dimethylcyclohexanone trimethylsilyl enol ether, 77172-48-6; 4,4-dimethylcyclohexanone enol acetate, 77172-49-7; 4-methylcyclohexanone enol acetate, 22422-17-9; *exo*-3-(chloromercuri)-2-norbornanone, 77172-50-0; *endo*-2-norbornylmercuric chloride, 52251-50-0; *exo*-2-norbornylmercuric chloride, 52251-51-1; *cis*-3-methylcyclohexylmercuric chloride, 77172-51-1; 3,3-dimethylcyclohexylmercuric bromide, 77172-52-2; *trans*-2-(chloromercuri)-4-methylcyclohexanone, 77172-53-3; *cis*-2-(chloromercuri)-4-methylcyclohexanone, 77172-54-4; 4-methylcyclohexanone, 589-92-4; *trans*-2-(chloromercuri)-4-*tert*-butylcyclohexanone, 77172-55-5; *cis*-2-(chloromercuri)-4-*tert*-butylcyclohexanone, 77172-56-6; 4-*tert*-butylcyclohexanone, 98-53-3; 2-(chloromercuri)-4,4-dimethylcyclohexanone, 77172-57-7; 4,4-dimethylcyclohexanone, 4255-62-3; 2-(chloromercuri)cyclohexanone, 14839-64-6; cyclohexanone, 108-94-1; cyclohexylmercuric acetate, 10341-90-9; (2*R**,2'*R**)-bis(2-oxocyclohexyl)mercury, 77172-58-8; (2*R**,2'*S**)-bis(2-oxocyclohexyl)mercury, 77172-59-9; (2*R**,2'*R**,4*S**,4'*S**)-bis(5-*tert*-butyl-2-oxocyclohexyl)-mercury, 77172-60-2; (2*R**,2'*S**,4*S**,4'*R**)-bis(5-*tert*-butyl-2-oxocyclohexyl)mercury, 77255-04-0; (2*S**,2'*R**,4*S**,4'*R**)-bis(5-*tert*-butyl-2-oxocyclohexyl)mercury, 77255-05-1; (2*S**,2'*S**,4*S**,4'*S*)-bis(5-*tert*-butyl-2-oxocyclohexyl)mercury, 77255-06-2; (2*R**,2'*R**,4*S**,4'*S**)-bis(5-methyl-2-oxocyclohexyl)mercury, 77172-61-3; (2*R**,2'*S**,4*S**,4'*R**)-bis(5-methyl-2-oxocyclohexyl)mercury, 77210-00-5; (2*S**,2'*R**,4*S**,4'*R**)-bis(5-methyl-2-oxocyclohexyl)mercury, 77210-01-6; (2*S**,2'*S**,4*S**,4'*S**)-bis(5-methyl-2-oxocyclohexyl)mercury, 77172-62-4; (2*R**,2'*R*)-bis(5,5-dimethyl-2-oxocyclohexyl)mercury, 77172-63-5; (2*R**,2'*S**)-bis(5,5-dimethyl-2-oxocyclohexyl)mercury, 77172-64-6.

Aromatic Substitution. 47.[1] Acid-Catalyzed Transfer Nitration of Aromatics with *N*-Nitropyrazole, a Convenient New Nitrating Agent

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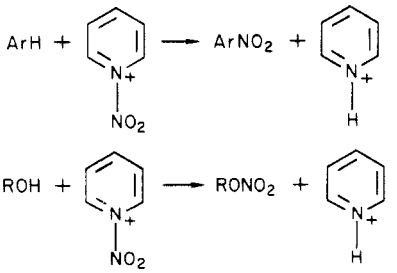
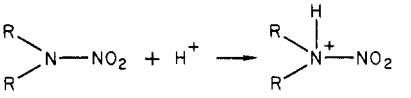
N-Nitropyrazole in the presence of Lewis or Bronsted acid catalysts was found to be an effective transfer nitrating agent for aromatic substrates. The nature of the acid catalyst affects both substrate and positional selectivities of the nitration of alkylbenzenes. No relationship was found between substrate and positional selectivities, which are considered to be determined in two separate steps.

The nitronium ion is usually the nitrating agent in electrophilic aromatic nitration. The nitronium ion is formed in situ from nitric acid, alkyl nitrates, acyl nitrates, etc., ($XONO_2$, X = H, R, RC(O)) in which it is bound to an oxygen atom.[2]

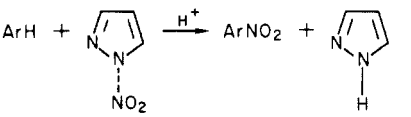
Even stable nitronium salts are utilized as nitrating agents. On the other hand, nitration with reagents in which the incipient nitronium ion is bound to nitrogen or other heteroatoms is rare. We have previously reported the nitration of aromatics and alcohols with *N*-nitropyridinium and *N*-nitroquinolinium salts, which undergo transfer nitration from nitrogen to π-donor and n-donor substrates.[3,4]



These nitrations take place readily at room temperature and the nitro aromatics and alkyl nitrates are obtained in excellent yields. One of the advantages in using *N*-nitropyridinium salts is the binding of the acid formed as a byproduct to the amine base, thus allowing the transfer nitrations to be carried out under essentially neutral conditions. *N*-Nitropyridinium salts are readily prepared from the corresponding pyridine and the nitronium salt. These salts are stable but require handling in a dry atmosphere because of their sensitivity to moisture. We have therefore been interested in developing suitable *N*-nitramines as nitrating agents, from which the *N*-nitrammonium salt can be generated in situ.



We report now on the use of *N*-nitropyrazole as a suitable new transfer nitrating agent.



X-ray structure determination of *N*-nitropyrazole showed that the nitro group is essentially coplanar with the heterocyclic ring.[5] The calculated angle between the ring plane and the plane of the nitro group is only 1.8°. On the other hand, the N–NO_2 bond length (1.399 Å) is considerably longer than in dimethylnitramine (1.30 Å) and other nitramines (average of 1.372 Å). This tends to indicate a greater lability of the N–NO_2 bond in *N*-nitro-

(1) For part 46, see: Olah, G. A.; Bruce, M. R.; Clouet, F. L. *J. Org. Chem.* **1981**, *46*, 438.

(2) For a comprehensive listing of nitrating agents, see: Olah, J. A.; Lin, H. C.; Olah, G. A.; Narang, S. C. *Proc. Natl. Acad. Sci. U.S.A.* **1978**, *75*, 1045-1049.

(3) Olah, G. A.; Narang, S. C.; Olah, J. A.; Pearson, R. L.; Cupas, C. A. *J. Am. Chem. Soc.* **1980**, *102*, 3507-3510.

(4) Olah, G. A.; Narang, S. C.; Pearson, R. L.; Cupas, C. A. *Synthesis* **1978**, 452-453.

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Table I. Boron Trifluoride Etherate Catalyzed Preparative Nitration of Aromatic Hydrocarbons with *N*-Nitropyrazole

substrate	% yield
benzene	89
toluene	92
p-xylene	96
mesitylene	91

Table II. Boron Trifluoride Etherate Catalyzed Competitive Nitration of Benzene/Alkylbenzenes with *N*-Nitropyrazole

substrate	relative rate, $k_{ArH}/k_{benzene}$	isomer distribution, %			
		o	*m*	*p*	*o/p*
benzene	1				
toluene	10.3	58	3	39	1.49
ethylbenzene	6.0	44	3	53	0.83
n-propylbenzene	3.1	41	3	56	0.73
isopropylbenzene	4.8	22	4	74	0.30
tert-butylbenzene	2.5	10	7	83	0.12
o-xylene	20.6	52% 3-nitro, 48% 4-nitro			
m-xylene	15.0	15% 2-nitro, 85% 4-nitro			
p-xylene	15.5				
mesitylene	14.1				
1,2,4-trimethylbenzene	13.3	11% 3-nitro, 61% 5-nitro, 28% 6-nitro			
1,2,3,4-tetramethylbenzene	17.7				

pyrazole than in other aliphatic nitramines.

We therefore chose *N*-nitropyrazole as a potential transfer nitrating agent because its N–NO_2 bond should be, in general, very labile toward nucleophiles, in analogy with the easy transfer of the acyl group from *N*-acylpyrazole,[6] and should become more labile upon complexation (protonation) of the pyrazole. These expectations have been realized and are reported below.

Results and Discussion

N-Nitropyrazole is readily prepared by the reaction of pyrazole with nitric acid and acetic anhydride, using acetic acid as a solvent.[7] It is a stable, crystalline compound which can be stored for prolonged periods of time and melts at 92–93 °C without decomposition. It was found to be an effective transfer nitrating agent when reacted with aromatic hydrocarbons in the presence of an acid catalyst.

Preparative Nitrations with *N*-Nitropyrazole. In order to evaluate the efficiency of acid-catalyzed transfer nitration of aromatics with *N*-nitropyrazole, a series of alkylbenzenes was nitrated. The corresponding nitroalkylbenzenes were obtained in excellent yield (Table I), showing that the transfer of the nitro group from *N*-nitropyrazole to alkylbenzenes is almost quantitative under the reaction conditions. Therefore, *N*-nitropyrazole can be used not only as a preparative reagent but also for mechanistic studies.

Substrate and Positional Selectivity in Competitive Nitrations. Mechanistic studies of transfer nitrations of aromatics were carried out under homogeneous conditions at 25 °C, using dichloromethane as a solvent. Although various acid catalysts were studied, nitrations were most convenient with boron trifluoride etherate as a catalyst. A large excess of aromatic was used in order to ensure a relatively constant ratio of excess aromatic over the nitrating agent. The substrate and positional reactivities obtaining in these experiments are shown in Table II.

Table III. Competitive Nitration of Toluene and Benzene with Various Reagents at 25 °C[2]

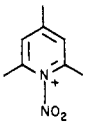
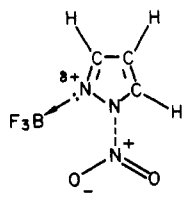
reagent/solvent	k_T/k_B	isomer distribution, %			
		o	*m*	*p*	*o/p*
N-nitropyrazole/BF_3 etherate/CH_2Cl_2	10.3	58	3	39	1.5
$NO_2^+BF_4^-$/CH_3NO_2	1.2	66	3	31	2.1
HNO_3/H_2SO_4/sulfolane	37	62	3	35	1.8
CH_3COONO_3/CH_3CN	44.3	61	2	37	1.7
 BF_4^-/CH_3CN	41.4	63	3	34	1.9

Table IV. Trifluoromethanesulfonic Acid Catalyzed Competitive Nitration of Alkylbenzenes and Benzene with *N*-Nitropyrazole

substrate	relative rate	isomer distribution
benzene	1	
toluene	17.8	56% 2-nitro, 3% 3-nitro, 41% 4-nitro
tert-butylbenzene	4.8	10% 2-nitro, 7% 3-nitro, 83% 4-nitro
o-xylene	37.6	60% 3-nitro, 40% 4-nitro
mesitylene	9.2	

Data in Table III show that substrate selectivities in nitration with *N*-nitropyrazole/BF_3 etherate are lower than in nitration with HNO_3/H_2SO_4 in sulfolane, acetyl nitrate, methyl nitrate/boron trifluoride, or *N*-nitropyridinium salts, but higher than in nitration with nitronium salts. These data indicate that the transition state in nitration with *N*-nitropyrazole/BF_3 etherate lies earlier on the reaction coordinate than even in nitrations with *N*-nitropyridinium salts, but the effective nitrating agent has the developing nitronium ion still loosely bound to the pyrazole ring and is not the free nitronium ion itself. The most plausible mechanism involves the coordination of the Lewis acid catalyst (i.e., BF_3) on nitrogen, activating the adjacent nitramine group for nucleophilic displacement.



If the nitrations with transfer nitrating agents were occurring via a predissociation equilibrium, i.e., with the free nitronium ion, the k_T/k_B ratio should have been close to that observed in nitrations with nitronium salts, i.e., unselective and close to unity. However, the k_T/k_B ratio is 10.3, whereas for nitration with *N*-nitro-2,4,6-collidinium tetrafluoroborate it is 41.4,[3] indicating that the nitronium ion is increasingly strongly bound to collidine in the transition state. Thus, there is significant variation in the

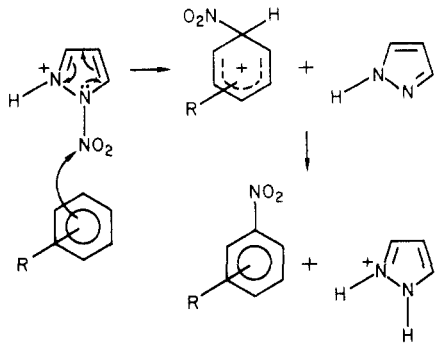
(6) Barthel, J.; Schmeer, G. *Justus Liebigs Ann. Chem.* **1970**, *71*, 102–110.
(7) Huttel, R.; Buchele, F. *Chem. Ber.* **1955**, *88*, 1586–1590.

Table V. Various Acid-Catalyzed Competitive Nitrations of Toluene and Benzene with *N*-Nitropyrazole

acid catalyst	k_T/k_B	isomer distribution, %			
		o	*m*	*p*	*o/p*
CH_3SO_3H	37.6	58	3	39	1.49
CF_3SO_3H	17.8	56	3	41	1.37
$ClSO_3H$	4.7	56	3	41	1.37
FSO_3H	3.0	58	3	39	1.49
$BF_3 \cdot 2Et_2O$	10.3	58	3	39	1.49

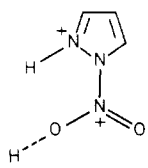
k_T/k_B ratios in transfer nitrations from those of typical nitronium salt nitrations under similar conditions.

In order to study the effect of the acid catalyst on the reactivity of the nitrating agent, we carried out competitive nitrations using a strong protic acid, i.e., trifluoromethanesulfonic acid, instead of the Lewis acid boron trifluoride etherate for activation of *N*-nitropyrazole (Table IV). The substrate selectivity under these conditions increased to $k_T/k_B = 17.8$ from $k_T/k_B = 10.3$ for the boron trifluoride etherate catalyzed nitration. The actual nitrating agent involved in trifluoromethanesulfonic acid mediated nitration is considered to be N-protonated *N*-nitropyrazole which is then displaced by the aromatic.



^{13}C NMR studies showed that protonation of *N*-nitropyrazole with fluorosulfuric acid does indeed occur on the unsubstituted nitrogen atom. Protonated pyrazole was not detected under these conditions, thus discounting the presence of free nitronium ion in any significant concentration, i.e., >2%.

In order to further study the effect of the acid catalyst on the reactions, competitive nitrations of toluene and benzene were alo carried out with various other strong Bronsted acid/*N*-nitropyrazole systems. The data in Table V show that the nature of the acid has a significant effect on the k_T/k_B ratio. The change in k_T/k_B ratio could be dependent upon the degree of protonation of *N*-nitropyrazole, which in turn would depend upon the strength of the acid. In addition, with very strong acids such as fluorosulfuric acid, diprotonation of *N*-nitropyrazole is also possible (the second protonation could take place at the nitro group). The resulting dicationic species could then be the effective nitrating species.



Such protosolvation of a nitronium salt is not unusual, since we have previously observed greatly enhanced reactivity of nitronium salts in strongly acidic media.[8] An examination of Table V reveals that although the substrate selectivities (k_T/k_B) change from 3.0 to 37.6, the variation in positional selectivity (as expressed by the ortho/para isomer ratio) is only from 1.37 to 1.49. The change in positional selectivity does not correspond to the change in substrate selectivity. There seems to be no relationship between the substrate selectivities and positional selectivities. Thus data of Table V indicate that substrate and positional selectivities are independent of each other and must be determined in separate steps. Although the substrate selectivities become as low as $k_T/k_B = 3.0$, the regioselectivity remains high ($o/p = 1.49$). At the same time the ortho–para isomer ratio is significantly different from those observed in nitronium salt nitration, where ratios exceeding 2 are commonly observed,[2] as also seen in Table III.

In conclusion, we have found that *N*-nitropyrazole when activated by an acid catalyst is a highly efficient transfer nitrating agent for aromatics. Our results indicate that the *N*-nitropyrazolonium ion or related Lewis acid complexed species is the actual nitrating agent displaced by the aromatics. Similarly, as with previously studied *N*-nitropyridinium ions,[3] there is no relationship between substrate and positional selectivities of nitration of alkylbenzenes, which must be determined in separate steps.

Experimental Section

All solvents, acid catalysts, and aromatic substrates were commercially available, highest purity materials, purified by the usual methods before use. *N*-Nitropyrazole was prepared by the method of Huttel and Buchele.[7]

General Method of Nitration of Toluene. Toluene (9.2 g, 0.1 mol) and *N*-nitropyrazole (1.14 g, 0.01 mol) were dissolved in dichloromethane (50 mL). Into this solution, a solution of triflic acid (0.75 g, 0.01 mol) in dichloromethane (10 mL) was added. The reaction mixture was vigorously stirred at 25 °C under a dry nitrogen atmosphere. After 10 h the reaction mixture was quenched with ice–water and extracted with ether (2 × 50 mL). The ethereal extract was washed with sodium bicarbonate solution (5%, 25 mL) and brine and dried over anhydrous magnesium sulfate. The ether was evaporated and the residue distilled to yield a mixture of nitrotoluenes (1.16 g, 92%).

Boron Trifluoride Etherate Catalyzed Competitive Nitration of Toluene and Benzene. In a typical experiment, benzene (50 mmol), toluene (50 mmol), and *N*-nitropyrazole (5 mmol) were dissolved in dichloromethane (50 mL). Into this solution was added a solution of borontrifluoride etherate (1.5 mL, ~12 mmol) in dichloromethane (10 mL) under stirring. The reaction mixture was stirred under a dry nitrogen atmosphere at 25 °C for 3 h. The reaction mixture was worked up as described above and the dried ethereal extracts were analyzed by GLC.

Other competitive nitrations were carried out in a similar manner by replacing boron trifluoride etherate with other acids.

Analytical Procedure. Analyses of nitroaromatic products were carried out by using a Varian Model 3700 gas chromatograph equipped with a hydrogen flame-ionization detector and an open tubular column. Peak areas were determined with a Varian CDS III electronic printing integrator. Details of the GLC conditions were reported in our previous work.[2]

The results of competitive nitrations are the average of three independent reactions analyzed three times for each sample. The average deviation of the substrate selectivities was less than 1.0 and that of the isomer distributions was 1.0%.

Acknowledgment. Support of our work by the U.S. Army Research Office, Durham, NC, is gratefully acknowledged.

Registry No. *N*-Nitropyrazole, 7119-95-1; benzene, 71-43-2; mesitylene, 108-67-8; nitrobenzene, 98-95-3; 2-nitro-1,3,5-trimethylbenzene, 603-71-4; ethylbenzene, 100-41-4; propylbenzene, 103-65-1; isopropylbenzene, 98-82-8; *tert*-butylbenzene, 98-06-6; *o*-xylene, 95-47-6; *m*-xylene, 108-38-3; *p*-xylene, 106-42-3; 1,2,4-trimethylbenzene, 95-63-6; 1,2,3,4-tetramethylbenzene, 488-23-3; 1-ethyl-2-nitrobenzene,

(8) Olah, G. A.; Lin, H. C. *J. Am. Chem. Soc.* **1971**, *93*, 1259–1261.

612-22-6; 1-ethyl-3-nitrobenzene, 7369-50-8; 1-ethyl-4-nitrobenzene, 100-12-9; 1-nitro-2-propylbenzene, 7137-54-4; 1-nitro-3-propylbenzene, 73585-59-8; 1-nitro-4-propylbenzene, 10342-59-3; 1-nitro-2-isopropylbenzene, 6526-72-3; 1-nitro-3-(isopropyl)benzene, 6526-74-5; 1-nitro-4-isopropylbenzene, 1817-47-6; 1-(*tert*-butyl)-3-nitrobenzene, 23132-52-7; 1-(*tert*-butyl)-4-nitrobenzene, 3282-56-2; 1,2-dimethyl-3-nitrobenzene, 83-41-0; 1,2-dimethyl-4-nitrobenzene, 99-51-4; 1,3-dimethyl-2-nitrobenzene, 81-20-9; 1,3-dimethyl-4-nitrobenzene, 89-87-2; 3-nitro-1,2,4-trimethylbenzene, 52414-96-7; 5-nitro-1,2,4-trimethylbenzene, 610-91-3; 6-nitro-1,2,4-trimethylbenzene, 609-88-1.

Highly Stereoselective Friedel–Crafts Alkylations via Epoxide Transannular Reactions[1]

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Received February 5, 1981

Under catalytic conditions, *trans*-5,6-epoxy-*cis*-cyclodecene (1) undergoes a Friedel–Crafts (FC) reaction with various aromatic molecules. Four chiral centers are formed via transannular ring closure in this remarkably stereoselective FC reaction (Scheme I). The side products are all consistent with the proposed reaction intermediate, for which oxygen bridging is proposed to account for experimental observations. Geraniolene monoepoxide (14) was also investigated for transannular FC reactions. In this case, FC alkylation was observed (in low yield) only when anisole was the aromatic solvent.

Typically, Friedel–Crafts (FC) alkylation reactions are accompanied by isomerization and disproportionation processes[2] and hence are not considered highly selective. Quite generally, this lack of selectivity has proved true for what few epoxides that have been studied.[2b,3-8] For example, seven products are formed in an alkylation of benzene by the simple compound propylene oxide, and for the most part very little work has been done on FC reactions of the more complex epoxides[8] (possibly because very complex product mixtures would be expected). However, recently the FC products of the latter reaction were shown to result from a stereospecific inversion reaction[5] despite the multiplicity of products. We further demonstrate the novelty of epoxide FC reactions and hope to encourage further interest in this area by reporting a highly stereoselective reaction that minimizes skeletal rearrangements and gives predominantly one product. In this reaction, four chiral centers are generated. Also, in contrast to other epoxides FC reactions,[3-8] our reaction requires only catalytic quantities of Lewis acid promoter.

Although exceptionally selective biomimetic epoxide cyclizations have been reported,[9-12] they differ from our intermolecular FC reactions in that they are strictly intramolecular and involve large amounts of acid promoter.[9-12]

The reaction was discovered while trying to isomerize *trans*-5,6-epoxy-*cis*-cyclodecene[13] (1) with $SnCl_4$ by a

Scheme I

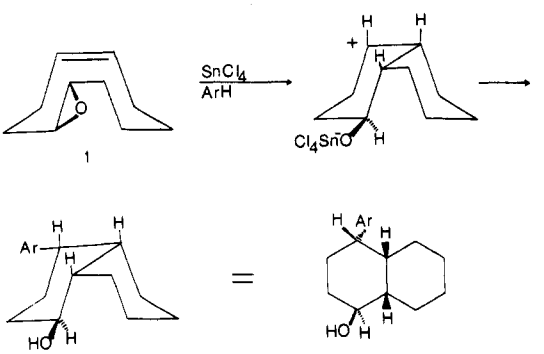

Table I. Products Obtained from Friedel–Crafts Reactions of *trans*-5,6-Epoxy-*cis*-cyclodecene

aromatic	Ar = (product no.)	isolated % yield (ratio of products)	mp, °C
toluene	*p*-methylphenyl (2)[a,b]	64 (75% GC)	156–158
	o-methylphenyl (3)[b]	(2:3 = 75:25)	
o-xylene	3,4-xylyl[a,b] (4)	76	144–146
methoxybenzene	*p*-methoxyphenyl (5)[b]	55	138.5–139
	o-methoxyphenyl (6)[b]	(5:6 = 53:47)	168–170
furan	2-furyl (7)[a]	48	97.5–99.5
ethylbenzene	*p*-ethylphenyl (8)[a,c]	50	128–129
thiophene	2-thienyl (9)[b]	30[d]	102–105

[a] Satisfactory C, H, combustion analytical data (±0.3%) were obtained for these compounds. [b] Satisfactory high-resolution mass spectral data (±0.002 amu) were obtained for these compounds. [c] The ortho isomer was not separated on Carbowax 20M, OV17, or OV1 columns, but a weak IR band was present at 750 cm^{-1}, suggesting some ortho compound was present. [d] Estimated yield (by NMR).

(1) Presented in part at the 179th American Chemical Society National Meeting, Houston, Tx, Mar 1980.
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(6) Inoue, M.; Sugita, T.; Kiso, Y.; Ichikawa, K. *Bull. Chem. Soc. Jpn.* **1976**, *49*, 1063.
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(12) (a) Goldsmith, D. J. *J. Am. Chem. Soc.* **1962**, *84*, 3913. (b) Goldsmith, D. J.; Cheer, C. J. *J. Org. Chem.* **1965**, *30*, 2264.

0022-3263/81/1946-2709$01.25/0