STUDIES OF ELECTRON-IMPACT FRAGMENTATIONS OF

PHENYL SUBSTITUTED HETEROCYCLIC COMPOUNDS

A THESIS PRESENTED FOR THE DEGREE OF

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BY

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To Christine

who helped to make

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SUMMARY

The electron impact fragmentation of 3(5),4-diphenyl-
pyrazole has been found to proceed by either ring cleavage processes
occurring without randomization of hydrogen between adjacent phenyl
rings or by complex skeletal-rearrangement mechanisms leading to the
formation of ions at m/e 165 ($C_{13}H_9^+$) which have randomized hydrogen.
Deuterium labelling and mathematical calculation of peak ratios has
allowed formulation of a hydrogen transfer process between the phenyl
and the heterocyclic ring which rationalizes the formation of m/e 165
($C_{13}H_9^+$) in a single step fragmentation.

The electron-impact spectra of a number of methylphenyl-
pyrazoles have been studied. All exhibit similar mass spectra.
Fragmentations have been found to occur by both simple cleavage of
the heterocyclic ring and by more complex skeletal-rearrangement
processes involving phenyl migration or cyclization mechanisms.

The spectra of benzylphenylketone derivatives contain ions
at m/e 165 ($C_{13}H_9^+$) which are produced by skeletal-rearrangement
processes. The rearrangement peak is most pronounced in the spectrum
of the oxime of benzyl phenylketone where it arises mainly from an
$M-H_2O$ species. Loss of H_2O from the molecular ion is found to be
hydrogen specific. Deuterium and ^{13}C labelling studies and metastable
characteristics are consistent with the M-18 species having the
properties of the 2,3-diphenyl-2-H-azirine molecular ion. Formation
of the ion m/e 167 ($C_{13}H_{11}^+$) from an M-HO$^\cdot$ species is found to involve

a phenyl migration process.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any University and to the best of my knowledge and belief, contains no material previously published or written by any other person, except where due reference is made in the text of the thesis. The experimental work described in this thesis was carried out in the Department of Organic Chemistry of the University of Adelaide between January, 1968, and September, 1969.

INTRODUCTION

CHAPTER ONE   <u>INTRODUCTION</u>

Many organic chemists still approach the mass spectra of organic compounds with misgiving because of their apparent complexity, and look only at the molecular ion for confirmation of a structure or composition already suggested by other physical and classical chemical methods. An approach such as this frequently misses much of the structural information to be derived from the fragmentations of the molecular ion.[†] Details of the application of normal electron-impact[††] fragmentation processes and instrumentation, readily available in books[1-6] and reviews,[7-12] have greatly aided structure elucidation of organic molecules. Rapid advances in instrumentation and high resolution techniques, coupled with deuterium and C^{13} carbon labelling studies, computer-aided methods[13-16] and advanced kinetic studies,[17,18] have, in the past decade, brought organic mass spectrometry to its present position of one of the most useful physical methods in organic chemistry.

Many interesting and as yet unpredictable fragment ions are often not recognized or are disregarded through a lack of information

[††] The term 'electron impact' is used to denote the ionization of a molecule by a high energy electron beam. It does not imply any specific mechanism for this process.

[†] The term 'molecular ion' is used to denote the singly charged radical cation produced upon 'electron impact', with structure corresponding to that of the molecule in its ground state.

and understanding of their formation. It is essential that such processes be fully investigated to increase the usefulness of mass spectrometry in the identification of the structures of organic molecules and to increase our understanding of the processes which occur upon electron impact.

The migration of groups other than hydrogen upon electron impact is termed skeletal rearrangement. Skeletal rearrangement processes, for which there are now many well documented examples,[12,23-25] can be broadly classified into two distinct types:

(a) the type ABC → AC + B, where A and C are originally joined only through B.

(b) when more complex reorganization of the molecular ion produces a spectrum in which fragment ions bear little relationship to those expected from a molecular ion structure based upon that of the molecule in its ground state.

The consequence of such rearrangements, especially if they occur to a significant extent, is the observation in the spectrum of ions composed of atoms which were not initially joined in the parent compound.

In general, skeletal rearrangements occur when simple fragmentations are unfavourable (as in the case of the stable aromatic hydrocarbons[19]) and are more prevelant when sites of unsaturation in the vicinity of the cleaved bond (s) allow formation of either radical or carbonium centres to which an insipient radical (or anion) may migrate.

The importance of such centres is emphasised in the mass spectra of organo-sulphur compounds which undergo extensive skeletal rearrangement in their positive-ion spectra.[12] Similar rearrangement peaks are not generally observed in the corresponding negative ion spectra.[20-22]

Skeletal rearrangement processes have been widely recognized and studied during the last decade.[12,23-25] A large proportion of these processes produced upon electron impact are accompanied by the expulsion of a stable neutral molecule such as carbon monoxide,[26-28] carbon dioxide,[29,30] formaldehyde,[31] hydrogen cyanide[28.32-34] or nitrogen,[35-37] all of which have either negative, or small positive heats of formation.[23] The recognition and rationalization of these processes has been aided by the detection of metastable ions in the spectra of compounds undergoing rearrangement.

The majority of mass spectra contain metastable ions as peaks of low intensity at non-integral mass numbers. The metastable peaks recorded in a mass spectrum obtained from a conventional double-focusing instrument result from decomposition of ions into smaller ions and neutral (or radical) fragments in the time interval occurring between the exit of the ions from the electrostatic sector and their entry into the magnetic analysing sector. Ions formed in this way are termed metastable ions (M^*). If a singly charged ion of mass M_1 (the parent ion) fragments to an ion of mass M_2 (the daughter ion) and a neutral (or radical) fragment, the position of the metastable ion in

the spectrum can be calculated from equation 1.[3]

$$M^* = (M_2)^2 / M_1 \tag{1}$$

Usually metastable peaks have a shape resembling a Gaussian distribution curve, but occasionally they are observed to be broader and have a relatively flat top.[38] It has been shown[39,40] that this flat top is due to the release of kinetic energy in the dissociation of the parent ion. The kinetic energy released (T) is related to the width of the metastable peak (d), the accelerating voltage (V), the masses of the parent (M_1) and daughter (M_2) ions according to equation 2.[40]

$$d = \frac{4(M_2)^2}{M_1} \sqrt{\frac{(M_1-M_2)T}{M_2eV}} \tag{2}$$

Metastable transitions involve decompositions which are similar to those proposed for decomposition reactions whereby the mass spectrum of a typical molecule is formed. Thus the presence of a metastable ion for the transition $M_1 \rightarrow M_2$ is regarded as evidence that the species of mass (M_1-M_2) is lost in a single uni-molecular process.[3,5] Frequently this is correct, particularly when the atoms lost correspond to simple stable molecules such as CO and N_2 or to well known radicals like CH_3 or CHO. Examples are known[41-43] however, where a metastable peak is observed for a decomposition occurring by a proven two-step process. In skeletal rearrangement processes the presence of a metastable ion for loss of a fragment therefore does not prove that the fragment lost exists as a structural entity in the

parent ion.

Ions identical in structure and energy distribution will behave identically.[11] Thus the characteristics of the daughter ion (M_2) and the metastable ion (M^*) formed reflect the character of the parent ions (M_1) and can be used to gain information on the structure and energy distribution of the ions M_1. This is especially true in the case of skeletal rearrangement processes which have been shown to occur at rates similar to metastable transitions (10^{-6} to 10^{-8} secs)[44,45] compared with the very rapid process, simple bond rupture, (10^{-12} to 10^{-14} secs).[45] These differences in rate have been detected by a comparison of electron impact and field-ionization mass spectra in which skeletal rearrangement peaks occurring in electron impact spectra are either absent or very small in comparison with others fragmentation peaks.[45]

The shape of a metastable peak, whose width is determined by the kinetic energy released upon fragmentation of M_1, is characteristic[44] and reflects the nature of M_2 formed by the same process, $M_1 \rightarrow M_2$. It follows that if the metastable peaks observed for the same transition $M_1 \rightarrow M_2$ in the spectra of two compounds have different shapes, the nature of the ion, M_1, differs in the two cases.[46-49] The converse is not necessarily true. The observation of metastable peaks for the above transition which are identical in shape does not prove that the ions of mass, M_1, are identical in each compound.[cf,50] This is especially so if the metastable peaks are of the normal Gaussian

distribution.

The abundances of both M^* and a daughter ion (b) of mass M_2, formed from a parent (a) of mass M_1 depend upon the rate constants for their respective fragmentation reactions, and upon the rates of all the competing reactions and the amounts of both parent and daughter ions which are able to fragment.[51] In the spectra of two different compounds undergoing a similar fragmentation the abundance of M^* can be used as a measure of the abundance of the common ion (a) from which the daughter ions (b) are produced.[50] .

For the comparison of metastable abundances, a much superior method is to utilize the decompositions occurring in the first field free region of a double-focusing mass sepctrometer (between the source and electric sector). The "metastable defocusing"[41,42,52] technique allows the accurate detection of metastable ions, gives very sharp signals, and enables the unequivocal determination of the decomposition which produces the metastable ion.

If in two spectra M_1 consists entirely of ions with structure and energy corresponding to (a) and M_2 consists of ions with structure and energy corresponding to (b), then the rate constants for the reactions will be equal and the ratios M_1/M^* and M_2/M^* will correspond in the two spectra for all values of the ionizing potential.

If the ratio M_1/M^* corresponds in the two spectra but the ratio M_2/M^* does not, then it follows that the peak at m/eM_1 corresponds entirely to ions of the type (a), but that the peak at m/eM_2, at least

in one of the compounds, consists of ions arising by some other

pathway.

Similarly, equivalence of $^M2/_{M*}$ but not of $^M1/_{M*}$, indicates

that the peak at $m/\underline{e}M_2$ consists entirely of ions (b) arising from

the common ion (a). Whereas the peak at $m/\underline{e}M_1$ consists in part,

at least in one compound, of ions which differ in structure and/or

energy distribution, or that in both compounds M_1 may correspond

to (a) but in one compound (a) has insufficient energy to fragment.

Observations such as these may sometimes indicate whether

the structures and energy distributions of particular ions produced

by different pathways are the same or different. This method has

been adopted for the study of the fragmentation pathways of closely

related compounds,[53,54] and to attempt to assign possible structures

to ions produced by skeletal rearrangements.[46,48,50] The advent of

ion-cyclotron resonance mass spectrometry and its successful

application to studies of intermediate fragment-ion structure[55,56]

has given new insight and impetus to studies in the field of

rearrangement fragmentations.

While these methods and high resolution measurements allow

the possible formulation of structures for fragmenting and fragment

ions, the rationalization and prediction of their genesis is generally

based upon consideration of the ground-state structure of the molecule.

Thus, the major fragmentation modes can frequently be rationalized by

assuming that fragmentation occurs through that form of the charged

species which has the positive charge (and radical if present) in the most stable position and by expelling a stable neutral (or radical) species.

It should be kept in mind that all fragmentations and rearrangements will only take place after distribution of the excitation energy throughout the molecule. The molecule will decompose only when the nuclei are in the proper configuration and a sufficient amount of vibrational energy has been concentrated among the necessary degrees of freedom.[17]

This hypothesis of the Quasi-Equilibrium Theory[17] is repeated here to stress that mechanistic formulations particularly of rearrangements involving simultaneous bond breaking and bond forming are at present rationalizations of the mass spectrometric events. This in no way diminishes the importance and value of mechanistic formulations in the understanding of the fragmentation modes of molecules upon electron impact.

The use of deuterium (^{2}H) and ^{13}C derivatives of molecules has enabled the recognition of particular atoms in fragment ions because of the shift in certain peaks in the spectra to higher mass numbers compared with those of the spectrum of the unlabelled molecule. While this procedure is extremely useful and important in determining fragment ion composition relative to the parent molecule, the now widely recognized phenomen of hydrogen randomization[57-59] and carbon randomization in aromatic systems[60] emphasises the extreme

·caution which must be used in postulating mass-spectrometric mechanisms without the aid of suitably labelled derivatives.

The pronounced skeletal rearrangement processes recognized in the aromatic hydrocarbons: diphenyl,[61] diphenylmethane (1),[62-65] triphenylmethane (2),[66,67] stilbene (3),[68-70] O-terphenyl,[71] and dihydrophenanthrene (4),[68,72,73] have been the subject of much recent study. All of these aromatic hydrocarbons undergo complex hydrogen randomization in their molecular ions. Compounds (1)-(4) fragment in a complex manner by loss of $CH_3^{\cdot}$ from the molecular ion with apparently complete randomization of carbon atoms in diphenyl-methane,[65] stilbene[68] and O-terphenyl.[71] The process M-$CH_3^{\cdot}$ in (3) and (4) and M-$H^{\cdot}\text{-}H_2$ in (1) produces a fragment ion $m/e\,165\,(C_{13}H_9)$ which has been shown by comparison of metastable ion characteristics[74] to have the same properties as the M-1 ion (a) of fluorene (5).

1

2

3

4

5          $\underline{a}$, m/e 165
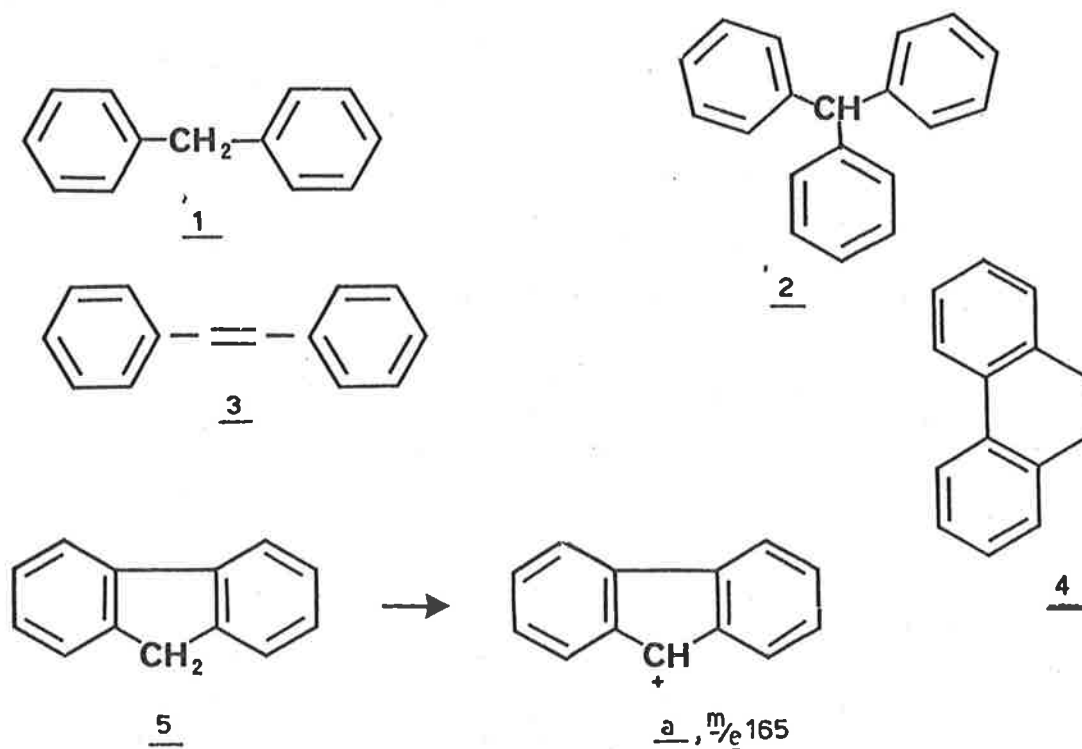
Many heterocyclic systems including oxazoles,[28,73], iso-oxazoles,[73,75-78] imidazoles,[73,79], benzimidazoles,[80] thiophens,[61,81] and benzothiophens,[61,82] also exhibit prominent rearrangement fragmentation pathways. Oxazoles[28,73] fragment by ring opening processes and when two or more substituents are present migration of substituents in the C-5 position to C-4 may occur. Rearrangements occurring in the isoxazole systems have been rationalized[75,76] on the basis of isoxazole conversion to an acylazirine species (b) (Scheme I). In the case of di- and tri-substituted isoxazoles rearrangements to an oxazole (c) in a manner similar to the photochemical isomerization[83] enables most fragmentations to be rationalized.[76,78]

Scheme 1

b   c
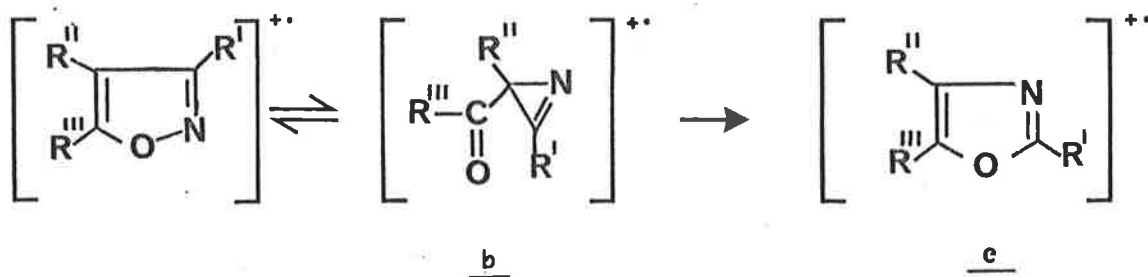
Hydrogen scrambling precedes loss of acetylene from the molecular ion of thiophen[61] and the corresponding process involves carbon and hydrogen randomization in benzothiophen.[61,82] One of the characteristic fragmentations of the thiophen ring is the loss of HCS from the molecular ion.[84] The loss of this fragment from the molecular ion of 2,5 diphenylthiophen[85] has been suggested to be the

result of valence isomerization of the thiophen ring in a manner

similar to the process occurring upon photolysis of phenylthiophens.[86-88]

Studies of diphenyl substituted aromatic heterocyclic

compounds[73,75] indicate that a number of these have in common with

the aromatic hydrocarbons a skeletal rearrangement peak at m/e165.

Exact mass measurements have indicated a composition $C_{13}H_9$ for this

fragment ion.[73]

The ion at m/e165 is pronounced in the electron-impact

spectra of 2,5-diphenyloxazole (6),[89] 4,5-diphenyloxazole (7),[89] 4,5-

diphenylimidazole (8),[73] 3,4-diphenylpyrazole (9),[73] 4,5-diphenylthiazole,[73]

3,4-diphenylisoxazole (10),[73,75] 4,5-diphenylisoxazole,[73,75] 2,5-diphenyl-

1,2,4-oxadiazole,[90] 4,5-diphenylpyrone,[91] and 3,4-diphenyl-4,5-epoxy-

2-cyclopenten-1-one.[91] The same fragment ion is produced in the

spectrum of thiobenzophenone[92] by the loss of H_2S and also in benzyl

phenyl ketoximes[93] by skeletal rearrangement processes. However, in the

case of diphenylsubstituted five-membered heterocyclic systems containing

only one hetero atom, m/e165 is absent or less than 10% of the base

peak.[73] In the spectra of six-membered heterocyclic systems m/e165 is

either absent or very small.

6

7

8

9   10
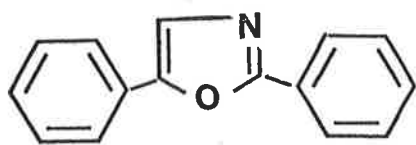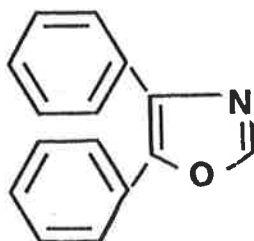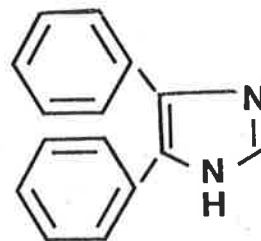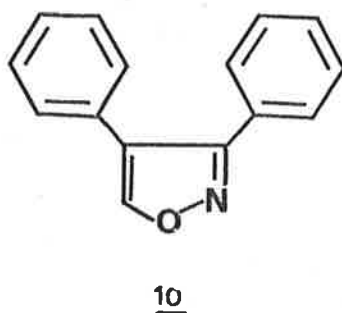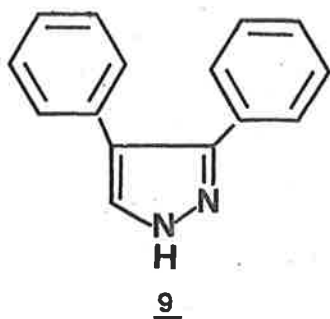
A deuterium labelling study of 4,5-diphenylimidazole[73] (7) found that the $C_{13}H_9^+$ ion was formed by fragmentation after a specific double hydrogen transfer involving phenyl substituent hydrogen and the N-1 hydrogen of the imidazole ring. On the assumption that

_m/e_ 165 ($C_{13}H_9^+$) had a structure corresponding to the fluorene cation (a), a mechanism was proposed to explain this skeletal rearrangement, Scheme II.[73*] (footnote on next page)

Scheme II

b   c   d

2 HCN + H˙

a, m/e 165

f   e
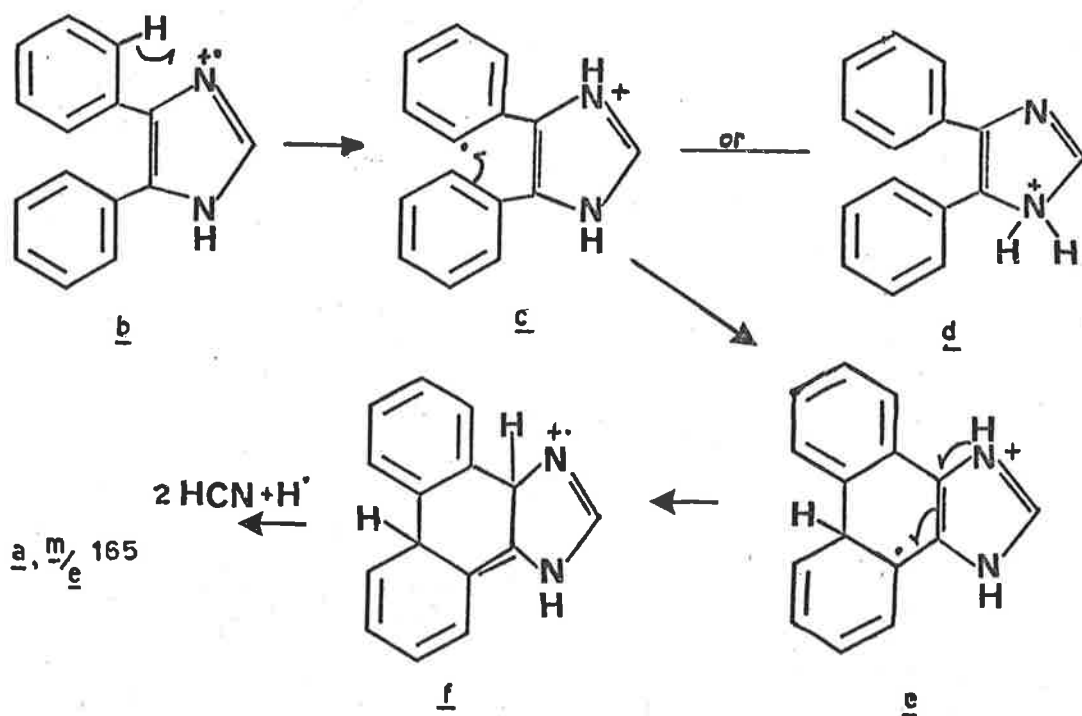
Although a mechanism has been proposed to explain the formation of (a) in the spectrum of (3)[69] it has not been possible to unequivocally establish the mode of formation because complex randomization of hydrogen atoms occurs upon electron impact.[68,73]

With the prominence of the m/e165 skeletal rearrangement peak in the electron impact spectra of such a diversity of compounds and its unexplained absence in others apparently well suited to the rearrangement, (for example, 2,3-diphenylthiophen,[73] 2-chloro-5,6-diphenylpyrazine[73]) it was essential to our understanding of the skeletal rearrangement processes which are possible on electron impact that this rearrangement be more fully investigated and dilineated. The present inquiry into the genesis and structure of the $C_{13}H_9^+$ fragment in diphenylpyrazoles and benzylphenylketone derivatives is directed toward this end.

* (footnote to previous page) The symbols used throughout the discussion are those adopted by Budzikiewicz, Djerassi and Williams[94] based upon the initial proposals of Shannon.[95,96] The presence of a metastable ion for a fragmentation is shown by an asterisk (*) in the text or in the figures.

CHAPTER I

I   THE DIPHENYL PYRAZOLES

Although the spectra of many pyrazoles have been reported,[73,78]
[97-100] a number of features of their fragmentation processes are still
only partly understood.   The pyrazole compounds undergo ready skeletal-
rearrangement upon electron impact in preference to more facile
fragmentations; 3,4,5-tribromopyrazole[98] fragments by loss of HCN:
3-trifluoromethyl-5-phenylpyrazole [97]   loses N_2HF from its molecular
ion: the phenyl pyrazoles undergo extensive rearrangement to hydrocarbon
fragments[73,99] (vide infra).

The major fragmentations of pyrazole compounds occur with
cleavage of the N-N bond and associated elimination of the atoms and
substituents in the 2-3 or 1-5 positions.[98]   It has been suggested that
fragmentation of this sort leads to fragment ions with the cyclic
azirine structure (i)[98,99] (Scheme III).

Scheme III.
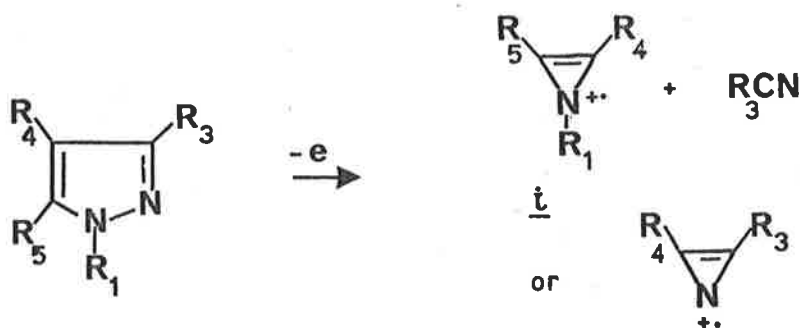
In some ways the fragmentations of the pyrazoles resemble

those of the imidazoles. It has been shown that these compounds
eliminate the 2-3 substituents and atoms in preference to other
possible fragments.[78] Similarly cyclic azirine intermediates are
postulated after initial losses of R-CN fragments. The electron
impact spectra of imidazole (<u>10</u>) (figure 1)[†] and pyrazole (<u>11</u>)
(figure 2) are almost identical. Although rearrangement of their
respective molecular ions to a common intermediate might occur, we
have no evidence to substantiate such a rearrangement. However, the
fragment ion <u>m/e</u> 40 (C_2H_2N) may correspond to the azirine cation (<u>j</u>)
in both spectra (Scheme IV)

Scheme IV
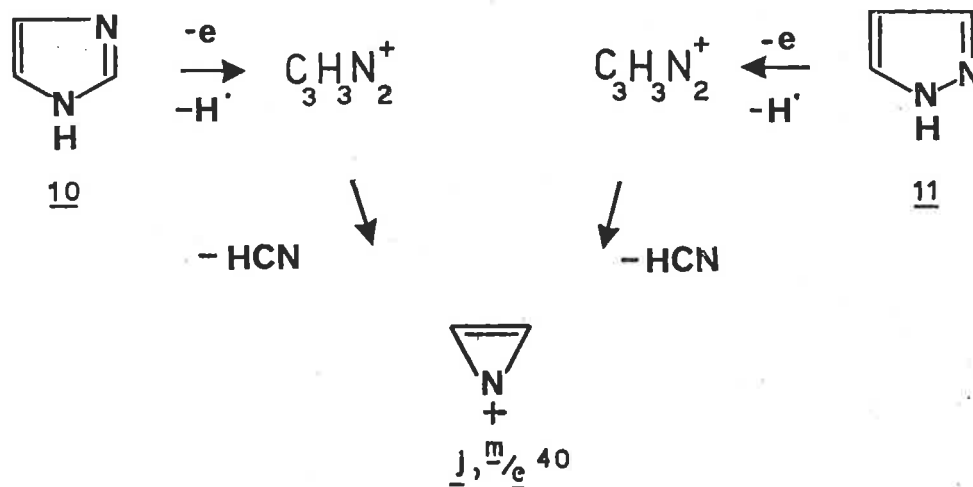
† The spectra of compounds referred to a figure in the text are to be
   found in fold-out form at the end of each section. All other spectra
   and those for which a partial spectrum is given in the figure are
   to be found in table form in Appendix I.

The spectra of a number of diphenyl and triphenyl substituted pyrazoles have been shown to contain ions produced by skeletal-rearrangement processes. One of the major fragments in these spectra is an ion _m/e_ 165 ($C_{13}H_9$) which is also observed in many other diphenyl substituted heterocyclic systems.[73,75] The formation of this ion by two pathways in 3(5),4-diphenylpyrazole (9), (figure 3) is substantiated by the presence of metastable peaks in the spectrum. Sequential loss of H˙ and two molecules of HCN occurs to produce _m/e_ 165 or alternatively the ion is formed by the direct loss of $C_2N_2H_3^{\cdot}$ from the molecular ion.

A mechanism for a similar fragmentation in the electron-impact spectrum of 4,5-diphenylimidazole (8) has been suggested (vide supra).

9a

9b

9c
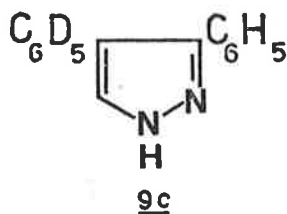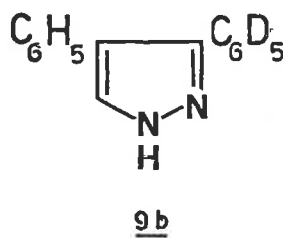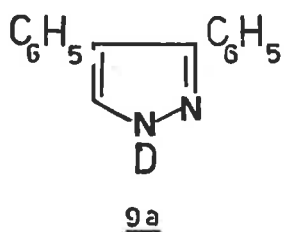
Examination of the spectra of the ^{2}H derivatives of (9) viz. N-d_1-3(5),4-diphenylpyrazole (9a) (figure 4), 3(5)-(d_5-phenyl)-4-phenyl-pyrazole (9b) (figure 5) and 4-(d_5-phenyl)-3(5)-phenylpyrazole (9c) (figure 6).indicates that two different modes of fragmentation of the

molecular ion (k) (Scheme V) are possible. Peaks in the spectrum

above m/e 130 are produced by skeletal-rearrangement processes

involving randomization of the hydrogen and deuterium atoms attached

to the phenyl substituents. Peaks in the lower mass region (below

m/e 130) are mainly produced by fragmentations of the pyrazole ring and

occur without inter-ring hydrogen scrambling.

Specific shifts of the peaks at m/e 77 and m/e 104 (C_7H_6N) in

the spectrum of (9) by five mass units to m/e 82 and m/e 109 respectively

in the spectrum of (9b) and the corresponding shift of the peak m/e 51

to m/e 54 in (9b), indicate that these fragment ions correspond to the

atoms and substituent phenyl in the 2 and 3 positions of the pyrazole

ring.

Similar shifts of m/e 77 and m/e 104 do not occur in the

spectrum of (9c). Instead, peak shifts which do not occur in (9b) are

observed. The peaks m/e 89 (C_7H_5) and m/e 116 (C_8H_6N) in the spectrum

of (9) are displaced by five mass units to m/e 94 and m/e 121 respectively.

Similarly m/e 63 is shifted to m/e 66, indicating that these fragments

are produced from the 1, 4 and 5 atoms and 4-phenyl substituent of the

pyrazole ring.

The unequivocal shift of particular peaks by five mass units

and fragmentation of the hydrocarbon fragments m/e 77 (C_6H_5) and m/e 89

(C_7H_5) by loss of m/e 28 (C_2D_2) when these peaks were shifted to higher

mass numbers indicates the total retention of deuterium on the phenyl

substituent. Thus it appears that these simple bond rupture processes

of the pyrazole ring occur without the incidence of hydrogen

randomization between the C-3 and C-4 phenyl substituents and indicates

that the time interval necessary for ^{1}H and ^{2}H randomization between

adjacent phenyl substituents is, in this case, greater than the rate

of simple bond rupture processes.

It is possible to explain the genesis of all the peaks

described, by normal cleavage of the pyrazole ring through the 1-2

and 3-4 bonds (Scheme V). Charge retention on either fragment would

produce ions which may correspond in structure to the protonated

benzonitrile cation (l) (m/e 104, C_7H_6N) and the phenylazirine cation

(m) (m/e 116, C_8H_6N). Fragmentation of these ions by loss of HCN

to the respective hydrocarbon fragments $C_6H_5^+$ (n) and $C_7H_5^+$ (o) with

subsequent elision of a molecule of C_2H_2 by these ions would produce

m/e 51 (p) and m/e 65 (q) respectively.

Scheme V

9 $\xrightarrow{-e}$

k, m/e 220

$-C_7H_6N^{\cdot}$ (*)

$-C_8H_6N^{\cdot}$ (*)

C_6H_5

m, m/e 116

$C_6H_5 - \overset{+}{C} = NH$

l, m/e 104

$\downarrow$ -HCN(*)

$C_7H_5^+$

o, m/e 89

$\downarrow$ -C$_2$H$_2$(*)

$C_5H_3^+$

q, m/e 63

$\downarrow$ -HCN(*)

$C_6H_5^+$

n, m/e 77

$\downarrow$ -C$_2$H$_2$(*)

$C_4H_3^+$

p, m/e 51
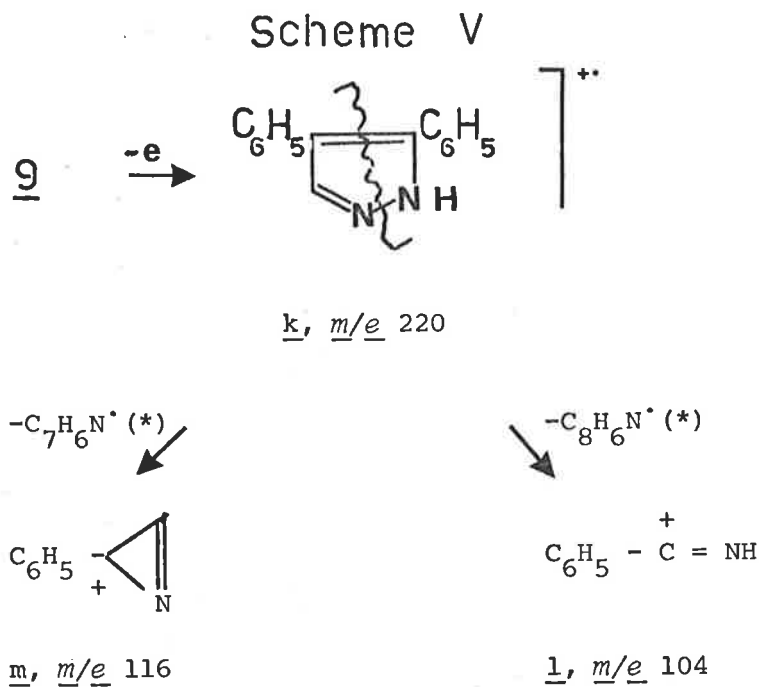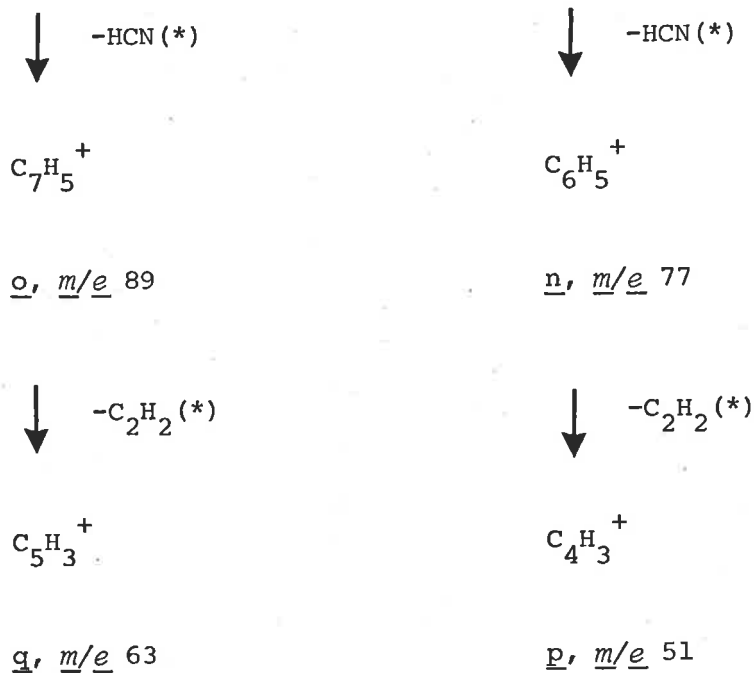
Fragmentations of the pyrazole ring by losses of N_2 or $N_2H^\cdot$ are minor processes producing (in part) the peaks at m/e 192 and m/e 191. Decomposition of the molecular ion of (9) by the scheme M-H$^\cdot$-HCN is also a minor process which does not take place at ionizing energies less than 25 eV. These fragmentation modes take place without randomization of hydrogen and deuterium between the phenyl and pyrazole rings in the deuterated derivatives of (9).

The mass spectrum of 3,5-diphenylpyrazole (12) is almost identical to the 'normal' fragmentation spectrum of 3(5),4-diphenyl-pyrazole (9). Major peaks appear at m/e 104 (C_6H_5CNH) and m/e 116 ($C_6H_5C_2NH$) by cleavage of the 1-2 and 4-5 pyrazole ring bonds. The ions so formed subsequently fragment to the hydrocarbon fragments

shown in Scheme V. By comparison with (9), 3,5-diphenylpyrazole (12)

does not fragment by loss of HCN from the (M-1) ion but an intense

peak at m/e 191 (M-N$_2$H$^{\cdot}$) is the major fragmentation pathway leading

to m/e 165 (C$_{13}$H$_9$) after cleavage of acetylene (C$_2$H$_2$) from m/e 191.

A skeletal-rearrangement peak at m/e 205 (C$_{14}$H$_9$N$_2$ h.r.)

formed by loss of CH$_3$$^{\cdot}$ from the molecular ion of 3(5),4-diphenyl-

pyrazole (9) is unexpected. A similar peak is not observed in

diphenyl derivatives of oxazoles,[28] isoxazoles[73,75,76] or imidazoles.[73,79]

However, diphenylthiophens[85] and thiazoles[12] have been shown to fragment

in this way which closely resembles the loss of CH$_3$$^{\cdot}$ from dihydro-

phenanthrenes[68,72,73] and stilbene.[68-70] The electron-impact spectra

of 3(5)-(d$_5$-phenyl)-4-phenylpyrazole (9b) and 4-(d$_5$-phenyl)-3(5)-

phenylpyrazole (9c) contain peaks at all values from m/e 207 to m/e 210

which indicate significant differences in the loss of deuterated

analogues of CH$_3$$^{\cdot}$ from their molecular ions (Table 1).

Complete randomization of hydrogen and deuterium between

the phenyl substituents requires a ratio of peaks m/e 207-210 of 1:5:5:1

and partial randomization of H/D would result in m/e 208 (M-CHD$_2$) and

m/e 209 (M-CH$_2$D) as the major peaks for both (9b) and (9c). Therefore

a more specific and complex process appears to be involved in the loss

of hydrogen from the phenyl rings. The system has a configuration

similar to a cis-stilbene and the methyl radical is lost from the

phenyl rather than the pyrazole ring, as indicated by the loss of

deuterium in (9b) and (9c) and the absence of a peak corresponding to

TABLE 1

Relative abundances[†] of peaks in the M-CH$_3$˙ region

for the spectra of 3(5)-(d$_5$-phenyl)-4-phenylpyrazole (9b)

and 4-(d$_5$-phenyl)-3(5)-phenylpyrazole (9c).

m/e	Origin	Relative Abundance (x5)	
		9b	9c
210	M-CH$_3$	(15)	(8)
209	M-CH$_2$D	(14)	(9)
208	M-CHD$_2$	(10)	(19)
207	M-CD$_3$	(7)	(13)

† Corrected for natural ^{13}C isotope.

M-CH$_2$D in N-(d$_1$)-3(5),4-diphenylpyrazole (9a). It is unlikely that

the mechanism proposed by Johnstone[69] to explain the loss of CH$_3$$\cdot$

from the stilbene (3) molecular ion via 9-methylfluorene could apply

to the pyrazole because of the hindering influence of the pyrazole

ring.

The ratios given in Table 1 indicate a preference for loss

of the methyl radical from the 4-phenyl:3-phenyl substituents in a

ratio of approximately 2:1. Thus (9c) has abundances 13 and 19% for

M-CD$_3$ and M-CHD$_2$ (from 4-phenyl) whereas (9b) has abundances 7 and

10% for the same fragmentations (from 3-phenyl). This is also

consistent with losses of CH$_3$$\cdot$ and CH$_2$D$\cdot$ from the 3-phenyl and

4-phenyl substituents. These values suggest that a charge localized

on either of the phenyl rings may produce elimination of CH$_3$$\cdot$ or

CD$_3$$\cdot$ from either phenyl substituent of the molecular ion in a manner

similar to the loss of CH$_3$$\cdot$ from the benzene molecular ion.[19] The

additional peaks M-CHD$_2$ and M-CH$_2$D may be produced by analagous

processes involving the removal of one atom of H or D from the

adjacent phenyl ring, rather than all three H or D atoms being lost

from the same phenyl substituent. It is also possible that the

preferential elimination of the methyl radical from the 4-phenyl

group may be preceded or accompanied by partial inter-ring scrambling

of the phenyl hydrogens.

The major skeletal-rearrangment pathway of 3(5),4-diphenyl-

pyrazole (9) produces the ion _m/e_ 165 (C$_{13}$H$_9$ h.r.). A number of

similarities exist between this fragmentation mode of (9) and

the fragmentation of 4,5-diphenylimidazole (8). Both fragment to

m/e 165 by two pathways, viz. successive losses of H·, HCN and HCN

which are negligible below 25 eV; and a concerted loss of a fragment

(or fragments) $C_2H_3N_2$ from the molecular ion which is the predominant

process at a nominal 15 eV. The spectra of the deuterium-labelled

derivatives of (8) and (9) indicate that the concerted fragmentation

leads to the incorporation of a deuterium atom, originally bound to

nitrogen of the heterocyclic ring into m/e 165. The spectra of

both molecules show the loss of either H_3, H_2D or HD_2 in the fragment

$C_2H_3N_2$ of their respective deuterio-phenyl derivatives. These

rearrangements were explained for (8) on the basis of a double

hydrogen transfer initiated by transfer of a hydrogen atom from a

phenyl ring to heterocylic nitrogen (Scheme II).

Abundant peaks at m/e 168 (M-$C_2HD_2N_2$), m/e 169 (M-$C_2H_2DN_2$)

and m/e 170 (M-$C_2H_3N_2$) are observed in the spectra of both (9b) and

(9c) (Table II). To investigate the mechanism by which (9) fragments

to m/e 165 statistical calculations of peak ratios m/e 168-170 for

a number of different mechanisms have been compared with the values

observed in the spectra of (9b) and (9c) at 15 eV ionizing energy

when fragmentation to m/e 165 by alternative pathways is negligible.

TABLE II

Abundances of peaks in the $C_{13}H_9^+$ ion region of the
spectra of deuterated 3(5),4-diphenylpyrazoles. (Values
normalized to 100% and corrected for isotope peaks).

	Ionizing Voltage/Abundance (% Total Process)					
m/e	15 eV		25 eV		70 eV	
	9b	9c	9b	9c	9b	9c
168	(22)	(19)	(21)	(17)	(24)	(21)
169	(49)	(48)	(48)	(48)	(47)	(45)
170	(29)	(33)	(31)	(35)	(29)	(34)

It had been shown[57] that randomization of hydrogen and
deuterium in aromatic systems increases as the energy is decreased.
The presence of peaks corresponding to loss of two, one or no
deuterium atoms in the deutero-pyrazole derivatives immediately
suggests that some degree of randomization of H/D occurs prior to
this skeletal-rearrangement. However, scrambling of all hydrogen and
deuterium atoms from the phenyl and pyrazole rings would lead to a peak
at *m/e* 167 corresponding to loss of a fragment $C_2D_3N_2$. The ratio of
peaks *m/e* 167-170 for completely random loss of H or D is calculated
to be 45:31.8:47.7:16.0 (Appendix II). The obvious discrepancy
between these calculated values and the observed ratios indicates
that randomization does not occur between the heterocyclic and phenyl

rings. This was also found to be the case in deuterated diphenyl-imidazoles.[73]

Fragmentation of 4,5-diphenylimidazole (8) occurs with exchange of hydrogen between the phenyl and heterocyclic rings.[73] All atoms other than a single hydrogen are then lost from the imidazole ring. While it is conceivable in the pyrazole (9) that the fragment $C_2H_3N_2$ consists of a molecule of C_2H_2 from a phenyl ring and N_2 and associated hydrogen from the pyrazole ring, a number of observations preclude such a mechanism. Firstly 40% of the deuterium attached to nitrogen in (9a) (figure 4) is incorporated into $C_{13}H_9^+$ forming an abundant ion $\underline{m/e}$ 166.

This can possibly be explained by a loss of either the hydrogen bound to N-1 or C-5 of the pyrazole ring. However randomization or equivalence of hydrogens was not observed in (8) where the hydrogen and carbon at C-2 were lost entirely in the fragmentation. The absence of a significant $\underline{m/e}$ 167 peak $(M-C_2D_3N_2)$ while $(M-C_2H_3N_2)$ is a major process rules out loss of all hydrogen atoms from the phenyl substituents and would necessitate 100% incorporation of deuterium into $C_{13}H_9^+$ in the spectrum of (9a). Thus we can eliminate this type of mechanism even though it appears to be highly specific and able to explain some observations such as the increased loss of deuterium when the label is in the 4-phenyl ring but not those already outlined. Similarly loss of only one carbon atom from a phenyl ring with hydrogen and fragments CN_2 from the pyrazole ring is most unlikely.

Information about the origin of the carbon atoms in the
fragment would be best obtained from a derivative which contains
one or more specifically sited ^{13}C atoms. Attempts to prepare a
sample of 3-^{13}C-3(5),4-diphenylpyrazole from 1-^{13}C-1,2-diphenyl-
ethanol as a precursor to benzylphenylketone and benzoylphenyl-
acetaldehyde were however unsuccessful. As a result we must infer
the loss of carbon atoms on the basis of hydrogen and deuterium losses
and on the model fragmentation of 4,5-diphenylimidazole (8).

The fragment at _m/e_ 165 ($C_{13}H_9$) has been suggested to have
a structure corresponding to the fluorenyl cation (a). In a
comparison of metastable ion characteristics,[74] Bowie and Bradshaw
have shown that _m/e_ 165 has the same properties as the phenalenyl
cation (r) in the spectra of 3(5),4-diphenylpyrazole (9) and
diphenylisoxazole. On the other hand diphenyloxazoles, stilbene and
dihydrophenanthrene fragment[74] to an _m/e_ 165 ion which corresponds to
the fluorenyl cation. Two different but complex processes involving
dramatic reorganization of carbon are occurring in these derivatives.

a

r
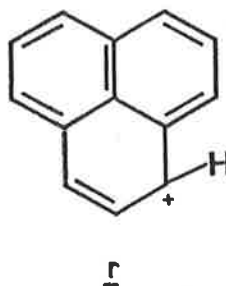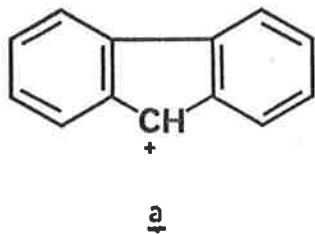
The fragmentation mode which best fits most of the information

derived from the labelled derivatives is one similar to the
fragmentation of the imidazole (8), in which a hydrogen transfer
occurs and all atoms except one hydrogen are lost from the
heterocyclic ring. If no exchange or transfer of hydrogen took
place then only one atom of deuterium could be included in the
fragment $C_2H_3N_2$. Therefore it is likely that an exchange of hydrogen
between phenyl and pyrazole rings is occurring. This process is most
definitely not a simple randomization of phenyl H/D with the N-1 hydrogen.
Calculation for peak ratios m/e 168-170 using the assumption that the
C-5 hydrogen is lost and all other hydrogens are randomized predicts
a ratio of peaks 18.2:54.5:27.3 for both (9b) and (9c). This is clearly
not the case since more deuterium is lost when the d_5-phenyl substituent
is at the 3 position.

A number of mechanisms for exchange of hydrogen between phenyl
substituents and pyrazole nitrogen can be envisaged. Transfer to N-1
of H· from either the 3-phenyl or 4-phenyl ring with or without
randomization of hydrogen between the two rings, followed by back
transfer of one of the two hydrogen atoms resident on N-1 to a phenyl
ring is the least likely. The distance between the nearest H· on the
4-phenyl ring, and heterocyclic nitrogen is sufficient to rule this out.
In addition transfer from either ring would be equivalent to transfer
from only one phenyl ring which had randomized H/D. Calculation of
the probability of transfer from either ring to achieve the peak ratios
indicated in Table I shows that 75% of the H· transferred would come

from 4-phenyl in (9c) (i.e. deuterium) while in (9b) 90% would be transferred from 3-phenyl.

Closer correlation to the observed values is achieved if it is considered that the phenyl H/D is randomized and transfer can only take place from the 3-phenyl ring, in particular the ortho position. The close proximity of this position to the pyrazole N-H bond in a model of the compound supports this proposition. This transfer mechanism implies that there would be two hydrogen atoms from the pyrazole ring and one from a phenyl substituent included in the fragment $C_2H_3N_2$. The investigation of the manner in which these hydrogen atoms are lost during the skeletal-rearrangement assumes that the hydrogen atom fragmenting from the phenyl ring will be lost in a random manner without the intervention of an isotope effect, and that there is no significant isotope effect in the transfer process from phenyl to the pyrazole nitrogen.

Initial transfer of phenyl hydrogen to heterocyclic nitrogen could occur in two ways. Firstly in the manner proposed for fragment-ation of 4,5-diphenylimidazole (8) such that the two atoms now bound to nitrogen become equivalent prior to transfer of one of these hydrogen atoms back to a phenyl ring with subsequent rearrangement and cleavage to *m/e* 165. Alternatively, an exchange of nuclei (cf. 101, 102) between the *o*-phenyl-H and pyrazole N-H is envisaged. When sufficient vibrational energy allows stretching and rocking of the bonds to a conformation in which exchange of the proximate nuclei may take place,

transfer occurs without the transfer of 50% of the originally transferred

hydrogen back to the phenyl substituents. A third alternative is the

transfer of pyrazole N-H to a phenyl ring as an initial step. This

however fails to account for the incorporation of only 40% of N-D into

m/e 165 (figure 4), and will not be considered further.

These models have been examined by comparison of

statistically calculated peak ratios and the observed peak ratios of

(9a), (9b) and (9c). A quantitative estimate of the deviation of a

particular calculation from observed values is made in each case by

calculation of the sum of the squared deviations for each peak in the

m/e 165 region, (Appendix II). This is a modification of the root mean

square deviation method of estimation and while being reliable for the

prupose of these calculations has the added advantage of minimising

computer time. Peak ratios have been calculated in two ways. Firstly,

they have been calculated from the percentage of H or D transferred

to nitrogen from the phenyl rings. In the case of the back transfer

mechanism, calculations indicate that no measurable isotope effect

controls this process of transfer of hydrogen back to a phenyl

substituent prior to or during fragmentation. Secondly, calculation

of the extent of randomization prior to either transfer or exchange of

hydrogen and deuterium between the phenyl and pyrazole rings has been

used to obtain expected peak ratios for values from 0% (a specific

transfer from the 3-phenyl ring) to 100% randomization (each phenyl

ring represented by a formula $(C_6H_{2.5}D_{2.5})$ and intermediate values

calculated for randomization of 3-phenyl ring (Equation 3).

$$\% \text{ Randomization} = \frac{\text{Number of H or D atoms x 100}}{2.5 \text{ (Number of H or D atoms 100\% randomization)}} \% \quad (3)$$

The values shown in Table III indicate that accurate
prediction of peak ratios from these models is not completely successful.
Variation of the parameters involved allows estimation of peak heights
in good agreement with the observed values for any model chosen. The
hydrogen exchange model if considered alone appears most promising but
it falls down in prediction of peak ratios for $N-(d_1)-4,5$-diphenyl-
pyrazole (9a). The ratios calculated are similar to the back-transfer
model. Indeed, if two exchanges are assumed the values are equal
although the predictions of degree of randomization are at considerable
variance. Models predicting randomization of the pyrazole hydrogen in
the C-5 position indicate a large difference in the degree of
randomization and predicted deuterium transfer. By far the most
consistent results are obtained by using the model previously proposed
to explain the skeletal-rearrangement of 4,5-diphenylimidazole.[73] That
is initial transfer of hydrogen to heterocyclic nitrogen with
subsequent back transfer of hydrogen to phenyl prior to or during
fragmentation. The results are not entirely consistent in that
varying degrees of randomization and/or deuterium transfer are predicted.
However, the incidence of site specific transfer prior to randomization
of H/D between phenyl rings can easily account for these differences

TABLE III

Calculated values of peak ratios for ions in the $C_{13}H_9^+$ region of the spectra of deuterated 3(5),4-diphenylpyrazole (9), showing values which give minimum deviations from observed values for corresponding values of deuterium transfer (%D) or percentage randomization of phenyl substituents (%R) for different rearrangement mechanisms.

Mechanism	9a		9b			9c		
	165	166	168	169	170	168	169	170
Observed Values	58	42	21.7	48.8	29.4	19.0	47.6	33.4
Back Transfer	55	45	18.0	54.5	27.5	15.6	53.8	30.6
%D				D=90			D=76	
	55	45	18.0	54.5	27.5	16.0	54.0	30.0
%R				R=20			R=40	
Back Transfer-Randomize C-5H	70	30	18.7	54.7	26.7	14.6	53.7	31.7
%D				D=70			D=55	
	70	30	19.8	54.9	25.3	16.0	54.0	30.0
%R				R=52			R=80	
Single Exchange	10	90	21.6	55.4	23.0	15.2	53.8	31.0
%R				R=92			R=76	
Double Exchange	10	90	18.0	54.5	27.5	16.0	54.0	30.0
%R				R=100			R=0	

involving greater loss of deuterium in (9b) then (9c) in which

deuterium is initially sited on the 4-phenyl substituent.

The fragmentation of 3(5),4-diphenylpyrazole (9) by

skeletal-rearrangement to $\underline{m/e}$ 165 ($C_{13}H_9$) is described in Scheme VI.

No attempt is made to predict the position of the second carbon atom

lost in the fragment (s) $C_2H_3N_2$. However, results[103] obtained from

^{13}C labelling of benzylphenylketoxime (vide infra) suggest that if an

azirine type intermediate is involved then either the C-3 or C-4

carbon atom would be lost equally.

Scheme VI.
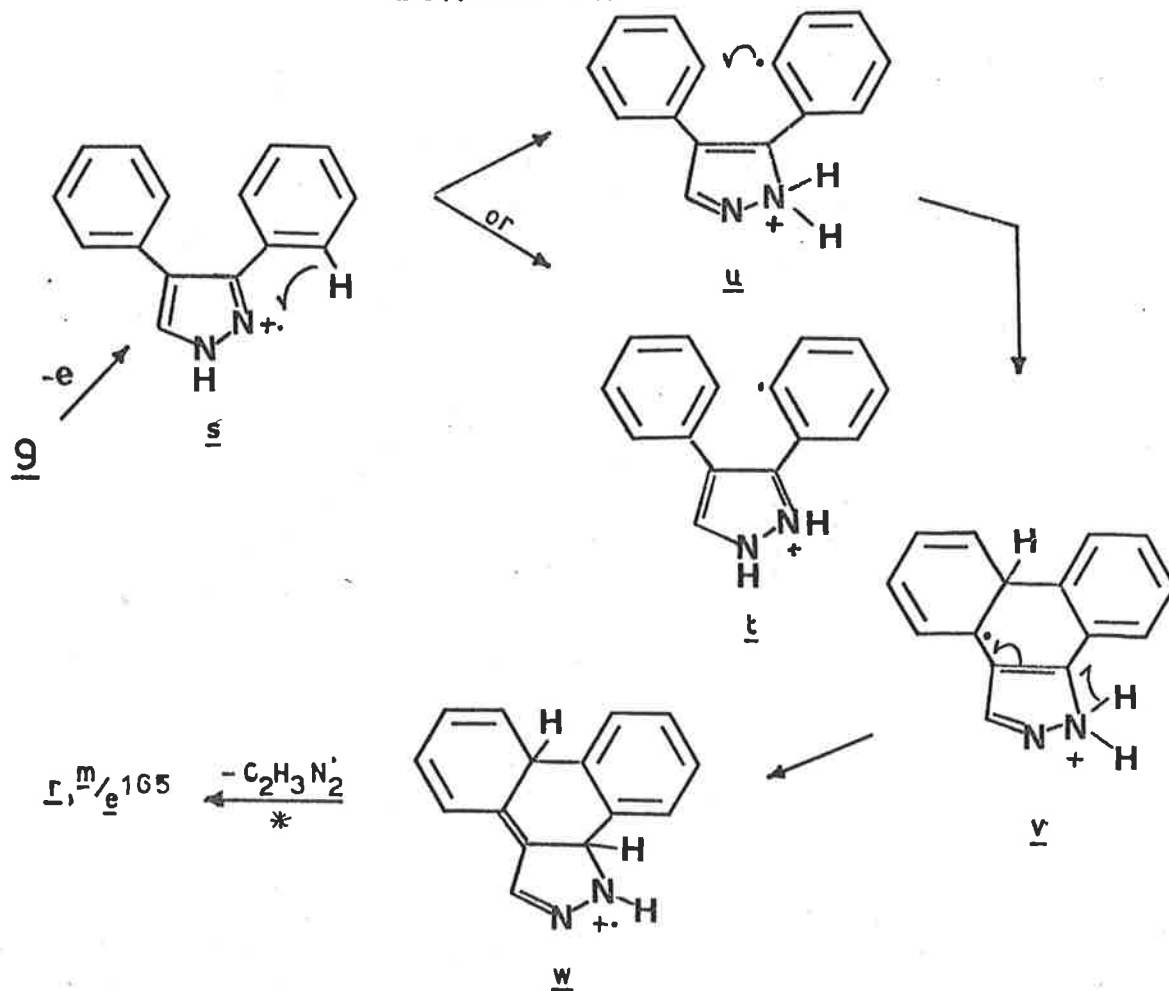
Fragmentation of (9) to m/e 165 by consecutive loss of H˙, HCN and HCN at high ionizing energies (>15 eV) occurs by normal ring fragmentation processes but the second molecule of HCN cleaved from m/e 192 would involve skeletal-rearrangement of the pyrazole ring to an azirine intermediate of the type (i) (Scheme III).

The initial fragmentation of H˙ from the molecular ion involves the hydrogen of the phenyl rings and not as might be expected hydrogen bound to the pyrazole ring. This can be inferred from a comparison of the spectra of (9) and 3,5-diphenylpyrazole in which the process M-H˙ is only 10%. Prediction of H or D loss in the deuterated diphenylpyrazoles on the basis of hydrogen interchange between phenyl and heterocyclic rings are shown in Table IV. The calculated values are in good agreement with those observed for the process. The high values of the M-H ion in (9b) and the increase in M-D for (9c) indicate that the atom lost is lost from the 4-phenyl substituent in preference to the 3-phenyl substituent. While the values which are slightly higher than expected for M-H in both (9b) and (9c) suggest the presence of an isotope effect of the order 1.1.

TABLE IV

Peaks in the molecular ion region of deuterated diphenyl-
pyrazoles and calculated values predicted on the basis of
hydrogen transfer between heterocyclic and phenyl rings.

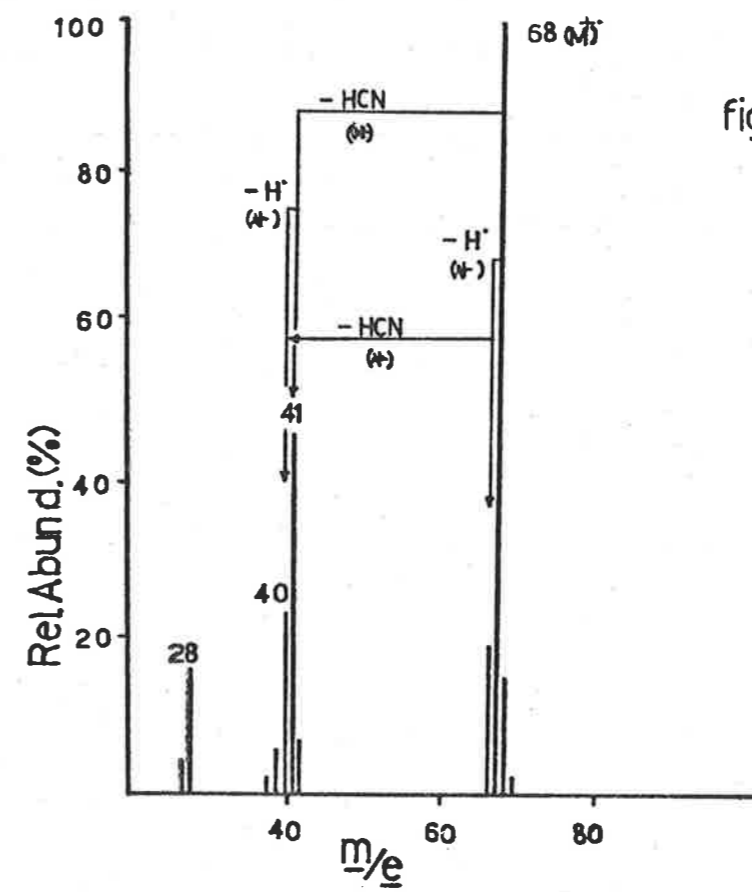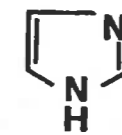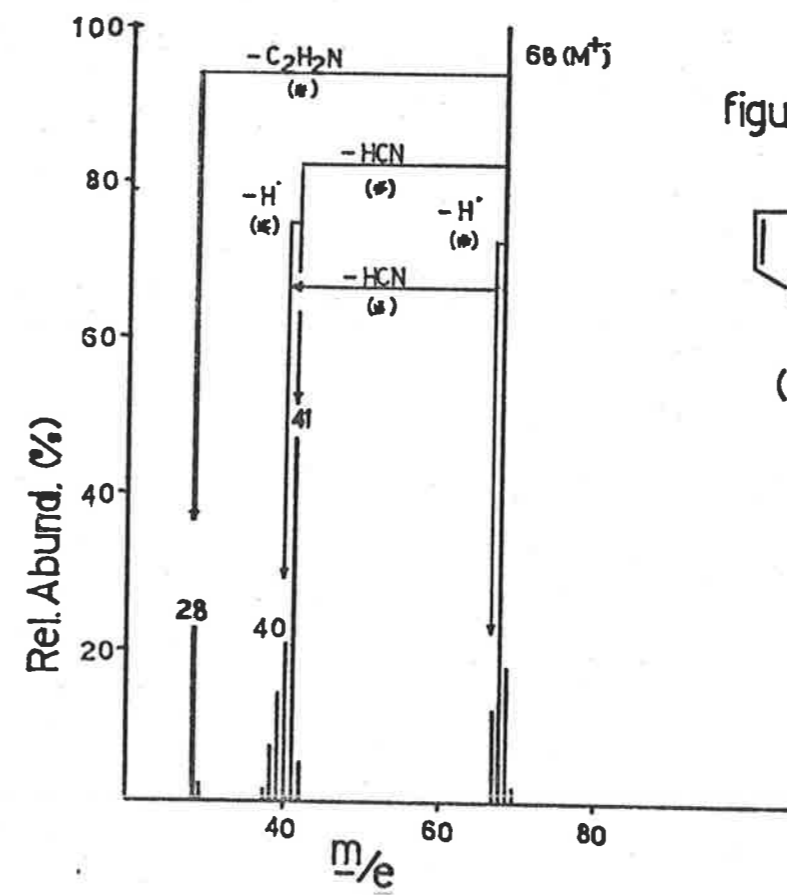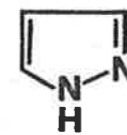| Relative Abundance (% Total)	9a		9b		9c	
	M-H	M-D	M-H	M-D	M-H	M-D
Observed	90 : 10		62 : 38		54 : 46	
Calculated	95 : 5		55 : 45		50 : 50	

figure 1.

(10)

figure 2.

(11)

figure 3.
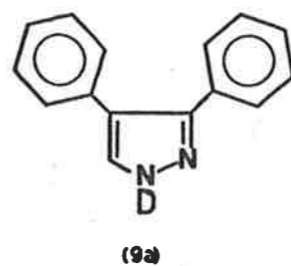
(9)

figure 4.

(9a)
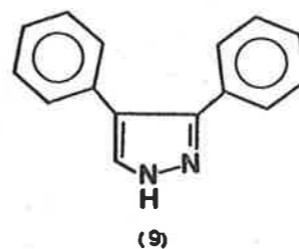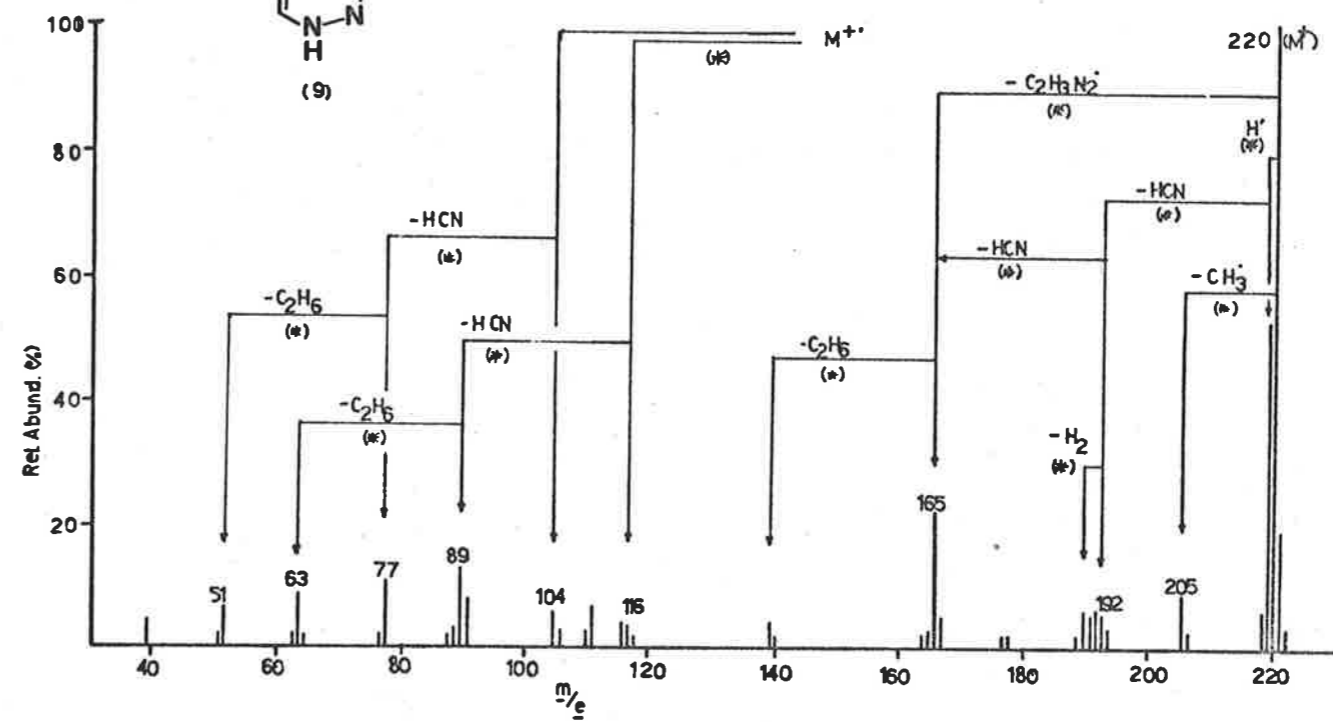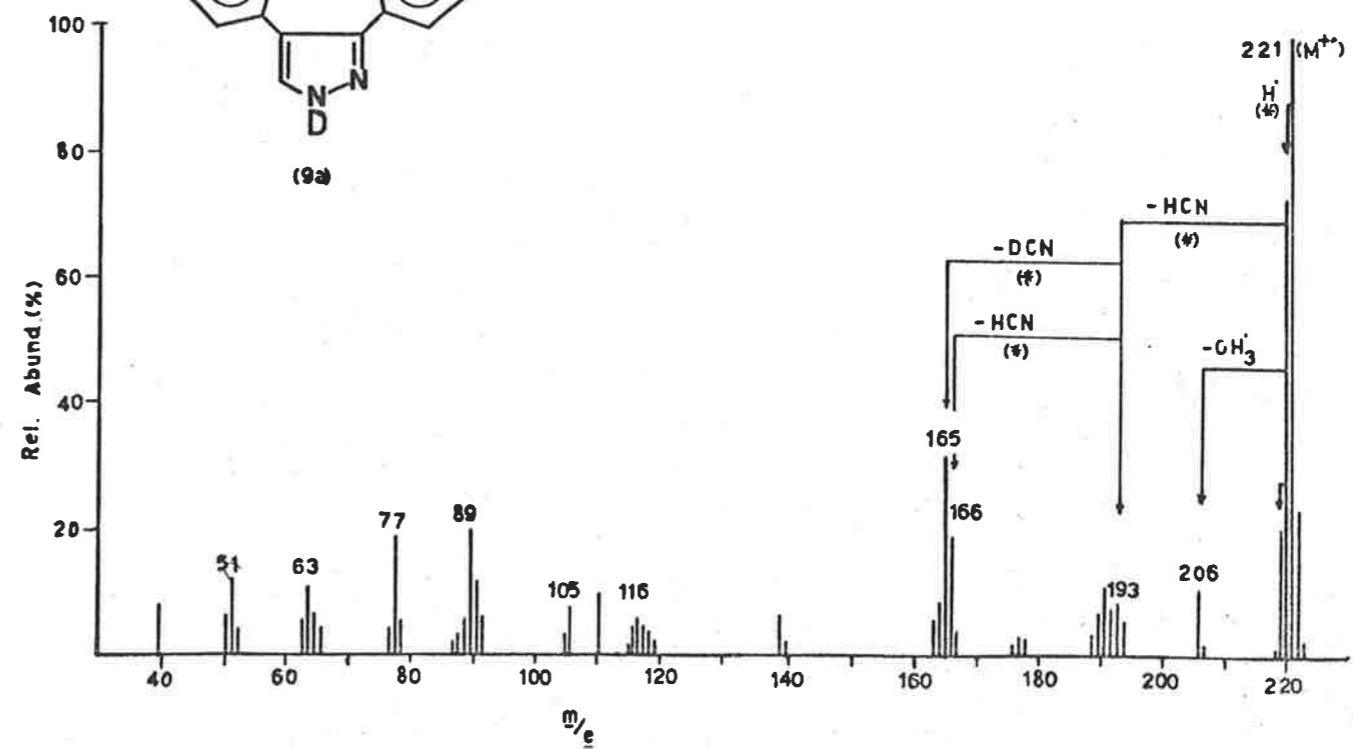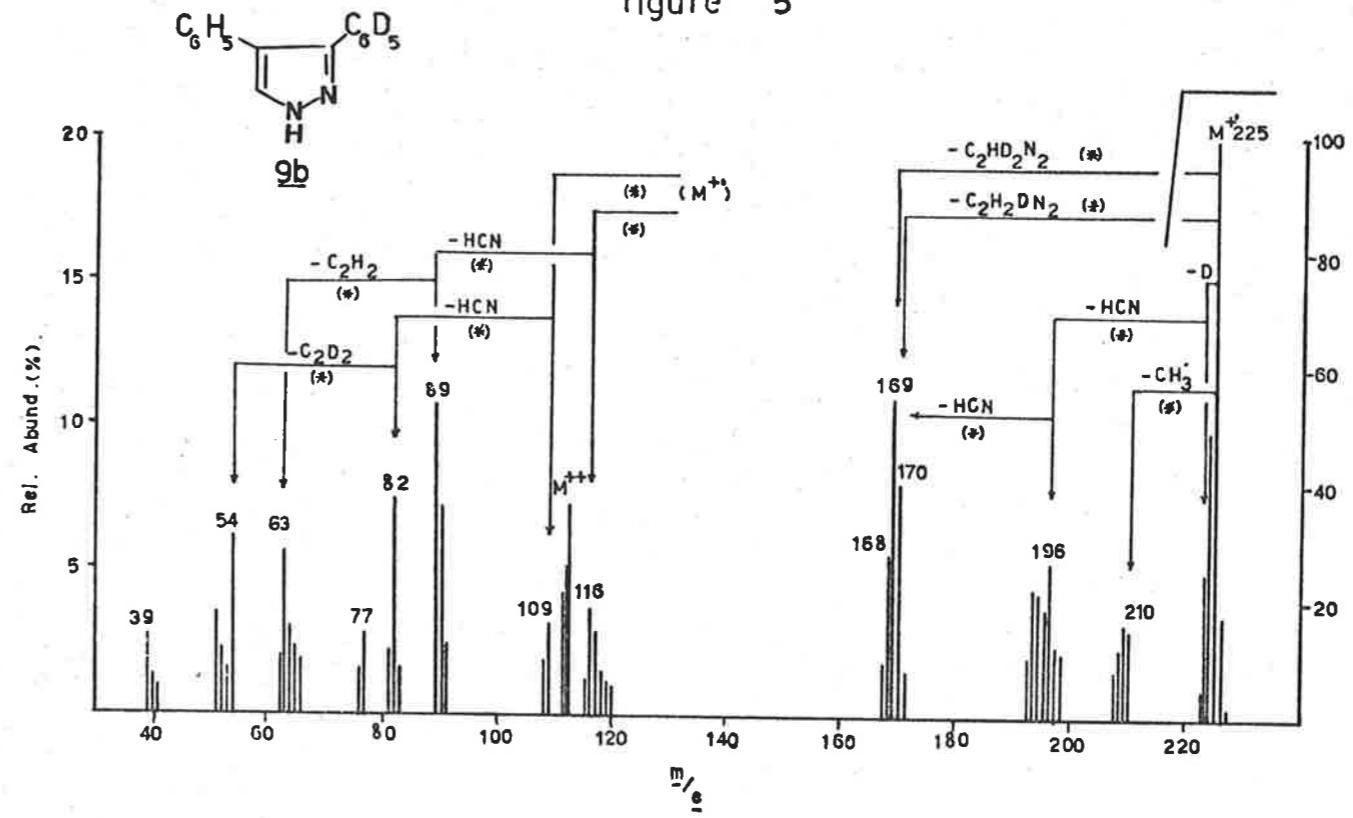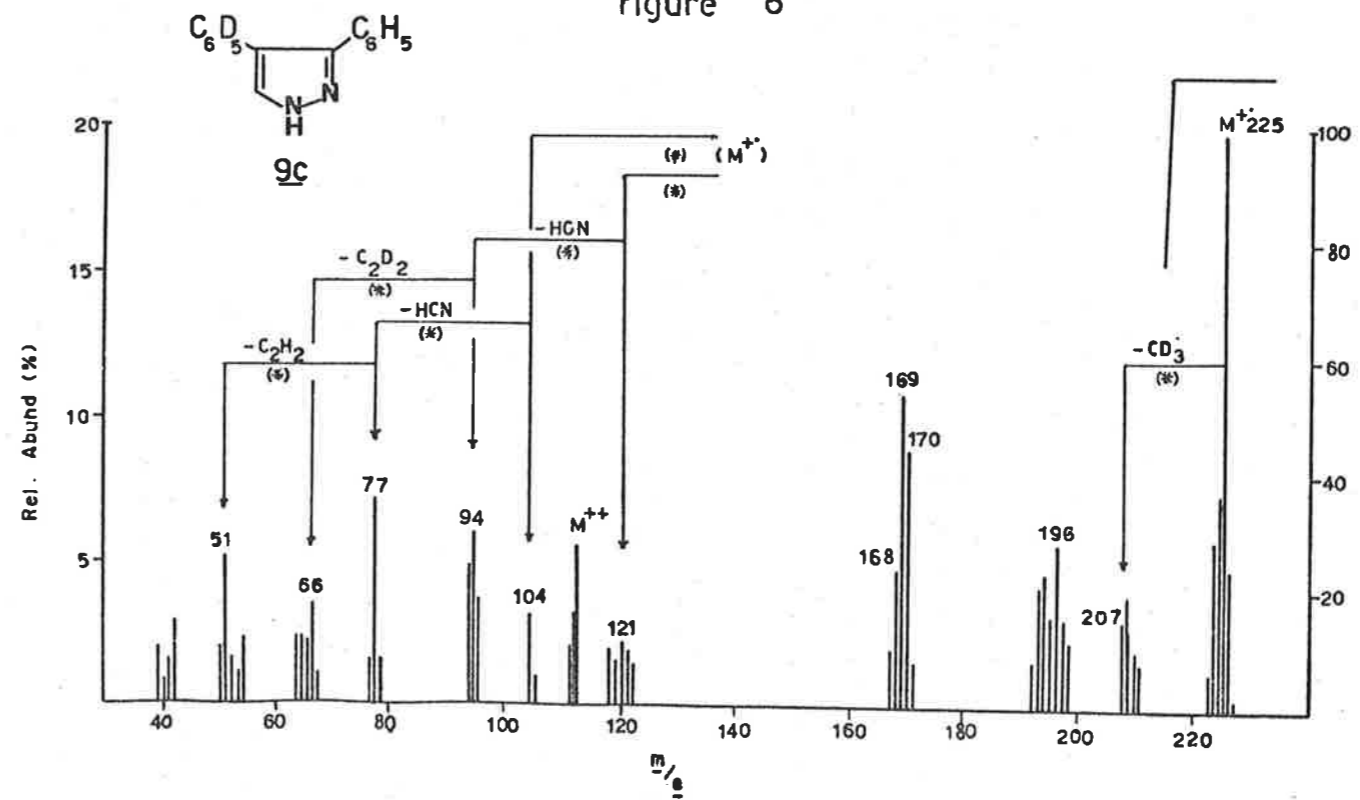
figure 5

figure 6

CHAPTER II

II   THE METHYLPHENYL PYRAZOLES

The major fragments in the isomeric methylphenylpyrazoles 3(5)-methyl-4-phenylpyrazole (13) (figure 7), 3(5)-methyl-5(3)-phenyl-pyrazole (14), 4-methyl-3(5)-phenylpyrazole (15) (figure 8), 3-methyl-1-phenylpyrazole (16), 5-methyl-1-phenylpyrazole (17) (figure 9), arise by rupture of the N-N bond. Loss of a fragment $N_2H^{\cdot}$ or N_2H_2 is a minor process in the spectra of (13), (14) and (15) and as would be expected does not occur in either of the N-phenyl derivatives (16) or (17).

13

14

15

16

17
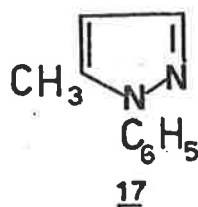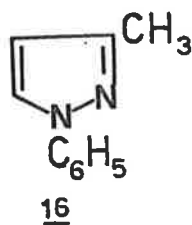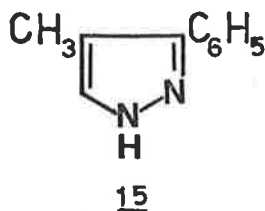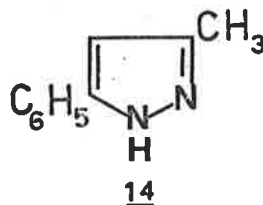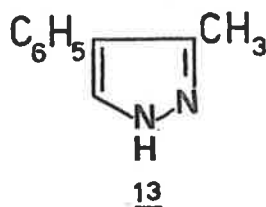
In those isomers, (13), (14), and (15), with a methyl

substituent adjacent to nitrogen, M-CH$_3$CN is a major process

producing an ion m/e 117 (C$_8$H$_7$N h.r.) (Table IV), by 1-2 and 3-4

bond cleavage. (Scheme II - R$_3$ = CH$_3$). This is not possible when

the methyl substituent is at C-4 and as expected m/e 117 is absent

in the spectrum of (15). However, in 5-methyl-1-phenylpyrazole (17),

fragmentation to m/e 117 (C$_8$H$_7$N h.r.) occurs by successive loss of

C$_2$H$_2$N (probably by 1-2 and 4-5 bond rupture, but not precluding

rearrangement of the molecular ion so that C$_2$H$_2$N is lost as an

azirine radical) and loss of a hydrogen atom H$^{\cdot}$. If the loss of H$^{\cdot}$

occurs from the 5-methyl substituent, cyclization to the N-phenylazirine

cation (x) is an attractive proposition (Scheme VII).

Scheme VII.

$$CH_3 \xrightarrow[-C_2H_2N^{\cdot}]{-e} C_8H_8N^+ \xrightarrow{-H^{\cdot}} x$$

$\underline{16}$ $C_8H_8N^+$ $\underline{m}/_e$ 118 $\underline{x}, \underline{m}/_e$ 117
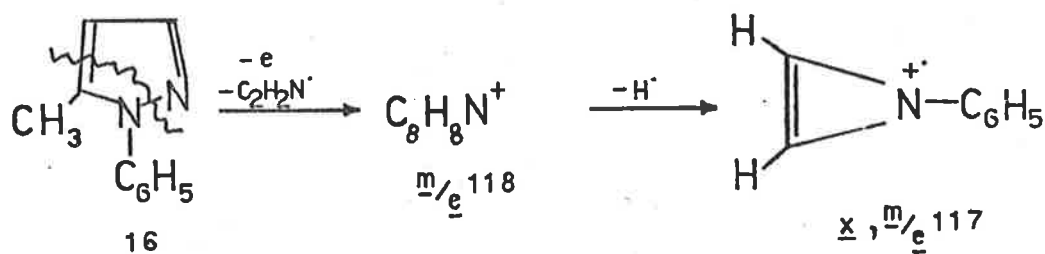
The intermediate azirine structure for m/e 117 is also

suggested by the presence in all the spectra of a further fragmentation

to m/e 90 (C$_7$H$_6$) by loss of HCN. This could be explained for (13) on

the ground state structure. Rearrangement reactions must be invoked

for compounds (14), (16) and (17), as is the case for the loss of HCN

from m/e 117 in (17).

TABLE V

Compositions of abundant fragment ions in the spectra

of methylphenylpyrazoles.

Compound	Ion m/e	Composition
3-methy-4-phenyl pyrazole (13)	130	C_8H_9N
	104	C_7H_6N (50%)
		C_8H_8 (50%)
	103	C_7H_5N (10%)
		C_8H_7 (90%)
3-methyl-5-phenyl pyrazole (14)	130	C_9H_8N
	129	$C_{10}H_9$
	128	$C_{10}H_8$
	117	C_8H_7N
	115	C_9H_7
	104	C_7H_6N
	103	C_8H_7 (65%)
		C_7H_5N (35%)
	102	C_8H_6
4-methyl-3-phenyl pyrazole	130	C_9H_8N
	128	$C_{10}H_8$ (70%)
		C_9H_6N (30%)

4-methyl-3-phenyl pyrazole (15)	104	C_7H_6N
	103	C_8H_7 (65%)
		C_7H_5N (35%)
5-methyl-1-phenyl pyrazole (17)	130	C_9H_8N
	118	C_8H_8N
	117	C_8H_7N
	116	C_8H_6N
	104	C_7H_6N (70%)
		C_8H_8 (50%)
	103	C_7H_5N (50%)
		C_8H_7 (50%)

The fragmentation process M-HCN has been observed in the methylpyrazoles,[98] methylimidazoles,[78] methyloxazoles[28] and methyl-isoxazoles[75] and in their respective parent compounds. In view of the ready loss of CH_3CN by simple bond rupture processes in compounds (13)-(17) it is most surprising that none of these isomers fragment by loss of HCN from the molecular ion. Instead, all isomers fragment by loss of a molecule of HCN from the M-H˙ fragment ion (*m/e* 157). (This process is substantiated by a metastable peak at *m/e* 107.6 in all spectra.)

The ion at m/e 130 (C_8H_7N h.r.) is prominent in all spectra. However, its appearance in the spectra of (14) and (16) can only be explained by methyl or phenyl migration or a more complex rearrangement of the M-1 fragment ion prior to elimination of HCN. Loss of HCN from an M-1 species is easily rationalized by a simple fragmentation process for (13), (15) and (17).

The origin of the hydrogen atom lost in the step M-H· is unknown. It is tempting nevertheless to suggest that the hydrogen atom is lost from the methyl group, (this has been proven in methyl-oxazoles,[28] pyrroles[104] and imidazoles[78]) and that the molecule rearranges by ring expansion to an intermediate form which consecutive loss of HCN can occur. A pyrimidine or pyrazine structure has been suggested[78] for the M-1 ions of the methylimidazoles. By analogy the pyrazoles might form a pyridazine intermediate. This appears to be unlikely since it has been shown[105] that the major fragmentations of pyridazine compounds occur by loss of N_2 from the molecular ion.

Whatever the structure of the precursor ions it is certain that the ions m/e 130 (C_9H_8N) do not have the same structure in all five spectra. While the C-phenyl derivatives (13) and (15) lose H_2 from their m/e 130 fragment ions, 3-methyl-5-phenylpyrazole (14) does not. The m/e 128 peak in this compound corresponds entirely to an ion $C_{10}H_8$ (h.r.) (Table V). The m/e 130 (M-HCN) species in the N-phenyl derivatives (16) and (17) does not fragment by the process

$(M-HCN)-H_2$.
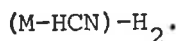
Further fragmentation of m/e 130 by loss of HCN does occur

in all spectra (metastable ion m/e 81.4-81.6 in all spectra except

that of (14)) with resulting formation of m/e 103 (C_8H_7 h.r.). A

fraction of this peak is produced by an ion (C_7H_5N h.r.) in all spectra.

It is impossible to explain this second elimination of HCN on the

basis of the parent molecule structure of any of the isomers. In

every case m/e 130 must fragment after rearrangement of this ion has

occurred.

A fragment ion peak at m/e 104 appears in all the spectra.

The ion corresponds (at least in part) to C_7H_6N (h.r.). Simple

fragmentation of the molecular ions of (14), (15) and (16) by 1-2 and

4-5 bond rupture readily explains its presence and a structure

corresponding to the protonated benzonitrile cation (y) can be

formulated. However, formation of this peak from the molecular ion

is supported by a metastable ion only in (15). The peak appears

also in the spectra of (13) and (17) where only a phenyl migration

could justify its presence in the spectra. It is interesting that

in these two spectra m/e 104 consists of two parts, C_7H_6N and

C_8H_8, whereas in other spectra m/e 104 consists entirely of ions

C_7H_6N (y).

$$\langle\!\!\!\bigcirc\!\!\!\rangle\!-C\equiv\overset{+}{N}H$$
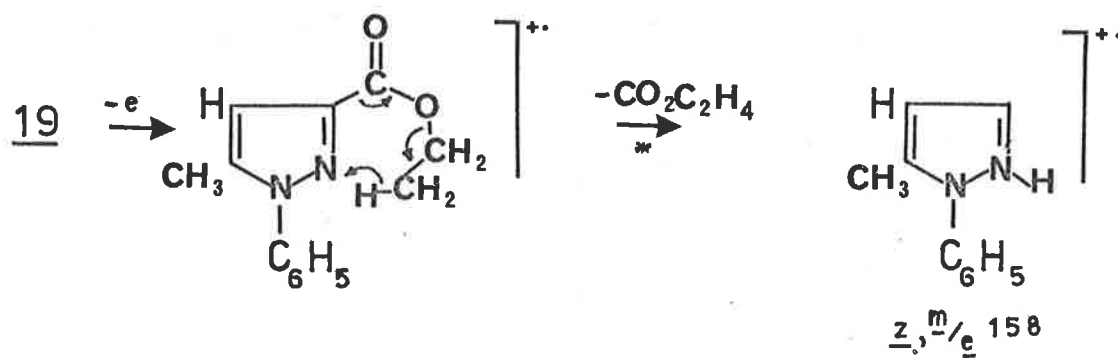
$\underline{y}$, m/e 104
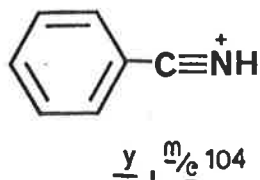
On this basis it is not unreasonable to postulate a four-membered cyclic structure for the fragment ion m/e 130. Rearrangement of the N-phenyl species and fragmentation by loss of either hydrocarbon or nitrile fragments could then account for all the observed fragment ions.

An outstanding feature of these spectra is the tendency for charge retention on the aromatic fragment, demonstrating that the charge is best stabilized in the presence of an aromatic ring. Even the usually abundant acetonitrile cation (m/e 41, CH_3CN^+) is either absent or very small in the spectra of the methylphenylpyrazoles. This retention of charge on the phenyl fragment ion produces spectra which are very similar in all the isomeric compounds. Simple cleavage of $CH_3^{\cdot}$ is a minor process and rupture of pyrazolephenyl bond appears to be more facile in the N-phenyl derivatives than the C-phenyl isomers. (Relative abundance m/e 77 in (16) = 100%). This has been noted in the diphenylpyrazoles[90] and has been explained in terms of the interaction of the molecular orbitals of the phenyl substituent and pyrazole ring.

Below m/e 158 the electron-impact spectra of the synthetic precursors of (16) ethyl-3-methyl-1-phenylpyrazole-5-carboxylate (18) and of (17) ethyl-5-methyl-1-phenylpyrazole-3-carboxylate (19), are very similar to methylphenylpyrazole spectra. An interesting feature of the spectra is the prominent hydrogen rearrangement associated with the loss of $CO_2C_2H_4$ to form ions of the same composition as the

molecular ions of (16) and (17). This can occur for (19) via a seven

membered transition state transfer of H to pyrazole nitrogen (Scheme VIII).

Scheme VIII.

figure 7

Ref. Abund. (%)

100 — M·⁺ 158
80 — − CH₃CN (₄)
− HCN (₅)
60 — − HCN (₆)
− CH₃CN
− HCN (₅)
40 — − C₂H₂ (₄)
130
− CH₃
20 — 51 63 77 90 103 117 143

40 60 80 100 120 140 160
m/e

C_6H_5 ⎯ CH_3

13

figure 8

Relative Abundance (%)

100 — (M·⁺) M·⁺ 158
− C₃H₄N (₄)
80 — − HCN (₄) − H (₄)
− HCN (₄) − HCN (₄)
60 — − CH₃ (₄)
40 — − H₂ (₄)
20 — 77 81 103 104 130 143

40 60 80 100 120 140 160
m/e

CH_3 ⎯ C_6H_5

15

figure 9

Relative Abundance (%)

100 — 77 − C₄H₅N₂ (₄)
− C₂H₂ (₄)
80 — − C₂H₂N (₄)
− H (₄) M·⁺ 158
60 — − HCN (₄) − HCN (₄) − H (₄)
− HCN (₄) − CH₃ (₄)
40 — − C₂H₂ (₄) 130
− H (₄)
20 — 39 51 63 81 90 103 118 143

40 60 80 100 120 140 160
m/e

CH_3 ⎯ C_6H_5

17

CHAPTER III

III BENZYL PHENYL KETONE DERIVATIVES

In view of the formation of abundant m/e 165 ($C_{13}H_9$) ions in the spectra of diphenyl substituted heterocyclic compounds[73] and aromatic hydrocarbons,[61-73] the presence of m/e 165 ions in the electron-impact spectra of benzyl phenyl ketone (20) and its derivatives was not unexpected.

20

$$C_6H_5\text{-}\underset{O}{\overset{\|}{C}}\text{-}CD_2\text{-}C_6H_5$$

20a

$$C_6H_5\text{-}\underset{O}{\overset{\|}{C}}\text{-}CH_2\text{-}C_6D_5$$

20b

21

22

$$C_6H_5\text{-}\underset{NOH}{\overset{\|}{C}}\text{-}CD_2\text{-}C_6H_5$$

22a

$$C_6H_5\text{-}\underset{NOH}{\overset{\|}{C}}\text{-}CH_2\text{-}C_6D_5$$

22b

$$C_6H_5\text{-}\underset{NOD}{\overset{\|}{C}}\text{-}CH_2\text{-}C_6H_5$$

22c

$$C_6H_5\text{-}\underset{NOH}{\overset{\|}{\overset{13}{C}}}\text{-}CH_2\text{-}C_6H_5$$

22d
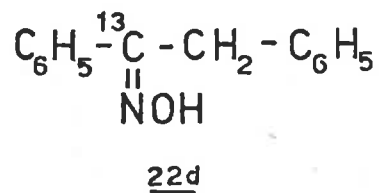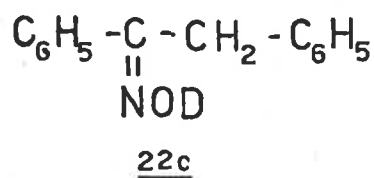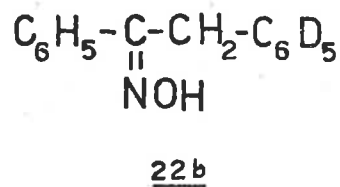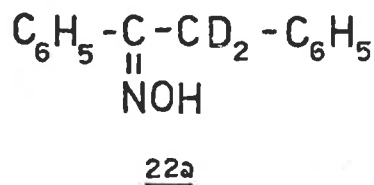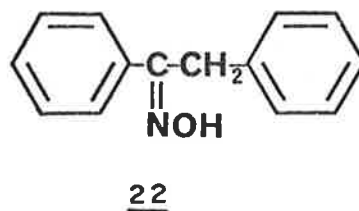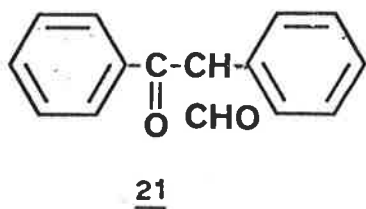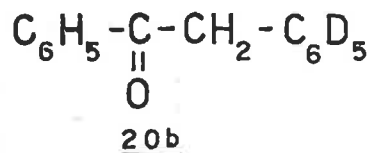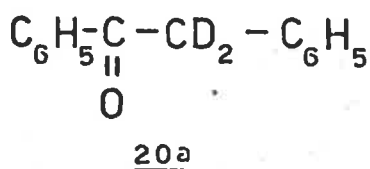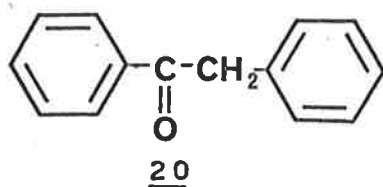
The spectra of benzylphenylketone (20), benzoylphenyl-
acetaldehyde (21) and benzylphenylketoxime (22) (figure 10) contain
ions at m/e 165 (Table VI) produced by various fragmentations from
their respective molecular ions. The overall process for the
formation of m/e 165 ion the spectrum of (2) is M-CH$_3$O. Peak shifts
in the spectrum of (20a) to m/e 167, 166 and 165 and in (20b) to
m/e 167, 168, 169, 170 indicate that the three hydrogen atoms are
lost almost randomly from the whole molecule. The observed ratio of
abundances in (20a) for m/e 165-167 is 8:42:50 in reasonable
agreement with the ratio calculated for random loss of three H or
D atoms (4.5: 4.10:54.5), but indicating that more benzylic hydrogen
is lost than would be expected for a completely random manner.

TABLE VI

Formation of m/e 165 in the spectra of (20), (21) and
(22). (All processes are substantiated by metastable
peaks.)

Compound	Process Producing m/e 165	Relative Abundance %
Benzylphenylketone (20)	M-H$^\bullet$-CO-H$_2$	2
Benzoylphenyl-acetaldehyde (21)	M-CO-H$^\bullet$-CO-H$_2$	8
Benzylphenylketoxime (22)	M-$^\bullet$OH-HCN-H$_2$	
	M-H$_2$O-HCN-H$^\bullet$	20
	M-H$_2$O-H$_2$CN	

The formation of m/e 165 in the spectrum of (21) must occur with migration of the formyl H˙ to form the molecular ion of (20) or its tautomeric enolform since successive eliminations mirror the fragmentations of this compound.

The Rearrangement Ions in the Spectrum of Benzylphenylketoxime (22)

The formation of $C_{13}H_9^+$ (m/e 165) is most pronounced in the spectrum (figure 10) of the oxime (22). Three distinct processes give rise to m/e 165 in the spectrum of (22); viz. (i) M-HO˙-HCN-H$_2$, (ii) M-H$_2$O-HCN-H˙ and (iii) M-H$_2$O-H$_2$CN. All eliminations are substantiated by metastable peaks.

(i)   The process M-HO˙-HCN-H$_2$

This process which involves the initial loss of HO˙ from the oxime moiety (Scheme IX) becomes more pronounces as the energy of the electron beam is decreased from 70 to 15 eV (figures 11 and 12). The ion (bb) loses HCN to yield m/e 167 which further fragments at 70 eV by loss of H$_2$ to m/e 165. These two ions may be represented as the phenyltropylium (dd) and fluorenyl (a) cations respectively by analogy with the decomposition of the diphenylmethane molecular ion[65] which fragments to the fluorenyl cation (a) via (dd) after initial loss of a hydrogen atom. This is a minor process in the spectrum of diphenylmethane at 70 eV and is completely absent at 15 eV. We conclude therefore that in the spectrum of the oxime (22) no significant formation of (a) from (dd) occurs at 15 eV, and that this process may

be ignored when considering other fragmentations. This is supported

by the absence of a metastable ion for the process $C_{13}H_{11}^+ \rightarrow C_{13}H_9^+$

at 15 eV.[†]

The partial mass spectra of benzylphenyl-^{13}C-ketoxime (22d)

(33.1% [13]C at the carbon adjacent to nitrogen) at both 70 and 15 eV

(figures 11 and 12) indicate that there is no shift of m/e 167

(>90% $C_{13}H_{11}$)h.r.) to m/e 168. This proves that the carbon adjacent

to nitrogen is specifically lost during the elimination of HCN from

the (M-HO˙) species, and indicates that a migration rather than a

cyclization has occurred during the elimination.

Peaks at m/e 169 and 168 in the spectrum of α,α-d_2-benzyl-

phenylketoxime (22a) and at m/e 172 and 171 in the spectrum of

d_5-benzylphenylketoxime   (22b) (figures 13 and 14) show that these

compounds eliminate both HCN and DCN from the (M-˙OH) species, and it

is clear that some randomization of hydrogen and deuterium is taking place.

The m/e 171 peak in the spectrum of (22b) is produced by both

loss of DCN from (M-HO˙) and loss of HCN from the (M-H$_2$O) species

(Table VII). It is therefore difficult to calculate a ratio for loss

of HCN or DCN from the (M-17) ion. In the spectrum of (22a) however,

m/e 169 and 168 are formed by a single process corresponding to loss

† The application of metastable ion characteristics has shown[74] that

   the ion at m/e 165 in the spectrum of (22) corresponds mainly to the

   properties of the phenalenyl rather than the fluorenyl cation; an

   observation which strongly supports the above proposal.

from the (M-HO˙) species of HCN and DCN respectively. At 70 eV the ratio of loss of HCN:DCN is 0.72:0.28. At 15 eV, when these processes are enhanced at the expense of fragmentations from the $(M-H_2O)$ species, the ratio becomes 0.67:0.33, which indicates an increased specificity for loss of DCN (i.e. benzylic hydrogen). Similar increases in the specificity of loss of HCN or DCN with decreasing energy of the electron beam have been noted in 2,4,6-d_3-benzonitrile[106] and diphenyl-1-d-acetoniltrile[65]. The

The theoretical figures for loss of HCN:DCN by (i) random-ization of H/D over the whole molecule and (ii) randomization within and loss of H or D from the benzyl substituent only are (i) 0.83:0.17 and (ii) 0.71: 0.29. (Refer to Table VII)

Estimation of the loss of HCN:DCN in (22b) based upon a calculation of [(M-17)-HCN] as a fraction (30%) of the total fragmentation in the unlabelled oxime (22) gives a value of approximately 0.40:0.60. Theoretical values for complete randomization and randomization within and specific loss from the benzyl group are 0.58:0.42 and 0.28:0.72 respectively.

These results show that there is some specificity in the loss of hydrogen from the benzylic position, that randomization occurs within the benzyl substituent, and that a small fraction (approximately 10-15%) of hydrogen in the HCN fragment originates in the unlabelled phenyl ring. These observations are best explained by proposing an

TABLE VII

Processes producing ions in the m/e 165 region of the spectra of $\alpha,\alpha\text{-d}_2$-benzylphenylketoxime (22a) and d_5-benzylphenylketoxime (22b) at 15 eV.

	Compound (22a)			Compound (22b)	
m/e	Process producing peak	Relative Abundance[†]	m/e	Process producing peak	Relative Abundance
169	M-·OH-HCN	76	172	M-OH-HCN	42
168	M-·OH-DCN	37	171	M-OH-DCN	100
				M-H_2O-HCN	
167	M-HDO-HCN	82	170	M-H_2O-DCN	96
				M-H_2O-H_2CN	
166	M-HDO-DCN	100	169	M-H_2O-HDCN	62
	M-HDO-H_2				
165	M-HDO-HDCN	33	168	M-H_2O-D_2CN	17

† The most abundant peak in the rearrangement ion region is arbitrarily assigned an abundance of 100% after correction for natural isotope abundances.

equilibrium (Scheme IX) between (bb) and (cc) which will allow randomization of the benzylic hydrogens and transfer of hydrogen to nitrogen from either phenyl via a five or six membered transition

Scheme IX

$-HO^{\cdot}$ $\underline{aa}, ^m/_e$ 211 $-H_2O$ $\underline{ff}, ^m/_e$ 193

$\underline{bb}, ^m/_e$ 194

$\underline{cc}, ^m/_e$ 194

$\underline{r}, ^m/_e$ 165

$-HCN$

$\underline{dd}, ^m/_e$ 167

$-H_2$

$\underline{a}, ^m/_e$ 165
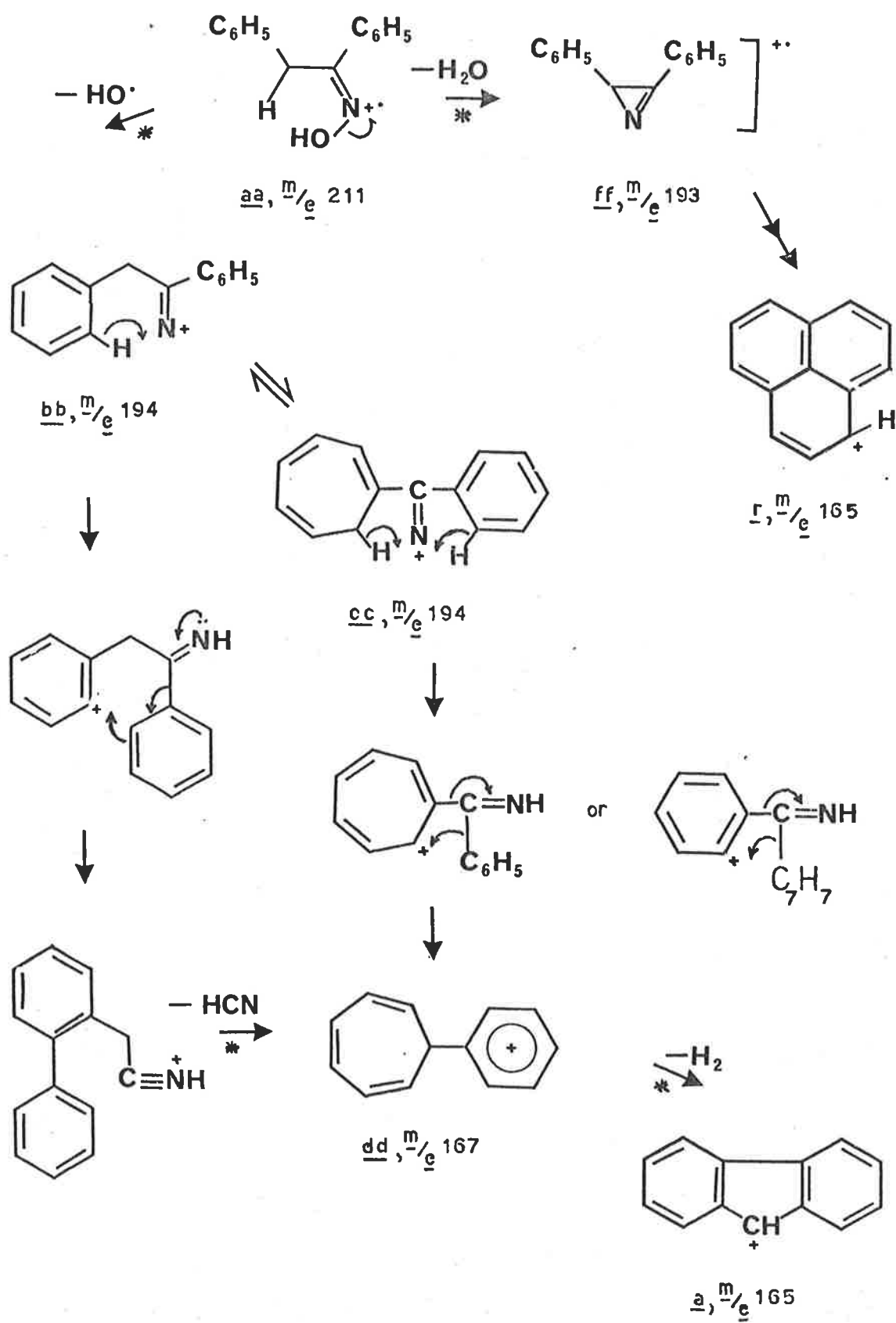
state. Upon fragmentation and loss of HCN migration of either group

to form (dd) m/e 167 is possible.

(ii) The processes $M-H_2O-HCN-H^{\bullet}$ and $M-H_2O-H_2HCN$

The spectra of the deuterium-labelled derivatives of

benzylphenylketoxime (22a), (22b), and (22c) at 70 and 15 eV show

that the loss of water from the molecular ion is hydrogen-specific,

involving the $^{\bullet}OH$ group and a benzylic hydrogen, e.g. $\alpha,\alpha-d_2$-benzyl-

phenylketoxime (22a) fragments by specific loss of HDO, d_5-benzylphenyl-

ketoxime (22b) fragments by loss of H_2O, and $N-d_1$-benzylphenylketoxime

(22c) loses HDO from the molecular ion. This is of particular interest

and indicates that hydrogen randomization does not precede this

elimination. The spectra of (22a) and (22b) show that the production

of d_2- and d_5-tropylium cations (m/e 93 and m/e 96 respectively) does

proceed with randomization of the phenyl and benzylic hydrogens and/or

deuterium (cf. the labelled ethylbenzenes[107]). This randomization is

also evident in the fragmentation of the (M-17) species (vide supra).

Two possible fragmentation modes (Scheme X) were considered

to account for the formation of m/e 165 ($C_{13}H_9^+$) from the (M-H_2O) species,

viz. (i) a phenyl migration similar to the [(M-HO$^{\bullet}$-HCN)] process,

forming the molecular ion (ee) of diphenylacetonitrile (23), or

alternatively, a cyclization forming the molecular ion (ff) of 2,3-

diphenyl-2-H-azirine (24).

Scheme X

$C_6H_5C-CH-C_6H_5$ in structure 22 (with N, OH, CH groups) $\xrightarrow[-H_2O\ *]{-e}$ structure **ff**, m/e 193

22

Structure 22 (second) $\xrightarrow[-H_2O\ *]{-e}$ $C_6H_5 / C_6H_5 \backslash CH-CN^{+\cdot}$ **ee**, m/e 193

22
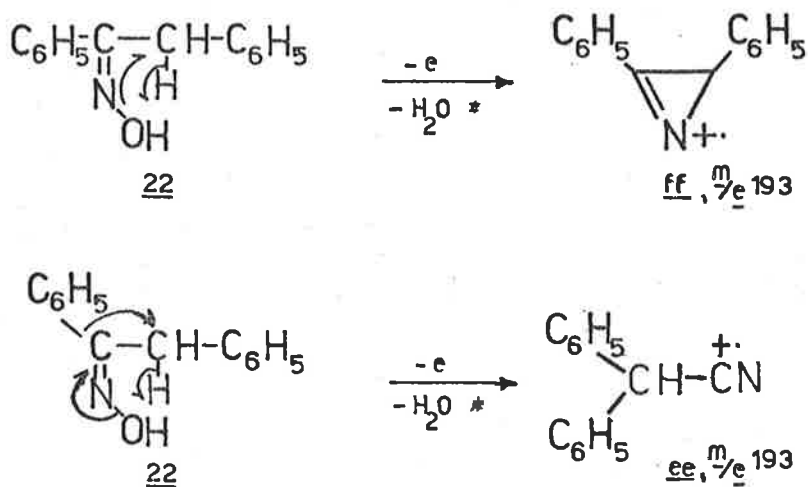
The spectra of (23) and (24) (figures 16 and 17, Appendix I) both contain pronounced peaks at m/e 165. To determine whether (ee) or (ff) corresponds to the M–H_2O species in the spectrum of the oxime (22), the ratios of the abundances of the metastable peaks for m/e 193–166 transitions, to the abundances of m/e 166 have been compared at various energies of the electron beam for all spectra (Table VIII) The metastable peak shapes in the m/e 140-144 region (figure 18) in the spectra of the oxime (22) and the nitrile (23) are quite different although the metastable peaks of diphenylacetoisonitrile (25) have the same shape as those of (23). In addition the m/e 166/m* ratios for these three compounds were quite different. The (M–H_2O) species in the spectrum of (22) is most unlikely to correspond in structure to either the nitrile (23) or the isonitrile (25) molecular ions and this evidence casts considerable doubt upon any mechanism which involves a specific phenyl migration.

TABLE VIII[†]

Ratios of the relative abundances of m/e 166 to the
metastable peak at m/e 142.8 (193—166) in the spectra
of (22)-(25).

Compound	70 eV	40 eV	30 eV	20 eV	15 eV
Benzylphenyl-ketoxime (22)	31	29	27	23	17
2,3-diphenyl-2-H-azirine (23)	40	39	37	32	24
Diphenylaceto-nitrile (24)	74	72	70	64	49
Diphenylaceto-isonitrile (25)	140	132	118	97	73

† Abundance of m/e 166 corrected for m/e 165 isotope

peak. Experimental error in m/e 166/m* is ±5%

calculated from an average of ten measurements.

The corresponding metastable shapes in the spectra of (22)
and (23) are similar, except that three metastable peaks are observed
for (22) and only two for the azirine (23). The additional metastable
peak (m/e 143.8) in the spectrum of (22) is that for the [(M-˙OH)-CHN]
elimination, a process which cannot occur for (23). The m/e 166/m*
ratios do not agree within experimental error, but the discrepancy

is small enough to be accounted for by the presence of the third

metastable ion (in the spectrum of (22)) which would have the effect of

slightly increasing the abundance of the metastable peak at m/e 142.8

(m^*). It appears reasonable to propose that those portions of the

(M-H$_2$O) species of (22) and of the 2,3-diphenyl-2-H-azirine molecular

ion which give rise to m/e 166 and 165, may have the same structure

and energy distributions.

Further evidence for this proposition is found in the mass-

spectrum of 1-^{13}C-benzylphenylketoxime (22d). High resolution studies[103]

(at 70 eV) indicate that m/e 165 corresponds to $(C_{13}H_9)^+$ and that

(80 ± 5%) of m/e 166 is $(C_{12}{}^{13}CH_9)^+$. Correction for the natural isotope

of m/e 165 gives a ratio of $(C_{13}H_9)^+$ m/e 165 : $(C_{12}{}^{13}CH_9)^+$ m/e 166 of

100:23. The fragmentation of m/e 167 to m/e 165 can be ignored at 70 eV

(for a full discussion see p. 45). As the (M-1) ion in the spectrum[74]

of phenalene has approximately twice the relative abundance as the

molecular ion, the decomposition of the $C_{13}H_{10}$ portion of m/e 166 to

m/e 165 will be small ($C_{13}H_{10}$ 7%, cf. m/e 165 100%). Consequently

the maximum contribution to m/e 165 in the spectrum of (22) would be

14%. When the accuracy of the mass measurements and the above

assumptions are considered, the absolute error in the ratio $(C_{13}H_9)^+$:

$(C_{12}{}^{13}CH_9)^+$ at 70 eV is $(100\pm15):(23\pm10)$.

There are a number of ways in which HCN (or H$_2$CN) may be

lost from the molecular ion of 2,3-diphenyl-2-H-arizine (23). The

carbon may be lost specifically from either of the two azirine ring

positions. Alternatively, there could be random loss of carbon over

the whole molecule. The theoretical figures for no loss of label,

and random loss of label in (22d) (^{13}C = 33.1%) are 100:50 and

100:46.5 respectively. As the results indicate that approximately

50% of the label is lost, each of the two original azirine ring

carbons must be lost to an equal extent. This is indicative of

fragmentation of m/e 193 (M-H$_2$O) in the spectrum of (22) through some

type of cyclized symmetrical species.

It is difficult to determine the origin of the hydrogen

lost in the fragments HCN and H$_2$CN when m/e 193 undergoes decomposition

because some peaks in the rearrangement ion region of the spectra of

(22a) and (22b) have two contributing processes (Table VII). Only

one process produces m/e 167 in the spectrum of α,α-d$_2$-benzylphenyl-

ketoxime (22a), viz. M-HDO-HCN. At 15 eV this accounts for 25% of

total fragmentations to rearrangement peaks, cf. 20% for the equivalent

process in the unlabelled oxime (22). This observation suggests that

the benzylic hydrogen is retained in the $C_{13}H_{10}^+$ fragment and not lost

during the rearrangement. The observation of an intense peak at

m/e 171 in the spectrum of d$_5$-benzylphenylketoxime (22b) which has as a

major contributor the process [(M-H$_2$O)-HCN], indicates that a major

portion of the hydrogen lost as HCN originates in the unlabelled phenyl

ring. (This of course can only be conclusively proved by labelling of

the phenyl ring with deuterium).

The hydrogen lost as H$_2$CN in the process M-H$_2$O-H$_2$CN could be

lost in a number of ways. There could be random loss of hydrogen

from the whole ion or a more specific loss from either of the two

phenyl rings, as suggested for the process M-H_2O-HCN, could occur.

Peaks at m/e 166 and 165 corresponding to the loss of H_2CN and HDCN

from the (M-HDO) species in the spectrum of (22a) are in a ratio of

approximately[†] 0.75:0.25. The calculated value for random loss of

H_2CN to HDCN is 0.82:0.18 which suggests some specific loss of label

from the benzylic position.

This proposal is supported by intensities of the peaks in

the m/e 170-168 region of the spectrum of (22b). If the contribution

to m/e 170 by the process ((M-18)-DCN) is small, the ratio of the

intensities of the peaks m/e 170-168 corresponding to loss of H_2CN,

HDCN and D_2CN respectively from the (M-H_2O) species is 0.50:0.39:0.11

(cf. random loss of H or D throughout the ion - 0.27:0.55:0.18). This

process proceeds with some degree of randomization of hydrogen and

deuterium between the phenyl substituents or by specific loss from

either ring. Of the two possibilities randomization between phenyl

substituents in the manner of the aromatic hydrocarbons and diphenyl-
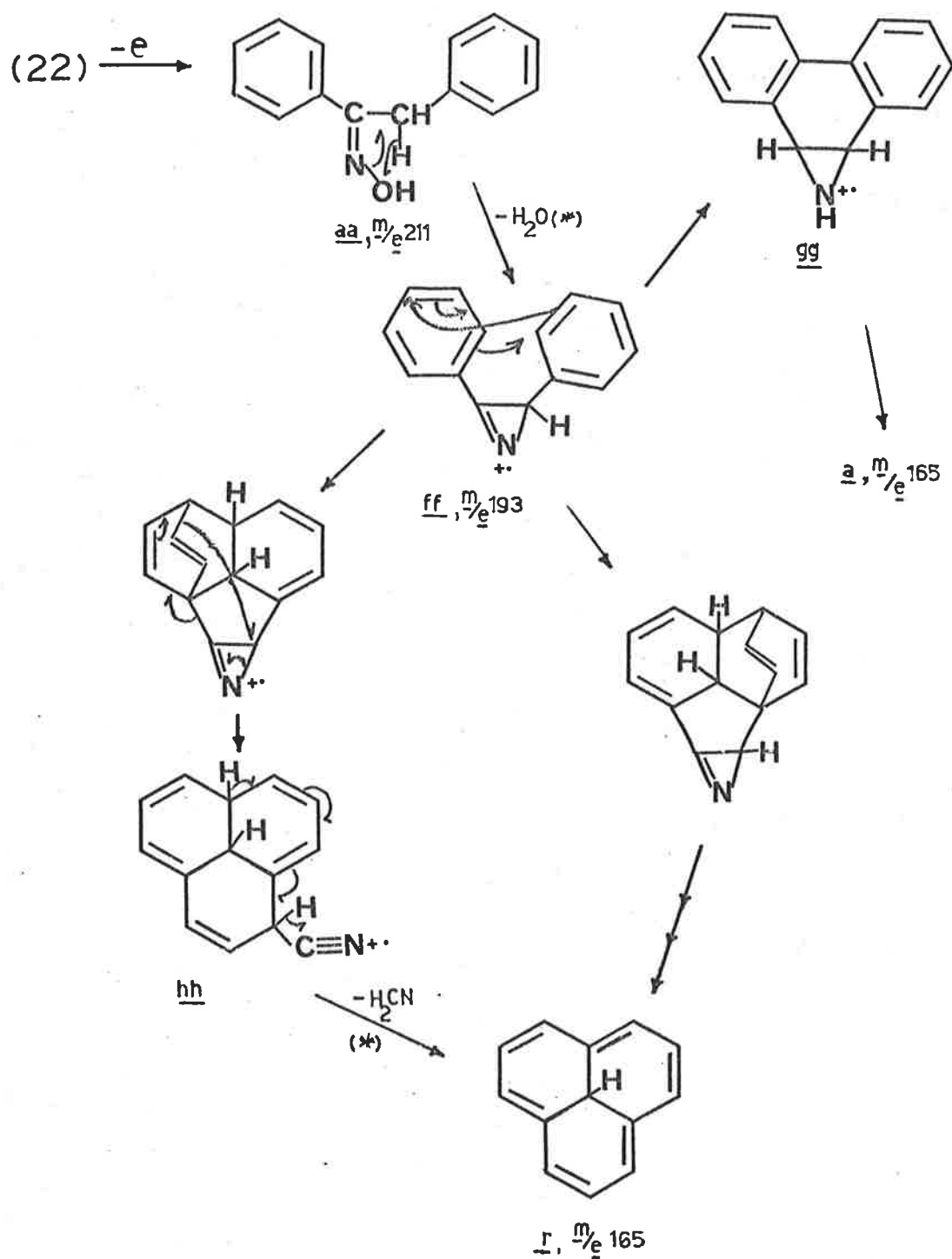
pyrazoles (vide supra) is the more likely.

† This assumes that the contribution to m/e 166 by the process

M-HDO-DCN is small as was suggested by the intensity of the m/e 167

peak (see above).

Fragmentations from the M-H$_2$O species in the spectrum of benzylphenylketoxime (22) occur by two distinct pathways. Loss of HCN leads to retention of the benzylic hydrogen in the hydrocarbon fragment C$_{13}$H$_{10}^+$. Loss of H$_2$CN occurs with preferential loss of the benzylic hydrogen associated with random loss of H and/or D from throughout the molecule.

Although the 2,3-diphenyl-2-H-azirine molecular ion (ff) is probably produced initially upon loss of H$_2$O from the molecular ion of (22), it is unlikely to be the species which eliminates HCN. The formation of the phenalenyl cation (r, *m/e* 165) from (ff) requires considerable rearrangement of the carbon skeleton of the molecule, and it would seem that an ion of structure (gg) (Scheme XI) would be more likely to produce the fluorenyl rather than the phenalenyl cation.

Mechanisms may be drawn to rationalize the formation of (r) from the diphenylazirine molecular ion, but these must be regarded as highly speculative. One such mechanism which explains the loss of either azirine-ring carbon; the specificity of benzylic hydrogen loss; the randomization of H and ^{2}H between phenyl rings and/or transfer from either phenyl ring; and the formation of the phenalenyl cation (r) is outlined in Scheme XI. Diels-Alder addition between the phenyl rings is proposed initially, followed by subsequent bond migration forming (hh), which may then fragment to (r).

Scheme XI

$\underline{aa}, m/_e 211$

$\underline{gg}$

$-H_2O(*)$

$\underline{ff}, m/_e 193$

$\underline{a}, m/_e 165$

$\underline{hh}$

$-H_2CN$

$(*)$

$\underline{r}, m/_e 165$

In conclusion it must be stated that these studies

illustrating the prevalence of specific skeletal-rearrangement

processes in organic mass spectrometry highlight certain weaknesses
in our interpretation of electron-impact spectra. Although the
ability to distinguish between hydrogen atoms is facilitated by the
use of deuterium labelling, the incidence of hydrogen randomization
between phenyl substituents may still lead to ambiguity in inter-
pretation of rearrangement mechanisms. Labelling of carbon with ^{13}C
atoms allows conclusions to be made about fragmentation but does
little to aid the understanding of the complex rearrangement of the
carbon skeleton observed here in the formation of the phenalenyl
cation from diphenyl substituted derivatives. With regard for these
problems it is possible to interpret and propose mechanisms which
may lead to greater understanding of the processes which are possible
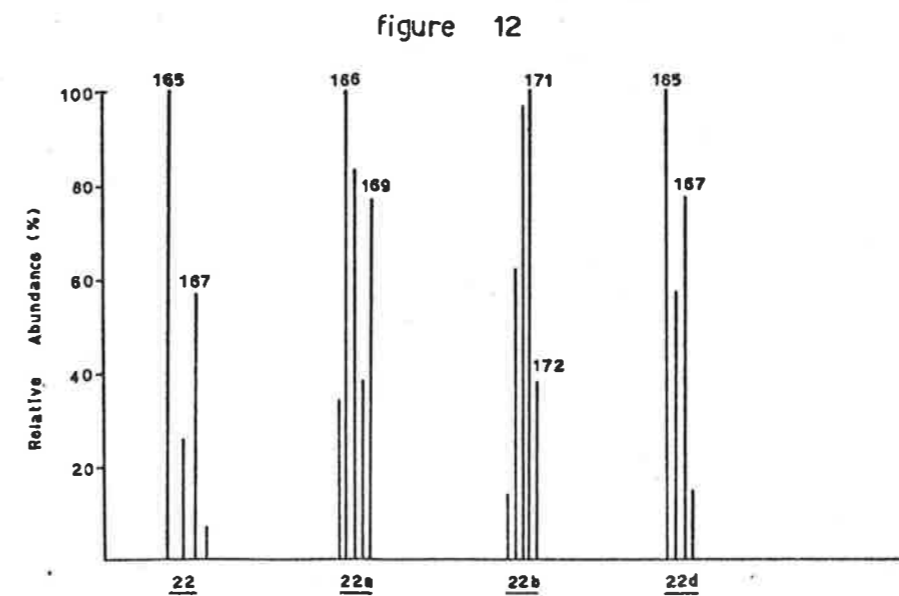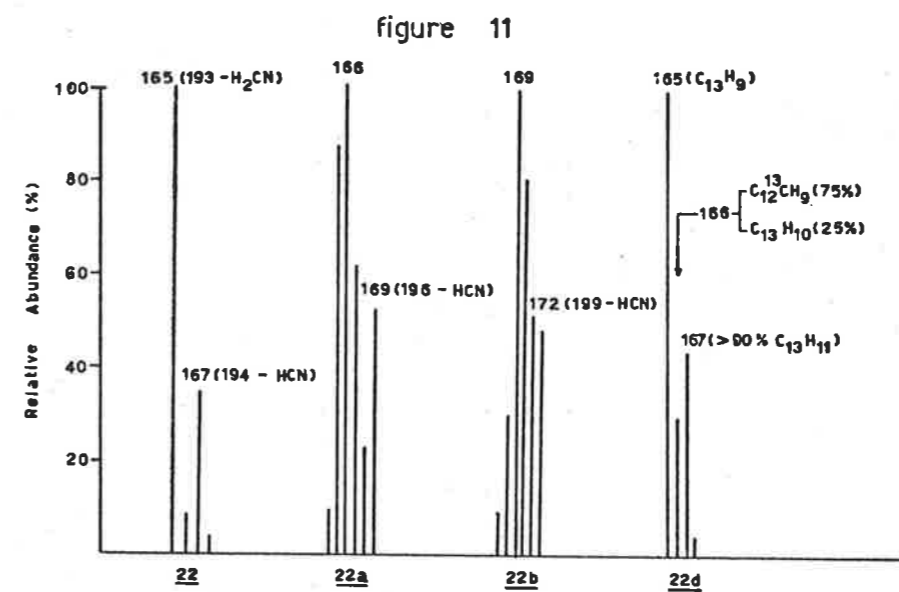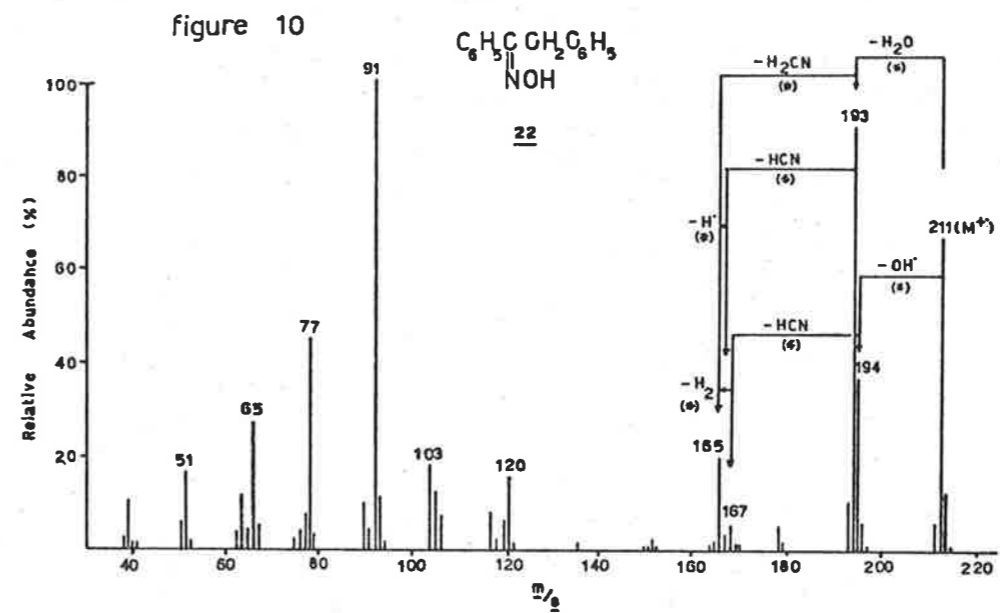upon electron impact.

figure 10
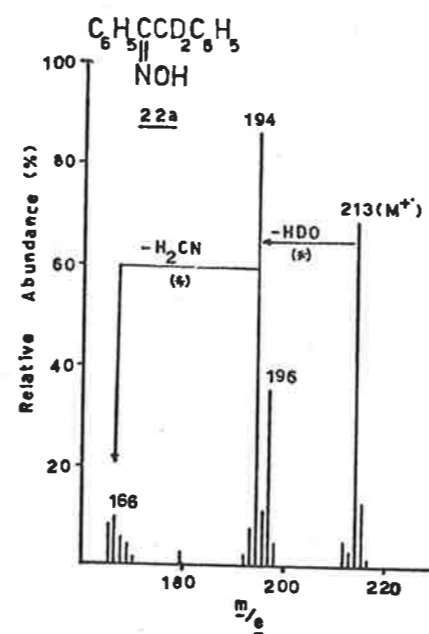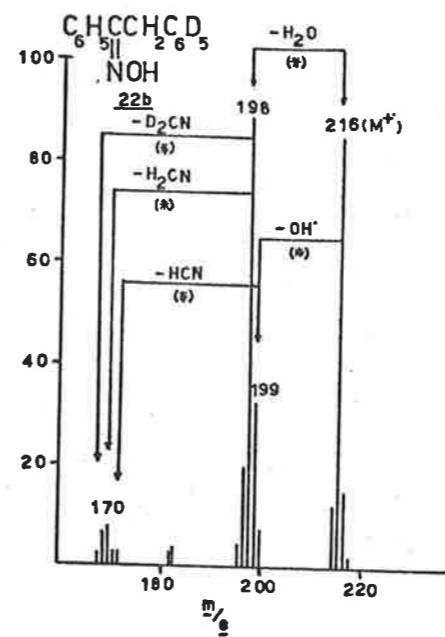

figure 11

figure 12

figure 13.

figure 14.

figure 15.

$C_6H_5CCDC_6H_5$
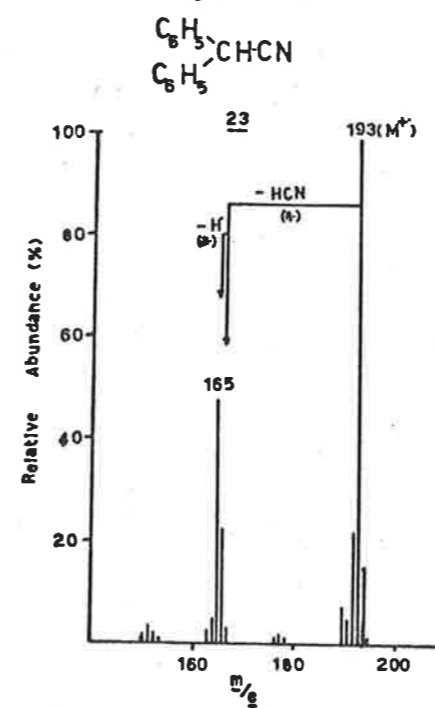‖
NOH

22a

figure 16.

figure 17.

C_6H_5
      CHCN
C_6H_5

23

24
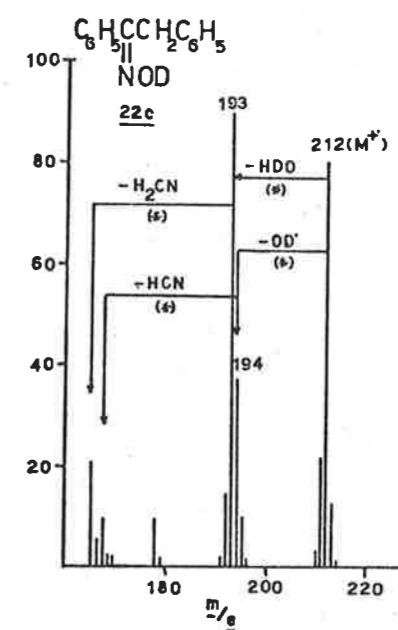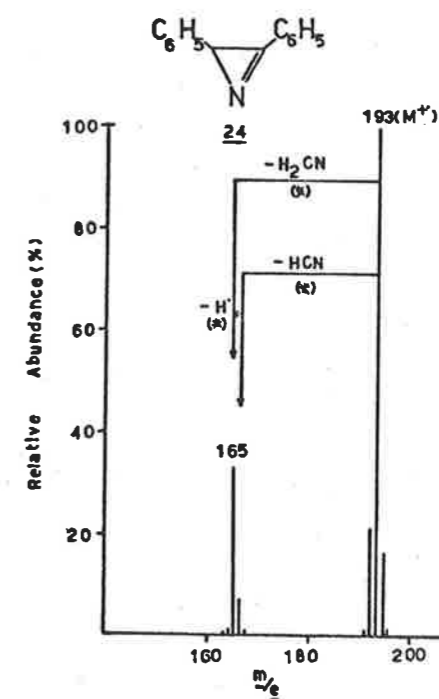
figure 18

Metastable Peak Shapes.
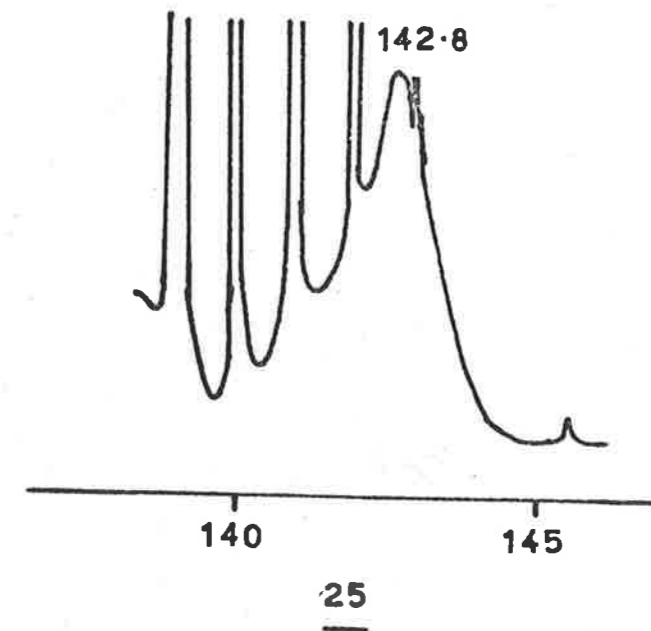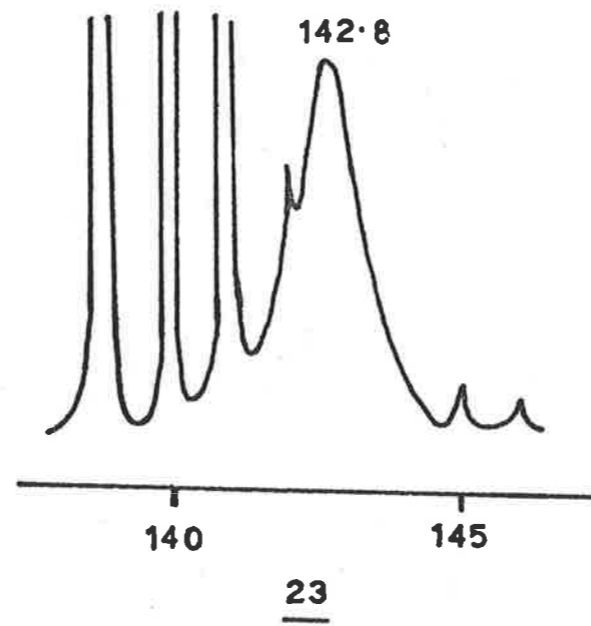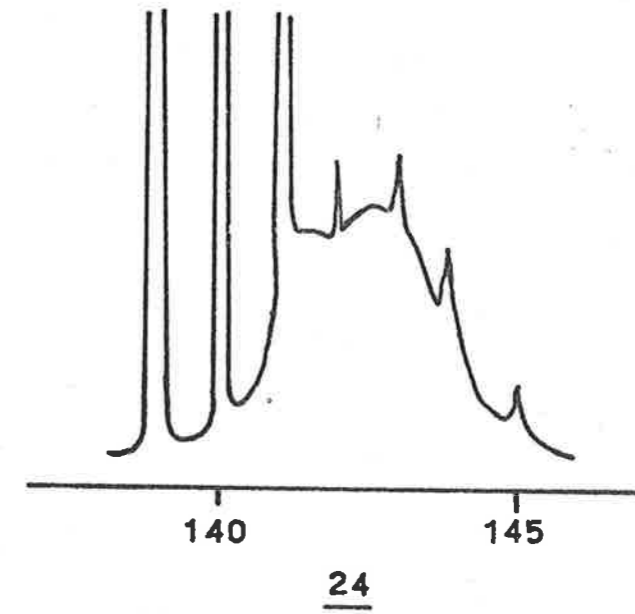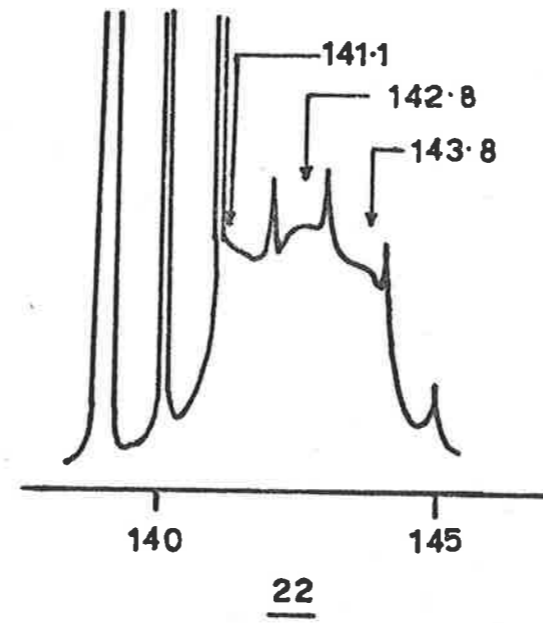
EXPERIMENTAL

INSTRUMENTATION

     All mass spectra were determined with an Hitachi Perkin-Elmer RMU-6D double-focusing mass spectrometer operating at 70 eV (unless otherwise specified). Samples were routinely introduced through an all-glass heated inlet system at temperature of 150° and a source temperature of approximately 150°C. Exact mass measurements were performed with an AEI MS-902 instrument with a resolution of 20,000 (10% valley definition) with heptacosafluorotributylamine providing reference masses. The spectra of the oxime derivatives (22)-(22d) were determined after introduction at an inlet temperature of 100°. The spectrum of 2,3-diphenyl-2H-azirine (24) was measured using the 'direct-insertion' procedure with the sample heater maintained at 70°.

     The isotopic purity of all labelled derivatives was determined by measurement of the molecular ion at or near the appearance potential.

     All samples were routinely checked for purity by mass spectrometry and nuclear magnetic resonance spectrometry with a Varian 60 Mc internal lock NMR Spectrometer system type DA60-IL.

     All melting points were determined with a Gallenkamp melting point apparatus and are uncorrected.

     A sample of 2,3-diphenyl-2-H-azirine (24) and $1-^{13}$C-1,2-diphenylethanol were respectively supplied by Professor A. Hassner and

Mr. P.Y. White.

Imidazole (11) was a purified commercial sample. The following compounds were prepared by reported procedures : pyrazole (10),[108] 3(5),4-diphenylpyrazole (7),[109] 3,5-diphenylpyrazole (12),[110] 3(5)-methyl-4-phenylpyrazole (13),[111] 3-methyl-5-phenylpyrazole (14),[112] 4-methyl-3(5)-phenylpyrazole,[113] (15), ethyl-3-methyl-1-phenylpyrazole-5-carboxylate (19),[114] 3-methyl-1-phenylpyrazole (17),[114] ethyl-5-methyl-1-phenylpyrazole-3-carboxylate (18),[114] 5-methyl-1-phenyl-pyrazole (16),[114] benzylphenylketone (20),[115] benzoylphenylacetaldehyde (21),[109] benzylphenylketoxime (22),[116] diphenylacetonitrile (23),[117] and diphenylacetoisonitrile (25).[118]

Preparation of Isotopically Labelled Derivatives

N-d_1-3(5),4-diphenylpyrazole (9a)

This compound was prepared by introducing a sample of 3(5),4-diphenylpyrazole (9) into the source with deuterium oxide.[119] Measurements at just above the appearance potential indicated d_1 = 82%, d_0 = 18%.

3-(d_5-phenyl)-4-phenylpyrazole (9b)

(a) The reaction between $d_6$benzene (4.0 g) and acetylchloride (4.0 g) with aluminium trichloride (10.0 g) in tetrachloroethane (25 ml) gave d_5-acetophenone (2.6 g, 58%), b.p. 201-202.

(b) d_5-Acetophenone (2.5 g) was converted[120] into 1-(d_5-benzoyl)-2-phenylethylene (4.6 g, 96%), m.p. 54-55° from ethanol.

(c) The reaction[121] of 1-(d_5-benzoyl)-2-phenylethylene (2.08 g) in methanol (25 ml) with hydrogen peroxide (7.0 ml, 15%) and aqueous sodium hydroxide (4N, 3.5 ml) gave 1-(d_5-benzoyl)-2-phenylethylene oxide (2.0 g, 95%), which crystallized as white plates from ethanol, m.p. 90-91.

(d) Treatment of 1-(d_5-benzoyl)-2-phenylethylene oxide (1.09 g) with a mixture of concentrated sulphuric acid and glacial acetic acid (1:1, 4 ml) by a reported procedure[122] gave d_5-benzoylphenyl-acetaldehyde (0.28 g, 28%), m.p. 112-113°. Purification of the product was achieved by chromatography over silicic acid. Eluting with light petroleum (b.p. 40-60°)/diethylether (97:3).

(e) Treatment[109] of d_5-benzoylphenylacetaldehyde (0.12 g) in glacial acetic acid (1.0 ml) with hydrazine hydrate (0.3 ml, 50%) gave 3-(d_5-phenyl)-4-phenylpyrazole (0.10 g, 60%) which crystallized from diethyl ether/light petroleum (1:1) as colourless needles m.p. 154-155°.

4-(d_5-phenyl)-3-phenylpyrazole (9c)

(a) d_8-Toluene (2.09 g) was converted[123] into d_7-benzylbromide (2.6 g

70%), b.p. 97-100°/35 mm Hg.

(b) The reaction[124] between d$_7$-benzylmagnesiumbromide (from d$_7$-benzyl-

bromide (2.6 g) and magnesium (0.36 g)) and benzaldehyde (1.51 g) in

sodium dry ether (6 ml) gave 2-d$_2$-2-(d$_5$-phenyl)-1-phenylethanol

(1.4 g, 70%), b.p. 134-140/1 mm Hg.

(c) 2-d$_2$-2-(d$_5$-phenyl)-1-phenylethanol (1.1 g) in acetone (10 ml) was

heated under reflux for 15 minutes with Jones reagent (1.6 ml).

Water (10 ml) was added, and the solution extracted with ether

(3x10 ml). The combined extracts were dried (Na$_2$SO$_4$), evaporated,

and distillation of the residue gave d$_7$-benzylphenylketone (1.0 g,

91%), b.p. 120-122/0.1 mm Hg.

(d) d$_7$-Benzylphenylketone (1.0 g) was added at 0°, with stirring to a

solution of sodium ethoxide (from sodium (0.12 g) and ethanol

(2 ml)) and ethylformate (0.33 g) which had been kept at 0° for

2 hours. The resultant solution was maintained at 4° for three

days, then poured into water (10 ml) acidified with dilute

sulphuric acid, and extracted with ether (3x10 ml). The combined

ether extract was washed with water, and dried (Na$_2$SO$_4$). After

removal of the solvent, the residue was chromatographed over

silicic acid eluting with benzene/light petroleum (b.p. 40-60°)

1:1 to yield benzoyl-(d$_5$-phenyl)-acetaldehyde (0.184 g, 23%) as

a pale yellow solid, m.p. 111-112°.

(e) Benzoyl-(d_5-phenyl)-acetaldehyde (0.10 g) was treated[109] with
hydrazine hydrate (0.30 g, 50%) to yield 4-(d_5-phenyl)-3-phenyl-
pyrazole (0.03 g, 30%) which crystallized from diethyl ether/
light petroleum (1:1) as colourless needles, m.p. 155-156°.

α,α-d_2-benzylphenylketoxime (22a)

(a) A solution of benzylphenylketone (3.0 g) and anhydrous potassium
carbonate (1.5 g) in deuterium oxide (15 ml) was heated under
reflux for 24 hours. The cooled mixture was extracted with
anhydrous ether (2x25 ml) and the combined extracts dried
(Na_2SO_4). Removal of the solvent and distillation of the product
gave α,α-d_2-benzylphenylketone (2.7 g, 90%), b.p. 120-125°/0.1 mm
Hg, m.p. 55-56. Measurement of the mass spectrum at just above
the appearance potential showed deuterium incorporation of d_2 = 95%,
d_1 = 4%, d_0 = 1%.

(b) A slurry of α,α-d_2-benzylphenylketone (0.50 g) and hydroxylamine-
hydrochloride (0.20 g) and pyridine (1.0 ml) in deuterium oxide
(5.0 ml) was maintained at 40-60° for two hours. The cooled
mixture was filtered at the pump, washed with water (2x2 ml) to
give α,α-d_2-benzylphenylketoxime (0.40 g, 80%) which crystallized
from hexane, m.p. 96-97°.

d_5-Benzylphenylketoxime (22b)

d_7-Benzylphenylketone (0.10 g) was converted[116] into d_5-benzyl phenylketoxime (0.10 g, 95%) which crystallized from hexane, m.p. 97-98°. Measurement of the mass spectrum at just above the appearance potential indicated $d_5 > 99\%$.

N-(d_1)-benzylphenylketoxime (22c)

A solution of benzylphenylketoxime (0.5 g) in benzene (5 ml) deuterium oxide (3 ml) was stirred at room temperature for 24 hours to give N-(d_1)-benzylphenylketoxime in quantitative yield. Mass spectrometry indicated the isotopic purity of (22c) to be $d_1 = 88\%$, $d_0 = 12\%$.

1-(^{13}C)-benzylphenylketoxime

(a) The reaction of 1-^{13}C-1,2,-diphenylethanol (0.10 g) with Jones reagent (as for (9c)) and purification by sublimation gave 1-(^{13}C)-benzylphenylketone, m.p. 54-55° in quantitative yield. A spectrum measured at just above the appearance potential indicated ^{13}C = 33.1%.

(b) 1-(^{13}C)-benzylphenylketone (0.01 g) was quantitatively converted[116] into 1-(^{13}C)-benzylphenylketoxime, m.p. 96-97° (from hexane).

APPENDIX I

APPENDIX I

Compound

3,5-diphenyl —	m/e	222	221	220	219	192	191
pyrazole (12)	RA(%)*	2	21	100 (M+)	5	5	23
		190	189	188	187	167	166
		5	9	2	2	2	2
		165	164	163	143	117	116
		7	3	2	3	3	11
		115	114	110	105	104	103
		4	4	8	3	13	2
		91	90	89	88	87	78
		4	10	11	3	3	3
		77	76	64	63	62	52
		22	4	4	10	4	4
		51	50	40	39	38	
		18	4	3	14	3	

3(5)-methyl-5(3)-	m/e	160	159	158	157	156	144
phenylpyrazole (14)	RA(%)	2	16	100 (M+)	39	3	3

* The abundance of all peaks of relative abundance 2% or greater in the spectra at 70 eV are recorded.

_m/e_	143	142	130	129	128	127
RA(%)	11	2	15	14	22	11
	126	118	117	116	115	114
	3	3	17	7	15	3
	104	103	102	91	90	89
	9	7	9	6	13	12
	88	87	79	78	77	76
	3	3	9	9	25	6
	75	74	65	64	63	62
	5	4	4	5	11	3
	56	55	54	52	51	50
	3	7	8	6	22	7
	39					
	5					

3(5)-methyl-1-phenylpyrazole (16)

_m/e_	160	159	158	157	156	143
RA(%)	2	13	100 (M+)	57	3	3
	132	131	130	129	118	117
	3	4	20	3	4	8
	116	115	104	103	91	90
	5	3	5	3	4	13
	89	79	78	77	76	65
	7	6	6	39	3	3

_m/e_	64	63	55	54	53	52
RA(%)	4	4	5	3	2	4
	51	50	42	39		
	21	5	2	5		

Ethyl 3-methyl-1-phenylpyrazole-5-carboxylate (18)

_m/e_	232	231	230	229	203	202
	2	17	100 (M+)	3	8	32
	186	185	183	159	158	157
	10	67	5	7	51	19
	156	155	144	143	142	131
	4	5	3	11	7	2
	130	129	128	118	117	116
	10	3	3	9	39	26
	115	104	103	91	90	89
	4	6	5	4	10	25
	78	77	76	63	62	53
	9	59	4	7	3	8
	52	51	50	43	42	41
	7	35	7	20	13	4
	39					
	12					

Ethyl 5-methyl-1-	*m/e*	231	230	202	187	186	185
phenylpyrazole-3-	RA(%)	10	50 (M+)	4	2	16	80
carboxylate (19)		184	183	145	144	143	142
		4	7	3	3	13	14
		131	130	129	118	117	116
		3	7	3	15	23	7
		104	103	93	92	90	78
		4	7	3	5	11	8
		77	76	63	62	61	51
		24	4	5	3	3	13
		39					
		5					

Benzylphenyl-	*m/e*	196	195	165	146	106	105
ketone (20)	RA(%)	6 (M+)	3	2	2	22	100
		102	91	90	89	78	77
		6	10	8	8	14	80
		76	65	63	62	51	
		10	9	7	2	25	

Benzoylphenyl —	*m/e*	224	223	196	178	167	165
acetaldehyde (21)	RA(%)	12	4	5	5	4	8
		146	119	118	106	105	102
		12	6	14	12	100	12

m/e	91	90	89	78	77	76
RA(%)	13	12	12	10	85	10
m/e	65	63	51	50		
RA(%)	11	10	24	4		

α,α-d$_2$-benzyl-phenylketoxime (22a)

m/e	214	213	212	211	197	196
RA(%)	17	67 (M+)	40	9	6	34
m/e	195	194	193	169	168	167
RA(%)	10	95	23	3	5	6
m/e	166	165	120	105	104	103
RA(%)	9	8	27	18	17	16
m/e	94	93	92	91	78	77
RA(%)	27	100	34	31	7	51
m/e	76	67	66	65	57	56
RA(%)	10	9	11	10	12	10
m/e	55	51	50			
RA(%)	5	10	5			

d$_5$-Benzylphenyl ketoxime (22b)

m/e	217	216	215	200	199	198
RA(%)	16	81 (M+)	8	8	4	90
m/e	197	196	183	182	172	171
RA(%)	21	5	5	4	4	4
m/e	170	169	168	121	120	119
RA(%)	9	8	3	10	21	11

_m/e_	105	104	103	97	96	95
RA(%)	3	10	21	32	100	25
	94	93	92	78	77	76
	8	11	5	7	49	6
	69	68	67	66	65	54
	14	14	2	3	4	4
	53	52	51	50	39	
	2	4	11	4	7	

N-(d$_1$)-benzyl-phenylketoxime (22c)

_m/e_	213	212	211	195	194	193
RA(%)	12	75	9	7	38	91
	192	167	166	165	164	121
	9	6	4	19	2	12
	120	105	104	103	92	91
	6	6	14	18	12	100
	90	89	78	77	76	66
	4	8	6	45	8	3
	65	64	63	51	50	
	24	4	12	20	8	

Diphenylaceto-nitrile (23)

_m/e_	195	194	193	192	191	190
RA(%)	2	17	100 (M+)	20	5	8
	178	177	167	166	165	164
	6	3	5	23	49	5

	m/e	153	152	139	117	116	115
	RA(%)	3	5	3	2	14	10
		114	91	90	89	88	87
		3	2	10	14	4	3
		83	77	76	65	63	62
		8	11	2	4	8	3
		51	50	39			
		18	5	6			
1,2-Diphenyl-2-H-azirine (24)	m/e	194	193	192	191	167	166
	RA(%)	17	100 (M+)	22	2	2	9
		165	164	118	104	103	91
		33	2	5	3	2	7
		90	89	77	76	64	63
		85	82	10	2	11	21
		62	56	51	50	43	41
		5	4	17	6	4	4
		40	39				
		4	13				
Diphenylacetoiso-nitrile (25)	m/e	194	193	192	191	190	168
	RA(%)	16	100 (M+)	15	6	9	7
		167	166	165	164	163	153
		60	53	91	6	2	4

_m/e_	152	151	139	116	115	114
RA(%)	16	3	6	15	13	4
	113	91	90	89	88	83
	3	3	12	19	16	7
	82	78	77	76	75	65
	6	13	13	6	5	6
	64	63	62	52	51	50
	3	13	6	6	22	7
	39					
	15					

APPENDIX II

APPENDIX II

I   STATISTICAL CALCULATION OF RANDOM HYDROGEN OR DEUTERIUM LOSS FROM

DEUTERATED DIPHENYLPYRAZOLES

For a molecule containing x atoms of H and y atoms of ^{2}H(D), i.e. HxDy which loses three atoms of H or D, successive loss of atoms are considered as dependent events such that -

$$\text{Probability of H loss} = \frac{\text{number of H}}{\text{Total H + D}} \quad \text{etc.}$$

$$\text{Probability of event } H_3 = \frac{x(x-1)(x-2)}{(x+y)(x+y-1)(x+y-2)} \times 1$$

$$H_2D = \frac{x(x-1)y}{(x+y)(x+y-1)(x+y-2)} \times 3$$

$$HD_2 = \frac{xy(y-1)}{(x+y)(x+y-1)(x+y-2)} \times 3$$

$$D_3 = \frac{y(y-1)(y-2)}{(x+y)(x+y-1)(x+y-2)} \times 1$$

i.e. Total Probability of Event = probability of event x

permutations of event

Thus for complete randomization of all H/D in d_5-phenyl-pyrazole derivatives the following results are obtained:-

H_7D_5

$$H_3 : H_2D : HD_2 : D_3 = 7 : 21 : 14 : 2$$

H_6D_5 (randomization of phenyl H/D + N-H)

$$H_3 : H_2D : HD_2 : D_3 = 4 : 15 : 12 : 2$$

H_5D_5 (randomization of phenyl H/D only)

$$H_3 : H_2D : HD_2 : D_3 = 1 : 5 : 5 : 1$$

II CALCULATION OF HYDROGEN OR DEUTERIUM LOSS FROM DEUTERATED DIPHENYL-PYRAZOLES USING HYDROGEN EXCHANGE MODELS BETWEEN PHENYL AND PYRAZOLE RING
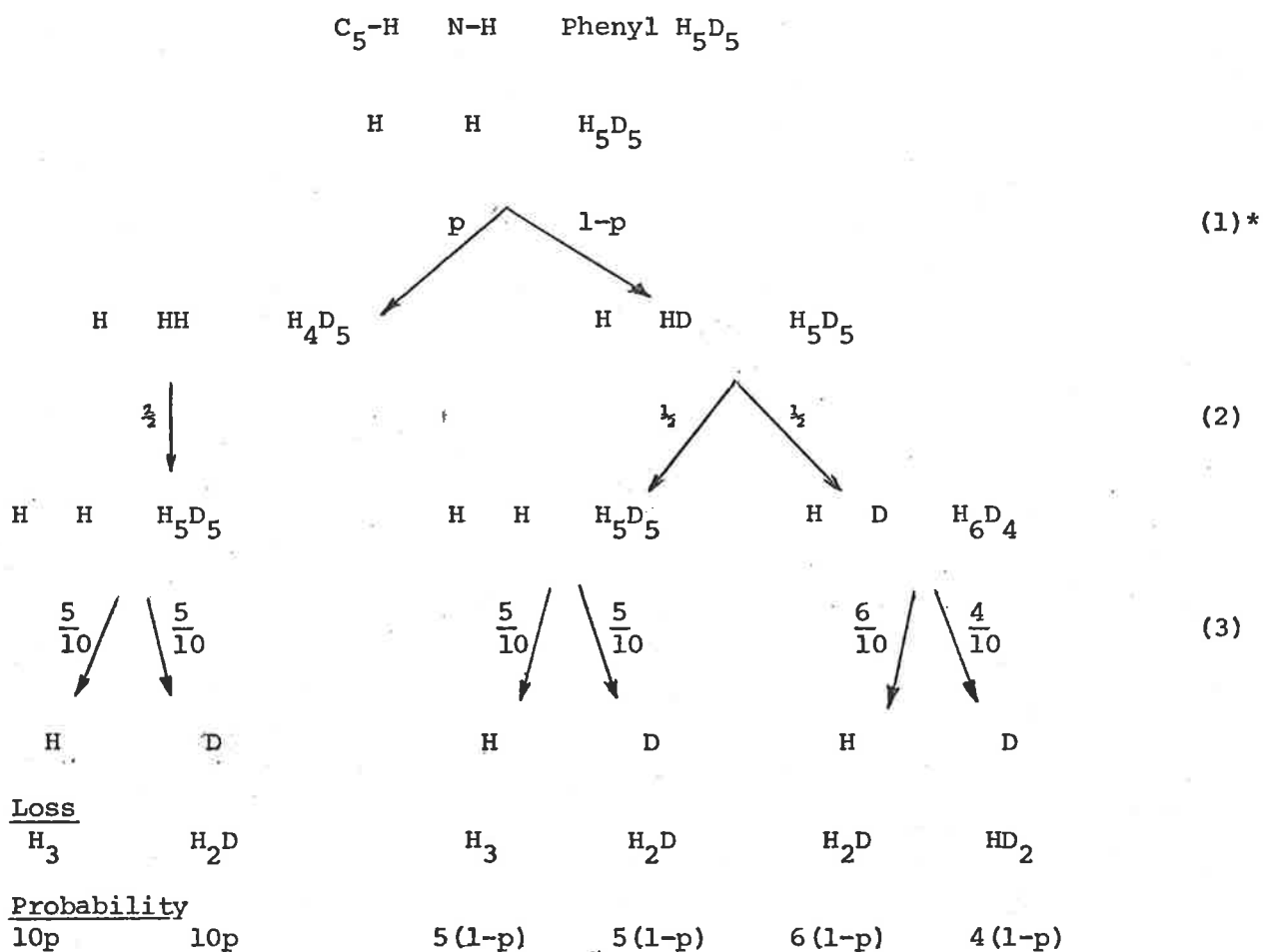
A fragmentation model is chosen and a fragmentation scheme including all possible transfers of H/D and loss of H/D from the phenyl rings is first drawn up. Parameters are then substituted for the probability variants of hydrogen loss P_H and deuterium loss P_D. Such that if the system is considered completely randomized, i.e. H/D distributed throughout the system H_5D_5, then $P_H = \frac{5}{10}$ and $P_D = \frac{5}{10}$ become $P_H = p$ and $P_D = 1-p$. Similarly, parameters may be included to account for back transfer and isotope effects in other models. In this way equations involving the parameter (s) can be calculated. By changing the value of the parameter different values for peaks corresponding to loss of HD_2, H_2D and H_3, (a, b, and c) are obtained for each value of p. These are then compared with the observed values A, B and C for $\underline{m/e}$ 168-170.

$$\text{Deviation} = (A - a)^2 + (B - b)^2 + (C - c)^2$$

Minimum deviation from observed values corresponds to minimum

deviation in all three peaks

(cf. Root mean square deviation $\overline{x}^2 = \sqrt{\dfrac{(x_1 - \overline{x})^2 + (x_2 - \overline{x})^2 \ldots (x_n - \overline{x})^2}{n}}$

e.g. Transfer to nitrogen with back transfer to phenyl without

randomization of pyrazole C-5 hydrogen

$$C_5\text{-H} \qquad \text{N-H} \qquad \text{Phenyl } H_5D_5$$

$$H \qquad H \qquad H_5D_5$$

Loss

| H_3 | H_2D | | H_3 | H_2D | H_2D | HD_2 |

Probability

| 10p | 10p | | 5(1-p) | 5(1-p) | 6(1-p) | 4(1-p) |

Substitute for values of p=0→1 to find peak ratios and %H or %D transfer.

$\underline{m/e}$ 170 - H_3 = 5 + 5 p $\underline{m/e}$ 169 - H_2D = 11 - p $\underline{m/e}$ 168 - HD_2 = 4 - 4p

(1)[*]   Substitute for probability of H transfer

(2)   Transfer either H/D to phenyl (no isotope effect)

(3)   Third atom lost randomly from phenyl rings.

In a similar way other mechanisms can be considered.

e.g. a)   randomization of C-5 hydrogen

     b)   exchange of ortho-H and N-H (no back transfer)

     c)   transfer from either of two ortho positions. This involves

three different parameters for H_2, HD or D_2 in those positions

and a grid plot to determine a minimum position for all

three. The result obtained is the same as for one ortho

position transferring hydrogen.

The use of additional parameters in each of these processes

enables estimation of isotope effects and also estimation of the

percentage of molecules not undergoing transfer processes. In both

cases there is no evidence to support the incidence of either isotope

effects or two pathways for fragmentation.

A second method of calculation of peak ratios follows much

the same reasoning as the estimations by probability of transfer.

Instead of assuming a randomized hydrocarbon H_5D_5 a partly randomized

3-phenyl ring of formula $C_6H_xD_{5-x}$ is used in the same fragmentation

scheme to calculate new equations for peak heights in terms of the

parameter x.

For the back transfer model illustrated above by this method

the equations become

m/e 170 - H_3 = 25 + 5x

m/e 169 - H_2D = 55 - x

m/e 168 - HD_2 = 20 - Hx

Values calculated and compared with observed values
by substituting for x = 0 → 5.

Similarly other models can be examined after calculation
of the necessary equations and if required other parameters for isotope
effects or specific processes can be added. However, the results
indicated that while it was possible to predict values very close
to the observed values as the number of variable factors increased
the prediction of randomization, isotope effect, specific transfer
all became less meaningful. For this reason the quoted results
(Table III) are those obtained from the use of a single parameter.
Either percentage H/D transfer or percentage randomization, this being
the most meaningful method of prediction.

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PUBLICATIONS

ELECTRON-IMPACT STUDIES—LIV:*

THE FORMATION OF $[C_{13}H_9]^+$ IN THE MASS SPECTRA OF BENZYL PHENYL KETOXIME AND 2,3-DIPHENYL-2-H-AZIRINE

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Abstract—The formation of m/e 165 in the spectrum of benzyl phenyl ketoxime involves the intermediacy of a rearranged 2,3-diphenyl-2-H-azirine radical ion. ^2H and ^{13}C labelling of the ketoxime together with ^2H labelling of the azirine has allowed certain proposals to be made concerning the complex processes producing m/e 165 in both spectra. The mode of formation of m/e 167 in the spectrum of benzyl phenyl ketoxime has also been studied.

The formation of m/e 165 ($[C_{13}H_9]^+$)† by skeletal-rearrangement processes has been observed in the spectra of a variety of compounds, including diphenyl heterocyclic systems,[2to8] stilbene and related species[9to12] and benzyl phenyl ketone derivatives.[13] Our studies in the heterocyclic series[5,8] have led to a search for intermediates in the rearrangement pathway. The most plausible of these is a rearranged 2,3-diphenyl-2-H-azirine radical ion, but to date the evidence,[8] although marginal, does not support an intermediate of this type. Our recent study[13] of the behaviour of benzyl phenyl ketoxime upon electron-impact showed, however, that m/e 165 was produced mainly from an $[M - H_2O]$ ion which did have the properties of the 2,3-diphenyl-2-H-azirine molecular ion.

	R¹	R²	R³
(IV)	H	H	H
(V)	D	H	H
(VI)	H	D	H
(VII)	H	H	D

(I) R = H
(II) R = D

(III)
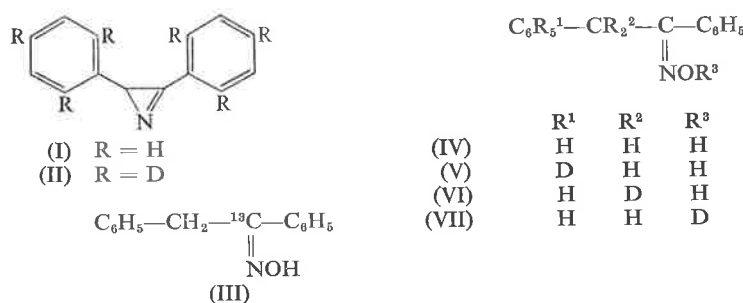
The aim of the present study was to investigate the processes leading to the formation of m/e 165 in the spectrum of the azirine (I). In order to do this, 2,3-di(2,4,6-d_3-phenyl)-2-H-azirine (II) was synthesised[cf.14] from *trans*-1,2-di(2,4,6-d_3-phenyl)ethylene. A derivative of I labelled with ^{13}C at a specific position in the azirine ring was also required. Unfortunately, the synthesis of such a compound could not be effected through a singly-labelled stilbene, as both the ring carbons in

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* For Part LIII, see Ref. 1.

† This ion is depicted as the fluorenyl cation and all mechanisms proposed in this paper are based on this formation. Alternative structures (e.g. the phenalenyl cation) are also possible. A study is now in progress which may distinguish between the possibilities in a variety of systems.

the product azirine would be labelled. We decided to synthesise the labelled oxime (III) and to prepare the labelled azirine molecular ion (III → a) in the mass spectrometer.* This paper now describes the fragmentation of I and the further information obtained (from the spectra of III to VII) concerning the complex rearrangements in the spectrum of IV.

$$(III) \quad \xrightarrow[-H_2O]{-e} \qquad \qquad \longrightarrow \quad \text{REARRANGEMENT}$$

$\cdot(a) \quad m/e$ 194
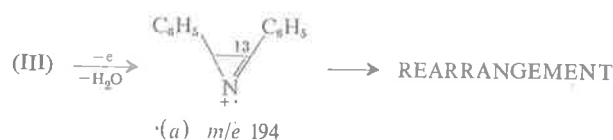
Before considering the fragmentations of the azirine (I) it is necessary to describe certain decomposition modes of the oxime (IV). The spectra of IV, VI and VII have already been reported,[13] and the partial spectra (corrected for isotope peaks) of III to VI at 70 and/or 15 eV are recorded in Figs. 1 to 2. The molecular ion of IV fragments
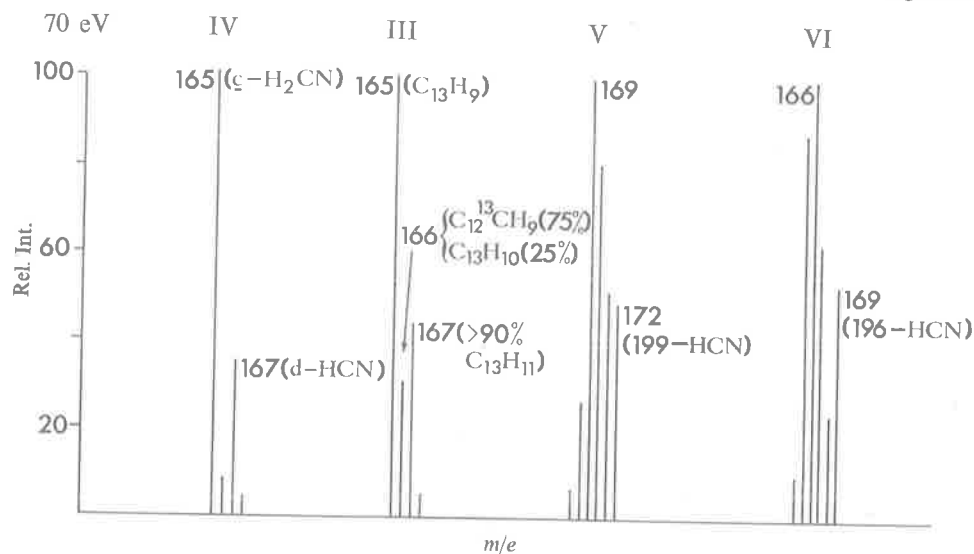
FIG. 1. 70 eV

by loss of water to produce the base peak of the spectrum (at 70 eV). This ion (c, m/e 193) is formed by the process $b \to c$.[13] In addition, the process [M — HO·] is noted. This decomposition is substantiated by a metastable peak (denoted by an asterisk in the text), and the fragment becomes more pronounced as the energy of the electron beam is decreased (see Figs. 1 and 2). The spectrum[13] of VII shows that this decomposition may be represented by the process $b \to d$. The ion c fragments to both the fluorenyl cation (g) and the fluorene ion radical (see below), but d loses HCN to

* The dangers of this method are appreciated. The argument rests on the assumption that m/e 193 in the spectrum of IV does correspond to either the intact or rearranged 2,3-diphenyl-2-H-azirine molecular ion. Our evidence at present supports this supposition.[13]
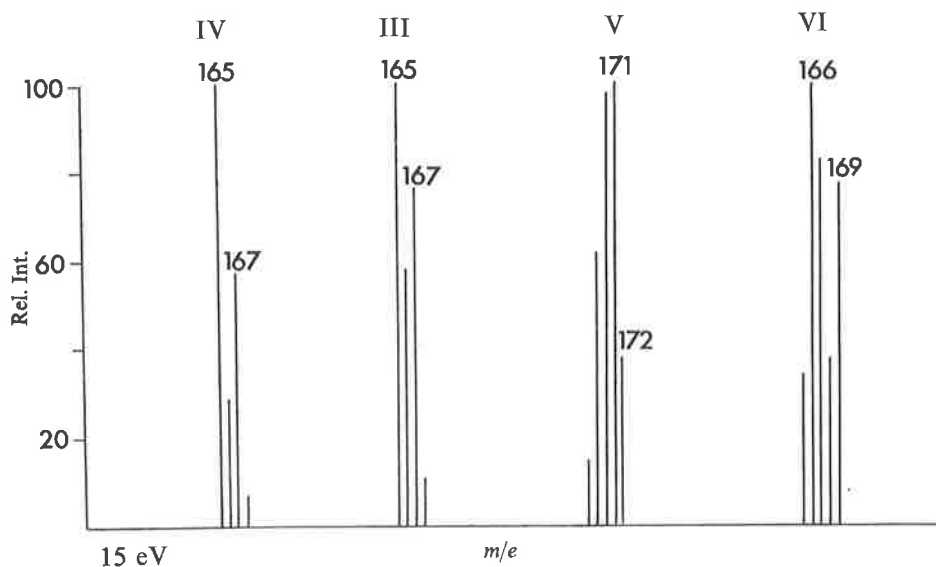
FIG. 2. 15 eV

yield m/e 167 (f). The abundance of f at 70 eV, is small compared with that of m/e 165, and we have shown[15] that f fragments by loss of hydrogen at 70 eV to yield g (relative abundance of $f:g$ is 10:1 at 70 eV), but that at 15 eV no formation of g from f is observed. We may conclude therefore that in the spectrum of the oxime (IV) m/e 167 does not produce m/e 165 to any significant degree, and that the process may be ignored for the following discussion.

(d) m/e 194   (b) m/e 201   (c) m/e 193

(e) m/e 194   —HCN C_7H_7 plus the other possibility

(f) m/e 167   —H$_2$ (g) m/e 165
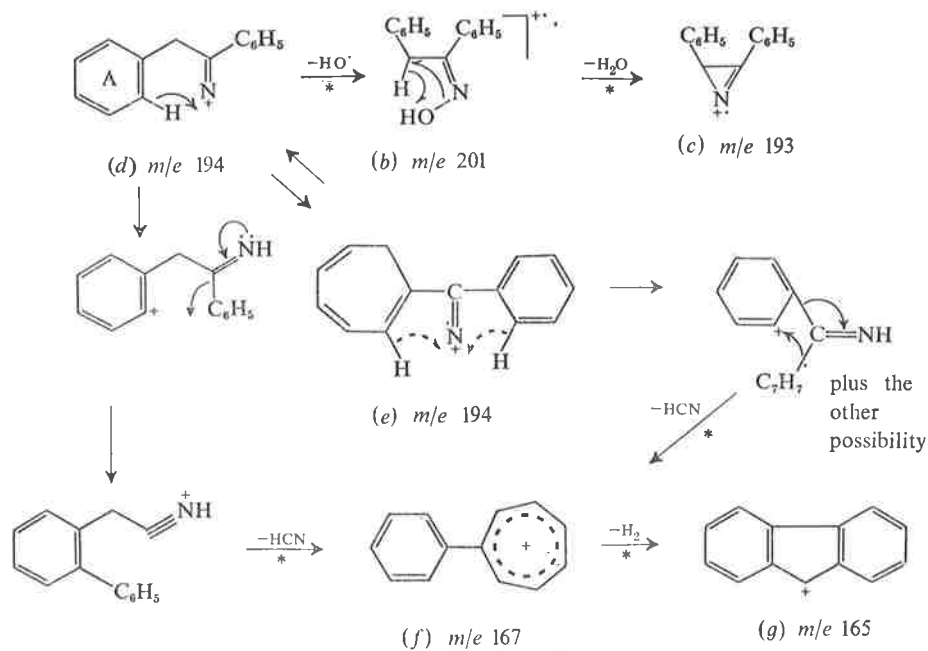
The partial mass spectra of III (33·1% ^{13}C at the carbon a to nitrogen) at 70 and 15 eV are recorded in Figs. 1 and 2. There is no shift of m/e 167 (>90% $C_{13}H_{11}$) to m/e 168 in the spectrum of III, proving that the carbon adjacent to nitrogen is specifically lost during the elimination of HCN from the [M − HO·] species. This result was not expected, and shows that a migration rather than a cyclization has occurred during the elimination. The partial spectra at 70 eV (Fig. 1) of the deuterium-labelled derivatives V and VI show that both compounds eliminate HCN and DCN from the [M − 17] species. Because the [(M − 17) − 28] peaks are due to losses of both DCN and H$_2$CN from the [M − 17] peak, we cannot calculate ratios for the relative processes [(M − 17) − HCN]/[M − 17) − DCN]. Even so, it is clear that a certain degree of randomization is occurring and we propose an intermediate of the type e to account for this observation. At 15 eV, a different mechanism operates. The spectra of V and VI show pronounced [(M − HO·) − DCN] and [(M − HO·) − HCN] peaks respectively. This can be explained by proposing an equilibrium between d and e, which will scramble the hydrogens of the A ring and the benzylic hydrogens, followed by hydrogen migration via a six-membered transition state and phenyl migration (cf. $d \rightarrow f$). Increased specificity of loss of HCN or DCN with decreasing energy of the electron beam has been noted previously, e.g. losses of DCN from 2,4,6-d_3-benzonitrile[16] and diphenyl-1-d_1-acetonitrile.[15]

There are a variety of ways in which HCN (and H$_2$CN) may be lost from the 2,3-diphenyl-2-H-azirine molecular ion. The carbon involved may be lost specifically from either of the two azirine ring positions, or it may be lost from both positions. Alternatively, there could be random loss of carbon over the whole molecule. The partial spectra (Figs. 1 and 2) of III distinguish between these possibilities. High resolution studies (at 70 eV) indicate that m/e 165 corresponds to [C$_{13}$H$_9$]$^+$ and that (80 ± 5%) of m/e 166 is [C$_{12}$ ^{13}CH$_9$]$^+$. When the abundance of the natural isotope is subtracted from m/e 166, the ratio of [C$_{13}$H$_9$]$^+$ (m/e 165) to [C$_{12}$ ^{13}CH$_9$]$^+$ (m/e 166) is 100:23. We have already shown that the fragmentation of m/e 167 to m/e 165 can be ignored at 70 eV. As a further approximation, we may neglect the decomposition of the C$_{13}$H$_{10}$ portion of m/e 166 [C$_{13}$H$_{10}$ has 7% relative abundance compared with m/e 165 (nominally 100%)] to m/e 165. This follows from the observation that the [M − 1] peak in the spectrum of fluorene has the same relative abundance as the molecular ion at 70 eV.[15] Consequently, the maximum contribution to m/e 165 in the spectrum of III would be 7%. When the accuracy of the mass measurement and the assumptions (above) are considered, the maximum error in the [C$_{13}$H$_9$]$^+$/[C$_{12}$ ^{13}CH$_9$]$^+$ ratio (at 70 eV) is (100 ± 8):(23 ± 10). The theoretical figures for no loss of label, and random loss of label are 100:50 and 100:46·5 respectively. As approximately 50% of the label is lost, each of the two original azirine ring carbons must be lost to an equal extent. This is indicative of fragmentation through a cyclized symmetrical species.

The spectrum (Fig. 3) of 2,3-di(2,4,6-d_3-phenyl)-2-H-azirine (II), at 70 eV, is extremely complex in the m/e 169 to 172 range. Losses of H· and D· from certain ions make interpretation difficult, but losses of HCN, DCN, H$_2$CN, HDCN and D$_2$CN from the molecular ion are noted. At a nominal 10 eV, two distinct and separate processes are observed in the spectrum of I, viz. [M − HCN] (to m/e 166) and [M − H$_2$CN] (to m/e 165). Both processes are substantiated by metastable peaks. The pronounced metastable ion at m/e 164·0 for the decomposition m/e 166 → 165
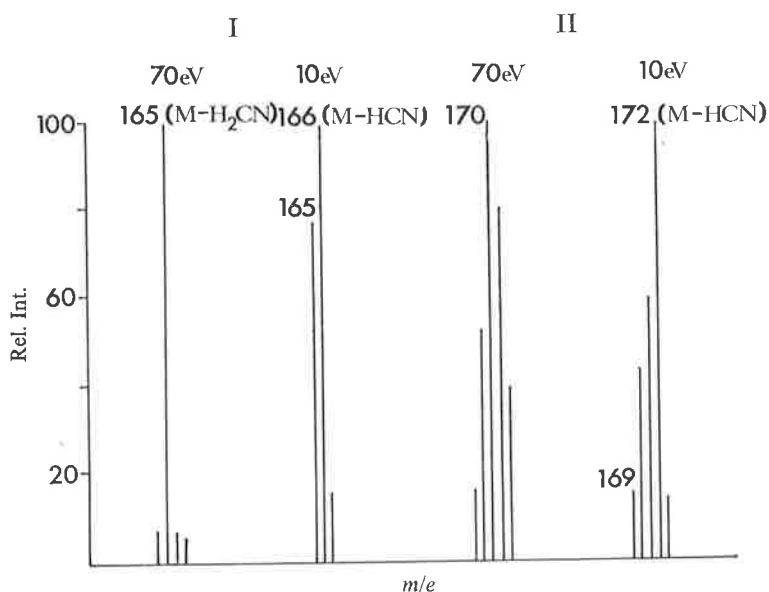
Fig. 3

disappears, however, at approximately 12 eV. We may assume therefore, that no loss of a hydrogen atom from m/e 166 occurs at 10 eV. After correction for isotope peaks, the ratio of m/e 169:170:171:172 at 10 eV, in the spectrum of II, is 7:21·5:28·5: 43, and m/e 165:166 in that of I is 45:55. The peak at m/e 171 in the spectrum of II is produced by loss of both DCN and H_2CN from the molecular ion. By utilizing the abundances of the peaks in the unlabelled compound, the ratio for II may be corrected to m/e 169:170:171:172 equals $7[M - D_2CN]:21·5[M - HDCN]:16·5[M - H_2CN] + 12[M - DCN]:43[M - HCN]$. At 10 eV, there is then a 78% loss of HCN and a 22% loss of DCN from the molecular ion of II, and if hydrogen scrambling within phenyl rings is taken into account, 63% of the hydrogen originates from the azirine ring with 37% coming from the phenyl rings. It is not possible to decide whether this means that there are two distinct losses of HCN or whether there is only one process which is preceded by a small amount of hydrogen randomization. We have previously suggested that k may account for the rearrangement peaks in the spectrum of I. The results obtained at 10 eV do not support a species of this type, and it seems that the elimination of HCN may be predominantly occurring through an intermediate of the type i (or perhaps j).

Losses of H_2CN, HDCN and D_2CN from the molecular ion of II are observed at 10 eV. There may be several ways in which these species may be eliminated. First, the losses of H_2CN, HDCN and D_2CN may be independent of the losses of HCN and DCN. If this is so, complete randomization may precede the eliminations. The ratio $[M - D_2CN]:[M - HDCN]:[M - H_2CN]$ should then equal 25:50:25 (found 15:49:36). Alternatively, the losses of H_2CN, HDCN and H_2CN may be intimately coupled with the losses of HCN and DCN. On this basis, specific loss of the azirine hydrogen together with random loss of H/D should constitute 63% of the overall process, while the remaining 37% should be completely random. This gives a
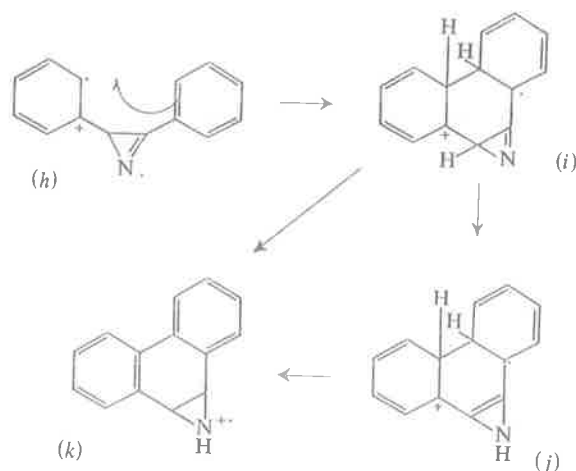
calculated ratio for $[M - D_2CN]:[M - HDCN]:[M - H_2CN]$ of $13:52:35$ in excellent agreement with the observed ratio $15:49:36$.

In summary, if it is assumed that the $[M - H_2O]$ species in the spectrum of benzyl phenyl ketoxime corresponds to the 2,3-diphenyl-2-H-azirine ion radical, then the elimination of H_2CN from the 2,3-diphenyl-2-H-azirine molecular ion involves a cyclization process followed by equal loss of either carbon of the original azirine ring. At 10 eV, the same intermediate(s) is(are) responsible for the elimination of both HCN and H_2CN, with both losses predominantly involving the hydrogen initially attached to the azirine nucleus.

EXPERIMENTAL

All mass spectra were determined with an Hitachi Perkin–Elmer RMU-6D double focusing mass spectrometer operating either at 70 eV or 15 eV. Exact mass measurements were performed with an AEI MS-902 instrument with a resolution of 20,000. The spectra of the oxime derivatives (III to VII) were determined after introduction via the all-glass heated inlet system at 100°. The spectra of the azirines (I and II) were measured using the 'direct-insertion' procedure with the sample heater maintained at 70°. The spectra of I and II cannot be measured at temperatures greater than 150°, as under these conditions isomerization to 2-phenylindole occurs.[17]

Compounds (IV to VII) were available from the previous study.[13] The ^{13}C labelled derivative (III) was prepared from α-^{13}C-benzaldehyde (33·1% [13]C) and benzylmagnesium bromide, followed by oxidation of the alcohol with Jones reagent and treatment of the ketone with hydroxylamine hydrochloride (overall yield 50% from benzaldehyde).

2,3-Di(2,4,6-d_3-phenyl)-2-H-azirine (II). 2,4,6-d_3-Benzaldehyde[18] was converted[19] into d_6-benzoin in 90% yield. Treatment of d_6-benzoin with zinc and acetic acid[20] gave trans-1,2-di(2,4,6-d_3-phenyl)-ethylene ($d_5 = 6$, $d_6 = 94\%$) in 70% yield. The d_6-stilbene was converted[14] into II in an overall yield of 20%. 2,3-Di(2,4,6-d_3-phenyl)-2-H-azirine crystallized from hexane as colourless needles m.p. 69 to 71°.

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ELECTRON IMPACT STUDIES—XLIX[1]

THE $C_{13}H_9$ SKELETAL-REARRANGEMENT FRAGMENT IN THE MASS SPECTRA OF BENZYL PHENYL KETONE DERIVATIVES

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Abstract—The spectra of benzyl phenyl ketone derivatives contain ions at m/e 165 ($C_{13}H_9$) which are produced by skeletal-rearrangement processes. The rearrangement peak is most pronounced in the spectrum of the oxime of benzyl phenyl ketone where it arises mainly from an $M—H_2O$ species. Deuterium labelling studies and metastable characteristics are consistent with the $M—18$ species having the properties of a 2,3-diphenyl-2-H-azirine molecular ion.

THE formation of m/e 165 ($C_{13}H_9$) by skeletal-rearrangement processes has been observed in the mass spectra of stilbene and related compounds,[2-6] 9,10-dihydrophenanthrene,[4-6] and a variety of diphenyl heterocyclic systems.[4, 7-12] As a continuation of this work, we have examined the spectra of the benzyl phenyl ketone derivatives (**1–11**) in order to see whether ions at m/e 165 (best represented as the fluorene cation) occur, and to study the modes of formation of any such rearrangement species.

$$C_6H_5—C—CH—C_6R^1_5$$
$$\underset{O}{\overset{\|}{}}\ \underset{R^2}{\overset{|}{}}$$
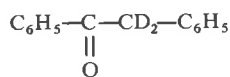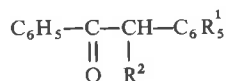
1: $R^1 = H$, $R^2 = H$
2: $R^1 = D$, $R^2 = H$
3: $R^1 = H$. $R^2 = CHO$

$$C_6H_5—C—CD_2—C_6H_5$$
$$\underset{O}{\overset{\|}{}}$$

4

$$C_6H_5—C—CH_2—C_6R^1_5$$
$$\underset{NOR^2}{\overset{\|}{}}$$
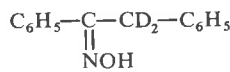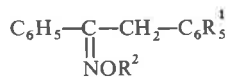
5: $R^1 = H$, $R^2 = H$
6: $R^1 = H$, $R^2 = D$
7: $R^1 = D$. $R^2 = H$

$$C_6H_5—C—CD_2—C_6H_5$$
$$\underset{NOH}{\overset{\|}{}}$$

8
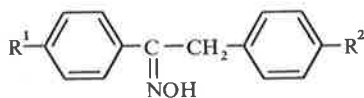
9: $R^1 = MeO$, $R^2 = H$
10: $R^1 = H$. $R^2 = MeO$
11: $R^1 = Me_2N$, $R^2 = Me_2N$

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TABLE 1. FORMATION OF m/e 165 IN THE SPECTRA OF **1, 3, 5** AND **9–10**
(All processes are substantiated by metastable peaks)

Compound	Processes producing m/e 165	Abundance of m/e 165 (%)
1	M—H·—CO—H$_2$	2
3	M—CO—H·—CO—H$_2$	8
5	M—H$_2$O—HCN—H· (see below)	20
9	M—H$_2$O—CH$_2$O—HCN—H·	8
10	M—H$_2$O—CH$_2$O—HCN—H·	4

All the spectra except that of **11**, contain an ion at m/e 165. The abundances of this ion and the processes producing it are recorded in Table 1. The all-over process for the formation of m/e 165 in the spectrum of benzyl phenyl ketone (**1**) is M—CH$_3$O. The three H atoms involved in this rearrangement come almost randomly from the whole molecule as evidenced by the spectra of **2** and **4**. For example the peak at m/e 165 in the spectrum of **1** is shifted to 165, 166 and 167 in that of **4**. The observed ratio of the abundances of 165/166/167 is 2 : 10 : 12, in reasonable agreement with the theoretical ratio (for random loss of three H atoms) 1 : 9 : 12.

The rearrangement is most pronounced (Table 1) in the spectrum (Fig. 1) of the oxime (**5**), and decreases predictably as substituents are placed on the aromatic rings (e.g. **9–11**, Table 1). The genesis of m/e 165 in the spectrum of **5** has been studied by deuterium labelling and by the application of metastable characteristics.[13–19]

There are three processes which give rise to m/e 165 in the spectrum of **5**; viz. (i) M—H$_2$O—HCN—H·; (ii) M—H$_2$O—H$_2$CN, and (iii) M—HO·—HCN—H$_2$. All eliminations are substantiated by metastable peaks (represented by an asterisk in a Fig. or in the text). The 70 eV spectra of the labelled compounds **6, 7** (Fig. 1) and **8** show the loss of water from the molecular ion to be hydrogen-specific, involving the OH group and a benzylic hydrogen. This is of particular interest and indicates that hydrogen randomization does not precede this elimination, although the spectra of and **8** show that the production of the d_2- and d_5-tropylium cations (m/e 93 and 96 respectively) does proceed with hydrogen scrambling of the phenyl and benzylic hydrogens and/or deuteriums, (cf. fragmentation of the labelled ethylbenzenes[20]). Two possible structures may now be written to account for the formation of m/e 165 (**c**) from the M—H$_2$O species, i.e. **5→a→c** and **5→b→c**.
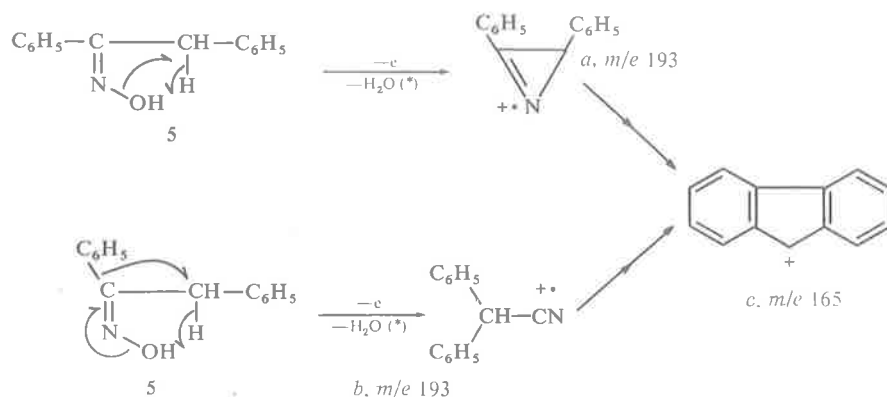
The partial spectra of 2,3-diphenyl-2-H-azirine[21] (12) and diphenylacetonitrile (13) are recorded in Fig. 2. Both spectra contain pronounced peaks at m/e 165, and to determine whether a or b corresponds to the M—H_2O species in the spectrum of 5, the ratios of the abundances of the metastable peaks for the 193→166 transitions, to the abundances of m/e 166 have been compared at various energies of the electron beam for all spectra (Table 2). In addition, metastable profiles are illustrated in Figs. 3 and 4. The metastable peak shapes in the m/e 140–144 regions in the spectra of the oxime 5 and the nitrile (13) are quite different, as are the ratios of m/e 166/m* in both spectra. The M-18 species therefore does not correspond to b.

TABLE 2†. RATIOS OF THE RELATIVE ABUNDANCES OF m/e 166 TO THE METASTABLE PEAK AT m/e 142·8 (193→166) IN THE SPECTRA OF 5 AND 12–14

Compound	70 eV	40 eV	30 eV	20 eV	15 eV
Oxime (5)	31	29	27	23	17
Azirine (12)	40	39	37	32	24
Nitrile (13)	74	72	70	64	49
Isonitrile (14)	140	132	118	97	73

† The m/e 165 isotope peak has been substracted to give the correct abundance of m/e 166. Experimental error in the m/e 166/m* ratio is ±5%, calculated from an average of ten measurements.

The corresponding metastable shapes in the spectra of 5 and 12 are similar, except that three metastable peaks are observed for 5 and only two for the azirine (12). The additional metastable peak (m/e 143·8) in the spectrum of 5 is that for the m/e 194 (M—HO·) → 167 elimination, a process which cannot occur for 12. The m/e 166/m* ratios do not agree within experimental error, but the discrepancy is small enough to be accounted for by the presence of the third metastable ion (in the spectrum of 5) which would have the effect of slightly increasing the abundance of the metastable peak at m/e 142·8 (m*). It appears reasonable to propose that those portions of the M-18 species (of 5) and of the 2,3-diphenyl-2-H-azirine molecular ion which give rise to m/e 166 and 165, have the same structure. Although a is probably produced initially in both cases, it is unlikely to be the species which eliminates HCN, and we will provide evidence (below) to show that m/e 166 and 165 are produced from a rearranged 2,3-diphenyl-2-H-azirine molecular ion, possibly e or a tautomeric structure.

J. H. Bowie *et al.*

$a \longrightarrow$ *e. m/e* 193
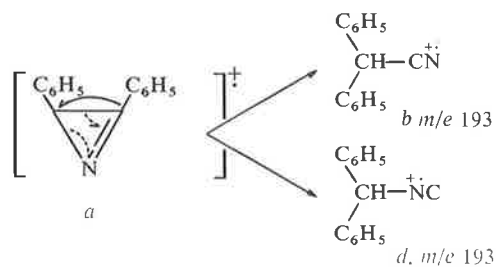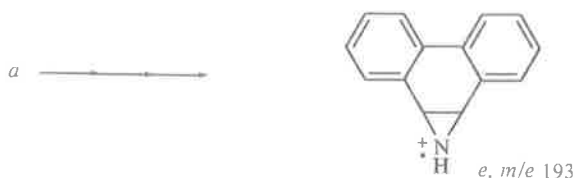
There are two general mechanisms for loss of HCN from *a*. One involves a cyclization of the type proposed to explain the formation of *c* from 4,5-diphenylimidazole,[5] or perhaps stilbene.[2,6] The other involves specific phenyl migration. Phenyl migration may produce either the nitrile (*b*) or isonitrile (*d*) radical ions. Comparison of the metastable characteristics (above) preclude the intermediacy of the diphenylacetonitrile radical ion (*b*), and a similar comparison with the corresponding isonitrile (Table 2 and Fig. 4) shows that it is not involved in the rearrangement. A cyclization mechanism is therefore favoured, but ^{13}C labelling would be necessary to prove that a cyclic intermediate (e.g. *e*, or a tautomeric structure) accounts for the formation of the fluorene cation.
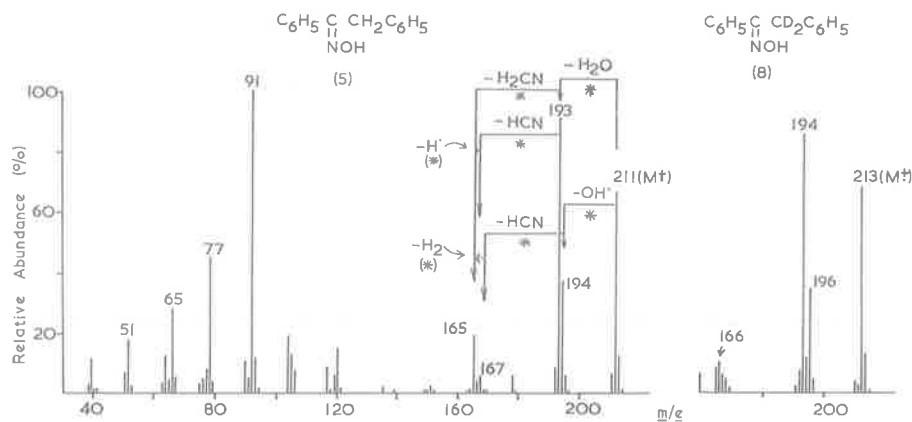
FIG. 1
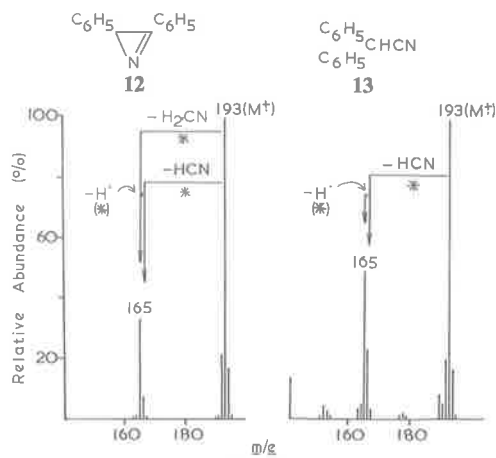
FIG. 2
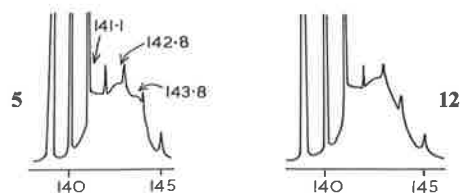
FIG. 3
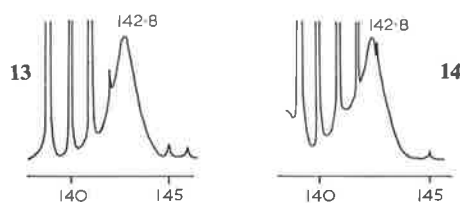
FIG. 4

EXPERIMENTAL

Mass spectra were determined with an Hitachi Perkin–Elmer RMU 6D double-focusing mass spectrometer operating at 70 eV (unless otherwise specified). Samples were introduced through an all glass heated inlet system at approximately 100°.

All unlabelled compounds were prepared by known procedures. Compound 2 was prepared by the reaction of $d_7$benzylmagnesium bromide with benzaldehyde, followed by Jones oxidation to the d_7-ketone. The d_7-ketone was heated under reflux in water containing sodium carbonate for 24 hr producing 2 (>95% d_5).

Compound 4 was prepared by heating benzyl phenyl ketone under reflux in D_2O containing Na_2CO_3 (isotopic purity of 4 > 95% d_2).

Compound 6 was prepared by stirring a benzene solution of 1 with D_2O for 24 hr (isotopic purity of 6, $d_0 = 12$, $d_1 = 88$%). Introduction of 5 directly into the source with D_2O^{22} produced a d_1-derivative.

Compounds 7 and 8 were prepared by treating 2 and 4 respectively with hydroxylamine hydrochloride.

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ELECTRON-IMPACT STUDIES—L:*

SKELETAL-REARRANGEMENT FRAGMENTS IN THE MASS SPECTRA OF DIPHENYLPYRAZOLES AND -ISOXAZOLES

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Abstract—The mass spectra of all diphenylpyrazoles and -isoxazoles contain rearrangement peaks at m/e 165 $[C_{13}H_9]^+$. In addition, the spectra of 3,5-diphenylisoxazoles contain peaks at m/e 180 $[C_{13}H_{10}N]^+$, which are produced by specific phenyl migrations. The mechanisms of both rearrangement processes have been studied by deuterium labelling.

THE EXTENSIVE rearrangement processes which occur in the mass spectra of aryl and alkyl-imidazoles,[2] oxazoles,[2 to 5] thiazoles[2] and isoxazoles[6] have been discussed. A report[7] of the formation of m/e 165 in the spectra of diphenylpyrazoles has appeared, but the mechanism of the rearrangement was not studied by deuterium labelling. The differences between the spectra of oxazoles and isoxazoles have been outlined[6] and it has been suggested[6,8,9] that the molecular ion interconversions [isoxazole]$^{+\cdot}$ $\rightleftarrows$ [azirine]$^{+\cdot}$ $\rightarrow$ [oxazole]$^{+\cdot}$ may account for many fragment ions in the mass spectra of substituted isoxazoles. The formation of m/e 165 by rearrangement processes is also noted in the spectra of 2,5-diphenyl-1,2,4-oxadiazole,[10] 4,5-diphenyl-2-pyrone,[11] 3,4-diphenyl-4,5-epoxy-2-cyclopenten-1-one,[13] stilbene and related compounds,[2,12,13,14] 9,10-dihydrophenanthrene[12,15] and benzyl phenyl ketone derivatives.[1]

(a) (b) (c)

$-C_2H_3N_2^{\cdot}$
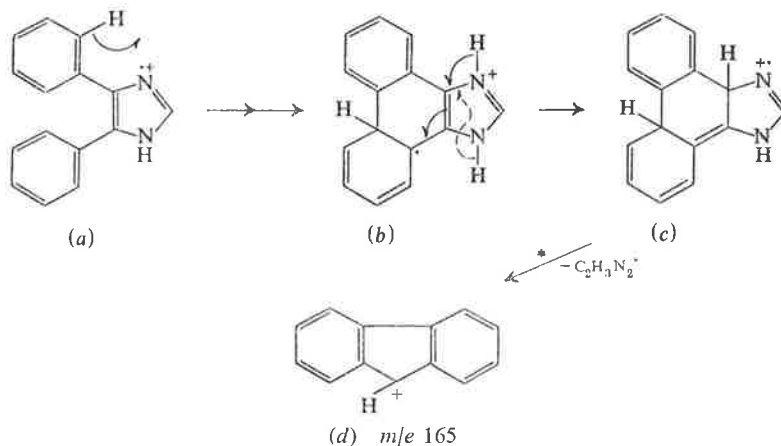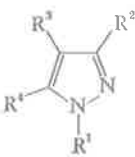
(d) m/e 165

We have previously shown[2] that a double hydrogen transfer and randomization of hydrogens within each phenyl ring precedes the formation of $d(m/e\ 165)$ from the

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molecular ion of 4,5-diphenylimidazole. One possible mechanism for this rearrangement is $a \rightarrow d$.[2] Similar rearrangements in the spectra of diphenylpyrazoles and -isoxazoles were noted previously[2] and the present investigation (outlined below) was planned in order to (a) investigate the scope of the rearrangement in pyrazoles and isoxazoles and (b) to determine the mechanism of the rearrangement for the unsymmetrical 3,4-diphenylpyrazole and the corresponding isoxazoles.

		R^1	R^2	R^3	R^4
	(I)	H	C_6H_5	C_6H_5	H
	(II)	D	C_6H_5	C_6H_5	H
	(III)	H	C_6D_5	C_6H_5	H
	(IV)	H	C_6H_5	C_6D_5	H
	(V)	H	C_6H_5	H	C_6H_5
	(VI)	D	C_6H_5	H	C_6H_5

		R^1	R^2	R^3
	(VII)	C_6H_5	C_6H_5	H
	(VIII)	C_6H_5	H	C_6H_5
	(IX)	C_6H_5	D	C_6H_5
	(X)	C_6H_5	I	C_6H_5
	(XI)	H	C_6H_5	C_6H_5
	(XII)	H	C_6H_5	C_6D_5
	(XIII)	C_6H_5	C_6H_5	C_6H_5
	(XIV)	$C_6H_2D_3$	C_6H_5	C_6H_5
	(XV)	C_6H_5	$C_6H_2D_3$	C_6H_5

Selected mass spectra of I to XV are illustrated in Figs. 1 to 8, and the abundances of rearrangement peaks are summarized in Table 1. The compositions of all ions produced by skeletal-rearrangements in the spectra of the unlabelled compounds have been established by exact mass measurements. The presence of an appropriate metastable peak is depicted by an asterisk in either a figure or the text.

It can be seen from Table 1 that the abundance of $d(m/e\ 165)$ is large when the

TABLE 1. RELATIVE ABUNDANCES (%) OF m/e 165 (d) IN THE SPECTRA OF DIPHENYLPYRAZOLES AND -ISOXAZOLES

Compound	% d	Compound	% d
(I)	21	(X)	2
(IV)	7	(XI)	36
(VII)	42	(XIII)	20
(VIII)	4		

two phenyl groups are adjacent and minimal when they are 1,3 to each other. This is in accord with previous observations of diphenylimidazoles and oxazoles.[2] The spectra of 3,4-diphenylpyrazole (I) and the labelled derivatives (II to IV) are illustrated in Figs. 1 to 3. It was anticipated that transfer of a hydrogen atom would proceed to charged nitrogen and that back transfer of either hydrogen on nitrogen to some radical centre in the hydrophenanthrene unit should follow the cyclization process (e.g. $e \rightarrow d$), but that because 3,4-diphenylpyrazole is unsymmetrical (unlike 4,5-diphenylimidazole) that the hydrogen transferred to nitrogen should come specifically from the 3-phenyl ring, viz. $e \rightarrow f$.
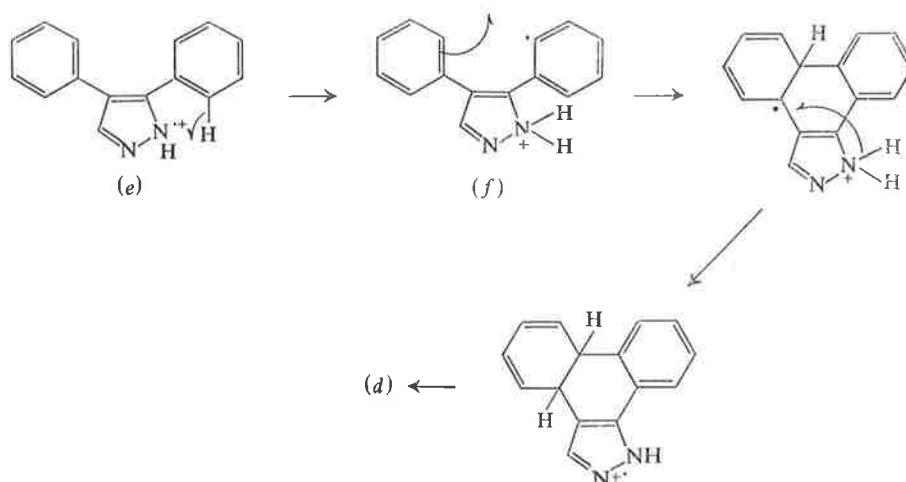
There are several possibilities which may either preclude or make unrecognizable the specific transfer of hydrogen or deuterium from the 3-phenyl system in a labelled derivative. First, the 3,4-diphenylpyrazole molecular ion may rearrange to the 4,5-diphenylimidazole molecular ion. Second, hydrogen/deuterium randomization on the two phenyl rings may precede the transfer. Third, hydrogen transfer may proceed from both the 3- and 4-phenyl rings.
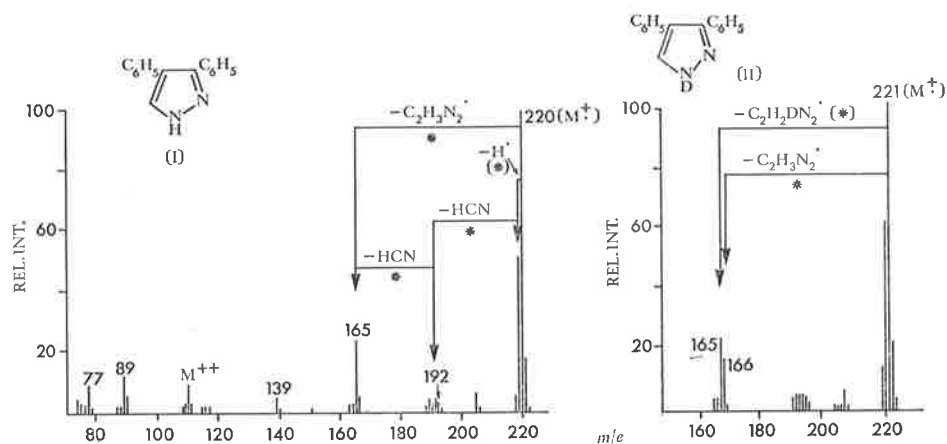

FIG. 1

Careful analysis of the spectra of the labelled derivatives allow certain proposals to be made. The ratio of the abundances (corrected for ^{13}C isotope peaks) of the m/e 165/166 ions in the spectrum of II is $1.37:1$ at 15 eV. The theoretical ratio obtained, assuming hydrogen transfer to nitrogen followed by back transfer of either hydrogen or deuterium is $1.22:1$. Ratios obtained for (a) the double hydrogen transfer process, but with scrambling of the H and D on nitrogen with the hydrogen at C-5 before the back transfer, and (b) for completely random loss of three hydrogens/deuterium are
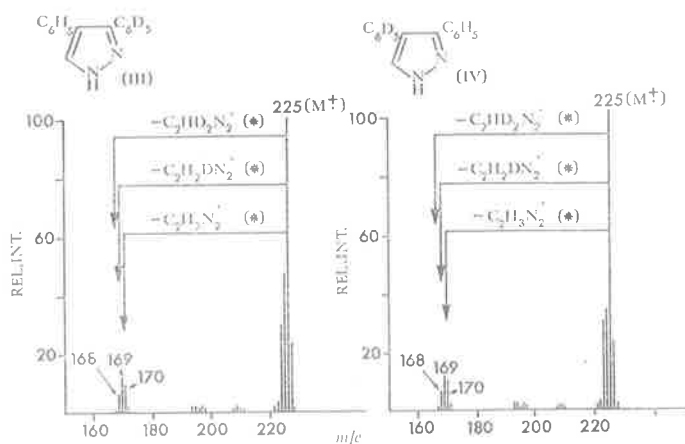
FIG. 2
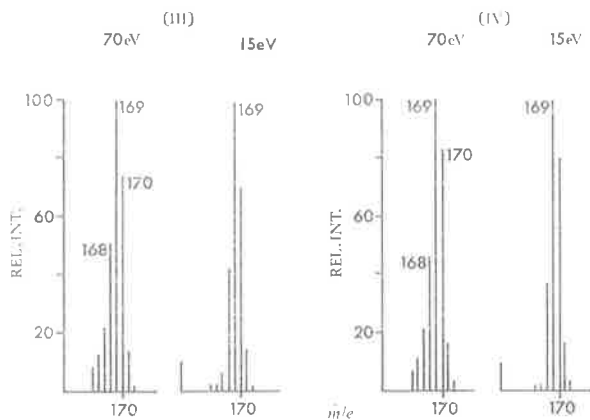
FIG. 3

2·3:1·0 and 3·0:1·0 respectively. These ratios show that after the initial hydrogen transfer to nitrogen that specific back transfer occurs. No randomization of the hydrogen/deuterium on nitrogen with any other hydrogen is observed. This is in accord with previous observations of diphenyloxazoles labelled with deuterium on the oxazole ring.[2]

The spectra (Figs. 2 and 3) of III and IV also show that the double hydrogen transfer does occur. The peaks in the m/e 168 to 170 region in the spectra of III and IV are qualitatively similar, indicative of either a symmetrical molecular ion, or of considerable randomization of the ten hydrogens/deuteriums of the phenyl rings, or of hydrogen transfer from either phenyl ring. There are two processes producing m/e 165 in the spectrum of I. A concerted process, substantiated by a metastable peak, produces the rearrangement ion directly from the molecular ion. A second process, M—H·—HCN—HCN, produces m/e 165 in a stepwise manner. At 70 eV both processes occur, but at 10 to 15 eV the stepwise process becomes minor in comparison to the concerted

process. Our arguments concerning abundance ratios will consequently be restricted to measurements at 15 eV, where it is assumed that the concerted formation of m/e 165 is the major process.

A detailed study* of the metastable peak shapes for the $220 \rightarrow 165$ and stepwise $220 \rightarrow 219 \rightarrow 192 \rightarrow 165$ processes in the spectra of I and 4,5-diphenylimidazole, and of the ratios of the abundances of the metastable ion at m/e 123·7 ($220 \rightarrow 165$) and m/e 165, and m/e 168·3 ($219 \rightarrow 192$) and m/e 192, shows that the daughter ions in the spectra of I do not have the properties of those in the spectrum of 4,5-diphenylimidazole. It is concluded that if the conversion $e \rightarrow a$ does occur, then it is only a minor process.

TABLE 2. RATIOS OF ABUNDANCES (CORRECTED FOR ^{13}C ISOTOPES) OF m/e 168 TO 170 IN THE SPECTRA OF (III) AND (IV) AT 15 AND 70 eV

eV	(III) Observed	Calculated 168:169:170	(IV) Observed 168:169:170
70	35:100:71	19:100:72	29:100:83
15	46:100:60		40:100:70

The ratios of the abundances of the m/e 168, 169 and 170 peaks in the spectra of III and IV are recorded in Table 2. If we now assume that the rearrangement process involves complete randomization of the five hydrogens and five deuterium atoms (cf. scrambling of the hydrogens in stilbene[14] and diphenyl[21]), followed by transfer of a hydrogen/deuterium atom to nitrogen (cf. e–also ignoring possible deuterium isotope effects) followed by specific back transfer of hydrogen/deuterium to the rearrangement centre ($f \rightarrow d$), with specific loss of HCN and random loss of HCN/DCN, a theoretical value of 19:100:72 for the $[M-C_2HD_2N_2]$, $[M-C_2H_2DN_2]$ and $[M-C_2H_3N_2]$ concerted processes of III and IV is obtained (these values are the same as those which should be observed if hydrogen is transferred equally from both phenyl rings). The observed ratios are outlined in Table 2. Bearing in mind that the stepwise process does occur (especially at 70 eV), these ratios are not inconsistent except that the process $[M-C_2HD_2N_2]$ is more pronounced than expected. This may indicate the operation of a small deuterium isotope effect. Computer calculations show that the observed ratios deviate more from the theoretical when the amount of initial randomization is less than 90%. Nevertheless, complete randomization does not occur, as the observed ratios (Table 2) and abundances (Fig. 3) show that the process $[M-C_2H_3N\cdot]$ is slightly more pronounced (and $[M-C_2HD_2N\cdot]$ less pronounced) in the spectrum of IV than in that of III. This must mean that at least *some* preferential hydrogen transfer occurs from the 3-phenyl substituent. Recalculation of the abundance ratios in the 15 eV spectrum of 4,5-di(2,4,6-d_3-phenyl)imidazole[2] also shows that complete randomization does not occur, and that some preferential transfer of the four *ortho* deuteriums occurs. We conclude that when 3,4-diphenylpyrazole is

* The theoretical background of this method has been described,[16,17] and its application widely used.[1,18,19,20] An analogous method to that used for this determination has been described.[1] The results have not been tabulated as no information can be gained from the figures except that there is no correlation of peak ratios. In all cases cited in this paper the abundance ratios of metastable and daughter ions being compared in various spectra were in error by a factor of more than 1:1·5.

subjected to electron-impact, that either unspecified (and incomplete) randomization of hydrogens of both phenyl rings precedes preferential hydrogen transfer to nitrogen from the 3-phenyl ring, with the further transfer and eliminations proceeding as outlined above, or alternatively that no hydrogen scrambling occurs between the phenyl rings but that hydrogens may be transferred from both the 3- and 4-phenyl rings with a slight preference for transfer from the 3-phenyl group. Of the two possibilities, we prefer the former.
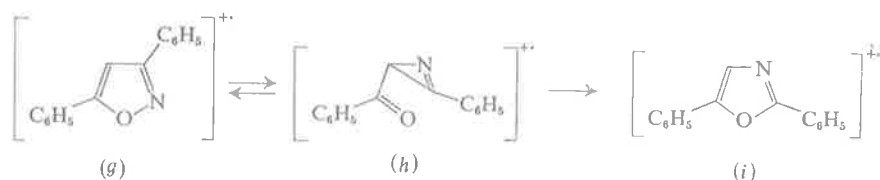
The rearrangement processes in the spectra of di- and triphenylisoxazoles are illustrated in Figs. 4 to 8, and are analogous to those observed in the spectra[2] of the corresponding diphenyloxazoles. It has been proposed[9] that the isoxazole → oxazole conversion, (e.g. $g \rightarrow i$) may account for the formation of d in the spectrum of 3,5-diphenylisoxazole. There is a qualitative correlation between the rearrangement ions in the spectra of the corresponding diphenylisoxazoles and -oxazoles (viz. 3,4-diphenylisoxazole–2,4-diphenyloxazole, 4,5-diphenylisoxazole and -oxazole, and 3,5-diphenylisoxazole–2,5-diphenyloxazole) but the application of metastable characteristics to the spectra of each pair of compounds does not substantiate the proposed
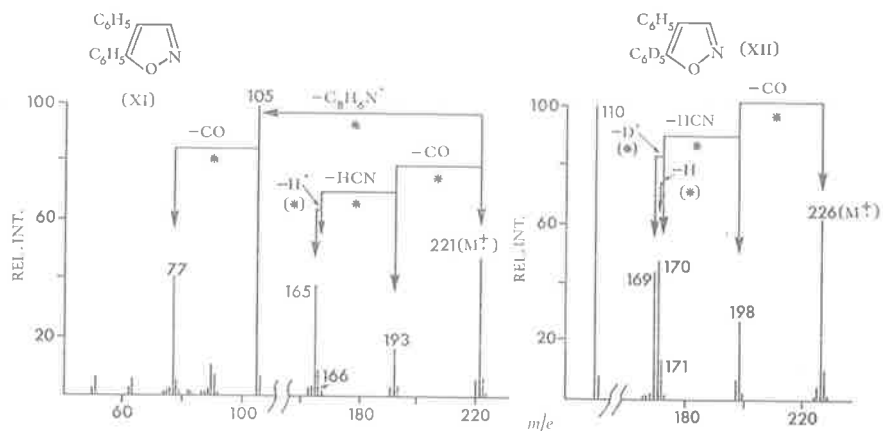
FIG. 4

molecular ion interconversions. The rearrangements are complex, occurring by both concerted and stepwise mechanisms in certain diphenyloxazole spectra,[2] but only by stepwise* elimination in those of the diphenylisoxazoles.

Although we consider it unlikely that major conversion to a diphenyloxazole species precedes the formation of $d(m/e$ 165) in the spectra of VII, VIII, XI and XIII it is not possible to completely unequivocate such an isomerization.

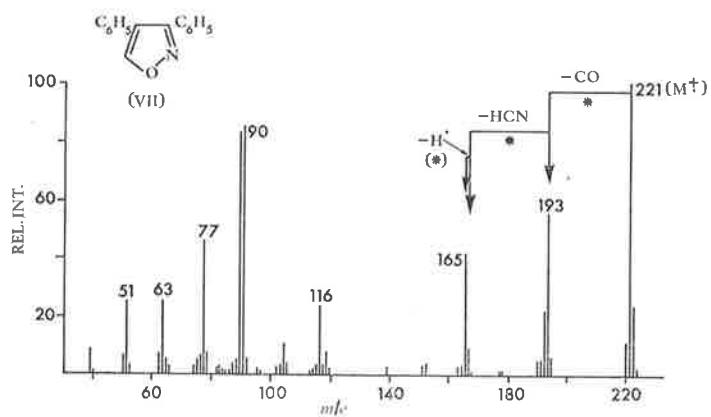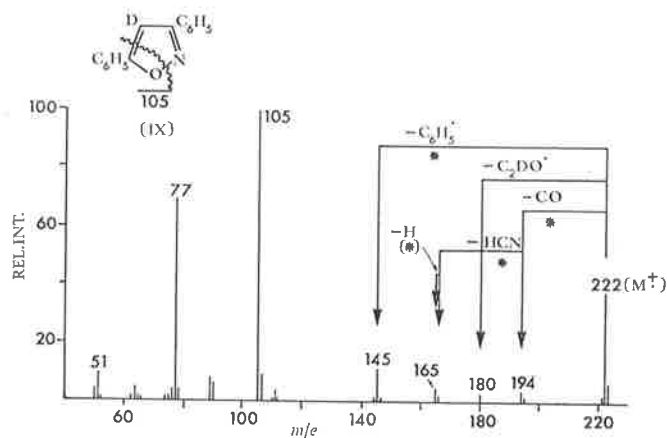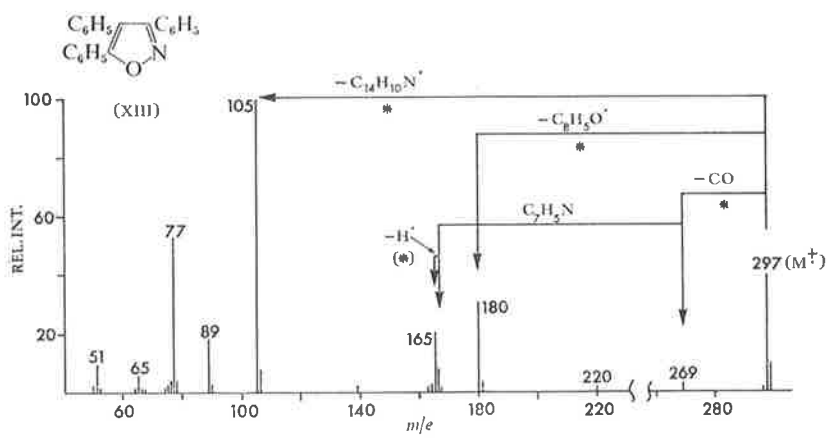* No appropriate metastable peaks substantiate the processes [M]+· → 166 (cf.[3]).
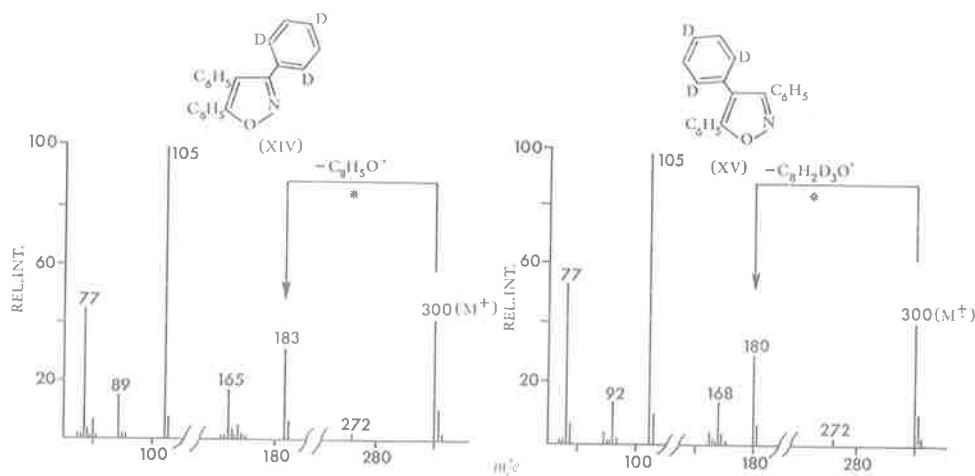
FIG. 5

FIG. 6

FIG. 7

FIG. 8

A plausible structure for the [M − CO] species in the spectra of VII, VIII and XI is the 2,3-diphenyl-2--2-H-azirine radical ion (*j*). The metastable characteristics of the *m/e* 193 → 166 decompositions were compared in the spectra of the azirine, VII, VIII and XI. In no case was any correlation of peak shapes or abundance ratios obtained. Another important feature of the spectra of the diphenylisoxazoles is that a hydrogen attached to an isoxazole ring does not randomize with phenyl hydrogens (see Fig. 6). It is not possible to ascertain whether the hydrogen transfer process (which occurs for 3,4-diphenylpyrazole) or a phenyl migration accounts for the formation of *m/e* 165 in the spectra of diphenylisoxazoles. The 'normal' fragmentations of substituted isoxazoles have been described, and are best rationalized by breakdown of an acylazirine intermediate[6,8,9] (cf. *h*).

(*j*) *m/e* 193
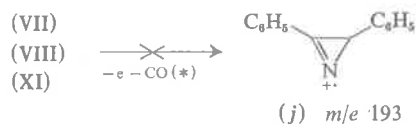
The spectra of 3,5-diphenylisoxazole derivatives contain an ion at *m/e* 180 $[C_{13}H_{10}N]^+$ which is produced by a specific skeletal-rearrangement. The abundances of this ion in the spectra of VIII, X and XIII are 3, 10 and 32% respectively. The rearrangement ion is most pronounced in the spectrum (Fig. 7) of triphenylisoxazole; where it is more abundant than *d*(*m/e* 165). This rearrangement does not occur

(*k*) *m/e* 180
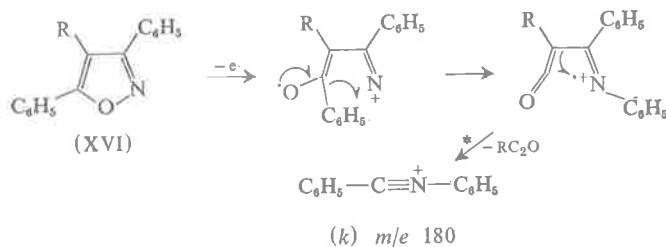
when 2,5-diphenyl and triphenyloxazole are subjected to electron-impact. Figure 8 shows that the 5-phenyl group is the migrating species, and that although hydrogen scrambling within a phenyl ring occurs, cross hydrogen randomization between the 5-phenyl hydrogens and the hydrogens of either the 4-phenyl or 4-H groups does not occur. A possible mechanism for this rearrangement is (XVI) → k, and the stability of m/e 180 is compatible with the properties of the Schiff's base cation k.[22]

EXPERIMENTAL

All mass spectra were determined with an Hitachi Perkin–Elmer RMU-6D double focusing mass spectrometer operating at 70 eV. Samples were introduced both through the all glass heated inlet system at 150° and 'direct insertion' at 70 to 80°. In all cases the two spectra were very similar except for very small differences in relative abundances of certain ions. The spectra recorded in Figs. 1 to 8 were all obtained after introduction of the samples through the heated inlet system. Exact mass measurements were performed at a resolution of 10,000 (40% valley definition) using heptacosa-fluorotributylamine to provide reference masses.

All compounds were recrystallized and checked for purity by n.m.r. and mass spectrometry. Light petroleum refers to the fraction b.p. 40 to 60°. All melting points were determined with a Gallenkamp melting point apparatus and are uncorrected.

The following compounds were prepared by reported procedures: I,[23] V,[24] VII,[25] VIII,[26] X,[27] XI[28] and XIII.[29]

Labelled compounds

The spectra of II and VI were obtained by introducing I and V directly into the source with deuterium oxide.[30]

3-(d₅-Phenyl) -4-phenylpyrazole (III)

(a) The reaction between d_6-benzene (4·0 g) and acetylchloride (4·0 g) in tetrachloroethane (25 cc) with aluminium chloride (10·0 g) gave d_5-acetophenone (2·6 g, 58%) b.p. 201 to 202°.

(b) d_5-Acetophenone (2·5 g) was converted[31] into 1-(d₆-benzoyl)-2-phenylethylene (4·6 g, 96%) m.p. 54 to 55° from ethanol.

(c) The reaction[32] of 1-(d₅-benzoyl)-2-phenylethylene (2·08 g) in methanol (25 cc) with hydrogen peroxide (7·0 cc, 15%) and aqueous sodium hydroxide (4 N, 3·5 cc) gave 1-(d₅-benzoyl)-2-phenyl-ethylene oxide (2·0 g, 95%), which crystallized as white plates from ethanol, m.p. 90 to 91°.

(d) 1-(d₅-benzoyl)-2-phenylethylene oxide (1·09) was converted into d₅-benzoylphenylacetaldehyde (0·28 g, 28% m.p. 112 to 113°) by a reported procedure.[33] Purification of the product was achieved by chromatography over silicic acid (Mallinckrodt, 100 mesh) eluting with light petroleum/diethyl-ether (97:3).

(e) Treatment[23] of d₅-benzoylphenylacetaldehyde (0·102 g) with hydrazine hydrate (0·3 g, 50%) in glacial acetic acid (1 cc) gave 3-(d₅-phenyl)-4-phenylpyrazole (0·120 g, 60%) which crystallized from diethylether/light petroleum (1:1) as colourless needles, m.p. 154 to 155°.

3-Phenyl-4-(d₅-phenyl)pyrazole (IV)

(a) d_8-Toluene (2·09 g) was converted[34] into d_7-benzyl bromide (2·6 g, 70%) b.p. 97 to 100°/35 mm Hg.

(b) The reaction[35] between d_7-benzyl magnesium bromide [from d_7-benzyl bromide (2·6 g) and magnesium (0·36 g)] and benzaldehyde (1·51 g) in ether (6 cc) gave 2-d₂-2-(d₅-phenyl)-1-phenyl-ethanol (1·4 g, 70%), b.p. 134 to 140°/1 mm Hg.

(c) 2-d₂-2-(d₅-phenyl)-1-phenylethanol (1·1 g) in acetone (10 cc) was heated under reflux for 15 minutes with Jones reagent (1·6 cc). Water (10 cc) was added, and the solution extracted with ether (3 × 10 cc), the ether extract dried (Na₂SO₄), evaporated, and distillation of the residue gave d₇-benzyl phenyl ketone (1·0 g, 91%), b.p. 120 to 122°/0·1 mm Hg.

(d) d₇-Benzyl phenyl ketone (1·0 g) was added at 0°, with stirring, to a solution of sodium ethoxide [from sodium (0·12 g) and ethanol (2 cc)] and ethylformate (0·33 g) which had previously been kept at 0° for 2 hours. The resultant solution was maintained at 4° for three days, then poured into water (10 cc), acidified with dilute sulphuric acid, and extracted with ether (3 × 10 cc). The combined

ether extract was washed with water, and dried (Na$_2$SO$_4$). After removal of the solvent, the residue was chromatographed over silicic acid, eluting with benzene/light petroleum 1:1 to yield *benzoyl*-(d$_5$-*phenyl*)-*acetaldehyde* (0·184 g, 23%) as a pale yellow solid, m.p. 111 to 112°.

(e) *Benzoyl*-(d$_5$-*phenyl*)*acetaldehyde* (100 mg) was treated[34] with hydrazine hydrate (0·15 g, 50%) to yield *3-phenyl*-4(d$_5$-*phenyl*)*pyrazole* (0·03 g, 30%) which crystallized (as above) as colourless needles, m.p. 155 to 156°.

4-d-3,5-*Diphenylisoxazole* (IX)

To a solution of *n*-butyl lithium (1·0 g) in dry ether (50 cc) was added a suspension of 3,5-diphenyl-4-iodo-isoxazole (0·5 g) in ether (25 cc) with stirring, at −50°, under nitrogen, over a period of 15 minutes. After addition of deuterium oxide (1·5 cc), the ether layer was separated, dried (Na$_2$SO$_4$) and evaporated. The residue was crystallized from ethanol to yield (IX) as colourless needles, m.p. 178 to 179°. Yield 0·3 g (45%).

4-*Phenyl*-5-(d$_5$-*phenyl*)*isoxazole* (XII)

Treatment[28] of d$_5$-*benzoylphenylacetaldehyde* (0·029 g) with hydroxylamine hydrochloride (0·1 g) gave *4-phenyl*-(5-d$_5$-*phenyl*)*isoxazole* (0·011 g, 50%) which crystallized from ethanol as colourless needles, m.p. 68 to 69°.

3-(d$_3$-*Phenyl*)-4,5-*diphenylisoxazole* (XIV)

d$_3$-Benzaldehyde[36] (0·5 g) was converted[37] into *d$_3$-benzaldoxime* (0·50 g, 83%), m.p. 30 to 31° *d$_3$-Benzaldoxime* (0·50 g) was converted[29] into *d$_3$-benzohydroxamyl chloride* (0·5 g, 80%). The crude chloride (0·5 g) was treated[29] with aqueous sodium hydroxide to produce *d$_3$-benzonitrile oxide* to which was added trans-stilbene (0·80 g) to yield colourless needles of trans-3-d$_3$-*phenyl*-4,5 *diphenylisoxazoline* (0·61 g, 45%), m.p. 140 to 141° (white needles from ethanol). Treatment[29] of the isoxazoline (0·55 g) with N-bromosuccinimide and sodium methoxide, gave 3-d$_3$-*phenyl*-4,5-*diphenylisoxazole* (0·31 g, 56%) which was crystallized from ethanol as colourless needles, m.p 210 to 212°.

3,5-*Diphenyl*-4-(d$_3$-*phenyl*)*isoxazole* (XV)

To a solution of phenylnitromethane (0·5 g) and *d$_3$-benzaldehyde*[36] (0·4 g) in ethanol (2 cc) was added a saturated solution of ammonia in ethanol (0·5 cc). After standing at room temperature for 12 hours, the solid was filtered off and heated under reflux with aqueous potassium hydroxide (1 N, 5 cc). On cooling, XV was filtered and crystallized from ethanol as colourless needles, m.p. 211 to 213°. Yield 0·52 g (51%).

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ELECTRON IMPACT STUDIES—XXIX[1]

THE $C_{13}H_9$ SKELETAL-REARRANGEMENT FRAGMENT IN THE MASS SPECTRA OF HETEROCYCLIC SYSTEMS CONTAINING DIPHENYL SUBSTITUENTS. A DEUTERIUM LABELLING STUDY

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Abstract—The m/e 165 ion ($C_{13}H_9$) has been noted in the mass spectra of a variety of heterocyclic systems containing two (or more) phenyl substituents. This skeletal-rearrangement fragment is most prominent in the spectra of particularly substituted oxazoles, imidazoles and thiazoles. Deuterium-labelling studies have allowed probable mechanistic formulations in the case of the 4,5-diphenylimidazoles, and the detection of two alternate rearrangement pathways in the spectrum of 2,4,5-triphenyloxazole. A comparison is made between the formation of m/e 165 in the spectrum of stilbene and 9,10-dihydrophenanthrene.

DURING a study of the mass-spectral fragmentations of substituted imidazoles,[2] it was observed that the spectra of 4,5-diphenylimidazoles exhibited pronounced skeletal-rearrangement fragments at m/e 165 ($C_{13}H_9^+$, high resolution). This ion is formed directly from the molecular ion, and its formation demands a Ph migration. Similar phenomena are observed[3] in the spectra of the isomeric diphenyloxazoles, and tentative mechanisms have been proposed for the genesis of the rearrangement ion. The $C_{13}H_9$ ion is also observed in the spectra of 2,5-diphenyl-1,2,4-oxadiazole

TABLE 1. RELATIVE ABUNDANCE OF m/e 165. FRAGMENTS IN THE MASS SPECTRA OF DIPHENYL HETEROCYCLES

| Compound	Abund. of m/e 165 (%)	Compound	Abund. of m/e 165 (%)
4,5-Diphenylimidazole	42	2,4-Diphenylthiazole	1
2-Isopropyl-4,5-diphenylimidazole	26	3,5-Diphenylisoxazole	4
2,4,5-Triphenylimidazole	100	3,5-Diphenylpyrazole	7
4,5-Diphenyloxazole	75	3,4-Diphenylpyrazole	21
2-Methyl-4,5-diphenyloxazole	86	2,5-Diphenylfuran	3
2-Ethyl-4,5-diphenyloxazole	100	5-Methyl-2,3-diphenylpyrrole	2
2-n-Pentyl-4,5-diphenyloxazole	73	2,3-Diphenylthiophen	7
2,4,5-Triphenyloxazole	80	2,4-Diphenylthiophen	5
2,5-Diphenyloxazole	53	2,5-Diphenylthiophen	2
4,5-Diphenylthiazole	85	2-Chloro-5,6-diphenylpyrazine	2
2-Amino-4,5-diphenylthiazole	45	3,6-Diphenylpyridazine	0

(53% of the base peak),[4] 4,5-diphenyl-2-pyrone (18%),[5] 3,4-diphenyl-4,5-epoxy-2-cyclopenten-1-one (21%)[5] diphenylmethane (29%),[6] stilbene (30%)[7] and 9,10-dihydrophenanthrene (30%).[8]

As a knowledge of skeletal-reorganization processes in mass spectrometry is extremely important,[9] it was decided to investigate (a) whether the presence of a prominent $C_{13}H_9$ peak is characteristic of all compounds containing the Ph—C=C—Ph

unit, and (b) to study the genesis of the rearrangement ion in the spectra of the 4,5-diphenyloxazoles, the 4,5-diphenylimidazoles, stilbene and 9,10-dihydrophenanthrene, by deuterium-labelling studies. This paper deals primarily with these problems.

The relative abundances of the $C_{13}H_9$ fragments in the mass spectra of some heterocyclic compounds are summarized in Table 1. It can be clearly seen that the rearrangement fragment is pronounced in the spectra of 4,5-diphenyloxazoles (where in several cases it constitutes the base peak of the spectrum), 4,5-diphenylimidazoles, 4,5-diphenylthiazoles and 2,5-diphenyloxazoles. In the case of the 5-membered heterocycles containing one heteroatom, and with adjacent Ph substituents, the rearrangement peak is less than 10% of the base peak,* while the m/e 165 peak is either small or absent in the spectra of the two 6-membered compounds. Therefore, a pronounced $C_{13}H_9$ peak is not characteristic of the Ph—C=C—Ph moiety, but is

generally confined to 5-membered heterocyclic systems containing two heteroatoms (normally in 1,3 positions), and to isolated instances, including diphenylmethane, stilbene and dihydrophenanthrene.

1: R = Ph

3

2: R =
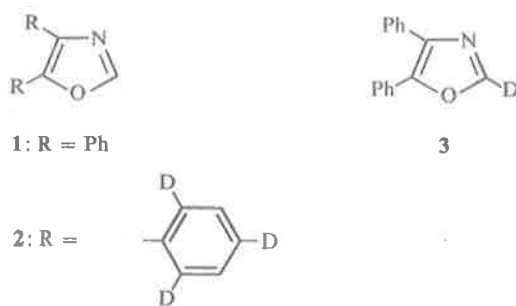
The mass spectra of 4,5-diphenyloxazole 1 and the two labelled derivatives 2 and 3 are recorded in Figs 1–3. It has been shown previously that hydrogens on aromatic rings become equivalent upon electron impact[10, 11] and that randomization does not occur for isolated hydrogen substituents attached to the oxazole nucleus.[12] This situation has also been apparent throughout this study, and consequently, even though the benzene rings are specifically labelled with deuterium, fragmentations involving loss of deuterium and/or hydrogen atoms from the benzene rings of 2 will occur in the ratio 3:2 (D:H) (ignoring possible isotope effects). In the spectrum (Fig. 1) of 4,5-diphenyloxazole 1, m/e 165 may be formed by two pathways: viz.

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* The skeletal-rearrangement fragments observed in the mass spectra of isoxazoles, pyrazoles, 2,5-diphenyl-furan, -pyrrole and -thiophen, will be the subject of a future publication.
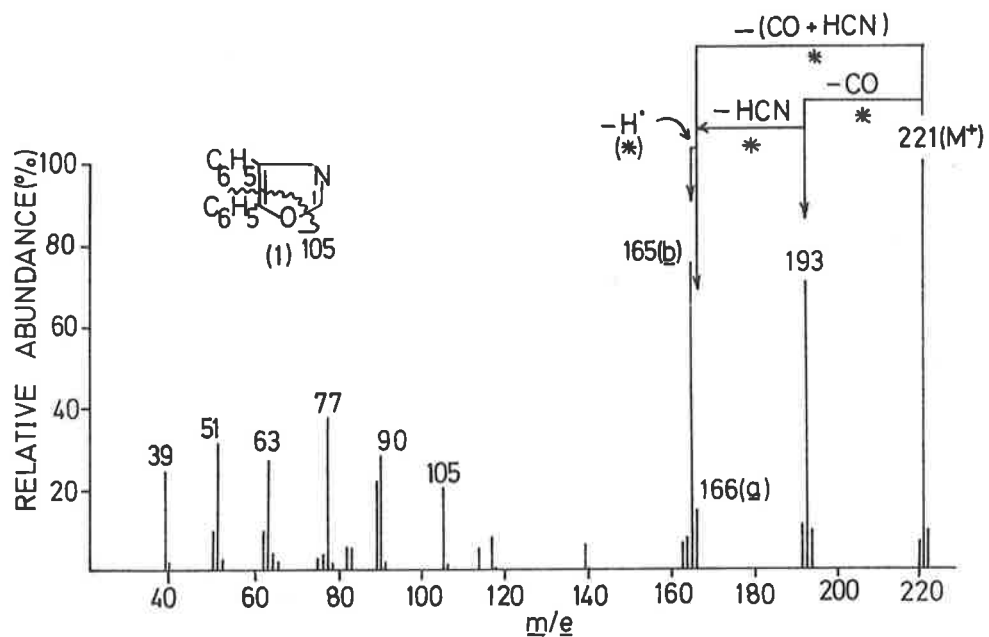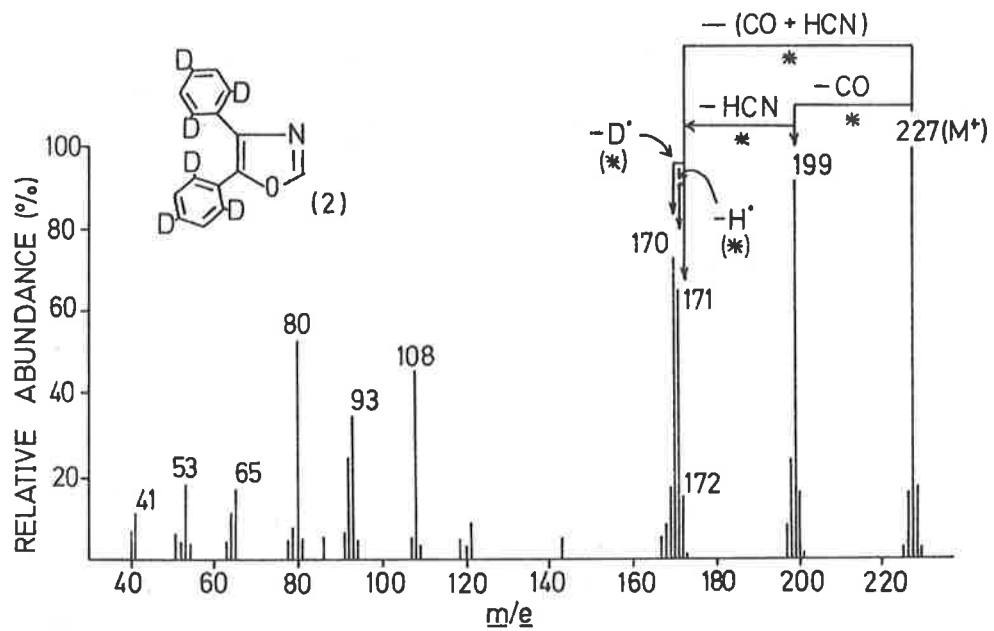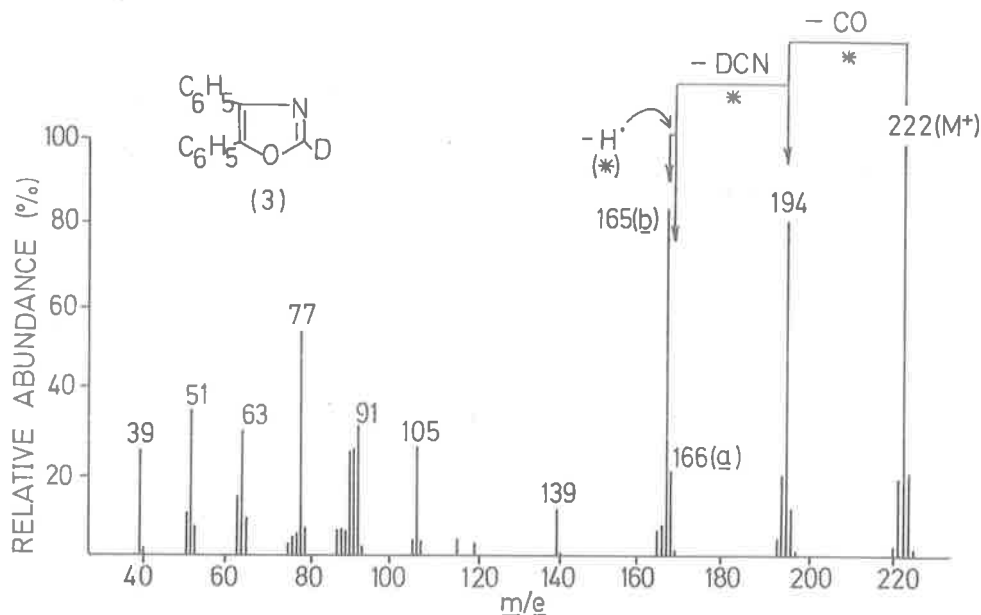
FIG. 1.

FIG. 2

FIG. 3.

(a) M—(CO + HCN)—H· and (b) M—CO—HCN—H· [appropriate metastable ions (denoted by an asterisk in the Figs) substantiate all processes]. These processes are modified in the spectra of all the 2-substituted 4,5-diphenyloxazoles to M—(CO + RCN)—H· and M—CO—RCN—H·. When the energy of the electron beam is reduced to 10 eV, the process M → m/e 166 is always pronounced, with m/e 165 being the minor component. Even though structures drawn for fragment ions are nominal only, it is argued that the most plausible structures for m/e 166 and 165, correspond to the fluorene radical ion (a) and cation (b), respectively, although this does not preclude the possibility of more extensive rearrangement.
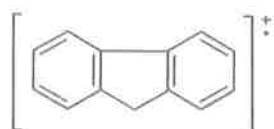
a: m/e 166
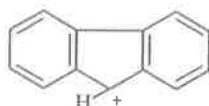
b: m/e 165

The spectra (Figs 2 and 3) of the labelled compounds 2 and 3 show that the two Ph rings are involved in the formation of the fluorene cation [i.e. the processes M CO -HCN—H· or M—CO—HCN—D· produce m/e 171 or 170 respectively (Fig. 2)], and that the deuterium at C-2 in (3) is specifically lost in the initial process, and plays no part in the formation of the rearrangement ion. The latter observation negates the earlier mechanistic proposal[3] for the formation of m/e 165 from 4,5-diphenyloxazole, as this mechanism invokes the participation of the hydrogen at

C-2 in the transformation. Nevertheless, the above observations still do not allow unequivocal proposals to be advanced for the mechanism.

	R¹	R²
4	H	Ph
5	D	Ph

6	H	

	R¹	R²	R³
7	H	Ph	Ph
8	D	Ph	Ph

9	H	Ph

10	H	
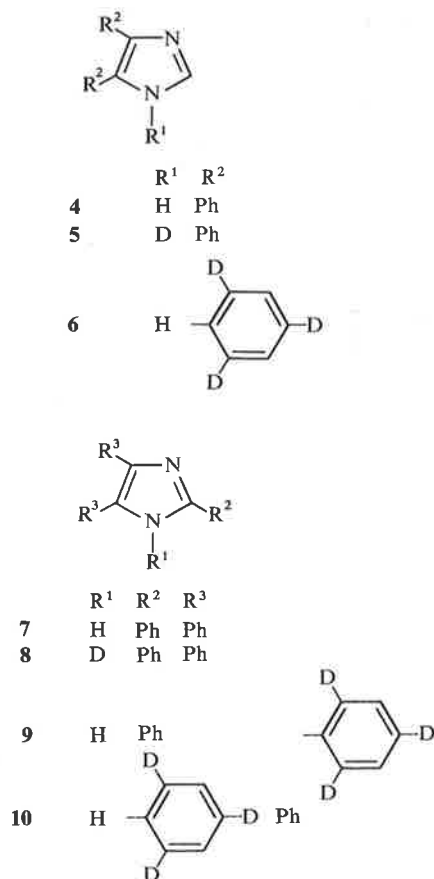
However, the spectra of the imidazoles **4–10** permits conclusions to be reached concerning the genesis of the ion *b*. The spectra (Figs 4 and 6) of 4,5-diphenylimidazole (**4**) and 2,4,5-triphenylimidazole (**7**) are different from that of 4,5-diphenyloxazole (**1**), as in these spectra, *b* (*m/e* 165) is formed directly from the molecular ions (concerted losses of $C_2H_3N_2 \cdot$ and $C_8H_7N_2 \cdot$ respectively). Metastable ions substantiate these processes, which, although concerted, do not necessarily occur by one-step processes.[13] The spectra (e.g. Fig. 6) of the $N-d_1$ derivatives **5** and **8** show incorporation of deuterium into the rearrangement peaks, and after a calculation (which is approximate because of M-1 and M-2 peaks) to allow for incomplete labelling, a value of $50 \pm 10\%$ is obtained for the incorporation of deuterium into the rearrangement ions (now *m/e* 165, 166 and 167). Such a value is much too high to be accounted for by randomization of the label, and a specific transfer process is indicated. It is of interest to note that the spectrum (Fig. 7) of **10** shows that the phenyl substituent at C-2 is not involved in the rearrangement process.
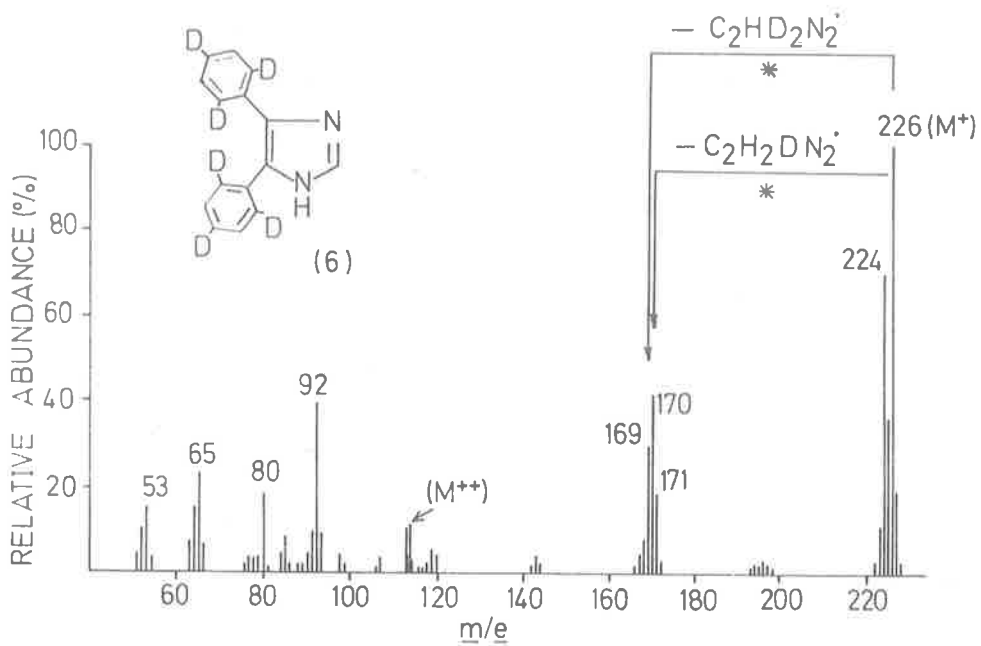
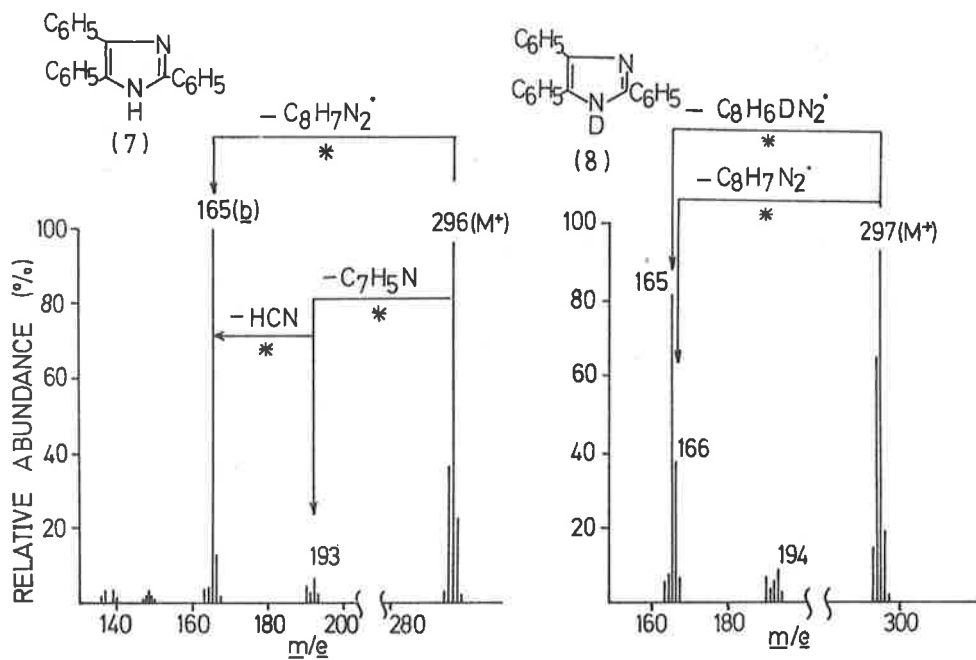J. H. Bowie, P. F. Donaghue, H. J. Rodda and B. K. Simons
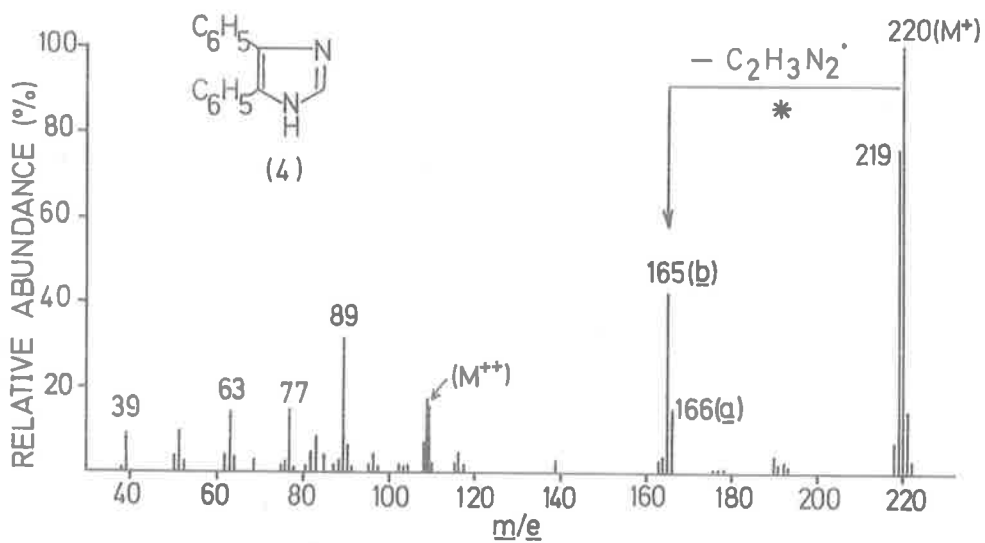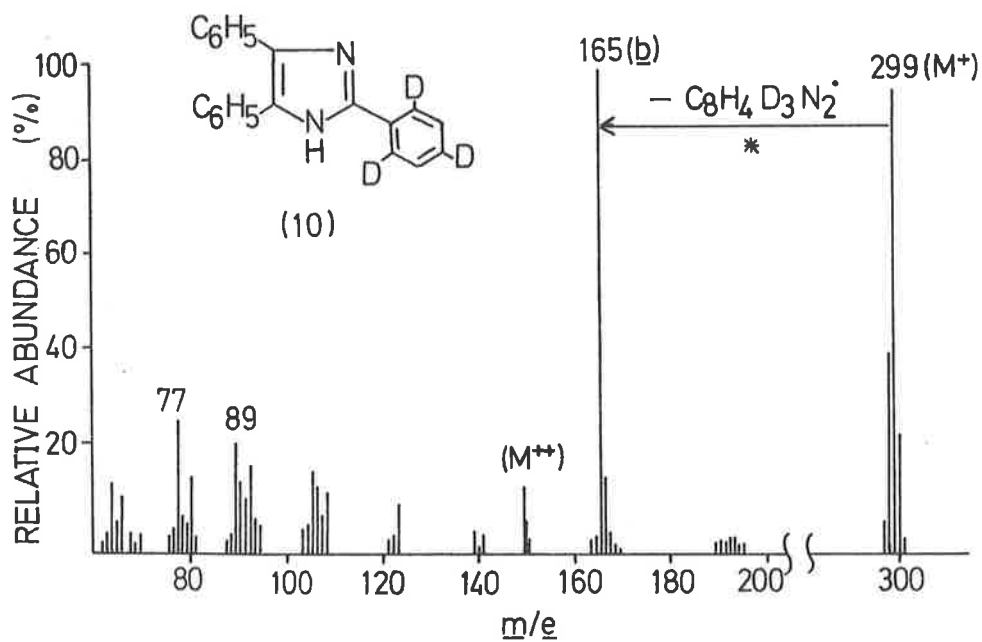

FIG. 4.

FIG. 5.

FIG. 6.

FIG. 7.

The spectra of the d_6-derivatives **6** and **9** demonstrate the participation of a second hydrogen-transfer process. The spectrum of **6** is illustrated in Fig. 5, and it should be noted that the ratios of m/e 169:170:171 are identical in the spectra of **6** and **9**, although the relative abundances of the peaks are not the same in the two spectra. Two concerted eliminations are noted, viz. in Fig. 5, M—$C_2H_2DN_2$· (to m/e 170) and M—$C_2HD_2N_2$· (to m/e 169). The presence of the second process can only mean that a deuterium has migrated from a Ph ring to the imidazole ring in order to allow the loss of the second D atom in the rearrangement. This migration must of course involve both D and H atoms in the ratio 3:2. To explain this double hydrogen rearrangement, Scheme 1 is proposed for the formation of *b*. Migration of a H atom to either nitrogen, produces *d* or *e*, which cannot be distinguished (we have a marginal preference for *d* because it forms symmetrical intermediates). The production of *d* (or *e*) provides an electron-deficient centre on one of the aromatic rings to which the other may migrate (e.g. *d* → *f*). In order for the rearrangement to proceed, either hydrogen on nitrogen must migrate back to the "fluorene-centre". There is an equal probability of either hydrogen migrating, as *f* may be considered as a symmetrical intermediate, and although the acceptor-site of the rearrangement is not known, a possible formulation is *g* (it is possible that the imidazole ring may have opened by this stage), which may now readily fragment to the fluorene cation.

SCHEME 1
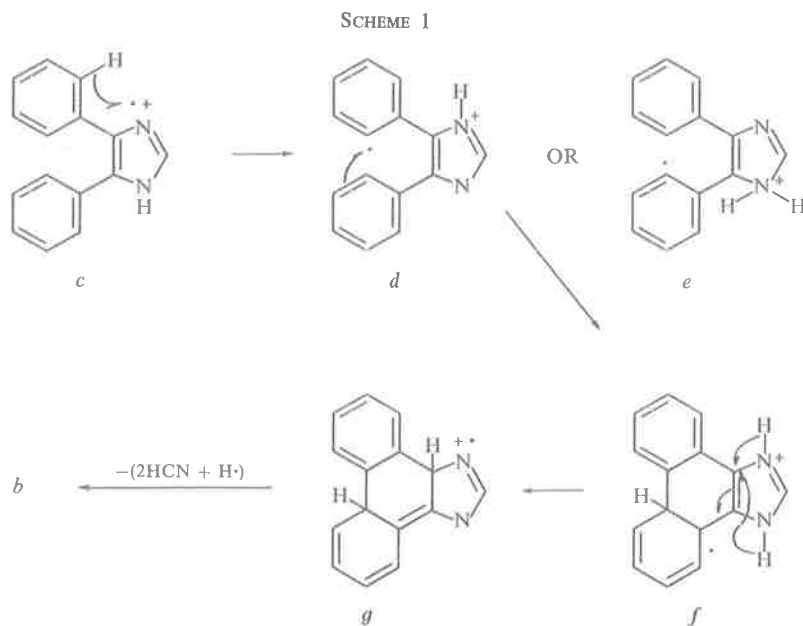
Although this rationale is speculative, it explains the hydrogen rearrangements, and may be correlated with the ratios of m/e 169:170:171 in the spectra of **6** and **9**. A simple calculation assuming deuterium/hydrogen rearrangement to nitrogen in the ratio 3:2, followed by 50% back exchange of each atom (H or D) on nitrogen together with the possible eliminations to produce the rearrangement ions, gives a calculated ratio for the m/e 169, 170 and 171 peaks as 1·0:2·1:1·2. When isotopic corrections,

and approximate corrections due to incomplete labelling are made, the observed ratios are 1·0:1·5:0·9. These ratios are not inconsistent when the approximations inherent in the calculations are considered, and also as possible isotopic effects have been ignored. If one argues by analogy, a similar mechanism could apply to the formation of *b* in the spectra of the 4,5-diphenyloxazoles and -thiazoles, although it is recognized that this double-hydrogen rearrangement could not occur in such cases.

11: R = H
12: R = D

R¹ R²
13 Ph Ph
14 ... D Ph
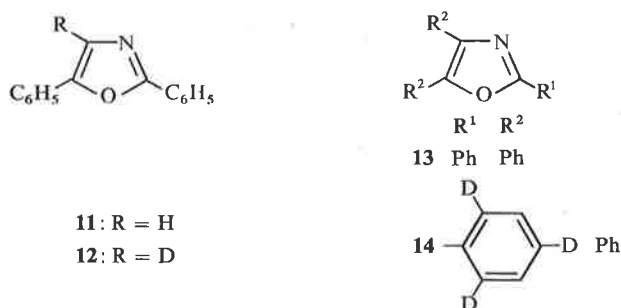
The formation of the fluorene cation (*b*) in the spectrum of 2,5-diphenyloxazole (11) has been noted previously,[3] and a mechanism has been proposed for its formation. We wished to compare this rearrangement with that observed in the spectrum of 4,5-diphenyloxazole. The spectra of 11 and 12 are illustrated in Fig. 8, and it can be seen that the hydrogen at C-4 is not involved in the formation of *b*. Apart from the fact that Ph migration must occur, no concrete proposal can be presented for the mechanism, but it is noteworthy that the formation of *b* in the spectrum of 2,4-diphenyloxazole occurs only to the extent of 5%.[3] It has already been shown (*vide supra*) that the 2-phenyl group of 2,4,5-triphenylimidazole is not involved in the formation of *b*,
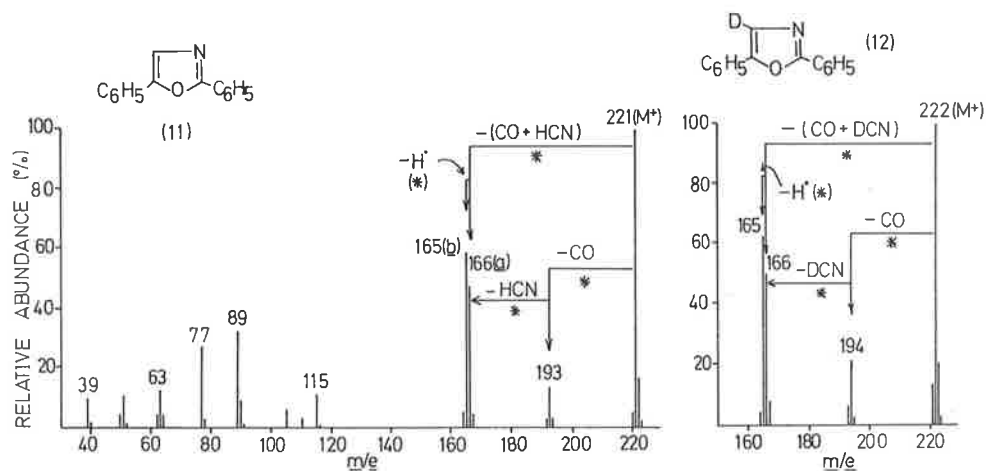

FIG. 8.

but because of the pronounced rearrangement occurring in the spectrum of 2,5-diphenyloxazole, the spectra (Fig. 9) of 2,4,5-triphenyloxazole (13) and 14 were examined. Fig. 9 shows the occurrence of two distinct processes, *viz.* (a) the formation of *b* from the 4,5-Ph groups via the normal pathway (60%), and (b) formation of the
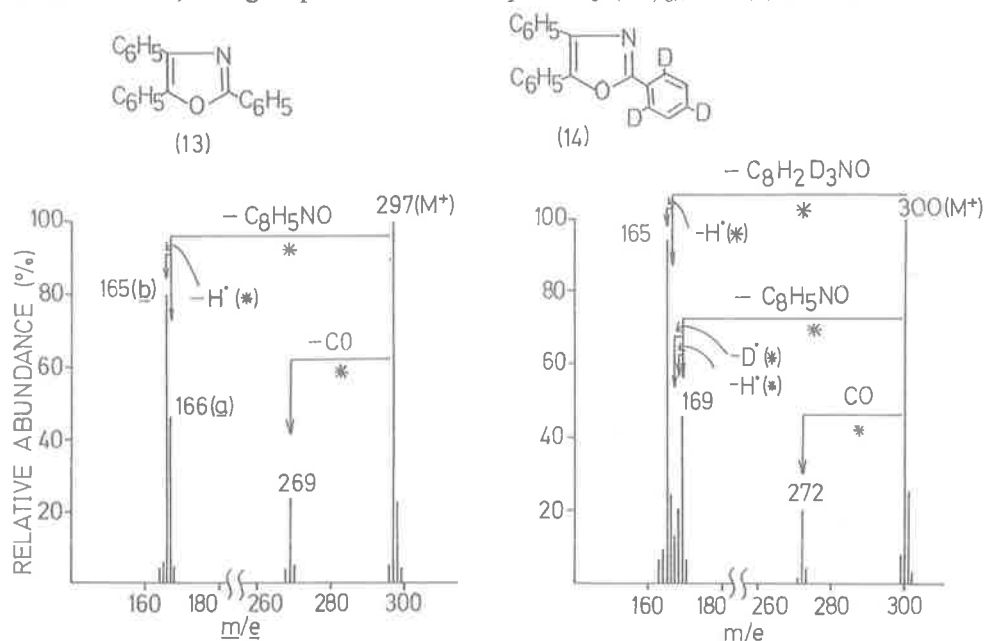

(13)   (14)

FIG. 9.

d_3-fluorene radical ion (*m/e* 169) from the 2,5-phenyl substituents (40%). This ion (*m/e* 169) may either lose a H atom (to *m/e* 168) or a D atom (to *m/e* 167). When the energy of the electron beam is reduced to 10 eV, only two ions are observed in the *m/e* 165–170 region; *m/e* 166 and 169 in the ratio 2:3. This implies that the formation of the fluorene radical ion (*a*) from the 2 and 5 Ph groups is more energetically favourable than its formation from the 4 and 5 Ph substituents. It is assumed that bond formation does not occur between the 2 and 4 Ph substituents, because of the small relative abundance of *b* in the mass spectrum of 2,4-diphenyloxazole. The loss of carbon monoxide from the molecular ions of 2,4,5-trisubstituted oxazoles has been reported previously.[12]

	R¹	R²
15	H	H
16	H	D
17	D	D

18: R = H
19: R = D
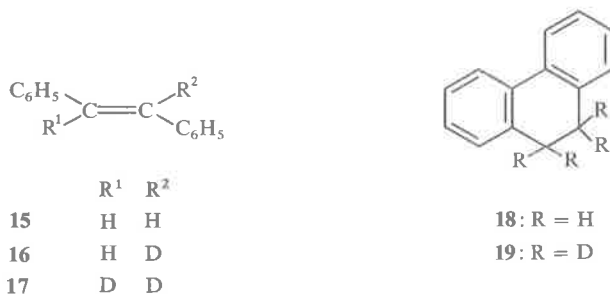
Finally, it was of interest to examine the almost identical spectra of stilbene[7] and 9,10-dihydrophenanthrene,[8] which both lose a Me radical from their molecular ions to form m/e 165 (b, 30% of the base peak). In order to examine this feature, **17** was required. The synthesis of this compound was approached by equilibration of desoxybenzoin with MeOD/Na, then reduction with LAD followed by elimination of D_2O. Unfortunately, the initial step gives only 65% of the d_2 species, any further equilibration then results in deuteration of the aromatic system. As the final product contains only ca. 75% d_2, compound **16** was used for this study. The partial spectra of the stilbenes **15** and **16** are illustrated in Fig. 10. The ratios of the 165/166 peaks
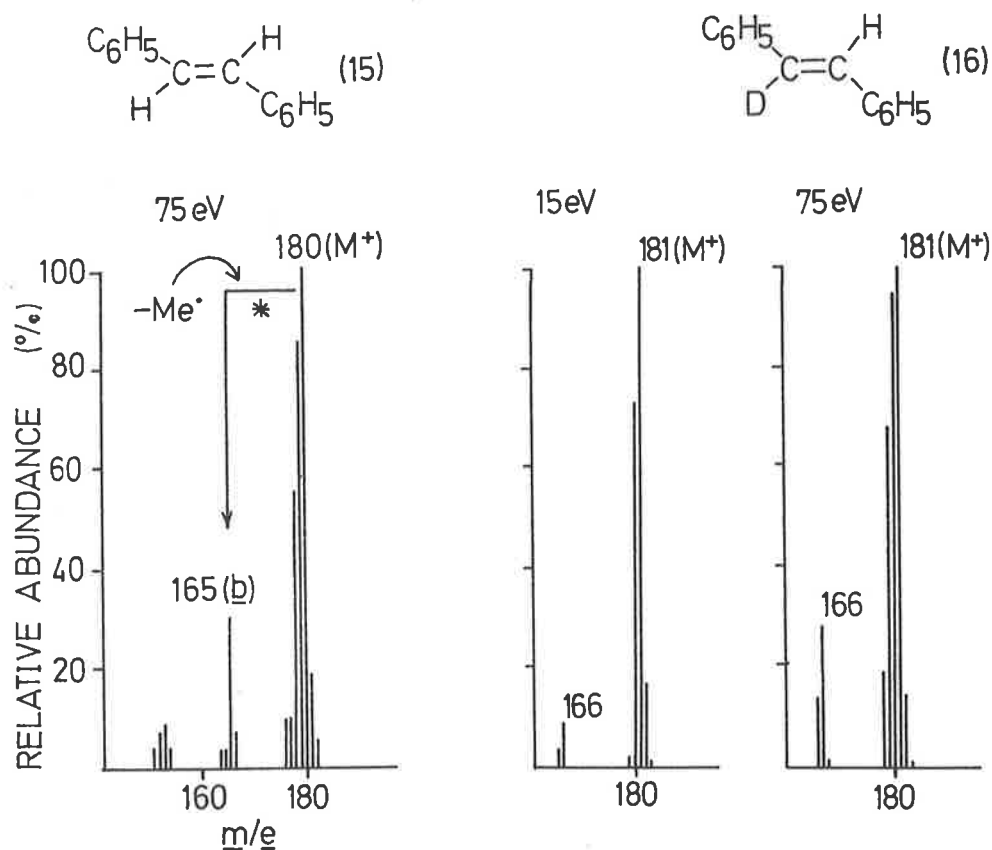
FIG. 10.

in the spectrum of **16** are unchanged at 75, 20, 15 and 10 eV and each spectrum shows 34% relative loss of $CH_2D\cdot$ and 66% of $CH_3\cdot$. This cannot be explained by randomization of the hydrogen (or deuterium) on the olefinic link with the aromatic hydrogens, nor can it be explained by an intermediate of the type h, which would be the species obtained from an adaptation of the mechanism outlined in Scheme 1 (the participation of such an intermediate is unlikely in any case, as it has been demonstrated above that the heteroatoms play a significant part in the mechanism

outlined in Scheme 1). Further rearrangement of h has been previously used to explain the loss of a methyl radical from the stilbene molecular ion.[14] Although the mechanism for the loss of Me· from the stilbene molecular ion is not clear, it seems that at least

h : m/e 181 i : m/e 184
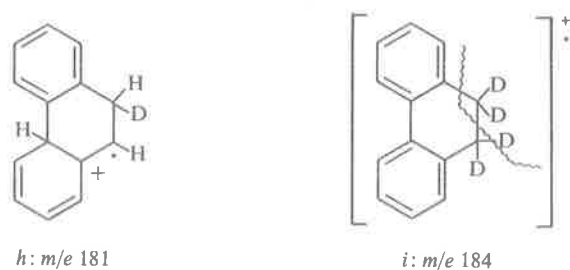
two processes may be involved. The loss of a methyl radical from 9,10-dihydro-phenanthrene (18) is even more difficult to explain. The spectrum (Fig. 11) of the d_4-derivative (19) might be expected to exhibit loss of CD_3· (see i). However, the
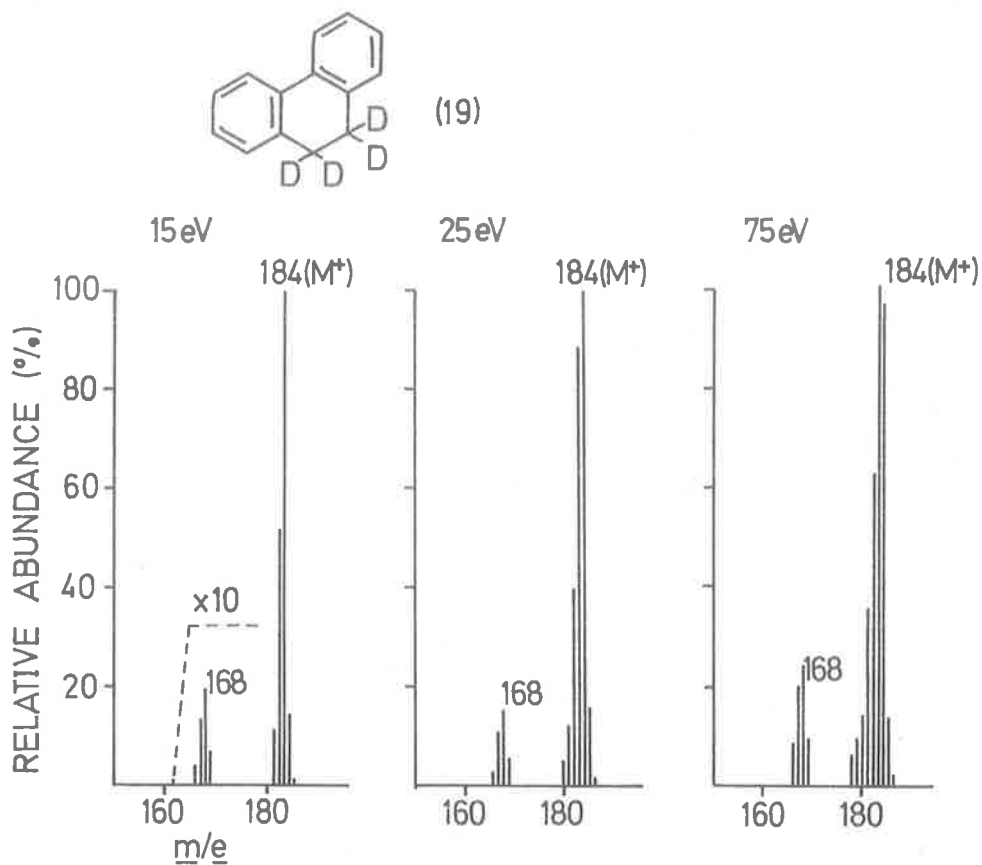
Fig. 11.

loss of $CD_3\cdot$ is minor, the major losses being $CH_2D\cdot$ and $CD_2H\cdot$. Again, the m/e 166, 167, 168, 169 ratio is not markedly affected by decreasing the energy of the electron beam (see Fig. 11), and it appears that little randomization of deuterium occurs. In a previous paper[8] it was assumed that hydrogen lost in the $M—H_2$ process [to produce the phenanthrene molecular ion (m/e 178)] originated from the 9,10 positions of 9,10-dihydrophenanthrene. This is not the case, as the major loss in the spectrum of **19** is H_2 and not D_2, and probably indicates considerable rearrangement of the molecular ion. Although the losses of Me· from stilbene and 9,10-dihydro-phenanthrene are complex, there is little doubt that the formation of *b* proceeds differently in these cases than it does for 4,5-diphenylimidazole.

These studies demonstrate yet again that extreme caution must be exercised when postulating mass-spectrometric mechanisms without the aid of the spectra of suitably labelled derivatives.

EXPERIMENTAL

All mass spectra were determined with an Hitachi Perkin–Elmer RMU 6D double focussing mass spectrometer operating at 75 eV (unless otherwise specified) with a source temp of approximately 150° and an inlet temp between 50° and 200°.

All samples used in this study were routinely checked for purity by nuclear magnetic resonance and mass spectrometry.

4,5-Diphenylimidazole, 2-isopropyl-4,5-diphenylimidazole and 2,5-diphenyloxazole were purified commercial samples. The following compounds were prepared by reported procedures: 2,4,5-triphenylimi-dazole,[15] 4,5-diphenyloxazole,[16] 2-methyl-4,5-diphenyloxazole,[17] 2-ethyl-4,5-diphenyloxazole,[18] 4,5-di-phenyl-2-n-propyloxazole,[18] 2-n-pentyl-4,5-diphenyloxazole,[12] 2,4,5-triphenyloxazole,[17] 4,5-diphenyl-thiazole,[19] 2-amino-4,5-diphenylthiazole,[21] 2,4-diphenylthiazole,[22] 3,5-diphenylisoxazole,[23] 3,5-diphenyl-pyrazole,[23] 3,4-diphenylpyrazole,[24] 2,5-diphenylfuran,[25] 2,5-diphenylpyrrole,[26] 5-methyl-2,3-diphenyl-pyrrole,[27] 2,3-diphenylthiophen,[28] 2,4-diphenylthiophen,[29] 2,5-diphenylthiophen,[29] 2-chloro-5,6-diphenyl-pyrazine,[30] and 3,6-diphenylpyridazine.[31]

The spectra of 5 and 8 were obtained by introducing 4 and 7 into the source with deuterium oxide.[32]

Labelled compounds

2,4,6-d_3-*Benzaldehyde*. Prepared from 2,4,6-d_3-aniline by the method of Williams *et al.*[11]

2,4,6-d_3-*Benzoylchloride*. Prepared in quantitative yield by oxidation of 2,4,6-d_3-benzaldehyde with $KMnO_4$ aq, followed by treatment of 2,4,6-d_3-benzoic acid with $SOCl_2$.

2,4,6,2′,4′,6′-d_6-*Benzoin*. Prepared from 2,4,6-d_3-benzaldehyde by the benzoin condensation.

2,4,6,2′,4′,6′-d_6-*Benzil*. Prepared in quantitative yield by HNO_3 oxidation of 2,4,6,2′,4′,6′-d_6-benzoin. ($d_5 = 4\%$, $d_6 = 96\%$).

2-d-4,5-*Diphenyloxazole* (**3**). 4,5-Diphenyloxazole (0·58 g) in dry ether (10 cc) was added to a soln of n-BuLi [from Li (0·086 g) and n-BuBr (0·69 g)] in dry ether (20 cc) at −65°, under dry O_2-free nitrogen. After stirring for 30 min, D_2O (5 cc) was added, the ethereal soln was separated, dried (Na_2SO_4) and evaporated. The product was purified by preparative VPC (30% SE30, 12′). The NMR spectrum lacked the singlet at 2·19 τ indicative of the 2-H of 4,5-diphenyloxazole.[20]

4,5-*Di*(2,4,6-d_3-*phenyl*)*oxazole* (**2**). Prepared from d_6-benzoin by the method of Theilig.[18] Purified by preparative VPC (see above) b.p. 190–194°/14 mm Hg.

2-(2,4,6-d_3-*Phenyl*)4,5-*diphenyloxazole* (**14**). 2,4,6-d_3-Benzoylchloride (1·3 g) and benzoin (2·1 g) were warmed on a water bath for 1 hr. The benzoin-d_3-benzoate was cyclized to 14 by the method of Davidson *et al.*[17] The crude product was chromatographed over alumina in ether, and crystallized from EtOH as colourless prisms, m.p. 115–116°.

4-*Bromo-2,5-diphenyloxazole*. To a soln of 2,5-diphenyloxazole (4·4 g) in glacial AcOH (100 cc), boiling under reflux, was added a soln of Br_2 (3·2 g) in AcOH (15 cc) over a period of 1 hr. The mixture was cooled and a solid ppt removed. The filtrate was poured onto ice (800 g), extracted with ether (3 × 100 cc), and the combined extracts washed with Na_2CO_3 aq, water, and then dried (Na_2SO_4). Removal of the ether left a solid which was chromatographed over alumina in light petroleum:ether (92:8) to give

G

4-bromo-2,5-diphenyloxazole (1·1 g, 31 %), which crystallized from light petroleum as colourless needles, m.p. 70–71°. (Found: C, 60·2; H, 3·5; N, 4·6; Br, 26·3. $C_{15}H_{10}Br$ requires: C, 60·5; H, 3·4; N, 4·7; Br, 26·6%). The NMR spectrum lacks the singlet at 2·68 τ attributed to the 4-H of the oxazole system.[20]

3-d_1-2,5-*Diphenyloxazole* (**12**). To 4-bromo-2,5-diphenyloxazole (0·3 g) in dry ether (10 cc) was added soln of n-BuLi [from Li (0·07 g) and n-BuBr (0·68 g)] in ether (20 cc), at −65°, for 1 hr, decomposed with D_2O (4 ml) and worked up as for 3. The product (0·2 g) was purified by sublimation, followed by preparative VPC (see above), m.p. 72–73°. The NMR spectrum completely lacked the characteristic singlet at 2·68 τ in the spectrum of 2,5-diphenyloxazole.[20]

4,5-*Di*(2,4,6-d_3)*phenylimidazole* (**6**). Prepared from d_6-benzil, formaldehyde and formamide (cf. Ref. 15). Crystallized from aqueous EtOH as colourless needles, m.p. 232–233°, yield 61 %.

2-*Phenyl*-4,5-di(2,4,6-d_3)*phenylimidazole* (**9**). Prepared from d_6-benzil, benzaldehyde and formamide (cf. Ref. 15). Crystallized from aqueous EtOH as colourless needles, m.p. 270–272°, yield 60%.

2-(2,4,6-d_3)*Phenyl*-4,5-*diphenylimidazole* (**10**). Prepared from benzil, 2,4,6,-d_3-benzaldehyde and formamide as for 9, m.p. 273–274°.

d_1-*Stilbene* (**16**). Reduction of desoxybenzoin with LAD gave 1-d_1-1,2-diphenylethanol, which was dehydrated in DMSO to give d_1-stilbene, m.p. 124–125° (cf. Ref. 33). This was purified by preparative VPC. The NMR spectrum indicated quantitative incorporation of D (>99% d_1).

9,10-d_2-9,10-*Dideuterophenanthrene* (**19**). Reduction of the dimethyl ester of diphenic acid with LAD gave 2,2′-(d_2-hydroxymethyl)diphenyl, which was converted to 19 by the method of Hall et al.[34] Purification by preparative VPC gave 19, b.p. 174°/17 mm Hg. The NMR spectrum indicated quantitative incorporation of D (>99% d_4).

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Skeletal-Rearrangement Processes in the Mass Spectra of Organo-Sulphur Compounds

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1 INTRODUCTION

The application of mass spectrometry greatly simplifies the elucidation of the structures of organic molecules. During the last decade, the number of publications per year in the field of organic mass spectrometry has grown enormously, and the application of high resolution data, labelling studies, and more recently, computer-aided mass spectrometry[1] and the kinetic approach[2,3], has enabled the interpretation of the fragmentation processes in the mass spectra of many types of organic molecules.

Details of the method, the application of normal fragmentation processes to structure elucidation, and the instrumentation of mass spectrometry are available by reference to many books[4-23], reviews[24-34] and compendia of reference data[35-44]. A recent publication, *Mass Spectrometry Bulletin* (published by the Mass Spectrometry Data Centre, AWRE, Aldermaston, Berkshire, England) covers the major literature in a convenient manner.

The migration of groups other than hydrogen upon electron impact has only been widely recognized within the last five years. Such processes, termed skeletal-rearrangement processes, are particularly important from a mechanistic viewpoint, and cannot be predicted *a priori* with any degree of certainty. A knowledge of such processes is therefore of extreme importance if the organic chemist is to use mass spectroscopy for structure elucidation, and the presence of such processes places limitations on the application of computer-aided mass spectrometry, especially the elegant 'element-mapping' technique[1].

Skeletal-rearrangement processes generally fall into one of two classifications, although in certain cases it is difficult to differentiate between the two. They are: (a) the type ABC → AC + B, where A and C are originally joined only through B. This process may occur from either an odd or an even electron species. (b) When reorganization of the molecular ion produces a spectrum which bears little relation to that expected from a mole-

cular-ion structure based on that of the intact molecule. In general, skeletal-rearrangement processes may occur when normal fragmentations are energetically unfavourable, and in addition such processes are more favoured when sites of unsaturation in the vicinity of the bond cleavage allow formation of either radical or carbonium ion centres to which the incipient radical (or anion) may migrate. Two excellent reviews of skeletal-rearrangement processes are available[45].

This review is primarily a compendium of the skeletal rearrangement processes exhibited by organo-sulphur compounds upon electron impact, and covers in more detail those rearrangements which are not covered by the earlier review. This class of compound has been chosen for the survey because of the large number and variety of skeletal-rearrangement processes which occur, *viz.* of the type ABC → AC + B [e.g. thioethers and disulphides (2.1) etc.], reorganization of the molecular ion [especially sulphinylamines (3.5)] and migration to carbonium ion centres [a special case of (b) above, e.g., thioglycollates (2.3)].

The symbolism used throughout this review is that developed by Budzikiewicz, Djerassi and Williams[11,22] from initial proposals by McLafferty[7,18] and Shannon[46,47]. In the text, fragmentation processes of cations are indicated by arrows (⌢) (heterolytic cleavage-two electron shift) whereas fragmentations of radical cations (odd-electron species) are depicted by fish-hooks (⌢) (homolytic cleavage-one electron shift). The use of the fish-hook is not intended to indicate that two-electron shifts may not operate for odd-electron species. Nominal structures for ions have only been drawn in order to relate the fragmentation processes to structures of the molecules in the ground state. Evidence for a concerted process [either one-step (ref. 4, pp. 251-262, ref. 5, pp. 153-157 and ref. 48) or multi-step[49]], for example ion A → ion B, is given by the presence of a metastable peak, the position of that peak being given by the expression $m^* = [m(B)]^2/m(A)$. Metastable peaks are indicated in either the text or a figure, by an asterisk. Most rearrangements discussed have been substantiated by high resolution measurements.

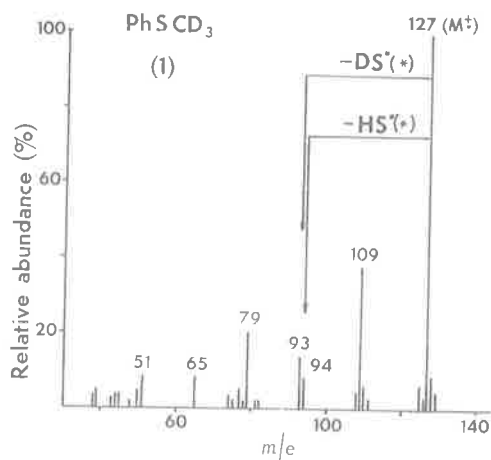## 2 THIO DERIVATIVES

2.1 Sulphides and disulphides

Figure 1

The simplest rearrangement of the type ABC → AC + B in sulphur compounds, occurs in the spectra of sulphides[50-56] and disulphides[57-58]. Loss of sulphur, HS· and H_2S are noted, and for dialkyl sulphides[52] and disulphides[57] the rearrangements are only pronounced when the alkyl groups are either methyl or contain unsaturation [e.g. $CH_3-S-C≡CH$, M−HS· is 10% of the base peak, whereas for $(CH_3)_2S_2$, M−H_2S = 100%]. The process M−HS· is important in the spectra of arylthioethers[52,56] and this rearrangement has been studied by deuterium labelling for the case of thioanisole. The spectrum (Fig. 1) of trideuteromethylthioanisole (1) shows the processes M−SD·/M−SH· in the ratio 2:1. As there is apparently no deuterium/hydrogen randomization, the elimination is considered[52] to occur from a rearranged molecular ion. Increasing the size of the side chain decreases the abundance of the rearrangement ion (e.g. the spectrum of thiophenetole shows a 6% M−SH· peak while that of *n*-butyl-phenylsulphide has no rearrangement peak). The spectra of thioanisole derivatives which contain an additional substituent which may itself fragment simply (e.g. OR, COOR) are generally devoid of rearrangement ions. The spectrum of *o*-methoxythioanisole is an exception, exhibiting the process M−Me·−CS. Deuterium labelling[52] indicates that the loss of methyl originates from the methoxy group and

that the second methyl migrates from sulphur to oxygen before the loss of carbon monosulphide.

The three methylthioanisoles, as well as exhibiting substituent effects which are analogous to the corresponding methylanisoles[59,60], contain M−SH· ions, the relative abundances of which follow the order *meta* > *para* > *ortho* (23%, 7% and 4% respectively). This effect is due to the occurrence of simple reactions (e.g. M−Me·) being more prominent for *ortho* and *para* substitution than for *meta* substitution (see also section 3.5).

b, m/e 152   *m/e 154*
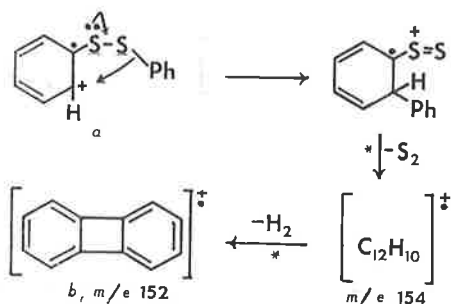
Aryl disulphides may lose S, SH·, H₂S or S₂ from their molecular ions[57]. For example the spectrum (Fig. 2) of diphenyl disulphide (2) exhibits the process M−S₂−H₂, to produce *m/e* 152, best represented as the biphenylene radical ion (*b*). Ionization of a double bond will produce both a radical and a carbonium ion site. The other phenyl group may migrate to either of these sites (e.g. *a → b*). Thiuram disulphides[58], e.g. (3), have peaks in their spectra resulting from the loss of four sulphur atoms. Fragment ions pro-

duced by the migration of phenyl to sulphur are also observed.

                    (3)
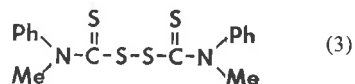
2.2 Cyclic sulphides

Skeletal-rearrangement ions are rare in the mass spectra of cyclic sulphides. Loss of sulphur with C−C bond formation is common, however by definition this is not a skeletal rearrangement, because of the cyclic nature of the compound (compare with the loss of CO from quinones[22,34] which is also a bond-forming but not a true skeletal rearrangement process).

The propylene dithioacetal (4) has a pronounced M−S₂H· ion in its mass spectrum (Fig. 3). This process is substantiated by an appro-

priate metastable peak. The rearrangement decreases when there are substituents attached to the phenyl ring (e.g. OR, NR₂ or NO₂), and
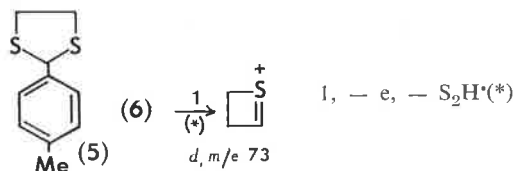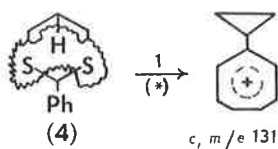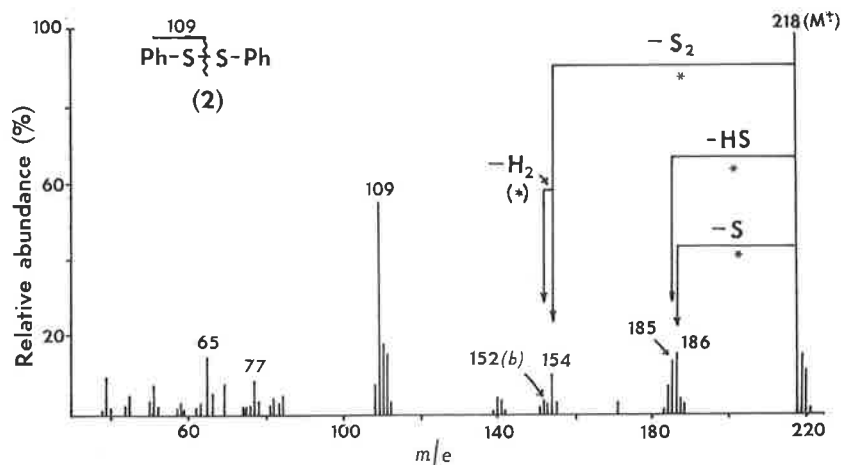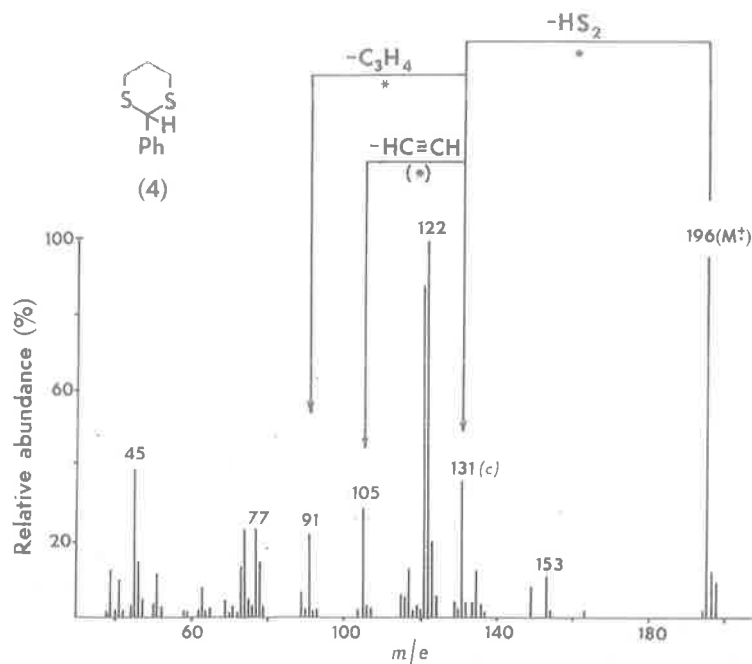

Figure 2

Figure 3

does not occur with the ethylene dithioacetal. Of particular note is the observation that the spectra of (4) and (5) are entirely different, with that of (5) containing no M—S$_2$H$\cdot$ ion. Deuterium labelling studies[61] show the loss to originate as indicated in (4) with some scrambling of the six methylene hydrogens. If the loss of S$_2$H$\cdot$ occurs in a one-step process then five bonds are broken simultaneously during the rearrangement. It is more likely that the mechanism is multi-stage, involving not a skeletal rearrangement, but a hydrogen rearrangement followed by bond cleavage and bond forma-

tion. The possible formation of the cyclopropyltropylium cation (*c, m/e* 131) may account for the propensity of the rearrangement. The presence of a phenyl ring is not necessarily a prerequisite for an M—S$_2$H$\cdot$ process. For example the spectrum of (6) shows an M—S$_2$H$\cdot$ ion, possibly *d, (m/e* 73)[62].

2.3   Thioglycollic acid and β-thiopropionic acid derivatives

The skeletal rearrangements considered so far, have occurred primarily because simple cleavage has been unfavourable. The following rearrangements are exceptions to this statement, and are examples of specific migration to electron-deficient sulphur atoms and to carbonium-ion centres.
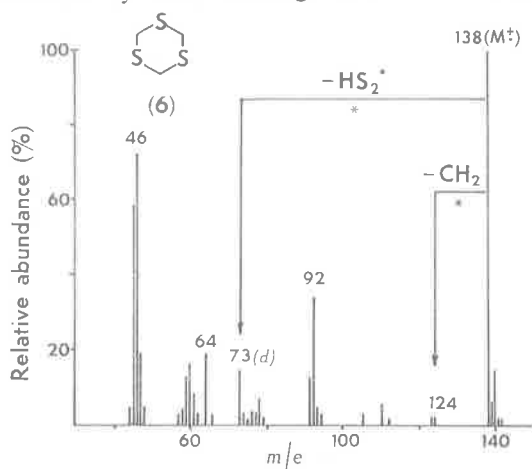
The mass spectra (e.g. Fig. 5 and 6) of thioglycollates (7) a n d β-thiopropionates (8)[63,64] show rearrangement peaks due to specific migration of the ester substituent (R) to charged sulphur, followed by loss of a hydrogen atom and C–S bond fission to produce RS$^+$. The rearrangement occurs in all the spectra studied, is generally substantiated by a metastable ion (see Table 1), and is most pronounced when R is benzyl or allyl. Even when R is alkyl, the abundance of the rearrangement ion lies between 15 and 25% of the base peak. It was originally suggested that

Figure 4

Table 1 Rearrangement ions in the spectra of thioglycollate and β-thiopropionate derivatives

Compound	RS+ (m/e)	Relative abundance (%)	Metastable ion for M → RS+
HSCH$_2$COOR			
R = Et	61	3	—
nPr	75	13	42·0
isoPr	75	18	42·0
nBu	89	13	53·4
secBu	89	17	53·6
isoAm	103	6	65·4
cyclohexyl	115	12	76·8
benzyl	123	28	83·2
MeCH(SH)COOR			
R = allyl	73	66	36·5
benzyl	123	46	77·2
HSCH$_2$CH$_2$COOR			
R = benzyl	123	16	77·3

Figure 5

Figure 6

HS(CH₂)ₙCOOR (7) n = 1
(7) (8) (8) n = 2
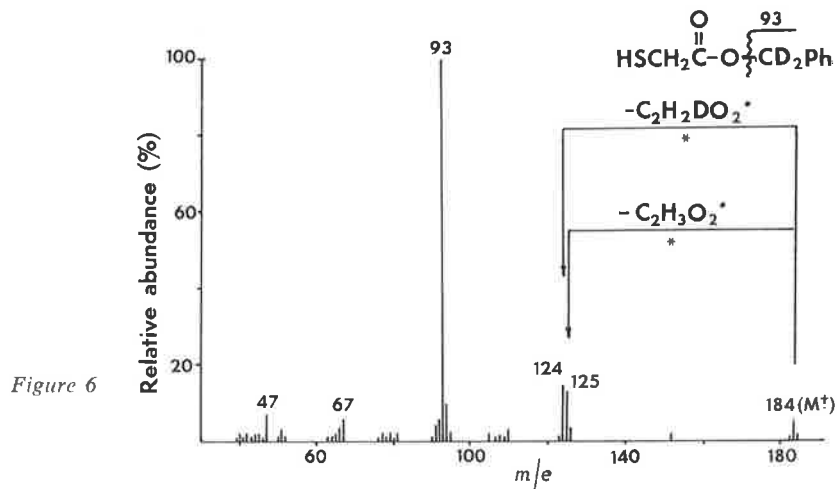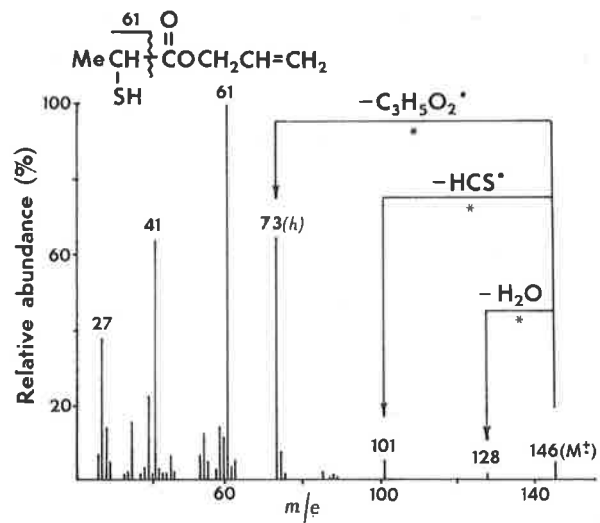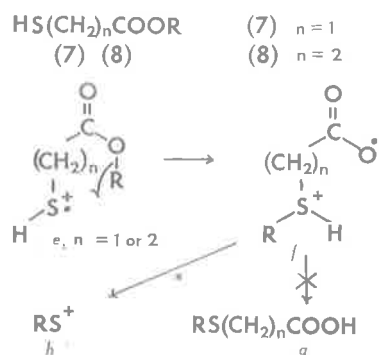
the intermediate responsible for the production of RS⁺ is *g*, however it has since been shown (see below) that such species themselves undergo characteristic rearrangements at low energies, and as these rearrangements are not observed in the spectra of (7) and (8), *g* cannot be the reactive intermediate. Deuterium-labelling studies are consistent with only 50% of the hydrogen atom lost originating from the

hydrogen attached to sulphur, with the remainder coming from R. It is concluded that although the initial migration ($e \rightarrow f$) is specific, further decomposition of *f* to produce the rearrangement ion is complex.

The spectra of *S*-alkylthioglycollates (9)[65,66] contain rearrangement ions produced by the loss of X⁻ [X > Y > Z, see (9)] with migration of RO to the carbonium-ion centre followed by cleavage of the S—CH₂ bond, *viz.* M—X⁻—CO. It has been proposed that this rearrangement proceeds by the process (9) → *i*.

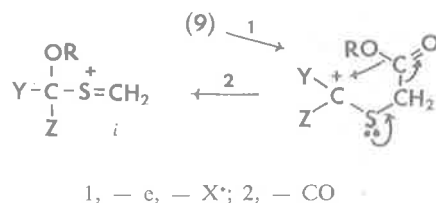Examples of the spectra are illustrated in

1, — e, — X⁻; 2, — CO

Table 2 Relative abundances of ions involved in rearrangement processes in the spectra of compounds of the general type (9)

$$\begin{array}{c} X \\ Y{-}CSCH_2COOR \ (X > Y > Z) \\ Z \end{array} \qquad (9)$$

X	Y	Z	R	YZCSCH₂COOR⁺ m/e	%	RYZC₂H₂SO⁺ m/e	%
Me	H	H	H	105	2	77	10
Et	H	H	H	105	6	77	20
Me	Me	H	H	119	3	91	1
*n*Pr	H	H	H	105	10	77	39
*iso*Pr	H	H	H	105	25	77	63
Et	H	H	H	119	16	91	6
Me	Me	Me	H	133	2	105	—
vinyl	Me	H	H	105	—	77	4
Ph	H	H	H	105	—	77	—
Me	H	H	Me	119	1	91	3
Et	H	H	Me	119	3	91	6
*n*Pr	H	H	Me	119	5	91	7
*iso*Pr	H	H	Me	119	13	91	18
Ph	H	H	Me	119	—	91	—

Fig. 7 and 8 and the abundances of the rearrangement ions in Table 2. The relative abundances of i may be correlated with the nature of X, Y, Z and R. The rearrangement

X increases. These observations are in accord with the carbonium ion mechanism. If RO migrated to sulphur, the rearrangement should be M−X˙−CH₂CO not M−X˙−CO[67,68].
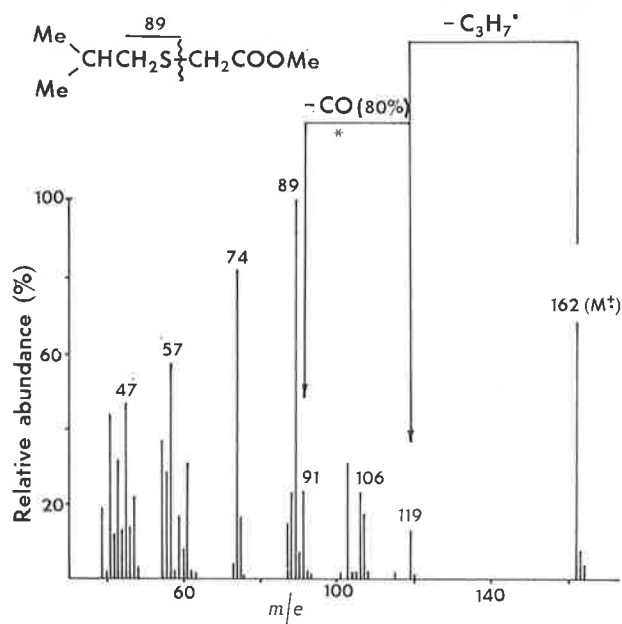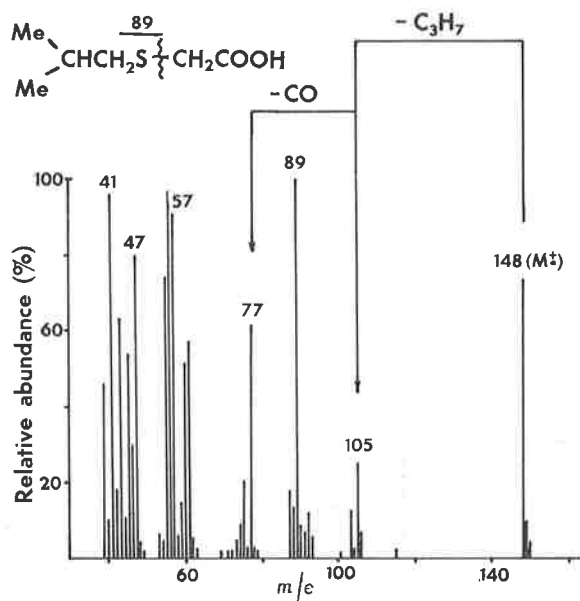
$$Me \diagdown \atop Me \diagup CHCH_2S \overset{\underline{89}}{\big|} CH_2COOH$$

Figure 7

$$Me \diagdown \atop Me \diagup CHCH_2S \overset{\underline{89}}{\big|} CH_2COOMe$$


Figure 8

is more pronounced in the spectra of acids than of the esters. The amount of rearrangement depends on the nature of the carbonium ion, e.g. primary > secondary > tertiary, the order expected for migration. When X is alkyl the rearrangement increases as the length of

As the spectra of S-alkylthioglycollates show the processes M−X˙−CO, it would be predicted that the spectra of corresponding S-alkyl-β-thiopropionic acids s h o u l d contain M−X˙−CH₂CO ions. Although this fragmentation does occur[69], a more striking rearrange-

ment, M—X˙—YZCO, can also be seen (Fig. 9 and 10 and Table 3). In marked contrast to the S-alkylthioglycollates, the abundances of the rearrangement peaks do not appear to be dependent upon whether the incipient carbonium ion is primary or secondary. No migration proceeds to a tertiary carbonium ion. The rearrangements possibly proceed by the processes (11) → k and (11) → l.

1, − e, − X˙; 2, − CH$_2$CO; 3, − YZCO'˙

Figure 9

Figure 10
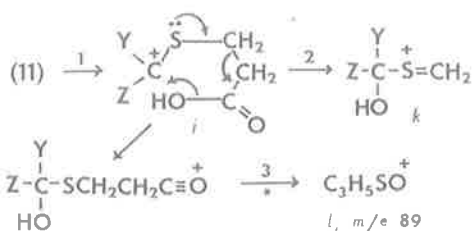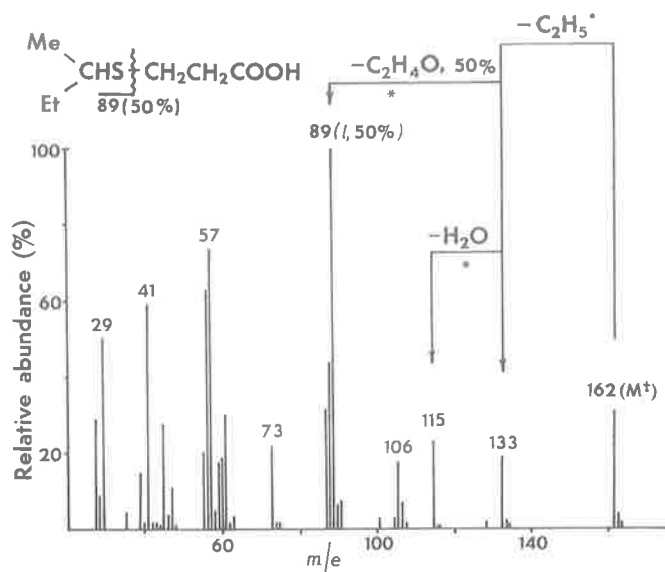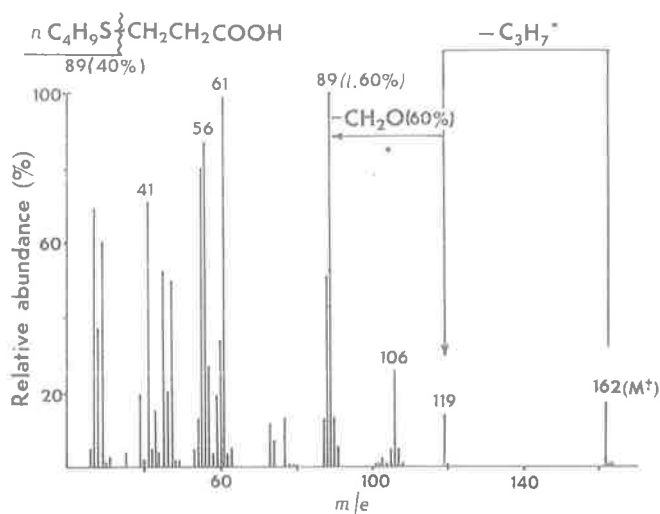
When the alkyl group attached to sulphur is not branched (Y=Z=H), the second rearrangement [(11) → l] is simply M—X˙—CH$_2$O. Although such a rearrangement demands migration to a carbonium centre, it is not clear why n-alkylthiopropionic acids eliminate formaldehyde from the M—X˙ ion when the corresponding thioglycollic acids do not. Whether the hydrogen migrates to oxygen or sulphur is a matter of conjecture,

Table 3   *Rearrangement ions in the spectra of* S-*alkyl-β-thiopropionic acids*

$$\begin{array}{c} X \\ \diagdown \\ Y\!-\!CSCH_2CH_2COOH \qquad (11) \\ \diagup \\ Z \end{array}$$

X	Y	Z	M—X· (%)	M—X·—CH₂CO	M—X·—YZCO
Me	H	H	1	3	6
Et	H	H	3	5	14
Me	Me	H	7	1	35
iPr	H	H	14	13	60
isoPr	H	H	8	16	70
Et	Me	H	19	2	50
Me	Me	Me	—	—	—
vinyl	H	H	1	1	16
Ph	H	H	—	—	—

s is the structure of *l*, which may have under-one complex rearrangement, as it shows no apparent loss of carbon monoxide. The corresponding rearrangements either do not occur, or are very small, in the spectra of the methyl -alkyl-β-thiopropionates.

2.4   Thioesters and thiocarbamates

The mass spectra[70] of simple S- and O-alkyl-thioesters show peaks due to alkyl rearrangement to oxygen and sulphur respectively. The rearrangement peaks are summarized in Table, and their formation is not substantiated by metastable ions. The rearrangements possibly

Table 4   *Rearrangement ions in the spectra of* S- *and* O-*alkylthioesters*

$$\begin{array}{c} R\!-\!C\!-\!OR' \\ \| \\ S \end{array}$$

R	R'	R'S+ (%)
Me	Me	20
Me	Et	39
Ph	Me	4
Ph	Et	3·5

$$\begin{array}{c} R\!-\!C\!-\!SR' \\ \| \\ O \end{array}$$

R	R'	R'O+
Me	Me	1·5
Me	Et	23
Ph	Me	0·5
Ph	Et	45

proceed by the four-centre mechanisms $m \rightarrow q + r$ and $n \rightarrow o + p$.
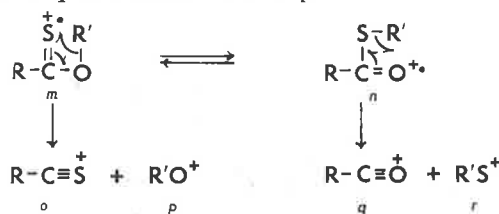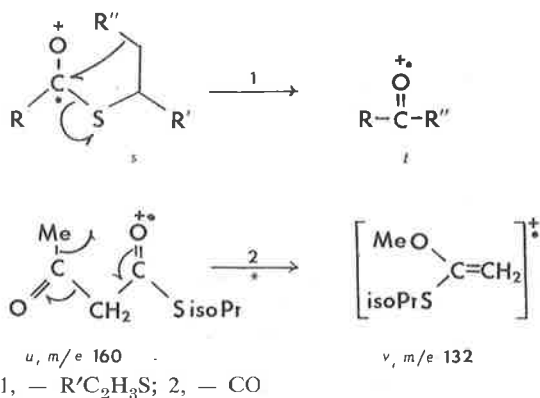

S-Alkylthioesters of the type:— $RCOS(CH)R'CH_2R''$, undergo a different rearrangement, *viz.* M—SCH(R')CH₂. In some cases the rearrangement ion may carry up to 10% of the total ion current, but is generally less abundant[71]. The rearrangement should be compared with the losses of formaldehyde from the molecular ions of simple esters[72-74], and may be represented by the process $s \rightarrow t$. Although the mechanism is drawn as a migration to a radical centre it could equally involve migration to a carbonium ion.

u, m/e 160

v, m/e 132

1, — R'C₂H₃S; 2, — CO

β-Ketothioesters undergo alkyl migration[75] with accompanying loss of carbon monoxide. This process is also a feature[75,76] of the behaviour of β-ketoesters upon electron impact where it has been shown (by ^{18}O labelling) that the ketone moiety is lost during the rearrangement. By analogy with this observation it is suggested that the loss of carbon monoxide from the molecular ions of β-ketothioesters proceeds by the process $u \to v$ (for the specific example of the *iso*propylthioester, where the M—CO peak has a relative abundance of 10%).
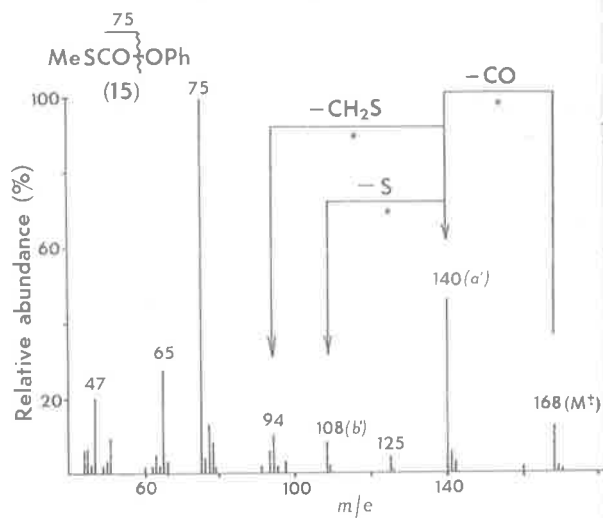
Small rearrangement peaks are observed in

Alkyl migrations are noted in the spectra c alkylisothiocyanates[79,80]. For example th spectrum of isopropyl isothiocyanate exhibi a peak at m/e 72, which may arise by th process $y \to z$.

$$\underset{\substack{+\bullet \\ y,\; m/e\; 101}}{\overset{\overset{\displaystyle Me}{|}}{MeCHN=C=S}} \to \underset{\substack{\bullet \quad + \\}}{\overset{\overset{\displaystyle H_{\bullet}CH_2}{\diagup |}}{MeCH\,N=C=S}} \to \underset{\substack{+ \\ z,\; m/e\; 72}}{H_2C=N=C=S}$$
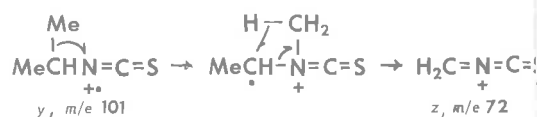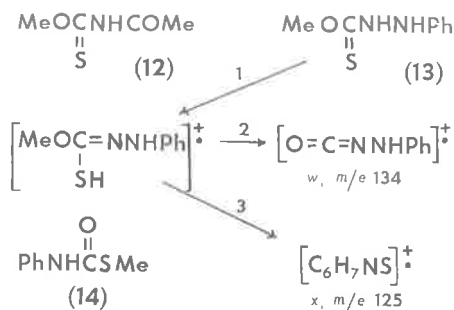
2.5 Thiocarbonates

Arylthiocarbonates undergo a series of strik ing rearrangements upon electron impact[81] an

Figure 11

a variety of other thiocarbonyl derivatives[77]. Particularly noteworthy is the loss of CO (5%) from (12), and the elimination of methylmercaptan and MeOCN from the molecular ion of (13), *viz.* (13) $\to w$ and (13) $\to x$.

$$\underset{(12)}{\overset{\overset{\displaystyle O}{\|}}{MeOCNHCOMe}} \qquad \underset{(13)}{\overset{\overset{\displaystyle O}{\|}}{Me\,OCNHNHPh}}$$

$$\left[\underset{SH}{\overset{\overset{\displaystyle |}{\displaystyle }}{MeOC=NNHPh}}\right]^{+\bullet} \xrightarrow{2} \left[O=C=N\,NHPh\right]^{+\bullet}_{w,\; m/e\; 134}$$

$$\underset{(14)}{\overset{\overset{\displaystyle O}{\|}}{PhNHCSMe}} \qquad \left[C_6H_7NS\right]^{+\bullet}_{x,\; m/e\; 125}$$

1, — c; 2, — MeSH; 3, — MeOCN

Weak rearrangement peaks are observed for M—CO and M—HNCO processes in the spectrum of *S*-methyl phenylthiocarbamate (14)[78].
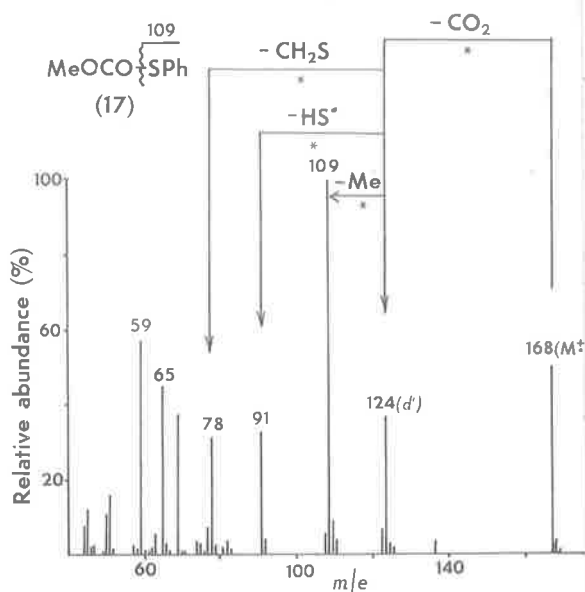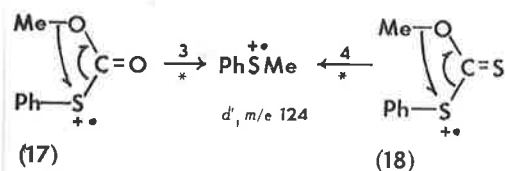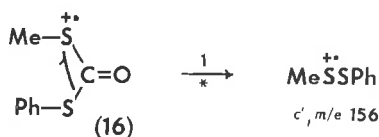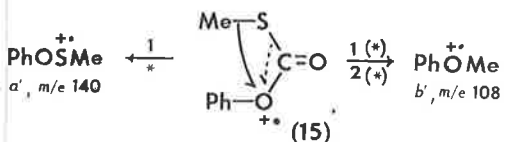

Figure 12

ese should be compared with the rearrange-
ents in the spectra of the corresponding car-
onates[82-84]. The rearrangements are summar-
ed below for S-methylphenylthiocarbonate

$$
PhO\overset{+\bullet}{S}Me \xleftarrow[*]{1}
\begin{array}{c} Me-S \\ \diagdown \\ C=O \\ \diagup \\ Ph-O \\ +\bullet \end{array}
\xrightarrow[2(*)]{1(*)} Ph\overset{+\bullet}{O}Me
$$

a', m/e 140   (15) b', m/e 108

$$
\begin{array}{c} Me-\overset{+\bullet}{S} \\ \diagdown \\ C=O \\ \diagup \\ Ph-S \end{array}
\xrightarrow[*]{1} Me\overset{+\bullet}{S}SPh
$$

(16) c', m/e 156

$$
\begin{array}{c} Me-\overset{+}{O} \\ \diagdown \\ C=O \\ \diagup \\ Ph-S \\ +\bullet \end{array}
\xrightarrow[*]{3} Ph\overset{+\bullet}{S}Me \xleftarrow[*]{4}
\begin{array}{c} Me-O \\ \diagdown \\ C=S \\ \diagup \\ Ph-S \\ +\bullet \end{array}
$$

(17) d', m/e 124   (18)

, — CO; 2, — S; 3, — CO$_2$; 4, — COS

15), S-methyl-S-phenyldithiocarbonate (16),
nethyl-S-phenylthiocarbonate (17) and O-
nethyl-S-phenyldithiocarbonate (18). Abun-
lant losses of CO, COS and CO$_2$ are noted in
nany spectra, and it has been suggested[81] that
referred charge retention on sulphur offers a
ationale for the occurrence of such diversified
earrangements in many spectra. The spectra
f (15) and (17) are illustrated in Fig. 11
nd 12.

3 COMPOUNDS CONTAINING THE S—O GROUP

3.1 Sulphoxides

Although the spectra of purely aliphatic sulph-
oxides[85-88] are devoid of abundant skeletal-
rearrangement peaks, those of aryl sulph-
oxides[86,87,89] have ions which arise by both
molecular-ion rearrangements and the process
ABC → AC + B. The rearrangements are
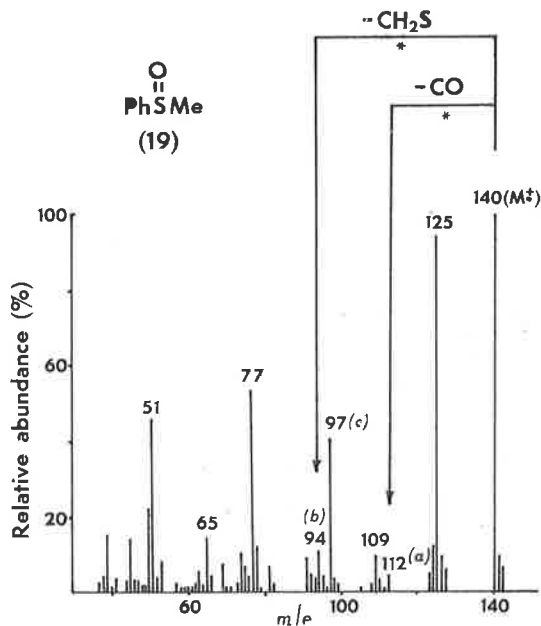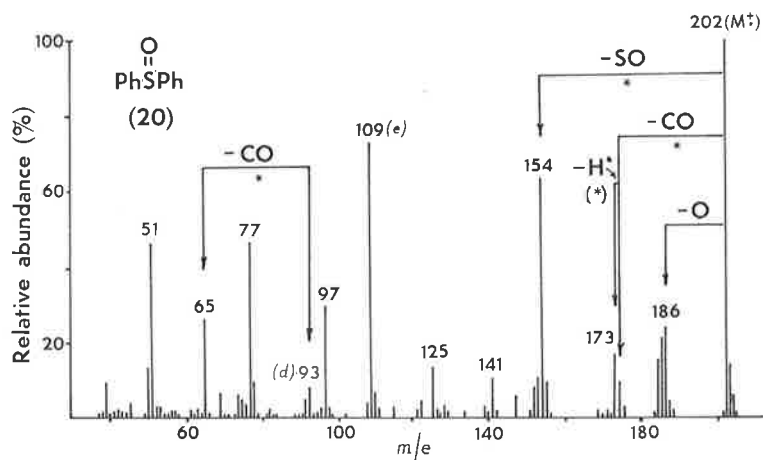typified by the spectra (Fig. 13 and 14) of

Figure 13

Figure 14

methylphenylsulphoxide (19) and diphenyl-
sulphoxide (20). The formation of M—CO
fragments, together with the phenol radical ion
and cation, necessitates C—O bond formation.
The scheme below serves to rationalize the
molecular ion rearrangement. Loss of SO
could either occur from rearranged or un-
rearranged molecular ions.

3.2 Sulphones, sulphonamides, sulphonyl chlorides and sulphonates

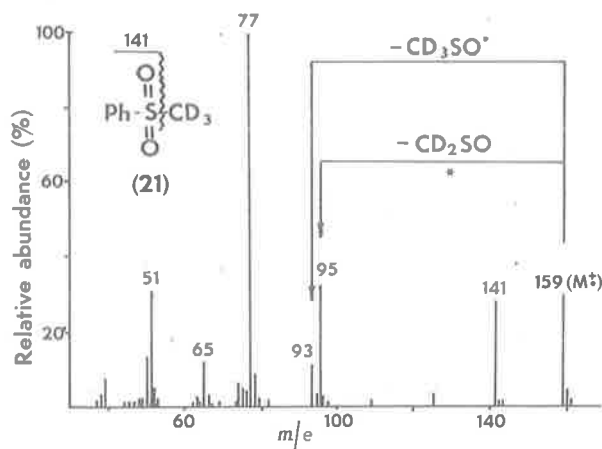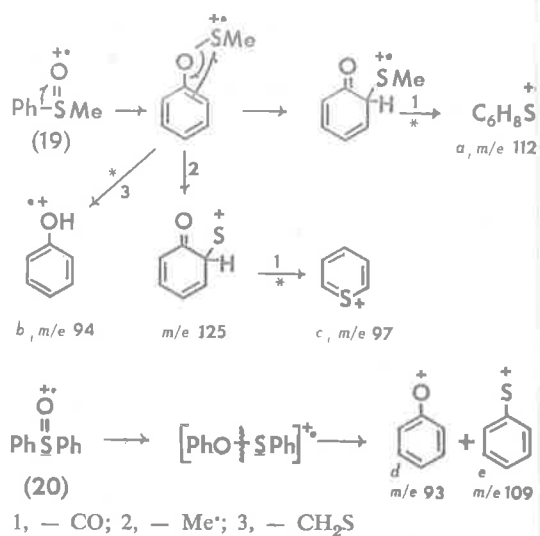Compounds of this group behave like the sulph-
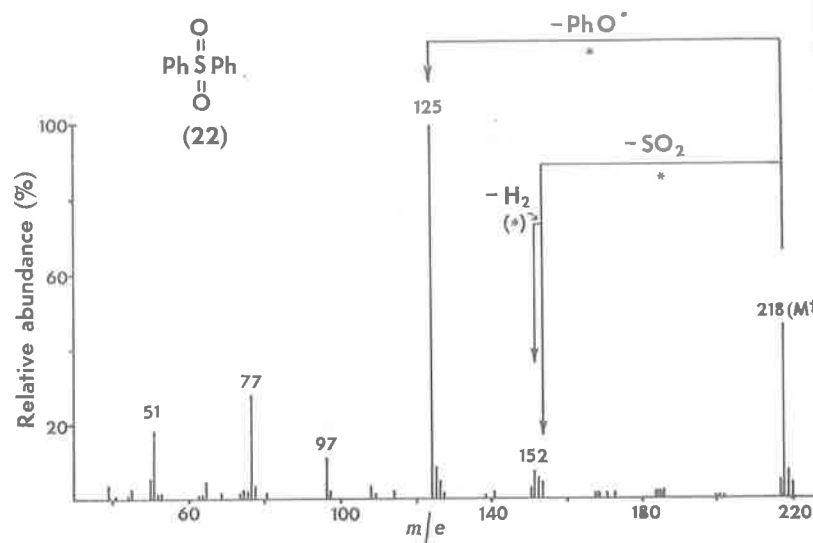oxides (section 3.1). Extensive skeletal-

1, — CO; 2, — Me·; 3, — CH₂S

Figure 15

Figure 16

Figure 17

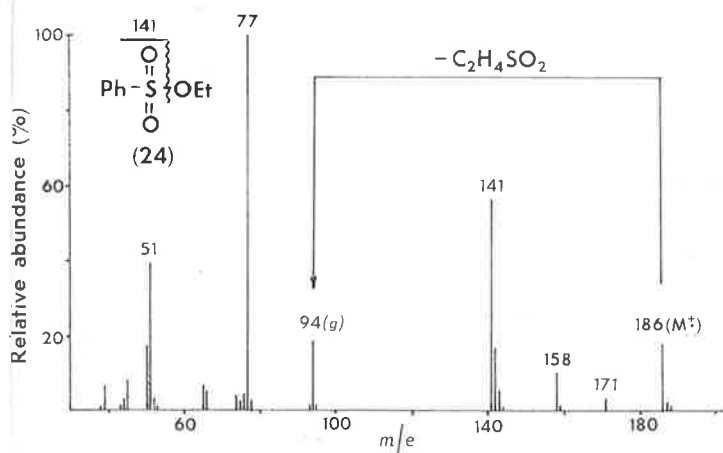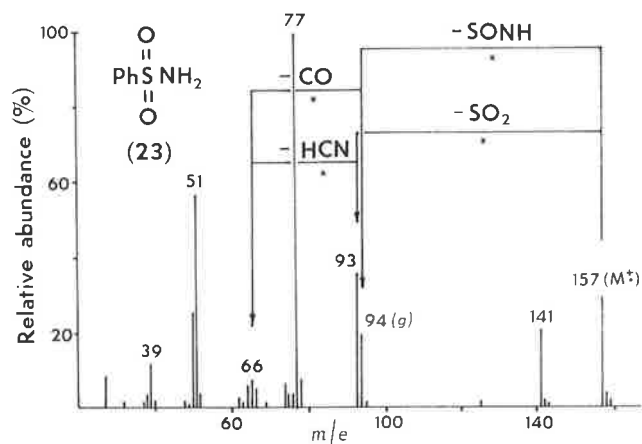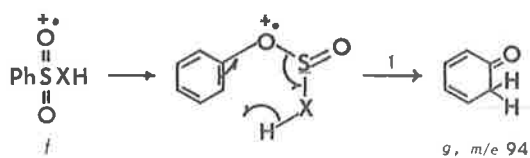*Figure 18*

rearrangement is observed in the spectra of arylsulphones[86,87,90-93] (not alkylsulphones[86,87]) arylsulphonamides[95,96], arylsulphonyl chlorides[96] and arylsulphonates[62] (not alkylsulphonates[94]). Sulphones and sulphonamides undergo both C–O bond formation and $ABC \rightarrow AC + B$ elimination. Sulphonyl chlorides eliminate SO_2 but there is no evidence of C–O bond formation, while the only arylsulphonate so far studied undergoes C–O formation but no elimination of SO_2. The spectra (Fig. 15-18) of trideuteromethylphenylsulphone (21), diphenylsulphone (22), benzenesulphonamide (23) and ethyl benzenesulphonate (24) illustrate the general rearrangements. A feature of the spectra of alkylarylsulphones and aryl-

sulphonamides is the elimination of SOX (see $f \rightarrow g$) with hydrogen rearrangement, to produce the keto form of the phenol radical ion. Hydrogen rearrangement with elimination of $C_2H_4SO_2$ in the spectrum (Fig. 18) of the sulphonate (24) also produces g, but this rearrangement has not been studied by deuterium labelling.

g, m/e 94

(X = CHR or NR); 1, — SOX
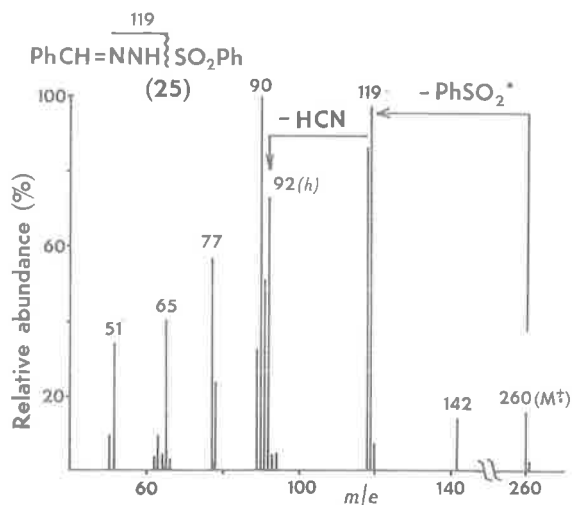
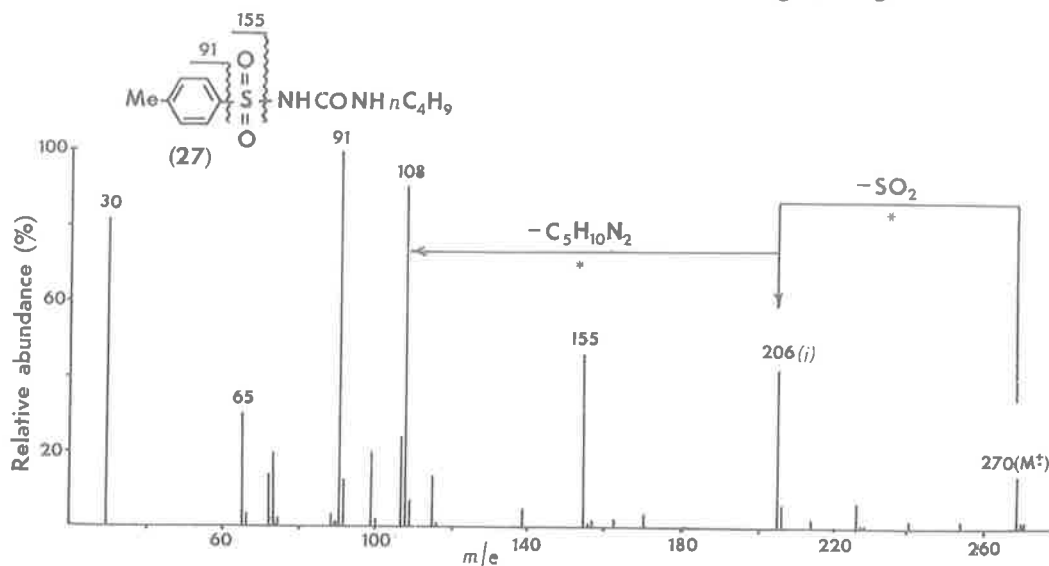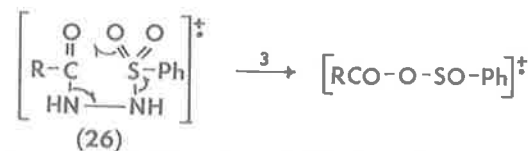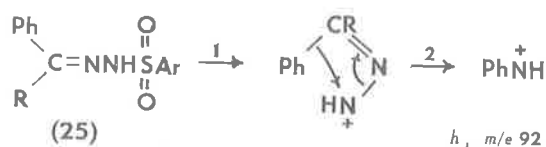### 3.3 Sulphonylhydrazones, sulphonyl-hydrazines and sulphonylureas

$$PhCH=NNH\overbrace{}^{119}SO_2Ph$$

(25)

Figure 19

The spectra[97] of the arylsulphonylhydrazon (25, R = H, Me, or Ph) do not exhibit typic rearrangement or elimination of the sulphon group, but instead eliminate RCN from th M−ArSO₂⁺ ion [(25) → h] (see Fig. 19 N-p-Toluenesulphonyl-N′-acylhydrazines (26 eliminate a molecule of diimide from the mol cular ion and it has been suggested[97] that th proceeds by the cyclic mechanism (26) → i.

(27)
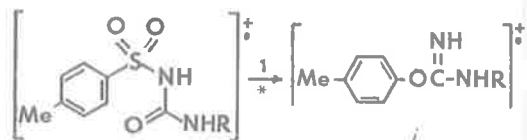
1, − SO₂(*)

Intense M−SO₂ ions can be seen in the mas spectra[98] of arylsulphonylureas [(27) l = alkyl]. As an illustration see Fig. 20 Deuterium-labelling and high-resolution studie

$$Me-\langle\rangle-\overset{\overset{O}{\|}}{\underset{\underset{O}{\|}}{S}}-NHCONH\,nC_4H_9$$

(27)

Figure 20

are consistent with O−C migration [(27) → j] being favoured over the alternate N−C bond formation.

3.4 Cyclic sulphites

Methyl and phenyl migrations are observed in the mass spectra of cyclic sulphites[99,100], and these rearrangements are analogous to those exhibited by the corresponding carbonates[82-84] upon electron impact. The best example is

(25)

h , m/e 92

(26)

1, − e, − ArSO₂⁺; 2, − RCN; 3, − N₂H₂

drobenzoin sulphite (28) where loss of sul-
ur dioxide from the molecular ion is accom-
nied by both hydrogen and phenyl migra-
n, with hydrogen migration predominating.
he M−SO$_2$ peak (3% of the base peak)
rresponds to both k and l as evidenced by
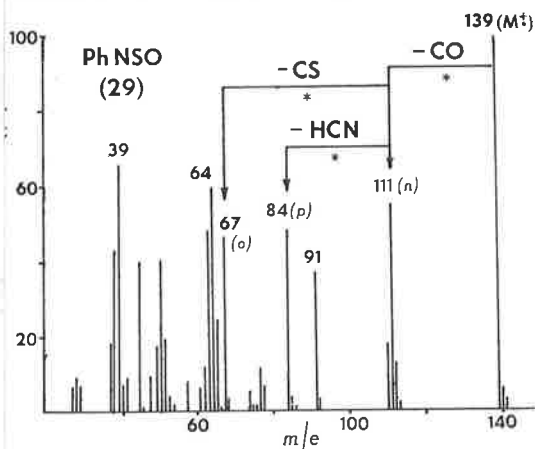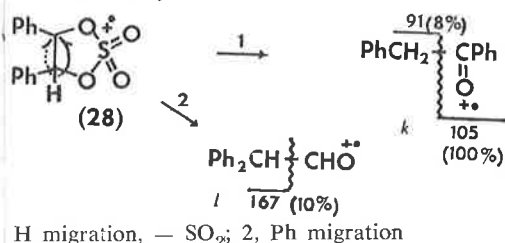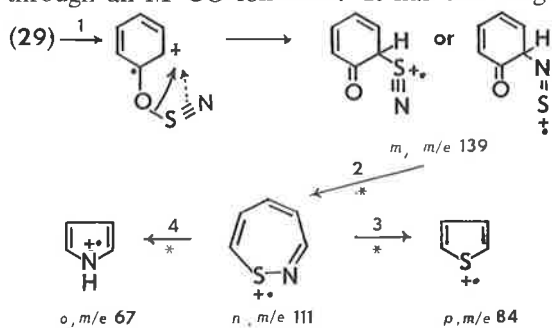e fragmentation of these ions to m/e 91 and
57 respectively.

H migration, − SO$_2$; 2, Ph migration

3.5 Sulphinylanilines

The major fragmentations in the spectrum
(Fig. 21) of sulphinylaniline (29) proceed
through an M−CO ion[101,102]. It has been sug-

1, − e; 2, − CO; 3, − HCN; 4, − CS

gested[102] that C−O bond formation followed
by C−S formation produces a rearranged mole-
cular ion, m, which may then eliminate carbon
monoxide. The ion produced by this elimina-
tion may be cyclic (e.g. n) as it loses both CS
and HCN to yield o and p respectively. The
spectra of substituted sulphinylanilines[102] also
exhibit rearrangement peaks, the abundances
of which depend upon both the nature and
position of the substituent. For example, the
spectrum (Fig. 22) of *meta*-methoxysulphinyl-
aniline (30) shows pronounced rearrangement
while those of the *ortho* and *para* isomers are
devoid of such peaks. This is a further ex-
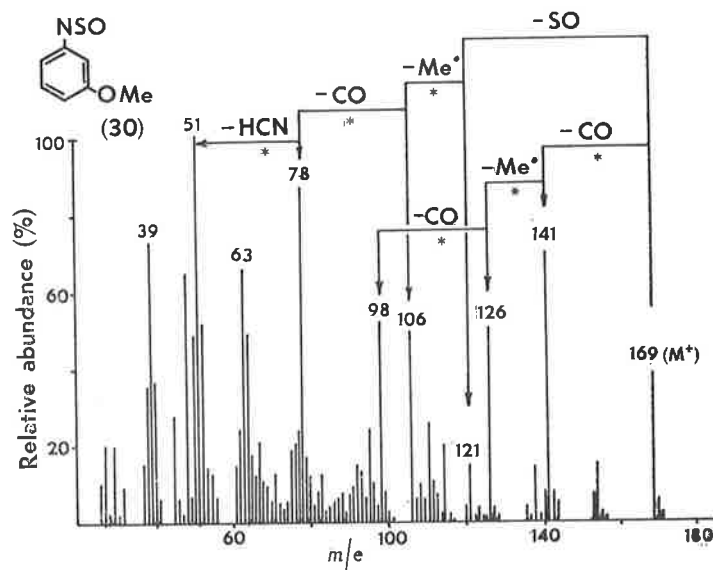ample (see also section 2.1) where a decrease

Figure 21

Figure 22

in the proclivity of simple fragmentations in *meta*-substituted compounds (as opposed to the *ortho* and *para* cases) allows skeletal reorganization to occur in the molecular ion.

4 HETEROCYCLIC COMPOUNDS
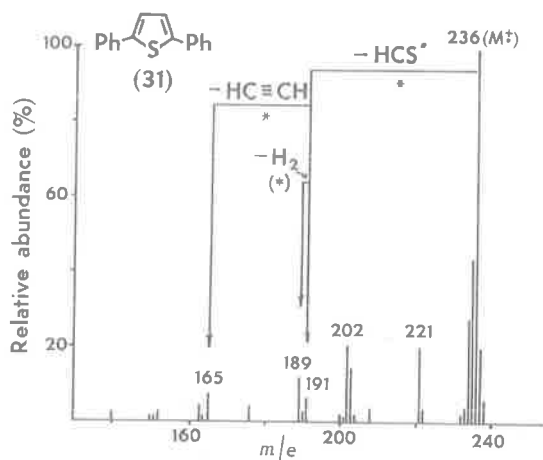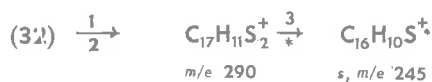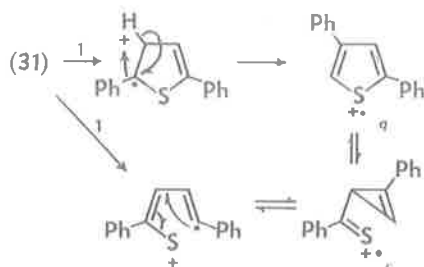
4.1 *Thiophens and thio[18]annulenes*

Figure 23

$(32) \xrightarrow{\frac{1}{2}} C_{17}H_{11}S_2^+ \xrightarrow{\frac{3}{*}} C_{16}H_{10}S^{+\cdot}$

$m/e\ 290 \qquad s,\ m/e\ 245$

1, $-$ e; 2, $-$ HS$^{\cdot}$(*); $-$ H$^{\cdot}$(*); 3, $-$ HCS(*)

One of the characteristic fragmentations the thiophen-ring system is elimination HCS$^{\cdot}$ from the molecular ion[105]. It would predicted that this loss of HCS$^{\cdot}$ should n occur when the 2- and 5-positions of tl thiophen nucleus are blocked by substituen which do not fragment readily themselves (e. phenyl and chloro). However, the spectra such compounds [e.g., 2,5-diphenylthiophe (31), Fig. 23] do contain M$-$HC ions[103,106-108]. There are two possible types mechanism for this elimination, *viz.* a migr
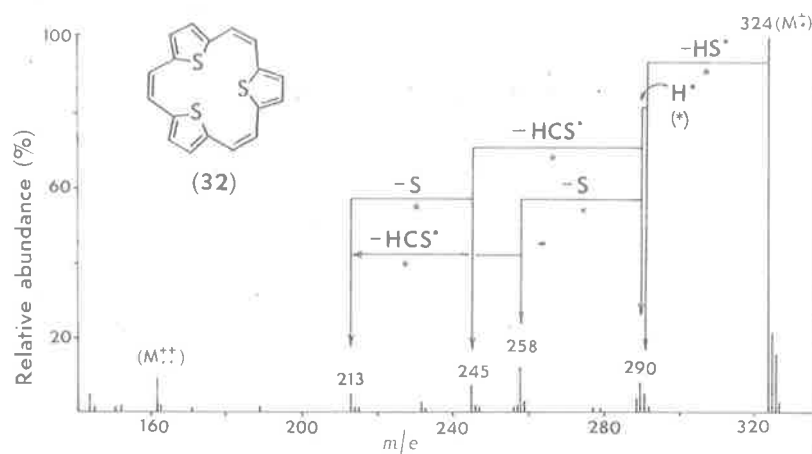
Figure 24

The spectra of benzoylthiophens[103,104] and thiophen carboxylic acids[103] exhibit M$-$CO peaks. As alkyl and aryl carboxylic acids do not lose carbon monoxide upon electron impact, but both thiophen 2- and 3-carboxylic acids do, it seems plausible that sulphur affects the rearrangement, and that a common rearranged intermediate may be responsible for the rearrangement.

tion mechanism (31) $\rightarrow$ *q*, or an isomerizatio: [e.g. (31) $\rightarrow$ *r* $\rightarrow$ *q*]. The latter mechanisn is the more reasonable, but ^{13}C-labelling studie would be necessary to differentiate between th two types of mechanism. It is of interest t note that phenylthiophens undergo a simila photochemical isomerization[109-111]. The spectr of hetero[18]annulene derivatives[112] are furthe examples of this rearrangement. For example

ie spectrum (Fig. 24) of the trisulphide (32) iows the p r o c e s s M–HS˙–H˙–HCS˙ 32 → s).

4.2   Diphenylthiazoles

)xazoles, isoxazoles, imidazoles, pyrazoles, iiazoles and isothiazoles containing two ad-icent aryl groups undergo a characteristic re-rrangement upon electron impact to form the uorene cation (u, m/e 165)[108,113]. This re-rrangement has been studied by deuterium ibelling for imidazoles, pyrazoles, oxazoles nd isoxazoles but not for the corresponding ilphur analogues. The extent of the re-rrangement can be seen in the spectrum (Fig. 5) of 4,5-diphenylthiazole (33). The peak

at m/e 165 in this spectrum constitutes 85% of the base peak, while the corresponding ion in the spectrum of 2,4-diphenylthiazole is only 1% of the base peak. The mechanism of the rearrangement is thought to be (33) → u, (by analogy with the diphenylimidazoles) but it is not clear whether the cyclized ion t accounts for the rearrangement, or whether phenyl migration occurs prior to the formation of the cyclic intermediate.

4.3   Transition metal π-complexes

Extensive skeletal rearrangement of sulphur containing transition metal π-complexes has been observed[114]. The chromium complex (34) (R = Me or Ph) undergoes the decomposition (34) → v.

Figure 25
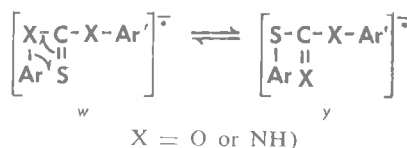

u, m/e 165

1, — HCN(*), — HCS˙(*)
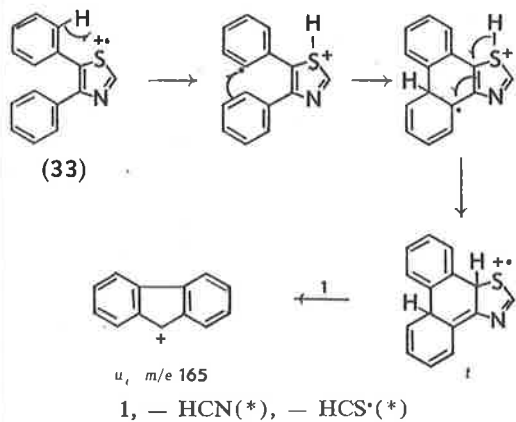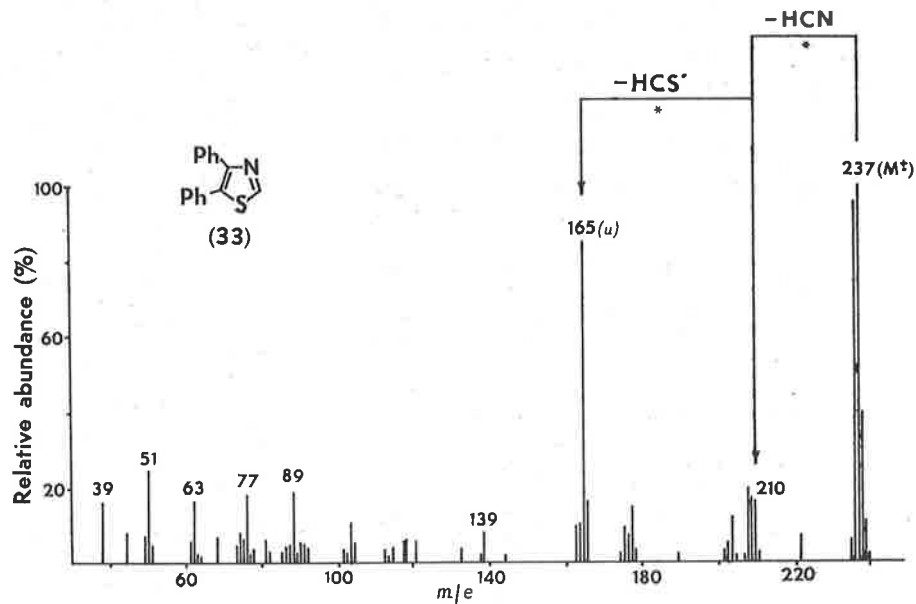
5   NEGATIVE-ION MASS SPECTRA

The negative-ion mass spectra of organo-sulphur compounds are devoid of skeletal-rearrangement peaks if the spectra are deter-

(34)

v, m/e 182

1, — e, — 2R˙, — CrS₂;
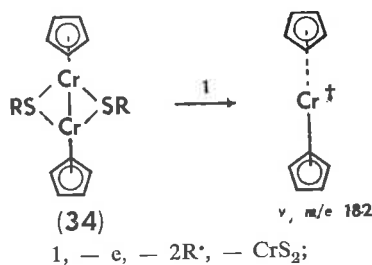
mined at low-source pressure (10^{-6}-10^{-7}mm Hg) in order to avoid ion-molecule reactions[115,116]. Under these conditions reproducible spectra may be obtained, with fragment ions being produced either by simple cleavage or cleavage with hydrogen rearrangement. Compounds studied are those of sections 2.1, 2.3, 3.1, 3.2, 3.5, 4.1 and 4.2.

If the pressure in the source is increased to 10^{-2}-10^{-3}mm Hg, ion-molecule reactions may

occur, and in special cases, skeletal-rearrangement processes are observed. The general approach of this work has been reviewed[11] and a series of skeletal rearrangements of the type $w \rightarrow y$ have been described[118].

$$\begin{bmatrix} X-C-X-Ar' \\ | \; || \\ Ar \; S \end{bmatrix}^{\bar{\cdot}} \rightleftharpoons \begin{bmatrix} S-C-X-Ar' \\ | \; || \\ Ar \; X \end{bmatrix}^{\bar{\cdot}}$$

$$w \qquad\qquad y$$

$$X = O \text{ or } NH)$$

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