acetylenic compounds as well as with those for the product from the reaction of (*Z*)-methyl α-chloro-*p*-nitrocinnamate (**5**) with



5, X = Cl
6, X = SPh

thiophenoxide ion. Table I lists the NMR data for the β-chloro esters **1a–d**, β-phenylthio esters **2a–d**, and the products from addition experiments, **4a–c**.

These values are in line with those reported earlier for similar systems.[7,9,12] The product obtained from the reaction of **1d** with thiophenoxide ion, different from those obtained from **1a–c**, shows peaks for both *Z* and *E* isomers in the vinylic as well as in the OCH_3 regions (Table I).

The UV spectra of the products **2a–d** from the reaction of para-substituted methyl β-chlorocinnamates with thiophenoxide ion exhibit almost the same absorption bands, whereas the product **6** from (*Z*)-methyl α-chloro-*p*-nitrocinnamate (**5**) shows different λ_{max} and ε values. Similarly, the IR spectra are similar for the β series and differ from those of the α series. The mass spectra showed a peak for the PhS^+ ion in all products, as expected when a thiophenyl group is bonded to the benzylic carbon (see Experimental Section).

From consideration and inspection of the above spectral data we can arrive at the following conclusions. (i) The products obtained from the reaction of compounds **1a–d** and thiophenoxide ion are β-phenylthio derivatives, and no evidence for the formation of the α derivatives is found. (ii) All the products obtained from this reaction with the exception of **2d** are one isomer and possess the *Z* configuration. (iii) The products obtained from **1d** and thiophenoxide ion as well as those from the addition of thiophenoxide ion to **3a–c** in methanol are mixtures of *Z* and *E* isomers.

Kinetics and Mechanism of the Reaction. The rate of liberation of chloride ion from substrates **1a–d** on reaction with thiophenoxide ion was determined electrometrically. Pseudo-first-order and second-order rate constants and activation parameters are calculated graphically and by the least-squares method. Electron-attracting groups were found to cause a large increase in rate, thus **1d** was found to react more than 200 times faster than **1b**. Table II lists the specific rate constants and the activation parameters.

A Hammett correlation is found to hold well for the reaction of thiophenoxide ion with chloro esters **1a–d**. The ρ values (least-squares method)[13] range from 2.28 ± 0.24 ($r = 0.998$) at 30 °C to 1.73 ± 0.18 ($r = 0.989$) at 50 °C.

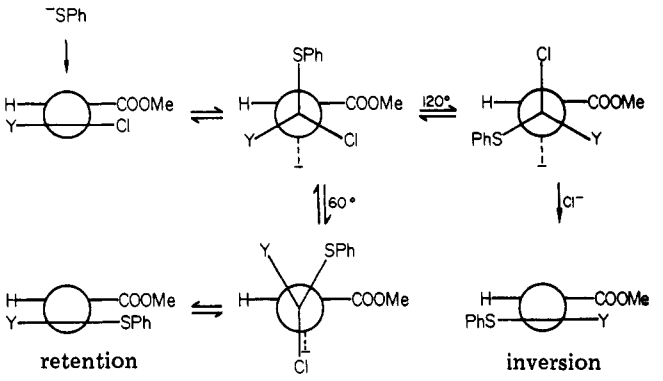
There are two possible mechanisms consistent with the observation that para-substituted methyl β-chlorocinnamates (**1**) react with thiophenoxide ion by a second-order process to give substitution products.

(a) A mechanism in which addition of the nucleophile is followed or accompanied by loss of chloride ion which can be formulated as shown in Scheme I. If addition of ^-SPh and loss of Cl^- ions occur together, the mechanism becomes a synchronous substitution process.

(b) A mechanism in which base-catalyzed elimination of hydrogen chloride is followed by addition to the triple bond thus formed is shown in Scheme II. The latter mechanism, however, can be rejected on the following grounds. (1) No acetylenic intermediate could be identified either by isolation or by spectroscopy from the reaction. (2) If it is assumed that both para-substituted (*Z*)-methyl β-chlorocinnamates **1a–d** and para-substituted (*Z*)-methyl α-chlorocinnamate **5** react with thiophenoxide ion by the same mechanism and if mechanism b is operating, one and the same product or products should be obtained from both chloro esters by addition of thiophenoxide ion to acetylenic intermediate as shown in Scheme III. Exper-

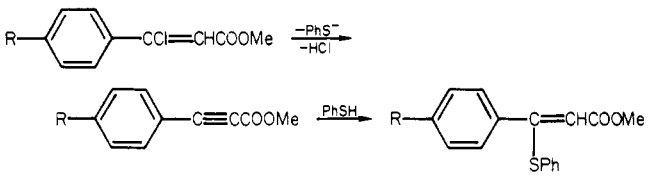
(7) (a) F. Théron, *Bull. Soc. Chim. Fr.*, 278 (1909). (b) F. Théron and Roger Vessiere, *Bull. Soc. Chim. Fr.*, 2994 (1968).
(8) (a) W. E. Truce and J. A. Simms, *J. Am. Chem. Soc.*, **78**, 2756 (1956); (b) W. E. Truce, H. C. Klein, and R. B. Kruse, *ibid.*, **83**, 4636 (1961); (c) J. S. Pizey and W. E. Truce, *J. Org. Chem.*, **30**, 4355 (1965).
(9) J. E. Dolfini, *J. Org. Chem.*, **30**, 1298 (1965).
(10) R. Huesgen, B. Giese, and H. Huber, *Chem. Ber.*, **100**, 1883 (1967).
(11) Donald J. Burton and John R. Greenwald, *Tetrahedron Lett.*, 1535 (1967).
(12) D. E. Jones, R. O. Morris, C. A. Avernon, and R. F. White, *J. Chem. Soc.*, 2349 (1960).
(13) H. H. Jaffé, *Chem. Rev.*, **53**, 191 (1953).
(14) M. S. Newman and S. H. Merrill, *J. Am. Chem. Soc.*, **77**, 5549 (1955).

Scheme I[a]



[a] Y = p-RC$_6$H$_4$; R = H, CH$_3$, Cl, NO$_2$.

Scheme II



imentally, however, both **1d** and **5** gave different products on treatment with thiophenoxide ion under the same conditions as identified by melting point, UV, IR, and NMR spectra (Experimental Section).

The complete retention of configuration in the reaction can be visualized as shown in Scheme I. The incoming nucleophile and the electron pair enter trans in the plane of the original π orbital, and the halide ion departs. Rotation 60° clockwise or removal of Cl⁻ instantly results in retention of configuration as observed for **1a–c**, whereas 120° counterclockwise rotation gives inversion of configuration. The identification of some inverted product from **1d** can be due either to increased stability of the intermediate anion that allows rotation of the halide ion counterclockwise through 120°, leading to some inversion of configuration, or to partial isomerization of the product by an annexed route. Differentiation between these two possibilities needs further investigation.

Experimental Section

Infrared and ultraviolet spectra were taken on Unicam SP 1025 and 1805 spectrometers, respectively. The NMR spectra were measured at 60 MHz by using tetramethyl silane as an internal standard and CD_3Cl as the solvent. The mass spectra were carried on an AEI MS 3076 spectrometer operating at 70 eV and 180 °C (York University, England).

Preparation of Materials. The synthesis of para-substituted methyl β-chlorocinnamates **1a–d** has been reported earlier.[1a]

Reaction Products. The following procedure was adopted for all compounds. The appropriate material (0.5–1 g) was dissolved in absolute methanol, and an equimolar amount of sodium thiophenoxide was added. The solution was flushed with nitrogen and thermostated at 50 °C for more than 10 half-lives in each case. At the end of the reaction time, the mixture was poured into a large volume of ice-cold water, and the precipitated solid was filtered and crystallized from the appropriate solvent (Table III).

Methyl α-(Phenylthio)-p-nitrocinnamate (6). Methyl α-chloro-p-nitrocinnamate (0.5 g) was treated with thiophenoxide ion under similar conditions as above and worked up to give a solid which was crystallized from methanol: 0.6 g; mp 114–116 °C; IR strong bands at 1740 (C=O), 1175 (CO), 1520–1350 (CNO_2), aromatic), and 850 (aromatic CH), medium bands at 2980 (CH), 1610 (C=C), and 696 (CS) cm⁻¹; UV λ 213 nm (ε 27 600), λ_{max} 272 (ε 9600).

Table III. Properties and Analysis of the Products from the Reaction of 1a–d with Thiophenoxide Ion in Methanol

compd	mp, °C	yield, %	λ_{max},[a] nm (ε)	ν(C=O, CS), cm⁻¹	principal fragments in mass spectrum (M⁺) m/e	principal fragments in mass spectrum (M⁺) formula	molecular formula	% calcd (% found)
2a	67–68	87	214 (11 460), 268 (5555)	1700, 600	109	$(SC_6H_5)^+$	$C_{16}H_{14}O_2S$	C, 71.07; H, 5.22; S, 11.87 (C, 71.10; H, 4.80; S, 12.10)
					211	$(PhC(SC_6H_5)=CH)^+$		
					239	$(PhC(SC_6H_5)=CHCO)^+$		
2b	65–66	87	214 (9333), 290 (4400)	1715, 660	109	$(SC_6H_5)^+$	$C_{17}H_{16}O_2S$	C, 72.10; H, 5.40; S, 10.99 (C, 71.79; H, 5.67; S, 11.28)
					225	$(p\text{-}CH_3C_6H_4C(SC_6H_5)=CH)^+$		
2c	75–76	91	214 (9460), 268 (4533)	1705, 655	109	$(SC_6H_5)^+$	$C_{16}H_{13}O_2ClS$	C, 63.03; H, 4.49; S, 10.53; Cl, 11.64 (C, 62.90; H, 4.20; S, 10.50; Cl, 12.00)
					245	$(p\text{-}ClC_6H_4C(SC_6H_5)=CH)^+$		
					273	$(p\text{-}ClC_6H_4C(SC_6H_5)=CHCO)^+$		
2d	93–95	100	214 (6600), 282 (4650)	1720, 650	109	$(SC_6H_5)^+$	$C_{16}H_{13}O_4NS$	C, 60.92; H, 4.15; N, 4.44; S, 10.17 (C, 61.00; H, 3.90; N, 4.20; S, 9.70)
					284	$(p\text{-}NO_2C_6H_4C(SC_6H_5)=CHCO)^+$		

[a] In ethanol.

Scheme III

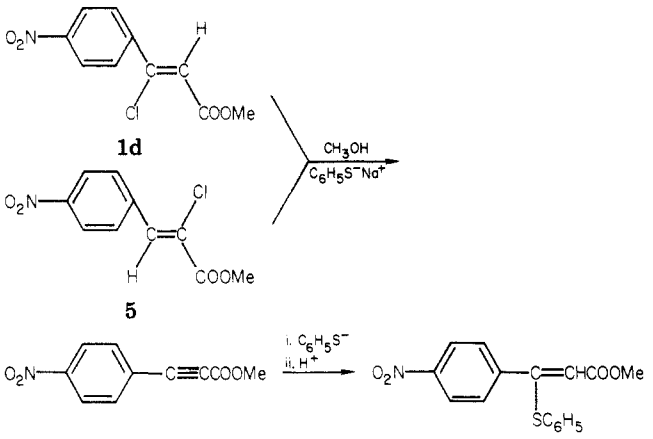


Table IV

compd	mp, °C	% yield	λ_{max},[a] nm (ϵ)	ν(C=O, CS), cm^{-1}
3a	63-65	88	260 (10 000)	1700, 660
3b	63-64	86	286 (4590)	1715, 650
3c	66-70	90	269 (5500)	1730, 630

[a] In ethanol.

Reaction of Para-Substituted Methyl Phenylpropiolates with Sodium Thiophenoxide in Absolute Methanol. Para-substituted phenylpropiolic acids were prepared by the dehydrobromination of the corresponding dibromide with 35% alcoholic potassium hydroxide. The methyl esters were synthesized by the reaction of the corresponding acids with absolute methanol in presence of dry hydrogen chloride. The addition experiments were carried out by treating the appropriate para-substituted methyl phenylpropiolate (0.5–1 g) dissolved in absolute methanol with an equivalent amount of sodium thiophenoxide under a nitrogen atmosphere for 3 days at 50 °C. The mixture was poured into ice-cold water, and the precipitated solid was filtered and crystallized from the appropriate solvent. Table IV lists the properties of the products from the reaction of para-substituted phenylpropiolates **3a–c** with thiophenoxide ion in methanol.

Kinetic Measurements. The rates of reaction were determined by following the rates of liberation of chloride ion by the electrometric method as previously reported.[1,15] Most reactions were followed to 80% completion, and in all cases the infinity titer was found to agree with the calculated value.

Acknowledgment. We are grateful to Professor Dr. B. Thomas of York University, England, for running and interpreting the mass spectra.

Registry No. 1a, 56377-29-8; **1b**, 56377-28-7; **1c**, 56377-31-2; **1d**, 56377-30-1; **2a**, 34875-03-1; **2b**, 78089-36-8; **2c**, 78089-37-9; (*E*)-**2d**, 78089-38-0; (*Z*)-**2d**, 78089-39-1; **3a**, 4891-38-7; **3b**, 7515-16-4; **3c**, 7515-18-6; (*E*)-**4a**, 34875-13-3; (*E*)-**4b**, 78089-40-4; (*E*)-**4c**, 78089-41-5; **5**, 14898-20-5; **6**, 78089-42-6; sodium thiophenoxide, 930-69-8; thiophenoxide(1–), 13133-62-5.

(15) (a) R. J. Best, *J. Agric. Sci.*, **19**, 533 (1929); (b) S. Snyder, *Soil Sci.*, **35**, 43, (1933).

Reactions of 2-Fluoro-2-nitro-1,3-propanediol. *p*-Toluenesulfonates[1]

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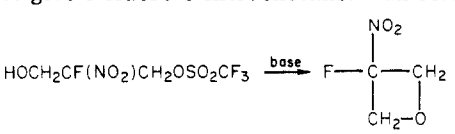
Received February 24, 1981

Displacement reactions of the tosylates derived from 2-fluoro-2-nitro-1,3-propanediol, 2-fluoro-3-hydroxy-2-nitro-1-propyl *p*-toluenesulfonate and 2-fluoro-2-nitro-1,3-propylene di-*p*-toluenesulfonate, were studied. Direct substitution products were obtained with these tosylates and sodium azide and with the monotosylate and lithium bromide. The monotosylate reacted under more strongly basic conditions to give products rationalized on the basis of the intermediate formation of 1-fluoro-1-nitroethylene. The monotosylate and potassium hydroxide gave a dimeric and a trimeric ether under conditions that did not affect the ditosylate. The monotosylate but not the ditosylate gave a methyl ether with potassium methoxide. Dimethyl sodiomalonate and the monotosylate gave dimethyl (2-fluoro-2-nitroethyl)malonate and dimethyl (2-fluoro-3-hydroxy-2-nitropropyl)malonate.

We have recently developed an improved synthesis of 2-fluoro-2-nitro-1,3-propanediol and investigated the reactions of its triflate derivatives.[2] The monotriflate cyclized under mild conditions in the presence of a variety of bases to give 3-fluoro-3-nitrooxetane.[2] In connection



with this work, we have examined the reactions of the corresponding tosylates. The tosylate group is a more commonly used leaving group for oxetane ring closures,[3] but in this system cyclization did not occur, and a different reaction course was followed.

The desired tosylates were prepared from 2-fluoro-2-nitro-1,3-propanediol by conventional procedures. The reaction of an excess of diol and pyridine with *p*-toluenesulfonyl chloride in refluxing chloroform afforded a 78% yield of 2-fluoro-3-hydroxy-2-nitro-1-propyl tosylate and a 10% yield of 2-fluoro-2-nitro-1,3-propylene ditosylate, whereas an excess of *p*-toluenesulfonyl chloride in pyridine gave the ditosylate in 67% yield.

$$HOCH_2CF(NO_2)CH_2OH \xrightarrow[TsCl]{pyridine} TsOCH_2CF(NO_2)CH_2OH + TsOCH_2CF(NO_2)CH_2OTs$$

Although the monotosylate was consumed within minutes in a reaction with potassium hydroxide at room temperature, no 3-fluoro-3-nitrooxetane was detected. A solid product was obtained in 34% yield identified as 2,6-difluoro-7-hydroxy-2,6-dinitro-4-oxa-1-heptyl tosylate, the

(1) This work was supported by the Office of Naval Research.
(2) Berkowitz, P. T.; Baum, K. *J. Org. Chem.* **1980**, *45*, 4853.
(3) Balsamo, A.; Ceccarelli, G.; Crotti, P.; Macchia, F. *J. Org. Chem.* **1975**, *40*, 473. Rowland, A. T.; Drawbaugh, R. S.; Dalton, J. R. *J. Org. Chem.* **1977**, *42*, 487.

0022-3263/81/1946-3816$01.25/0