NEW COMPOUND SECTION

Mono-, Di-, and Trisubstituted Acyl- and Alkylthiophenes. 2. Mass Spectrometry

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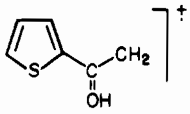
The mass spectra of 59 mono-, di-, and trisubstituted acyl- and/or alkylthiophenes are reported and fragmentation mechanisms are proposed. Deuterium labeling of one of the 2-(2-methyl)acyl-5-*n*-alkyl-4-methylthiophenes showed that the hydrogens of the methyl group on the acyl side chain are involved in at least two ways in the mass spectral fragmentation of this class of compounds.

In a previous paper (*13*), we reported the synthesis, ^{1}H NMR, and uv spectra of a series of mono-, di-, and trisubstituted acyl/alkylthiophenes. In the present paper, we report and discuss the mass spectra of these thiophenes.

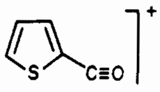
Results and Discussion

The significant fragment ions observed in the mass spectra from each group of compounds are discussed and listed in Tables I–X.

2-n-Acylthiophenes. Five homologous acyl compounds were studied (Table I). The fragmentation that was observed was essentially the same as that reported by Foster and Higgens (*7*) except that in the present study, the rearrangement ion at *m/e* 126, **1**, was found to be the base peak rather than the thienoylium ion at *m/e* 111, **2**.



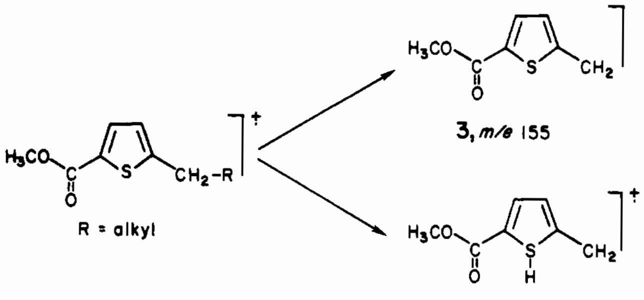
1, *m/e* 126



2, *m/e* 111

2-n-Alkylthiophenes (Table II). The mass spectral fragmentation of monoalkylthiophenes has received considerable attention (*4, 5, 6, 9, 10, 11, 16*). Several useful empirical rules have been drawn that aid in the interpretation of thiophene mass spectra (*3*). No significant differences were observed for five additional longer chained thiophenes when their spectra were compared with those published earlier. One exception was in the *m/e* 84 to *m/e* 85 ratio, which had a value greater than unity for 2-*n*-alkylthiophenes with carbon number 10 or less (*5*).

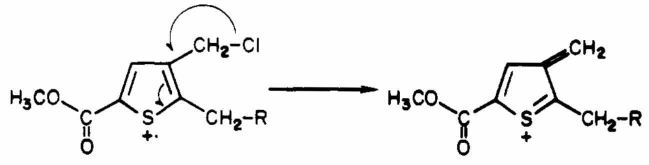
2-(Methoxycarbonyl)-5-n-alkylthiophenes. The significant fragment peaks for four compounds are shown in Table III. The spectra of these compounds were characterized by the presence of a molecular ion (10–85% relative intensity), losses of $CH_3O\cdot$ ($M^{\cdot+} - 31$), CH_3–O–CO· ($M^{\cdot+} - 59$), and two intense peaks at *m/e* 155, **3**, and *m/e* 156, **4**.



3, *m/e* 155

4, *m/e* 156

2-(Methoxycarbonyl)-4-(chloromethyl)-5-n-alkylthiophenes. Table IV lists the most significant ions for a series of five chloromethyl thiophene derivatives. The intensity of the molecular ion in the spectrum of each 2-(methoxycarbonyl)-5-*n*-alkylthiophene was characterized by an increase in relative intensity as the alkyl chain increased in length. Loss of chlorine was observed by the presence of the $M^{\cdot+} - 35$ peak and was probably the result of the homolytic elimination of chlorine radical as observed for benzylic halides (*15*) or halogenated thiophenes (*2*). In the chloromethylthiophene series, the most intense ions



5, R=alkyl

6, ($M^{\cdot+} - 35$)

Table I. Significant Peaks in the Mass Spectra of 2-Acylthiophenes

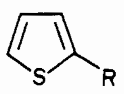
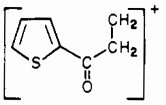
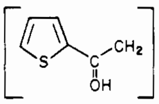
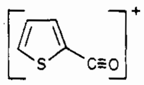
 R	$M^{\cdot+}$, *m/e* (%)	*m/e* 139 (%) 	*m/e* 126 (%) 	*m/e* 111 (%) 
n-$C_8H_{17}CO$	224 (8.0)	17.0	100.0	89.0
n-$C_{12}H_{25}CO$	280 (12.0)	16.5	100.0	43.5
n-$C_{16}H_{33}CO$	336 (15.5)	18.0	100.0	58.0
n-$C_{18}H_{37}CO$	364 (9.0)	16.5	100.0	32.0
n-$C_{19}H_{39}CO$	378 (5.0)	29.0	100.0	87.0

Table II. Significant Peaks in the Mass Spectra of 2-*n*-Alkylthiophenes

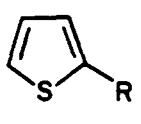
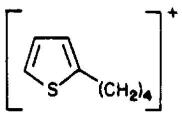
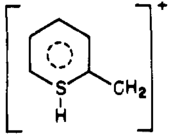
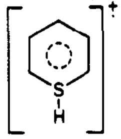
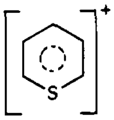
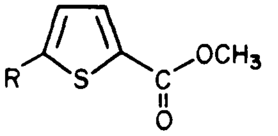
 R	M·+, *m/e* (%)	*m/e* 139 (%) 	*m/e* 111 (%) 	*m/e* 98 (%) 	*m/e* 97 (%) 
$n\text{-}C_9H_{19}-$	210 (8.0)	<1.0	8.0	40.0	100.0
$n\text{-}C_{13}H_{27}-$	266 (27.0)	1.5	21.0	50.0	100.0
$n\text{-}C_{17}H_{35}-$	322 (16.0)	4.0	25.0	41.0	100.0
$n\text{-}C_{19}H_{39}-$	350 (75.0)	3.0	18.0	44.0	100.0
$n\text{-}C_{20}H_{41}-$	364 (36.0)	2.5	17.0	43.0	100.0

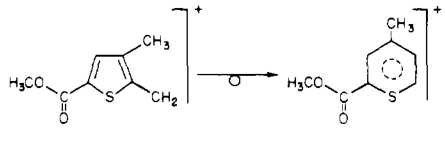
Table III. Significant Peaks in the Mass Spectra of 2-(Methoxycarbonyl)-5-*n*-alkylthiophenes



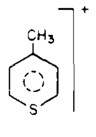
R	M·+, *m/e* (%)	M·+ − CH_3O· (M − 31) (%)	M·+ − CH_3OCO (M − 59) (%)	4, *m/e* 156 (%)	*m/e* 155 (%)	*m/e* 98 (%)	*m/e* 97 (%)
$n\text{-}C_9H_{19}-$	268 (10.0)	237 (<1.0)	209 (1.5)	39.0	100.0	8.0	32.5
$n\text{-}C_{13}H_{27}-$	324 (81.0)	293 (7.5)	265 (8.0)	58.5	100.0	1.5	10.5
$n\text{-}C_{15}H_{31}-$	352 (37.0)	321 (5.7)	293 (6.7)	44.5	100.0	2.2	16.7
$n\text{-}C_{17}H_{35}-$	380 (45.0)	349 (5.0)	321 (9.0)	53.5	100.0	2.0	20.5

in the spectra occurred as a result of a double elimination with a hydrogen transfer (**7** → **9**; *m/e* 169), which was the base peak, and simple cleavage between C_1 and C_2 on the alkyl side chain (**7** → **8**; *m/e* 203). It cannot be ascertained from the data whether ion **8** is of the thiophene type **8a** or the thiopyrylium type **8b**. Other observed processes involved the elimination of the elements of an alkylhalide **7** → **11**.

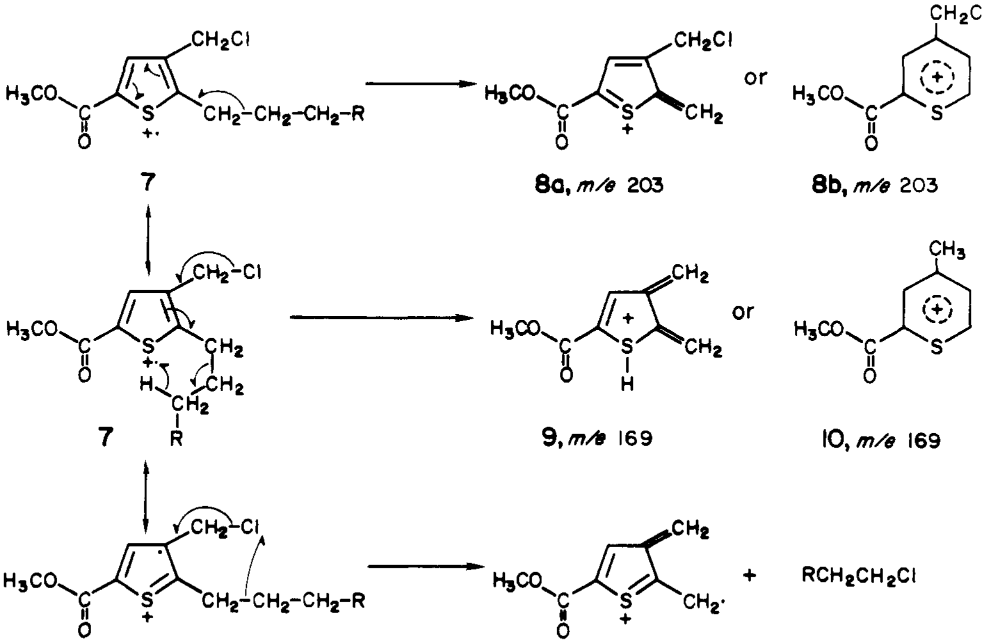
2-(Methoxycarbonyl)-4-methyl-5-n-alkylthiophenes (Table V). This series was characterized by the simple mass spectrum of each compound. The molecular ion, which increased in intensity with chain length, and a peak at M·+ − 31 (loss of the OCH_3) were the only two ions in that portion of the spectrum. The base peak for all four compounds appeared at *m/e* 169, **12** or **13**. Other ions appeared at *m/e* 41, 43, and 111 (a thiopyrylium ion, **14**).



12, *m/e* 169 13≡10(?), *m/e* 169



14, *m/e* 111



7

8a, *m/e* 203

8b, *m/e* 203

7

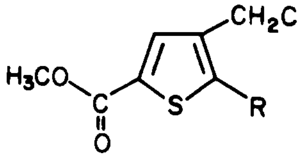
9, *m/e* 169

10, *m/e* 169

7

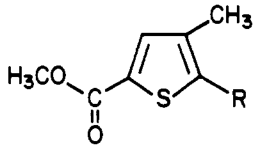
11, *m/e* 168

Table IV. Significant Peaks in the Mass Spectra of 2-(Methoxycarbonyl)-4-(chloromethyl)-5-*n*-alkylthiophenes



R	M·+, *m/e* (%)	M·+ − Cl· (M − 35) (%)	*m/e* 203 (%)	*m/e* 169 (%)	*m/e* 168 (%)	*m/e* 155 (%)
n-C_9H_{19}–	316 (15.0)	281 (41.5)	90.5	100.0	30.5	19.5
n-$C_{13}H_{27}$–	372 (15.0)	337 (27.5)	71.0	100.0	25.5	14.5
n-$C_{15}H_{31}$–	400 (55.0)	365 (42.0)	87.0	100.0	29.0	14.0
n-$C_{17}H_{35}$–	428 (45.6)	393 (32.6)	97.8	100.0	34.8	17.4
n-$C_{19}H_{39}$–	456 (45.3)	421 (27.0)	91.2	100.0	32.4	15.9

Table V. Significant Peaks in the Mass Spectra of 2-(Methoxycarbonyl)-4-methyl-5-*n*-alkylthiophenes



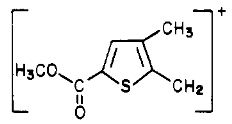
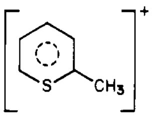
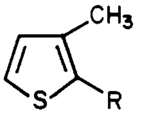
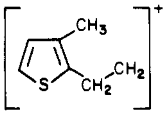
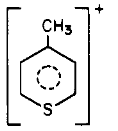
R	M·+, *m/e* (%)	*m/e* 169 (%) 	*m/e* 111 (%) 
n-$C_{13}H_{27}$–	338 (26.5)	100.0	13.0
n-$C_{15}H_{31}$–	366 (35.0)	100.0	5.0
n-$C_{17}H_{35}$–	394 (69.0)	100.0	6.0
n-$C_{19}H_{37}$–	422 (80.0)	100.0	7.0

Table VI. Significant Peaks in the Mass Spectra of 2-*n*-Alkyl-3-methylthiophenes



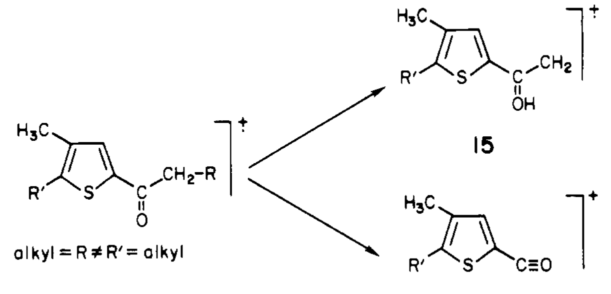
R	M·+, *m/e* (%)	*m/e* 125 (%) 	*m/e* 111 (%) 
n-$C_{13}H_{27}$–	280 (14.0)	5.5	100.0
n-$C_{15}H_{31}$–	308 (6.5)	4.0	100.0
n-$C_{17}H_{35}$–	336 (31.5)	4.0	100.0
n-$C_{19}H_{39}$–	364 (29.0)	3.0	100.0

The increase in the intensities of the molecular ions with carbon numbers of the compounds shown in Tables IV and V is of special interest. These results are exceptions to the generalization discussed by Hamming and Foster (*8*) and thus are of interest from an analytical as well as a mechanistic viewpoint.

2-n-Alkyl-3-methylthiophenes (Table VI). The 2-*n*-alkyl-3-methylthiophenes, unlike 2,3-dimethylthiophene (*10, 11*), which had a base peak at *m/e* 97 (M·+ − CH_3·), fragmented to give the base peak at *m/e* 111 by cleavage of the bond between C_1 and C_2 of the alkyl side chain. This mode of fragmentation was analogous to that which occurred in the 2-methyl-5-alkylthiophenes (*6, 9*) and 2,3-dialkylthiophenes (*11*).

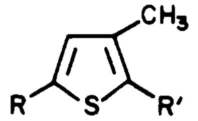
Ions for cleavage between C_2 and C_3 in the alkyl side chain were observed in the spectra (Table IV, *m/e* 125). Peaks in the region below 100 amu were typical of the alkylthiophenes and reflected a series of ions differing by 14 mass units of low relative intensity (<15%) (*12*).

2-n-Acyl-5-n-alkyl-4-methylthiophenes. The 2-*n*-acyl compounds of the trisubstituted series are characterized by having the McLafferty rearrangement ion **15** as the base peak (Table VII). Each compound had a significant molecular ion (8–32% of the base) and a peak as a result of the substituted thienoylium ion, **16** (*7*). The remaining peaks in the spectra were of low intensity and differed from each other by 14 mass units, as in the "new bond rule" series (e.g., 167, 153, 139 . . . 41) described by McLafferty (*12*).



2-(2-Methyl-n-acyl)-5-n-alkyl-4-methylthiophene. In this series (Table VIII), two significant changes occurred in the spectra relative to those of the unbranched series. The first was reflected in the increase in intensity of the thienoylium ion **16** (*m/e* 307), the formation of which was favored by the elimination of a more stable secondary radical from the molecular ion. The second significant change was the appearance of a peak at M·+

Table VII. Significant Peaks in the Mass Spectra of 2-*n*-Acyl-5-*n*-alkyl-4-methylthiophenes



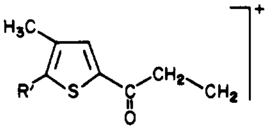
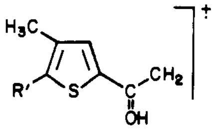
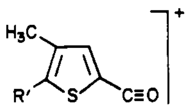
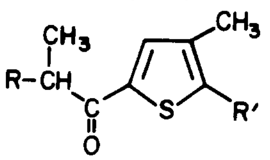
R	R′	Molecular ion (% rel intens)			
n-$C_5H_{11}CO$	n-$C_{13}H_{27}$–	378 (19)	335 (10)	322 (100)	307 (23)
n-$C_7H_{15}CO$	n-$C_{13}H_{27}$–	406 (16)	355 (16)	322 (100)	307 (15)
n-$C_9H_{19}CO$	n-$C_{13}H_{27}$–	434 (9)	335 (14)	322 (100)	307 (19)
n-$C_{11}H_{23}CO$	n-$C_{13}H_{27}$–	462 (21)	335 (14)	322 (100)	307 (17)
n-$C_{13}H_{27}CO$	n-$C_{13}H_{27}$–	490 (47)	335 (13)	322 (100)	307 (21)
n-$C_{15}H_{31}CO$	n-$C_{13}H_{27}$–	518 (50)	335 (20)	322 (100)	307 (17)
n-$C_{19}H_{39}CO$	n-$C_{13}H_{27}$–	574 (39)	335 (12)	322 (100)	307 (16)
n-$C_{15}H_{31}CO$	n-$C_{15}H_{31}$–	546 (13)	363 (6)	350 (100)	335 (7)
n-$C_{17}H_{35}CO$	n-$C_{15}H_{31}$–	574 (8)	363 (6)	350 (100)	335 (6)
n-$C_{13}H_{27}CO$	n-$C_{19}H_{39}$–	574 (24)	419 (4)	403 (100)	388 (3)

Table VIII. Significant Peaks in the Mass Spectra of 2-(2-Methyl)acyl-5-*n*-alkyl-4-methylthiophenes



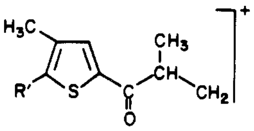
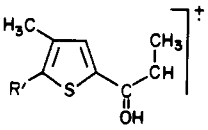
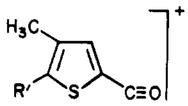
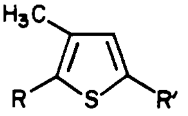
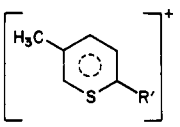
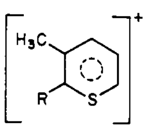
R	R′	Molecular ion (% rel intens)	$[M-42]\cdot^+$	 *m/e* 349 (%)	 *m/e* 336 (%)	 *m/e* 307 (%)
n-C_4H_9–	n-$C_{13}H_{27}$–	392 (12)	350 (6)	6	100	8
n-C_6H_{13}–	n-$C_{13}H_{27}$–	420 (13)	378 (12)	8	100	90
n-C_8H_{13}–	n-$C_{13}H_{27}$–	448 (15)	406 (12)	7	100	67
n-$C_{10}H_{21}$–	n-$C_{13}H_{27}$–	476 (14)	434 (10)	3	100	60
n-$C_{12}H_{25}$–	n-$C_{13}H_{27}$–	504 (12)	462 (11)	9	100	53
n-$C_{14}H_{29}$–	n-$C_{13}H_{27}$–	532 (17)	490 (14)	11	100	56
n-$C_{16}H_{33}$–	n-$C_{13}H_{27}$–	560 (5)	518 (4)	2	100	67
n-$C_{18}H_{37}$–	n-$C_{13}H_{27}$–	588 (6)	546 (5)	4	100	51

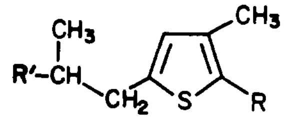
Table IX. Significant Peaks in the Mass Spectra of 2,5-Dialkyl-3-methylthiophenes

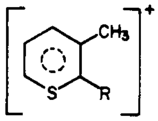
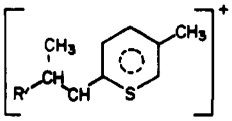
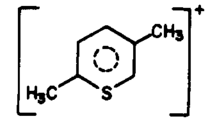


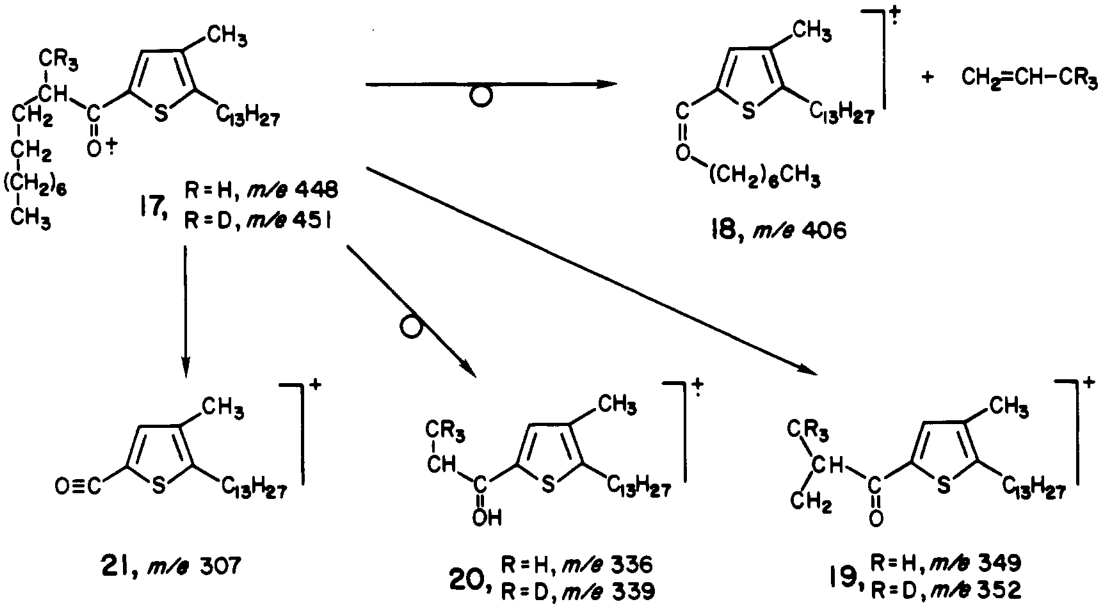
R	R′	Molecular ion (% rel intens)		
n-$C_{13}H_{27}$–	n-$C_{18}H_{37}$–	532 (100)	363 (21)	293 (3)
n-$C_{13}H_{27}$–	n-$C_{20}H_{41}$–	560 (100)	391 (12)	293 (7)
n-$C_{15}H_{31}$	n-$C_{16}H_{33}$–	532 (100)	335 (23)	321 (4)
n-$C_{15}H_{31}$	n-$C_{18}H_{37}$–	560 (100)	363 (8)	321 (3)
n-$C_{17}H_{35}$	n-$C_{16}H_{33}$–	560 (100)	335 (11)	349 (3)

– 42 mass units. The synthesis of the trideuteriomethyl compound, **17** (R = D), established that the fragment eliminated was propene. A mechanism for the formation of **18** is shown below. Both the labeled and unlabeled compounds yielded a thienoylium ion **21** of the same mass (*m/e* 307). Moreover, the product of the McLafferty rearrangement, ion **20**, retained the deuterium label, as expected. In the spectrum of the labeled compound **17** (R = D), the peaks resulting from the "new bond" series (*14*) were displaced upward by two mass units, which suggested that, in this process, one of the three deuterium atoms was transferred

Table X. Significant Peaks in the Mass Spectra of 2-*n*-Alkyl-3-methyl-5-(2-methylalkyl)thiophenes



R	R'	Molecular ion (% rel intens)			
n-$C_{13}H_{27}$–	n-C_4H_9–	378 (42)	293 (76)	209 (44)	125 (100)
n-$C_{13}H_{27}$–	n-C_6H_{13}–	406 (28)	293 (54)	237 (28)	125 (100)
n-$C_{13}H_{27}$–	n-C_8H_{17}–	434 (56)	293 (76)	265 (29)	125 (100)
n-$C_{13}H_{27}$–	n-$C_{10}H_{21}$–	462 (48)	293 (87)	293 (87)	125 (100)
n-$C_{13}H_{27}$–	n-$C_{12}H_{25}$–	490 (55)	293 (88)	321 (25)	125 (100)
n-$C_{13}H_{27}$–	n-$C_{14}H_{29}$–	518 (60)	293 (91)	349 (22)	125 (100)
n-$C_{13}H_{27}$–	n-$C_{16}H_{33}$–	546 (25)	293 (71)	377 (8)	125 (100)
n-$C_{13}H_{27}$–	n-$C_{18}H_{37}$–	574 (2)	293 (58)	405 (3)	125 (100)



17, R = H, *m/e* 448; R = D, *m/e* 451

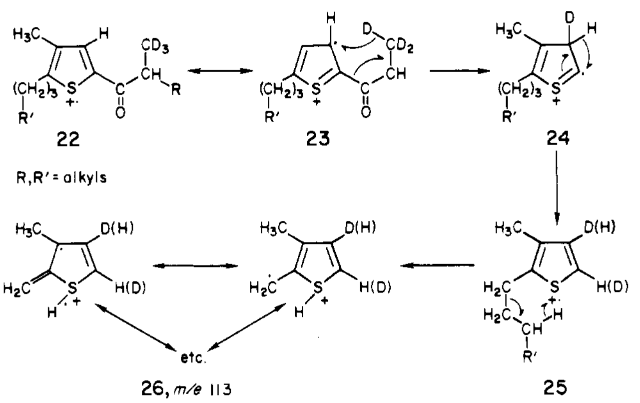
18, *m/e* 406

21, *m/e* 307

20, R = H, *m/e* 336; R = D, *m/e* 339

19, R = H, *m/e* 349; R = D, *m/e* 352

to the neutral fragment to yield fragments such as $[C_6H_5D_2S]^{\cdot+}$ or $[C_5HD_2OS]^{\cdot+}$ at *m/e* 113. Alternatively, one deuterium was transferred to the charged nucleus to yield a fragment $[C_6H_7DS]^{\cdot+}$ (**26**).



22

23

24

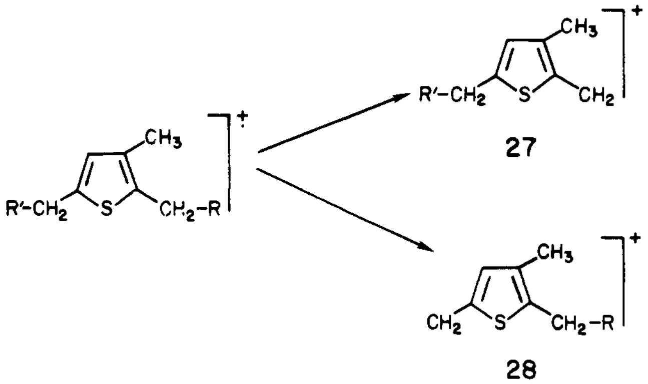
R,R' = alkyls

25

26, *m/e* 113

***2,5-Di-n-alkyl-3-methylthiophenes* (*Table IX*).** The two most striking features of the mass spectra of this series of homologues were (a) the simplicity of the spectra and (b) the molecular ion as the base peak. These two features, when considered jointly, were characteristic of 2,3,5-tri-*n*-alkylthiophenes and are recommended as an aid in the identification of these compounds.

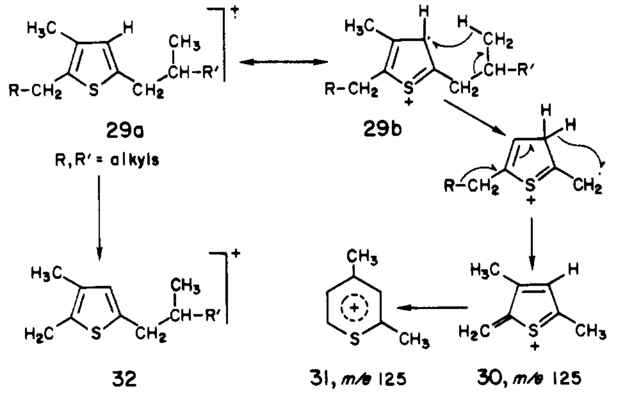
The two ions (**27** and **28**) that were a result of cleavage of either the 2- or the 5-*n*-alkyl groups at the bond between C_2 and C_3 were of low intensity (3–23%). Of these two ions, the one that resulted from cleavage of the bond between C_2 and C_3 of the *n*-alkyl group adjacent to the 3-methyl (e.g., ion **27**) was the more intense, regardless of chain length. Thus, ion **27** and **28** can be of diagnostic value, not only for determining the position of the substituent relative to the 3-methyl group but also for determining the chain length of the substituents.



27

28

2-n-Alkyl-3-methyl-5-(2-methyl-n-alkyl)thiophenes. The base peak in this series of homologues appeared at *m/e* 125 (Table X, **30**, **31**); the molecular composition was supported by high resolution mass spectrometry. This may have been the result of "new bond" formation (*14*) by a mechanism proposed below. The methyl substituent on the side chain exerted a definite influence on the fragmentation of the two alkyl substituents on the thiophene nucleus. Cleavage of the bond between C_1 and C_2 of the side chains yielded ions such as **30** and **32**. The more intense peak of these two ions resulted from C_1–C_2 bond cleavage of the alkyl most distant from the heteroaromatic methyl. The intensities of the resulting fragment ions were in contrast to those observed for the di-*n*-alkyl-substituted 3-methylthiophenes (**27** and **28**) where the intensities were reversed. Although the molecular ion was not the base peak, as in the normal alkyl series (Table IX vs. Table X), the ion current was of significant magnitude to give this peak diagnostic value.



Summary

The mass spectra of 59 mono-, di-, and trisubstituted acyl/alkylthiophenes have been reported and discussed. Certain generalizations have been drawn that are suggested as aids in the analyses of the mass spectra of these acyl- and alkylthiophenes. The 2-*n*-acylthiophenes, 2-*n*-alkylthiophenes, 2-(methoxycarbonyl)-5-*n*-alkylthiophenes, 2-(methoxycarbonyl)-4-(chloromethyl)-5-*n*-alkylthiophenes, 2-(methoxycarbonyl)-4-methyl-5-*n*-alkylthiophenes, 2-*n*-alkyl-3-methylthiophenes, and 2-*n*-acyl-5-*n*-alkyl-4-methylthiophenes gave spectra that were easily interpreted but characteristic of each series.

The 2-(2-methyl-*n*-acyl)-5-*n*-alkyl-4-methylthiophene series of compounds exhibited the following characteristic ions: (a) a significantly intense molecule-ion peak; (b) the McLafferty rearrangement ion as base peak; (c) a very intense peak for the thienoylium ion; (d) *loss of propene from the molecule-ion (M^{+} − 42) originating from the portion including the branched methyl group,* and (e) elimination of the acyl substituent with transfer of a hydrogen radical from the methyl branch to the charged thiophene nucleus.

For the 2,5-di-*n*-alkyl-3-methylthiophenes, *the molecular ion was the base peak* and also carried most of the ion current. Fragmentation of either of the bonds between C_1 and C_2 of the alkyl side chains resulted in two sets of peaks that were of diagnostic value in determining the size of the alkyl group and position of substitution on the thiophene ring; i.e., *the more intense of the two peaks was that which resulted from C_1–C_2 bond cleavage of the alkyl substituent adjacent to the heteroaromatic methyl group.*

The base peak at *m/e* 125 characterized the 2-*n*-alkyl-3-methyl-5-(2-methyl-*n*-alkyl)thiophene series. There were also two sets of peaks that were diagnostic of the position and size of the alkyl substituents. However, in this series, the more intense peak of the two ions was *that one which resulted from C_1–C_2 bond cleavage of the alkyl group furthermost removed from the heteroaromatic methyl substituent.*

The complete mass spectra of the compounds reported in this paper have been submitted for publication in the "Selected Mass Spectral Data of the American Petroleum Institute Research Project 44".

Experimental Section

The alkyl- or acylthiophenes were synthesized as described earlier (*13*) and were purified for mass spectrometry by GLC on a 20 ft × 1/8 in. stainless-steel column packed with 80–100 mesh Gas-Chrom Q coated with 1.88% of the liquid phase OV-101. The column temperature was programmed from 100 to 320° in 32 min with He as the carrier gas. Samples for mass spectral analysis were collected from the gas chromatograph by placing a 10:1 stream splitter at the exit of the column and allowing the eluting compound to condense in a 0.071-in. diameter glass tube.

The mass spectra were obtained with a Varian M-66 or a CH-5 DF mass spectrometer at 70 eV by placing the glass tube that contained the condensed sample in the solids sample probe. A GLC mass spectrometer (CH-5 DF) interface fitted with a two-stage Watson-Biemann separator was used to obtain the spectra for the 2-(2-methylacyl)-5-*n*-alkyl-4-methylthiophenes (Table VIII). Spectra were normalized by standard procedures (*1*).

2-(2-Methyl-d_3)-decanoyl-4-methyl-5-n-tridecylthiophene. The compound was synthesized from 2-*n*-decanoyl-4-methyl-5-*n*-tridecylthiophene and CD_3I (99% isotopic purity) in the presence of dimsyl ion by the procedure described earlier for the analogous unlabeled compound (**13**). The compound was purified for mass spectrometry by GLC.

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