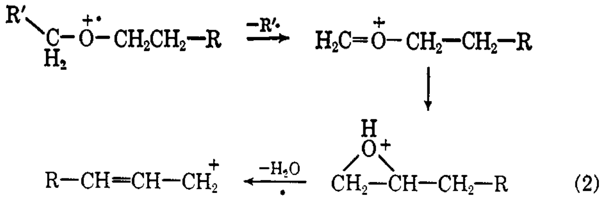

(2)

It is not intended to imply by this hypothetical rationalization that loss of water in the final step would be site specific. Indeed our results with the rearrangement ion b, the elimination of ethanol, and the formation of the ion of mass 56 from ethyl *n*-hexyl ether suggest that hydrogen abstraction would occur from various positions of the alkyl chain and that the contributions from any one position would in all probability depend upon the alkyl chain length.

Experimental Section[16,17]

Alkyl Ethers. All the ethers were made by the Williamson synthesis with the larger alkyl group present as the bromide and the smaller group as the alkoxide. The alkoxides of methanol and ethanol were generated with sodium metal in an excess of the alcohol; those of isopropyl alcohol, propanol, and butanol were generated with sodium hydride in excess alcohol. The following procedure is typical.

Ethyl *n*-Hexyl Ether. Sodium (0.1 g, 4.3 g-atoms) was dissolved in 5 ml of absolute ethanol in a 15-ml test tube and *n*-hexyl bromide (65 mg, 3.9 mmoles) was added. The tube was sealed and heated in a steam bath for 2 hr. The reaction mixture was diluted with 25 ml of water and extracted twice with ether. The ether extracts were washed with water, dried over anhydrous magnesium sulfate, and evaporated to an oil. Purification for mass spectrometry was performed by gas chromatography using a 10 ft × 0.25 in. column packed with 20% silicone gum SE-52 on DMCS-Chromsorb W at a temperature of 130°.

Deuterated *n*-Hexyl and *n*-Heptyl Bromides. *n*-Hexyl bromide-1,1-d_2 was prepared by lithium aluminum deuteride reduction of *n*-hexanoic acid followed by treatment of the alcohol with a 4:1 (v/v) mixture of 48% hydrobromic acid–98% sulfuric acid at 100° for 4 hr. *n*-Hexyl bromide-2,2-d_2 was prepared by first making *n*-pentyl bromide-1,1-d_2 from *n*-pentanoic acid as described above. The *n*-pentyl bromide was converted to the Grignard reagent and carbonated to give *n*-hexanoic acid-2,2-d_2 which was reduced to the hexanol with lithium aluminum hydride and then converted to the bromide as described above. *n*-Hexyl-3,3-d_2, *n*-hexyl-4,4-d_2, *n*-hexyl-5,5-d_2, and *n*-hexyl-6,6,6-d_3 bromide were prepared from the labeled 1-bromobutanes[18] by the following general sequence. The formation of the butylmalonic ester was followed by hydrolysis, decarboxylation, reduction with lithium aluminum hydride, and formation of the bromide as described above. Ethyl *n*-hexyl-4,4-d_2 ether has previously been synthesized by a slightly different procedure.[5] *n*-Heptyl bromide-5,5-d_2 was prepared by carbonation of the Grignard reagent of *n*-hexyl-4,4-d_2 bromide, followed by reduction to the alcohol and conversion to the bromide.

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[16] Mass spectra were determined with an Atlas CH-4 mass spectrometer using either the heated inlet system (TO-4 ion source at 200° with a gas cartridge) or the direct inlet system (TO-4 ion source with sample absorption on activated charcoal, ion source temperature approximately 70°). Metastable peaks were observed with the aid of a logarithmic transfer recorder.[17] All low-voltage spectra correspond to nominal electron volt values and were recorded with zero potential on the draw-out plates of the gas cartridge.

[17] R. T. Aplin, H. Budzikiewicz, H. S. Horn, and J. Lederberg, *Anal. Chem.*, 37, 776 (1965).

[18] A. M. Duffield, R. Beugelmans, H. Budzikiewicz, D. A. Lightner, D. H. Williams, and C. Djerassi, *J. Am. Chem. Soc.*, 87, 805 (1965).

Mass Spectrometry in Structural and Stereochemical Problems. CXLV.[1] Factors Governing the Preferential Loss of Small *vs.* Large Radicals in Ketones, Schiff Bases, and Ethers[2]

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Abstract: Study of the low-voltage (10 ev) spectra of a series of aliphatic ketones with regard to the α-cleavage process (I → a + b) reveals that the smallest alkyl radical is preferentially eliminated, contrary to the situation existing at 70 ev. A series of aliphatic Schiff bases at low voltage behave in a similar fashion. Aliphatic ethers lose an alkyl radical by α-cleavage (II → c) in preference to a methyl radical but when a choice between two alkyl radicals (ethyl or larger) exists, it is the smallest group which is preferentially eliminated at 9–12 ev. In all the classes of compounds examined loss of an alkyl group from the most highly substituted carbon atom has precedence over the loss of larger alkyl groups both at 70 and 10 ev. Possible rationalizations are presented for these observations.

The mass spectra of ketones have been extensively investigated using both deuterium labeling and high-resolution measurements.[4] One of the earliest recognized fragmentation modes of aliphatic ketones is α cleavage of the molecular ion (I → a + b)[5] and it has always been accepted (based on experience with 70-ev electron-impact spectra)[4] that the larger alkyl group is preferentially lost as a radical provided the same degree

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[1] Part CXLIV: W. Carpenter, A. M. Duffield, and C. Djerassi, *J. Am. Chem. Soc.*, in press.

[2] Financial assistance (Grant No. AM-04257) from the National Institutes of Health of the U. S. Public Health Service is gratefully acknowledged. The purchase of the Atlas CH-4 mass spectrometer was made possible by the National Aeronautics and Space Administration, Grant NsG 81-60.

[3] Recipient of a Senior Postdoctoral Fellowship while on leave from the U. S. Naval Ordnance Test Station, China Lake, Calif.

[4] For a review of the mass spectra of ketones see H. Budzikiewicz, C. Djerassi, and D. H. Williams, "Mass Spectrometry of Organic Compounds," Holden-Day Inc., San Francisco, Calif., 1967, Chapter 3.

[5] R_s represents the smaller and R_L the larger alkyl group throughout this paper and both, unless indicated otherwise, have the same degree of substitution at the α-carbon atom.

Table I. The Loss of Small *vs.* Large Alkyl Groups at 70 and 10 ev by α Cleavage in a Series of Aliphatic Ketones[a]

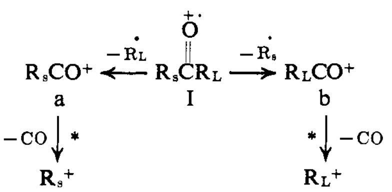
Entry	$R_sC(=O)R_L$: R_s	R_L	Percentage of total ionization (Σ_{29}): M − R_s (b), 70 ev	M − R_s (b), 10 ev	M − R_L (a), 70 ev	M − R_L (a), 10 ev	(M − R_s):(M − R_L) 70 ev	(M − R_s):(M − R_L) 10 ev
1	CH_3	C_2H_5	5	16	62	14	1:12.4	1.1:1
2	CH_3	*n*-C_3H_7	4	8	71	2	1:17.8	4.0:1
3	CH_3	*n*-C_4H_9	2	24	51	9	1:25.5	2.7:1
4	CH_3	*n*-C_5H_{11}	1	4	41	(0.7)	1:41.0	5.7:1
5	CH_3	*n*-C_6H_{13}	(0.4)	7	43	1	1:107.0	7:1
6	CH_3	*n*-C_7H_{15}	(0.3)	5	31	1	1:103.0	5:1
7	C_2H_5	*n*-C_3H_7	14	27	24	3	1:1.7	9:1
8	C_2H_5	*n*-C_4H_9	10	30	20	1	1:2.0	30:1
9	C_2H_5	*n*-C_5H_{11}	6	35	19	1	1:3.2	35:1
10	C_2H_5	*n*-C_6H_{13}	6	43	21	(0.9)	1:3.5	48:1
11	*n*-C_3H_7	*n*-C_4H_9	11	17	15	5	1:1.4	3.4:1
12	*n*-C_3H_7	*n*-C_5H_{11}	8	31	21	4	1:2.6	7.8:1
13	*n*-C_3H_7	*n*-C_6H_{13}	7	44	14	3	1:2.0	14.7:1
14	*n*-C_4H_9	*n*-C_5H_{11}	7	20	10	6	1:1.4	3.3:1
15	*i*-C_3H_7	*sec*-C_4H_9	6	43	7	6	1:1.1	7.1:1
16	*i*-C_3H_7	*sec*-C_5H_{11}	2	17	32	12	1:16	1.4:1
17	*i*-C_3H_7	*n*-C_5H_{11}	12	47	19	7	1:1.6	6.7:1

[a] High-resolution mass spectrometry was utilized to separate oxygen-containing from hydrocarbon peaks.

Table II. The Loss of Small *vs.* Large Alkyl Groups at 70 and 10 ev by α Cleavage in a Series of Schiff Bases

Entry	$R_sC(=NCH_3)R_L$: R_s	R_L	Percentage of total ionization (Σ_{29}): M − R_s, 70 ev	M − R_s, 10 ev	M − R_L, 70 ev	M − R_L, 10 ev	(M − R_s):(M − R_L) 70 ev	(M − R_s):(M − R_L) 10 ev
1	CH_3	*n*-C_6H_{13}	1	1	23	1	1:23.0	1.0:1
2	C_2H_5	*n*-C_4H_9	11	7	16	2	1:1.5	3.5:1
3	C_2H_5	*n*-C_5H_{11}	8	7	17	2	1:2.1	3.5:1
4	*n*-C_3H_7	*n*-C_4H_9	9	3	14	2	1:1.6	1.5:1
5	*n*-C_4H_9	*n*-C_5H_{11}	7	4	9	2	1:1.3	2.0:1
6	*i*-C_3H_7	*n*-C_5H_{11}	15	0.19	12	4	1:0.8	4.8:1

of branching exists on the α-carbon atoms. However, this assumption does not consider the rate of further decomposition of the initially formed α-fission products a and b, for example, loss of carbon monoxide[6] (or other fragments), and hence any differences in the rates of further decomposition of a and b will be reflected in the relative abundances of these ions. By determining the mass spectra of ketones with low-energy (10–12 ev) electrons[7] additional decompositions of a and b will be repressed and one should obtain a definitive answer to the very fundamental question of whether R_s or R_L is preferentially lost as a radical in the initial α-cleavage process.



We find (Table I) on decreasing the energy of the incident electrons to 12 ev or below that in the α-cleavage fragmentation of aliphatic ketones *the smaller alkyl group is preferentially expelled.* This result is in contrast to that found for the elimination of alkyl radicals from ethylene ketals and acetals[8] in which it was observed that the larger alkyl radical was lost in preference to the smaller one. In view of our results with aliphatic ketones we have investigated the low electron voltage spectra, with regard to α cleavage, of Schiff bases,[9] and ethers,[10] both of which have been subjected earlier to deuterium-labeling studies in our laboratory.

Ketones. The relative ease of elimination of large *vs.* small alkyl groups at 70 and 10 ev by α cleavage of a series of aliphatic ketones (I $\rightarrow$ a + b) is shown in Table I and is most conveniently evaluated by examining the last two columns. It is evident that while R_L is lost in preference to R_s at 70 ev the reverse is true at 10 ev. The only exception to this statement is entry 17 in which the smaller group is eliminated more readily at 70 ev and this is due to the fact that expulsion of R_s yields a secondary radical site compared to the alternative loss of R_L generating a primary radical. This agrees with the known facile expulsion of alkyl groups from the more substituted loci.[4,8]

It is pertinent to note that even such minor differences in the alkyl chain as betweeen *n*-butyl and *n*-pentyl (entry 14), although present at 70 ev, become more striking at 10 ev.

Schiff Bases. It is apparent from a comparison of Tables I and II that the preferred loss of alkyl groups according to size for aliphatic Schiff bases follows qualitatively the same pattern as that established for ketones. Thus at 10 ev the smaller alkyl group is

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(6) Metastable peaks were identified in the mass spectra of all the ketones examined corresponding to decarbonylation of ions a and b.

(7) For typical spectra see ref 1.

(8) J. T. B. Marshall and D. H. Williams, *Tetrahedron*, **23**, 321 (1967).

(9) M. Fischer and C. Djerassi, *Chem. Ber.*, **99**, 1541 (1966).

(10) C. Djerassi and C. Fenselau, *J. Am. Chem. Soc.*, **87**, 5747 (1965). For earlier studies see F. W. McLafferty, *Anal. Chem.*, **29**, 1782 (1957).

Table III. The Loss of Small *vs.* Large Alkyl Groups at 70 and 12 ev by α Cleavage in a Series of Aliphatic Ethers

	$R'\!>\!COC\!<\!R''$ / R_s R_L				Percentage of total ionization (Σ_{29})						
					M − R_s		M − R_L		(M − R_s):(M − R_L)	(M − R_s):(M − R_L)	(M − R_s):(M − R_L)
Entry	R′	R_s	R″	R_L	70 ev	12 ev	70 ev	12 ev	70 ev	12 ev	10 ev
1	H	H	H	n-C_5H_{11}	0	0	40	16	. . .	. . .	. . .
2	H	CH_3	H	n-C_3H_7	(0.3)	2	28	46	1:93.3	0.04:1	
3	H	CH_3	H	n-C_4H_9	0	0	24	34	. . .	. . .	
4	H	CH_3	H	n-C_5H_{11}	0	0	24	24	. . .	. . .	
5	H	CH_3	H	n-C_6H_{13}	0	0	22	19	. . .	. . .	
6	CH_3	CH_3	H	n-C_4H_9	6	69	8	0	1:1.3	. . .	
7	CH_3	CH_3	H	n-C_5H_{11}	4	45	7	0	1:1.8	. . .	
8	CH_3	CH_3	CH_3	C_2H_5	(0.4)	2	8	41	1:20	0.05:1	
9	H	C_2H_5	H	n-C_3H_7	3	19	5	15	1:1.7	1.3:1	
10	H	C_2H_5	H	n-C_4H_9	(0.5)	4	5	12	1:10.0	0.3:1	1.6:1.0
11	H	n-C_3H_7	H	n-C_4H_9	(0.8)	3	3	7	1:3.7	0.4:1	0.9:1.0

preferentially expelled while the type of radical lost (secondary as compared to primary, entry 6) intervenes even using 70-ev electrons. As with ketones minor differences in chain length (n-propyl *vs.* n-butyl and n-butyl *vs.* n-pentyl) cause a definite preference for removal of the smaller moiety.

Dialkyl Ethers. It has been well documented that a primary fragmentation at 70 ev of ethers of the general structure II occurs to the greatest degree by loss of the largest alkyl group provided the α-carbon atoms of II contain the same amount of branching.[10] It has also been established by using deuterated analogs that aliphatic ethers[10] undergo further fragmentation utilizing nonspecific hydrogen abstraction from one of the remaining alkyl chains with the formation of d. Using incident electrons of low electron voltage it is possible to prevent additional fragmentation of c and under these operating parameters it should be possible to determine the effect of size of the alkyl groups in decompositions of type II → c.

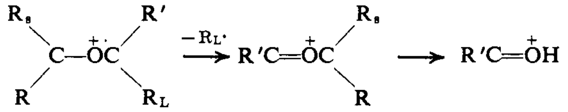
II c d

Table III summarizes the results of competitive α cleavage for a series of eleven aliphatic ethers. It can be seen that loss of a methyl radical (entries 2–5) never approaches at either 70 or 12 ev the facility for expulsion of an n-propyl, n-butyl, n-pentyl, or n-hexyl radical. However, if the loss of a methyl group generates a secondary radical site (entries 6 and 7), then this elimination is greatly enhanced over the removal of an n-pentyl or n-butyl radical.

It is interesting to observe that while at 70 ev the loss of a n-propyl radical exceeds that of an ethyl radical (entry 9) the opposite occurs at 12 ev. In the case of an ethyl *vs.* n-butyl radical loss (entry 10), it is necessary to drop to 10 ev before the preferential expulsion of the ethyl group becomes noticeable. A similar situation prevails (Table III) with n-butyl n-pentyl ether (entry 11) in which one has to go to 9 ev before the loss of a propyl exceeds that of an n-butyl radical (1.3 to 1.0).

Another important fragmentation in the 12-ev spectra of aliphatic ethers is the elimination of an alcohol molecule from the molecular ion. This process has been noted[11] in certain higher symmetrical dialkyl ethers and thoroughly investigated for the elimination of ethanol from ethyl n-hexyl ether with the aid of deuterated analogs.[12] It was shown in this instance that hydrogen abstraction occurs mainly by the intervention of five- and six-membered cyclic intermediates with a lower but significant contribution from a seven-membered cyclic transition state. All the ethers listed in Table III exhibit the preferential loss of the smaller alkyl group as an alcohol molecule leaving charge retention with the larger alkyl group less one hydrogen atom.

General Remarks. It is clear from the above results that contrary to expectation[4] the smaller alkyl group is expelled to a greater degree in the α-cleavage fragmentation processes of the molecular ions of aliphatic ketones, Schiff bases, and ethers (except where R_s = CH_3, c) at low electron voltages.[13] The greater abundance at 70 ev of R_sCO^+ (a) compared to R_LCO^+ (b) in the case of aliphatic ketones and of $R_sCH_2O^+{=}CH_2$ compared to $R_LCO_2^+{=}CH_2$ for ethers can be ascribed either to the greater number of decomposition modes available to b relative to a or faster rates of further fragmentation of b relative to the same process in a.

The transition state for decomposition in mass spectrometric fragmentation processes just prior to decomposition must resemble the products rather than the starting material. In order to explain the decided preference at low voltage for formation of R_LCO^+ (b) in aliphatic ketones rather than R_sCO^+ (a) it is necessary to invoke better stabilization by the larger alkyl chain in the transition state leading to b or alternatively of the acylium ion b. In either event this may be due to better σ-orbital overlap in the charged species, but it is remarkable over what distance this effect can still be noted (see preference for loss of butyl over pentyl in Tables I and II).

There still remains the question of reconciling our results with those obtained from the study of a series of alkyl-substituted ethylene acetals (III) and ketals (IV) in which it was found[8] that at both 70 and 15 ev the larger alkyl group was preferentially eliminated with the formation of e and f, respectively. As one would be concerned with the same carbonium ion (e for acetals

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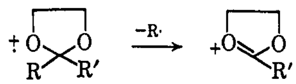
(11) M. Spiteller-Friedmann and G. Spiteller, *Chem. Ber.*, **100**, 79 (1967).

(12) W. Carpenter, A. M. Duffield, and C. Djerassi, *J. Am. Chem. Soc.*, **89**, 6164 (1967).

(13) A similar observation has been made by A. B. King, *J. Chem. Phys.*, **42**, 3526 (1965), in examining the preferential loss of alkyl radicals from phenylalkanes as a function of electron voltage.



III, R = alkyl; R′ = H e, R′ = H
IV, R = alkyl; R′ = CH_3 f, R′ = CH_3

and f in the case of ketals) produced by elimination of a series of alkyl groups in each case it may be that one is witnessing here a comparison of radical stabilities. In contrast our results with ketones, Schiff bases, and ethers differ in that they are comparing the relative stabilities of the carbonium ions formed. When the positive charge is delocalized over only one heteroatom (as in ketones, Schiff bases, and ethers) carbonium ion stabilities may be more important than when the positive charge is distributed over two heteroatoms[8] as in acetals and ketals.

Experimental Section[14]

Ketones. All ketones were either obtained commercially and purified by vpc or prepared from commercially available alcohols by Jones' oxidation.[16]

Schiff Bases. The method of synthesis of these compounds has previously been described.[9] The mass spectra were determined on samples immediately after purification by vpc.

Ethers. All unbranched ethers were prepared according to the procedure described earlier.[12] Isopropyl *n*-pentyl ether and isopropyl *n*-hexyl ether have been described.[10] Isopropyl *sec*-butyl ether was prepared by heating 0.1-mole quantities of 2-propanol, *sec*-butyl alcohol, and 98% sulfuric acid for 30 min, on the steam bath. Subsequent dilution with water and ether extraction provided a mixture of products from which isopropyl *sec*-butyl ether was separated by vpc.

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(14) All low-resolution mass spectra were determined with an Atlas CH-4 mass spectrometer using the TO-4 ion source (temperature 200°) and a gas cartridge. All low-voltage spectra correspond to nominal electron voltage values and were recorded with zero potential on the draw-out plates of the gas cartridge. Metastable peaks were observed with the aid of a logarithmic transfer recorder.[15] Where necessary isobaric ions were separated either by running at "medium resolution" (approximately 4000–5000) or at high resolution (15,000, 10% valley definition) by Mr. R. G. Ross using an A.E.I. MS-9 instrument.

(15) R. T. Aplin, H. Budzikiewicz, H. S. Horn, and J. Lederberg, *Anal. Chem.*, **37**, 776 (1965).

(16) K. Bowden, I. M. Heilbron, E. R. H. Jones, and B. C. L. Weedon, *J. Chem. Soc.*, 39 (1946).

Magnetic Circular Dichroism Studies. III.[1] Investigation of Some Optically Active Chlorins[2]

Bernard Briat,[3] David A. Schooley, Ruth Records, Edward Bunnenberg, and Carl Djerassi

Contribution from the Department of Chemistry, Stanford University, Stanford, California. *Received May 20, 1967*

Abstract: The magnetic circular dichroism (MCD) of optically active molecules has been investigated for a number of chlorophyll-like derivatives (metal-free substituted chlorins). Their absorption, circular dichroism, and magnetic circular dichroism spectra have been recorded through the spectral range 700–240 nm and the results indicate that MCD is by far the most sensitive of the three spectroscopic techniques to detect the influence of various external substituents on the chlorin framework. Some theoretical comments and suggestions for further investigations are also made.

During the past decade optical rotatory dispersion (ORD) and circular dichroism (CD) have been widely applied to many problems in the structure elucidation of optically active materials.[4] This activity in turn has stimulated a recent resurgence of interest in the superficially similar phenomenon of magnetically induced optical activity (the so-called Faraday effect). This effect may be produced in all substances by a magnetic field coincident with the direction of propagation of a beam of linearly polarized light. As with natural optical activity, one observes "anomalous" magnetooptical rotatory dispersion (MORD) as well as magnetic circular dichroism (MCD) when measurements are made through absorption bands. It follows from the above definitions that MORD and MCD can be measured with an ordinary spectropolarimeter, provided that a magnetic field is introduced in the sample compartment. A number of devices have now become commercially available or have been described in the literature.[5–7] Moreover, as the observed phenomena are proportional to the magnitude of the magnetic field, the recent use of superconducting magnets has greatly increased the possibilities in this area of research. Since the data are usually easier extracted from MCD rather than MORD measurements, main emphasis has been given to the former in our laboratory.

Faraday effect measurements have been motivated by the potentiality of this technique as a spectroscopic tool[8] as well as a means of empirically obtaining an-

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(1) Paper II: D. A. Schooley, E. Bunnenberg, and C. Djerassi, *Proc. Natl. Acad. Sci. U. S.*, **56**, 1377 (1966).

(2) We are indebted to the National Science Foundation (Grant No. GP-4304) and to the National Institutes of Health (Grants No. GM-12173 and CA 07195) for financial aid.

(3) Recipient of a NATO postdoctoral fellowship (1966–1967) and a Fulbright travel grant while on leave from the Laboratoire d'Optique Physique, E.S.P.C.I., Paris 5^e, France.

(4) (a) C. Djerassi, "Optical Rotatory Dispersion: Applications to Organic Chemistry," McGraw-Hill Book Co., Inc., New York, N. Y., 1960; (b) P. Crabbé, "Optical Rotatory Dispersion and Circular Dichroism in Organic Chemistry," Holden-Day, Inc., San Francisco, Calif., 1965; (c) L. Velluz, M. Legrand, and M. Grosjean, "Optical Circular Dichroism," Academic Press Inc., New York, N. Y., 1965.

(5) M. Billardon and J. Badoz, *Compt. Rend.*, **263**, 139 (1966).

(6) J. G. Forsythe, R. Kieselbach, and V. E. Shashoua, *Appl. Opt.*, **6**, 699 (1967).

(7) J. G. Foss, *Anal. Chem.*, **35**, 1329 (1963).