Mass Spectrometry in Structural and Stereochemical Problems.[1] CXXXI. The Mass Spectrometric Fragmentation of Thiuramdisulfides[2]

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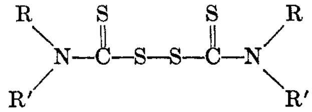
Eleven thiuramdisulfides have been prepared and their mass spectra have been determined and interpreted. Upon electron impact the thiuramdisulfides generally break down in a well-defined manner. By losses of one, two, and/or four sulfur atoms from the molecular ion, new migration reactions are recorded. In certain cases migrations of phenyl or benzyl groups from nitrogen to sulfur are also observed.

Sulfur compounds are of great potential interest in mass spectrometry because they have been shown often to undergo skeletal rearrangements upon electron impact (for a review on skeletal rearrangements, see ref 3). Although the mass spectra of disulfides have been thoroughly studied[4-9] no investigations on thiuramdisulfides have appeared. We have therefore undertaken a study of the behavior of a variety of thiuramdisulfides upon electron impact and the data (see Figures 1-11 and Table I) are discussed in this paper.

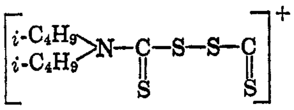


I, $R = R' = CH_3$
II, $R = R' = C_2H_5$
III, $R = R' = n\text{-}C_3H_7$
IV, $R = R' = i\text{-}C_3H_7$
V, $R = R' = n\text{-}C_4H_9$
VI, $R = R' = i\text{-}C_4H_9$
VII, $R, R' = (CH_2)_5$
VIII, $R, R' = (CH_2)_4$
IX, $R, R' = (CH_2)_2O(CH_2)_2$
X, $R = CH_3;\ R' = C_6H_5$
XI, $R = R' = C_6H_5CH_2$

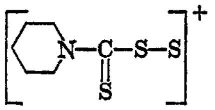
In general the mass spectra of the thiuramdisulfides I-XI contain small peaks at M + (55 to 64 mass units) due to traces of impurities (halogen, sulfur, sodium). These impurities cannot easily be removed since they may be bound to the thiuramdisulfide as a complex. In a few cases we have prepared the thiuramdisulfides by treating the amine with carbon disulfide without any other base than the corresponding amine, followed by oxidation with hydrogen peroxide. Hereby pure thiuramdisulfides are isolated and the mass spectra in these cases show no impurities. As the mass spectra from the different samples are virtually identical small peaks due to impurities are omitted from the reported spectra (Figures 1-11).

Generally speaking, most of the compounds investigated (Table I) give molecular ions which are easily recognized. Only in compound XI ($M^+ = 544$) is a very weak peak observed (Figure 11). The molecular ions are also relatively weak in the thiuramdisulfides with branched alkyl chains (IV and VI, Figures 4 and 6).

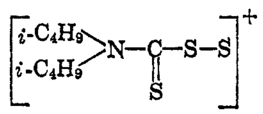
Certain of the thiuramdisulfides fragment with the formation of skeletal rearrangement ions. Thus, expulsions of one, two, and four sulfur atoms from the molecular ion are observed (Table I). It has recently been shown,[8,9] that disulfides, containing sites of unsaturation, lose one or two sulfur atoms under skeletal rearrangement, but that saturated aliphatic disulfides in general do not. Our experimental material is insufficient for wide generalizations but one can conclude that unexpected migrations do occur with thiuramdisulfides. The loss of four sulfur atoms from the molecular ion is the most remarkable feature of the electron-impact-promoted fragmentation of compounds II-IV and VI-X, although it does not mean that this elimination necessarily occurs in one step. High-resolution mass measurements of II, VI, VII, IX, and X have shown, that in these cases four sulfur atoms have been lost. Thus the M − 128 ion in the spectrum of compound VI does not contain any contribution corresponding to the ion a, while that present at M − 128 in VII contains equal amounts of ion b and that corresponding to the loss of four sulfur atoms. An ion of weak abundance at mass 236 in the spectrum (Figure 6) of compound VI was shown by high-resolution mass measurement to correspond to $C_9H_{18}NS_3$ and this can be assigned structure c (*m/e* 236).



a, *m/e* 280

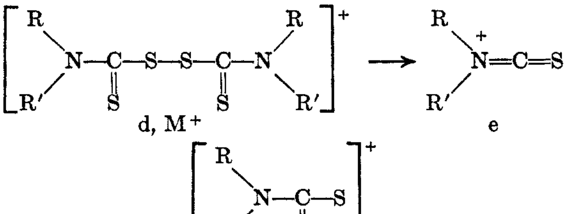


b, *m/e* 192



c, *m/e* 236

The base peak in the majority of the thiuramdisulfide spectra is derived according to the following sequence (d → e).



d, M^+

e

f

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[1] Paper CXXX: P. Brown and C. Djerassi, *J. Am. Chem. Soc.*, **89**, 2711 (1967).

[2] Financial assistance from Statens Almindelige Videnskabsfond to Aahrus University and from the U. S. Public Health Service (Grants No. GM-11309 and AM-04257), to Stanford University is gratefully acknowledged.

[3] P. Brown and C. Djerassi, *Angew. Chem.*, in press.

[4] B. G. Hobrock and R. W. Kiser, *J. Phys. Chem.*, **66**, 1648 (1962).

[5] B. G. Hobrock and R. W. Kiser, *ibid.*, **67**, 648 (1963).

[6] B. G. Gowenlock, J. Kay, and J. R. Majer, *Trans. Faraday Soc.*, **59**, 2463 (1963).

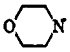
[7] Catalog of Mass Spectral Data, American Petroleum Institute Research Project 44, Carnegie Institute of Technology, Pittsburgh, Pa.

[8] J. Ø. Madsen, C. Nolde, S.-O. Lawesson, G. Schroll, J. H. Bowie, and D. H. Williams, *Tetrahedron Letters*, 4377 (1965).

[9] J. H. Bowie, S.-O. Lawesson, J. Ø. Madsen, C. Nolde, G. Schroll, and D. H. Williams, *J. Chem. Soc. B*, 946 (1966).

TABLE I

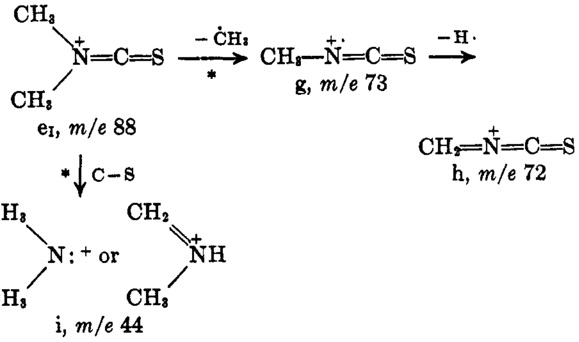
DETAILS OF THE MASS SPECTRA OF THE THIURAMDISULFIDES (I-XI)

Compd	Structure	Relative abundance (%) of ions									
	R N R′	M^+	M − S	M − 2S	M − 4S	$\left[\begin{array}{c}R\\ N{-}C{-}S\\ R'\quad \| \\ S\end{array}\right]^+$	R N=C=S R′	R $\overset{+}{N}$=C=S H	$H_2\overset{+}{N}$=C=S	R $\overset{+}{N}$ R′	$\overset{+}{R}NH$
I	CH_3 N CH_3	14	...	...	...	24	100	...	...	16	...
II	C_2H_5 N C_2H_5	13	...	...	13	40	100	49	37	17	43
III	n-C_3H_7 N n-C_3H_7	19	...	...	7	70	86	56	31	7	34
IV	i-C_3H_7 N i-C_3H_7	2	...	...	1	49	32	50	31	16	58
V	n-C_4H_9 N n-C_4H_9	1	1	...	6	25	60	49	19	5	18
VI	i-C_4H_9 N i-C_4H_9	5	...	...	3	29	32	28	7	2	9
VII		8	2	7	5	34	100	...	3	36	...
VIII		18	2	6	4	23	100	...	3	28	...
IX		15	...	9	8	40	100	...	11	53	...
X	C_6H_5 N CH_3	8	...	...	8	30	100	...	...	21	...
XI	$C_6H_5CH_2$ N $C_6H_5CH_2$	Very weak	1	...	...	5	9	1	...	2	8

In all spectra peaks corresponding to the ion f are found, however, no metastable ions support the transition f → e. When the R and R′ residues are saturated aliphatic groups larger than methyl, decomposition by elimination of R (or R′) occurs. That tropylium ion of mass 91 is responsible for the base peak in XI needs no further comment. The subsequent fragmentations of e and f and other features of the spectra are dealt with below for each compound.

In tetramethyl thiuramdisulfide I (Figure 1) only two simple fragmentations are observed.

SCHEME I



The m/e 88 ion e_I expels a methyl radical to give the ionized methylisothiocyanate g (m/e 73) (Scheme I). A metastable peak at m/e 60.6 ($73^2/88 = 60.6$) supports this transition.[10] The further fragmentation of g by expulsion of a hydrogen atom could lead to the even electron species h (m/e 72) and this ion is found in the spectra of alkyl isothiocyanates.[11,12] The m/e 88 ion also expels carbon monosulfide to give i (m/e 44), a transition which is supported by a metastable peak at m/e 22.0 ($44^2/88 = 22.0$). It is suggested that the energy of the electron bombardment is sufficient to "uncouple" a pair of π electrons of the N=C bond and then the elimination of carbon monosulfide can occur

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(10) Processes supported by an appropriate metastable peak are indicated by an asterisk (*).

(11) A. Kjaer, M. Ohashi, J. M. Wilson, and C. Djerassi, *Acta Chem. Scand.*, **17**, 2143 (1963).

(12) E. Bach, A. Kjaer, R. H. Shapiro, and C. Djerassi, *ibid.*, **19**, 2438 (1965).

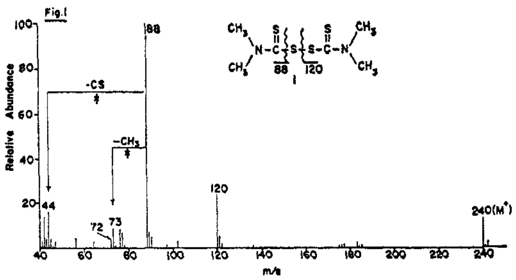


Figure 1.—Mass spectrum of tetramethyl thiuramdisulfide.

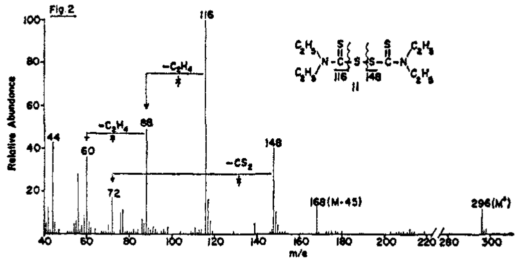


Figure 2.—Mass spectrum of tetraethyl thiuramdisulfide.

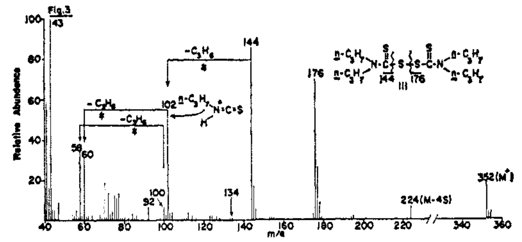


Figure 3.—Mass spectrum of tetra-*n*-propyl thiuramdisulfide.

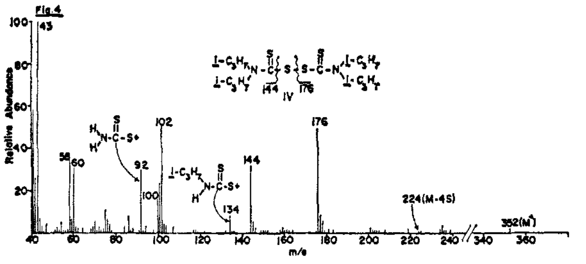


Figure 4.—Mass spectrum of tetraisopropyl thiuramdisulfide.

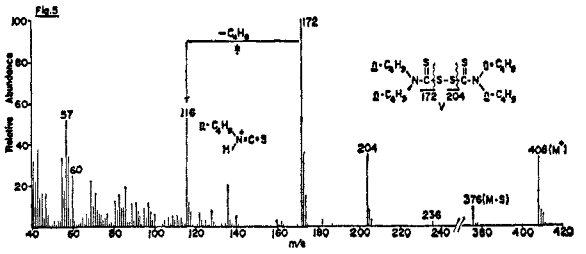


Figure 5.—Mass spectrum of tetra-*n*-butyl thiuramdisulfide.

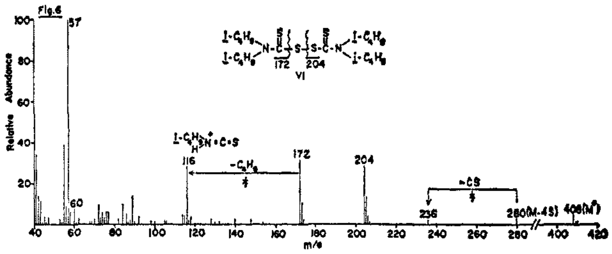


Figure 6.—Mass spectrum of tetraisobutyl thiuramdisulfide.

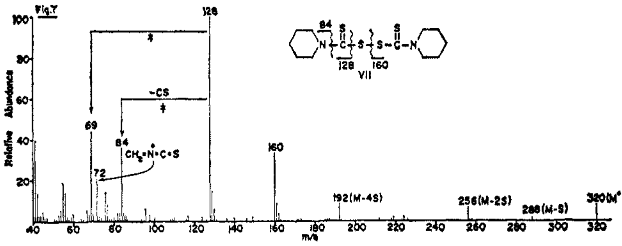


Figure 7.—Mass spectrum of dipiperidino thiuramdisulfide.

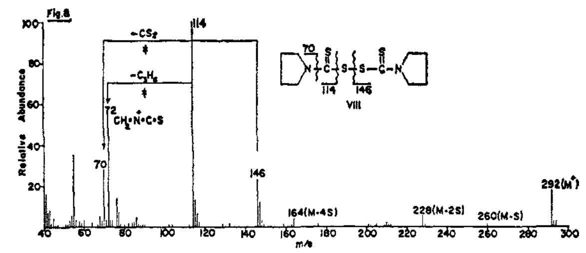
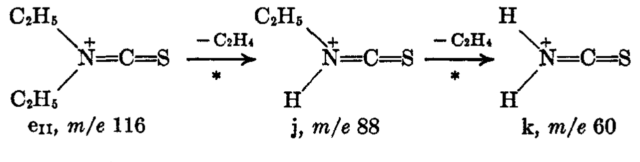


Figure 8.—Mass spectrum of dipyrrolidino thiuramdisulfide.

possibly with concurrent hydrogen rearrangement from a methyl group to the nitrogen atom ($e_I \rightarrow i$).

The internal hydrogen rearrangement in this and subsequent fragmentations is postulated to avoid resulting in an ion with an electron sextet on nitrogen.

In II ethylene is expelled successively from e_{II} (*m/e* 116) to give j (*m/e* 88) and then k (*m/e* 60). The formation of the protonated ion of ethyl isothiocyanate, j, is supported by a metastable peak at *m/e* 66.8 ($88^2/116 = 66.8$) as is the subsequent step from a



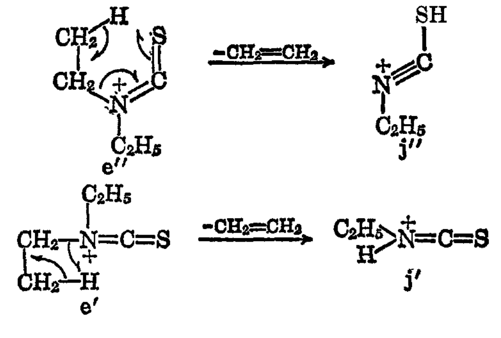
$$(C_2H_5)_2\overset{+}{N}{=}C{=}S \xrightarrow[*]{-C_2H_4} (C_2H_5)(H)\overset{+}{N}{=}C{=}S \xrightarrow[*]{-C_2H_4} H_2\overset{+}{N}{=}C{=}S$$

e_{II}, *m/e* 116 j, *m/e* 88 k, *m/e* 60

metastable peak at *m/e* 40.9 ($60^2/88 = 40.9$). The elimination of ethylene can take place either through a four-membered ($e' \rightarrow j'$) or *via* a six-membered ring intermediate ($e'' \rightarrow j''$), it being recognized that in the latter event "uncoupling" of the π bonds would be required to achieve the requisite geometry (Scheme II).

Another feature of the mass spectrum of II is the expulsion of carbon disulfide from the ion f_{II} (*m/e* 148) with probable hydrogen rearrangement to give l

SCHEME II



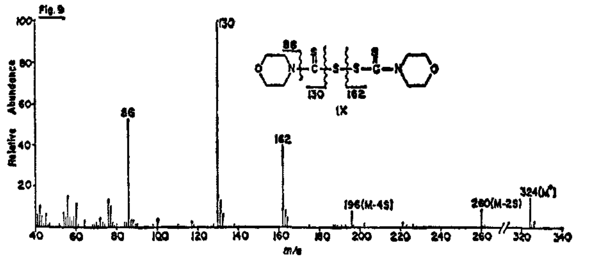
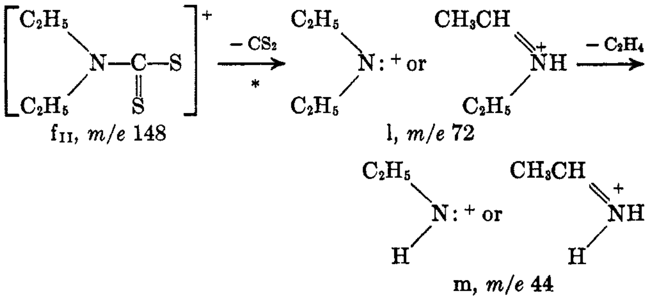


Figure 9.—Mass spectrum of dimorpholino thiuramdisulfide.

(m/e 72) and a metastable peak at m/e 35.1 ($72^2/148 = 35.0$) corresponding to this transition has been recognized. Ethylene can then be expelled from the ion l to give m (m/e 44).

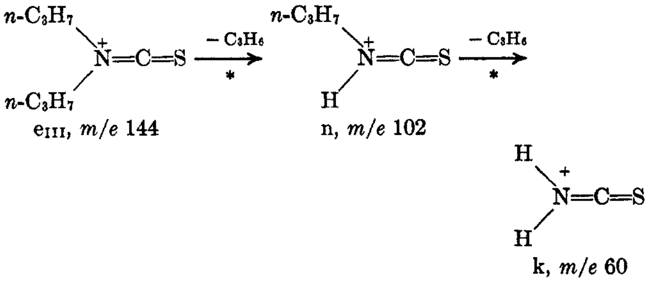


f$_{II}$, m/e 148

l, m/e 72

m, m/e 44

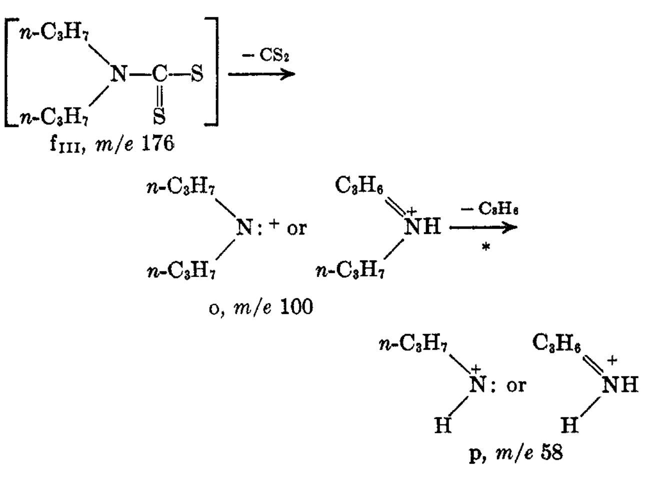
In the spectrum (Figure 3) of tetra-n-propyl thiuramdisulfide (III) the ion of mass 144 (e$_{III}$) is of great abundance and decomposes by two subsequent losses of propylene to give n and then k as is evidenced by the presence of metastable peaks at m/e 72.3 and 35.3, respectively ($102^2/148 = 72.3$, $60^2/102 = 35.3$). The expulsion of carbon disulfide from f$_{III}$ produces the low-intensity ion o (m/e 100) which then expels propylene to give p (m/e 58). This last process is verified by the presence of a metastable peak at m/e 33.7 ($58^2/100 = 33.7$).



e$_{III}$, m/e 144

n, m/e 102

k, m/e 60



f$_{III}$, m/e 176

o, m/e 100

p, m/e 58

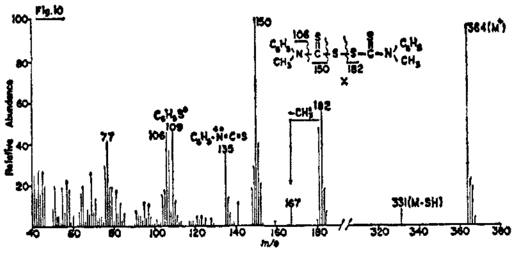


Figure 10.—Mass spectrum of diphenyl dimethyl thiuramdisulfide.

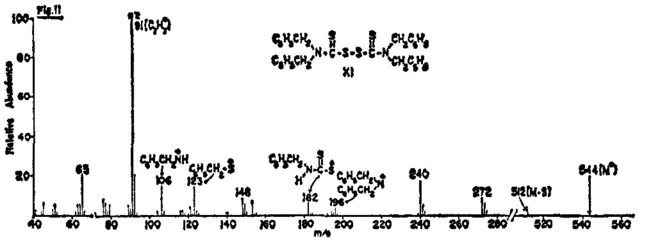
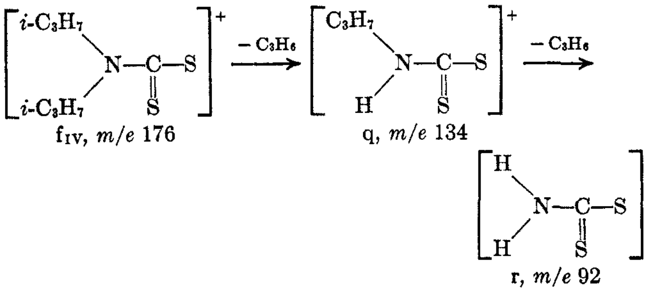


Figure 11.—Mass spectrum of tetrabenzyl thiuramdisulfide.

In the mass spectrum (Figure 4) of tetraisopropyl thiuramdisulfide (IV), the base peak occurs at m/e 43 ($C_3H_7^+$), and a similar result is found in the spectrum (Figure 3) of the n-propyl homolog III. Generally speaking, the observed fragmentations in IV are the same as in III with the exception of a decomposition sequence in IV which is more pronounced than in III. The ion of mass 176 (f$_{IV}$) expels propylene to give q (m/e 134), which in turn ejects a second molecule of propylene producing r (m/e 92).



f$_{IV}$, m/e 176

q, m/e 134

r, m/e 92

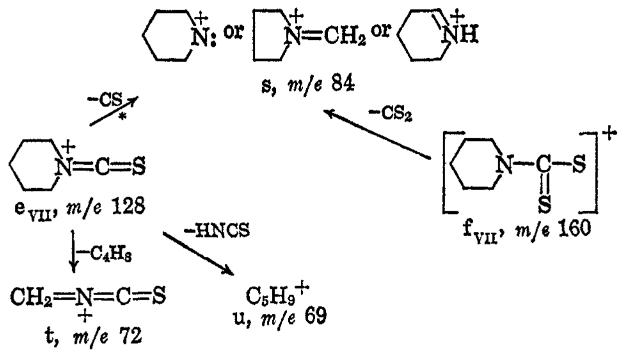
As in other eliminations of olefins in this series either a four-membered transition state with hydrogen transfer to nitrogen or a six-membered intermediate by hydrogen shift to sulfur can be envisaged.

The n- and isotetrabutyl thiuramdisulfides V and VI (Figures 5 and 6) fragment according to the general schemes outlined for compounds II-IV. In both spectra metastable peaks at m/e 78.2 define the transition 172 → 116 ($116^2/172 = 78.2$) which is thus analogous to the process e$_{III}$ → n → k discussed above.

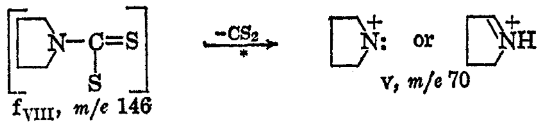
The fragmentation of VII can be evaluated from Figure 7 and the more notable features are indicated in Scheme III.

As in compound I, e$_{VII}$ (m/e 128) loses carbon monosulfide to give s (m/e 84), a transition supported by a metastable peak at m/e 55.2 ($84^2/128 = 55.1$). The same ion, s, can also come from f$_{VII}$ after expulsion of carbon disulfide. The ion of mass 128 expels C_4H_8 to produce t, m/e 72, an ion always found in the fragmentation of aliphatic isothiocyanates.[11,12] A metastable peak at m/e 37.2 supplies evidence for the transition 128 → 69 ($69^2/128 = 37.2$), but deuterium labeling

SCHEME III



would be required to establish the precise course of this reaction. No metastable peak verified the fragmentation 160 → 84 but the related decomposition in VIII (f_{VIII} → v) does yield a metastable peak at *m/e* 33.6 ($70^2/146 = 33.6$).



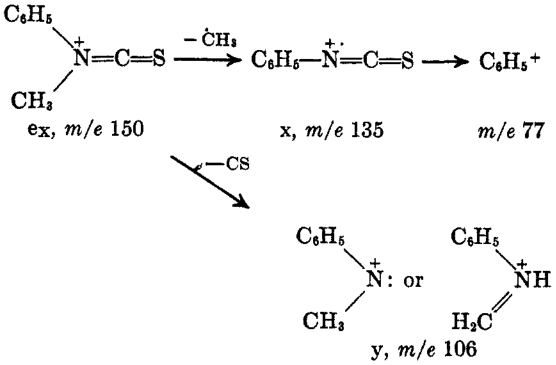
The ion of mass 114 in the spectrum (Figure 8) of the pyrrolidine derivative VIII loses a hydrocarbon fragment, C_3H_6 to produce t (*m/e* 72) whose origin is thus analogous to n (*m/e* 102) above. A metastable peak at 45.5 ($72^2/114 = 45.5$) verifies the process 114 → 72.

The principal difference between the spectrum of the morpholino derivative IX and that of the piperidine and pyrrolidine derivatives VII and VIII is that an ion of weak abundance at mass 72, t, is recorded in the spectrum (Figure 9) of IX.

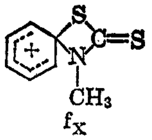
In the spectrum (Figure 10) of the phenyl-substituted derivative X an M − 33 (M − SH) peak is observed; this type of elimination is not observed in other spectra of this series. The ion (e_X) of mass 150 does lose a methyl radical to give ionized phenyl isothiocyanate, x (*m/e* 135), which is known[11] to decompose to $C_6H_5^+$. Expulsion of carbon monosulfide from e_X (*m/e* 150) (possibly with an internal hydrogen rearrangement) leads to y, (*m/e* 106) (Scheme IV).

A most interesting finding is the peak at *m/e* 109 (47% relative abundance) in the spectrum (Figure 10) of compound X which corresponds to C_6H_5S by high-resolution mass measurement. Thus the fragmentation of dimethyl diphenyl thiuramdisulfide formally must give rise to a phenyl migration. A possible rationalization would be charge retention in the aromatic ring and

SCHEME IV



formulation of *m/e* 182 ion as the cyclic structure f_X which could then undergo a facile, four-centered decomposition to z (*m/e* 109) and neutral methyl isothiocyanate.



f_X

z, *m/e* 109

In the spectrum of the dibenzyl derivative XI the stable benzylic ion (shown to be the tropylium ion[13]) dominates but the ions expected on the basis of the foregoing discussion are also found (Figure 11). A peak at *m/e* 123 (15% relative abundance) was shown by high-resolution mass measurements to correspond to C_7H_7S which would require the migration of a benzyl group to sulfur subsequent to electron impact. It appears, therefore, that the presence of aromatic substituents among thiuramdisulfides may give rise to deep-seated skeletal rearrangements upon electron impact.

Experimental Section

All mass spectra were obtained on an A.E.I. MS 9 mass spectrometer at 70 ev. Samples were introduced directly into the source which was maintained at a temperature of 180°. Exact measurements were determined at a resolution of between 14,000 and 16,000. All thiuramdisulfides are known and were prepared according to a general method.[14]

Registry No.—I, 137-26-8; II, 97-77-8; III, 2556-42-5; IV, 4136-91-8; V, 1634-02-2; VI, 3064-73-1; VII, 94-37-1; VIII, 496-08-2; IX, 729-46-4; X, 10591-84-1; XI, 10591-85-2.

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[13] P. N. Rylander, S. Meyerson, and H. M. Grubb, *J. Am. Chem. Soc.*, **79**, 842 (1957).

[14] J. v. Braun, *Ber.*, **35**, 817 (1902).