

INVESTIGATIONS INTO THE ELECTRON
IMPACT INDUCED REACTIONS OF
BENZOTRIAZOLES AND RELATED COMPOUNDS

A thesis presented by

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ABSTRACT

The formation of tropylium ion is reviewed and the possibility of formation of analogous ions in the mass spectra of benzotriazoles and related compounds investigated.

The loss of a molecule of N_2 from the molecular ion of substituted benzotriazoles and benzothiadiazoles and the loss of a molecule of NO from the molecular ion of substituted benzofurazans have been studied. The relative ease of these losses has been investigated by comparing the corresponding ionization and appearance potentials. It is observed that in general the loss of a molecule N_2 is more facile than the loss of NO in compounds in which the two hetero atoms are adjacent to each other. This is related to the greater stability of a nitrogen molecule.

The fragmentation patterns of benzotriazoles, benzoxadiazoles and benzothiadiazoles have been studied and compared, and the effect of substituents on these fragmentation patterns investigated.

TO MY PARENTS

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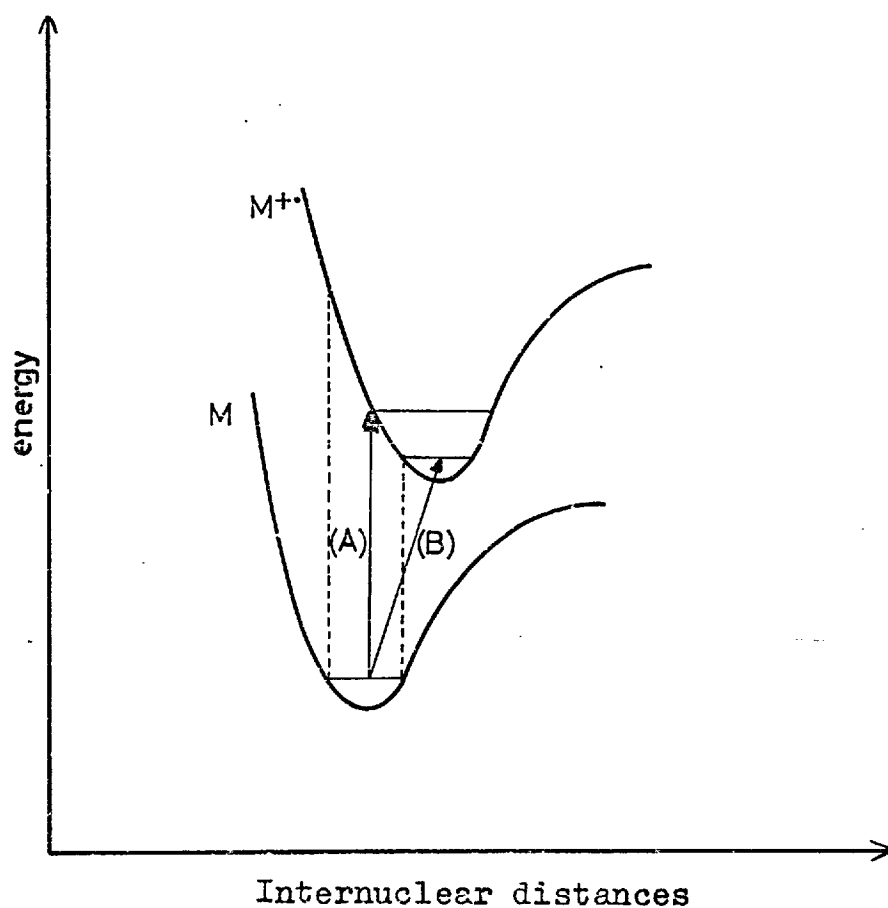
CHAPTER ONE

REVIEW OF LITERATURE

IONIZATION AND APPEARANCE POTENTIAL

In an electron impact mass spectrometer when a molecule is bombarded with a high energy beam of electrons (70 ev) the least energetic process that can be detected corresponds to removal of an electron from the highest occupied molecular orbital. The resulting ion is the molecular ion. The energy required for this process is the ionization potential (IP) of the molecule.

The velocity of a 50 ev electron has been mentioned¹ to be about 42×10^8 cm/s. An electron with such a speed traverses molecular diameters of a few Å in around 10^{-16} sec. The most rapid vibrations in molecules occur in about 10^{-14} sec., i.e. about 100 times slower. Therefore the process of removal of an electron from a molecule by electron impact will occur without changes in internuclear distances, i.e., the transition follows the Frank-Condon rule which requires that the configuration and momenta of the nuclei do not alter during the transition (fig. 1). Experimentally the molecular ion is usually left in a vibrationally excited state and the corresponding ionization potential is called the vertical IP,(A). The adiabatic IP,(B), on the other hand, is the amount of energy required to remove an electron from the molecule in its lowest vibrational level, leaving the resultant ion in its lowest vibrational level.

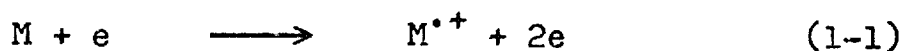


(fig. 1)

The probability of such an adiabatic process is very small. As a result the ionization process by electron impact is accompanied by some vibrational excitation. Because of this factor, the IP's by electron impact are slightly larger than those obtained by spectroscopic methods. Field and Franklin² have attributed this to the possibility that photon-impact gives adiabatic IP.

The minimum amount of energy necessary to produce an ion and a neutral fragment in the source of mass spectrometer is termed "appearance potential" (AP).

For the reaction



The IP and AP are related to heats of formation as follows:-

$$IP = H_f(M^{\bullet+}) - H_f(M) \quad (1-3)$$

$$AP = H_f(F^{\bullet+}) + H_f(N) - H_f(M) \quad (1-4)$$

$$AP = H_f(F^{\bullet+}) + H_f(N) - H_f(M^{\bullet+}) + IP \quad (1-5)$$

The appearance potential measured is in fact roughly the sum of the IP plus the activation energy (E_a) for the reaction (1-2).

It has been argued³ that the activation energy represented by $AP - IP$ is the sum of energy required to get to the transition state plus the energy required to obtain a reaction rate constant of about $10^5 s^{-1}$. This rate constant must be reached in the source of mass spectrometer if the daughter ion is to be detected. This extra amount of energy has been termed the "kinetic shift"⁴.

In order to look at the kinetic shift more closely a brief look at the quasi-equilibrium theory (QET) is necessary. According to the QET⁵ in its simplest form⁶ the assumption is made that the fragmentation process involves a series of competing, consecutive unimolecular decomposition reactions of energetically excited molecular ions. Another important assumption is that the initial excitation energy is randomized throughout the molecule at a faster rate than the rate

of dissociation. Fragmentation will only result when enough energy has gathered in the necessary bonds. The internal energy E and the rate constant for a given reaction have originally been related ⁵ as follows:-

$$k = \nu \left(\frac{E - E_a}{E} \right)^{s-1} \quad (1-6)$$

where E_a is the activation energy for the given reaction, s is the effective number of oscillators and ν is a frequency factor. In a given situation " s " represents the vibrational modes, i.e., the number of internal degrees of freedom and is given by $(3n - 6)$, where n is the number of atoms in the molecule. It has been shown ⁴ that one-third of this value should be considered to be the effective number of oscillators. The frequency factor " ν " is considered to be a constant for any given reaction and it can be, very roughly, thought of as the number of paths by which a reaction can occur. McLafferty⁷, qualitatively relates the magnitudes of " ν " to the looseness of the activated complex. A "loose complex" is the one in which the rotational states have increased at the expense of vibrational states. In a "tight complex", on the other hand, the rotational degrees of freedom are frozen. From the above equation (1-6) it can be seen that a relatively large internal energy as compared to the activation energy of a certain reaction makes the ratio $\frac{E - E_a}{E}$ approach unity and, hence, the rate constant " k " equals the vibrational frequency of the bond in question. If, however, the activation energy " E_a " is smaller but of the same order of magnitude

of internal energy "E", then the rate constant will be dependent on the size of the molecule and the frequency factor. The larger the molecule the larger the number of degrees of freedom, s. Since $(E-E_a)/E < 1$ a large value of "s" will reduce "k".

In a rearrangement reaction two things should be fulfilled before the reaction can occur. First, enough energy should be collected in the appropriate reaction coordinates, the activation energy. Second, in the transition state, the molecule should attain a specific orientation. The value of " ν ", the frequency factor, is dependent on the second factor. The more the specificity ⁶(or tightness of transition state ⁷) of orientation the lower the value of " ν ", and hence, the smaller the value of the rate constant.

As mentioned previously the amount of energy necessary to increase the rate constant of a reaction to about 10^5s^{-1} in the ion source is termed the "kinetic shift". The magnitude of this energy can be roughly generalized using the relationship between "k" and "E" ³,

$$k = \nu \left(\frac{E - E_a}{E} \right)^{s-1} \cong 10^5 \text{s}^{-1}$$

The kinetic shift is larger for larger molecules. The kinetic shift increases with increase in E_a . The kinetic shift increases with a decrease in ν .

Several workers ^{8,9,10} have measured the appearance potential of meta-stable peaks and have concluded that in general these values occur at or lower than the appearance potential of the daughter ion.

This would be expected since the meta-stable transitions occur at a slower rate and from lower energy states than the normal fragmentation (fig. 2). Beynon et al.¹¹ have suggested that the AP of metastable peaks reflect more closely the true activation energy.

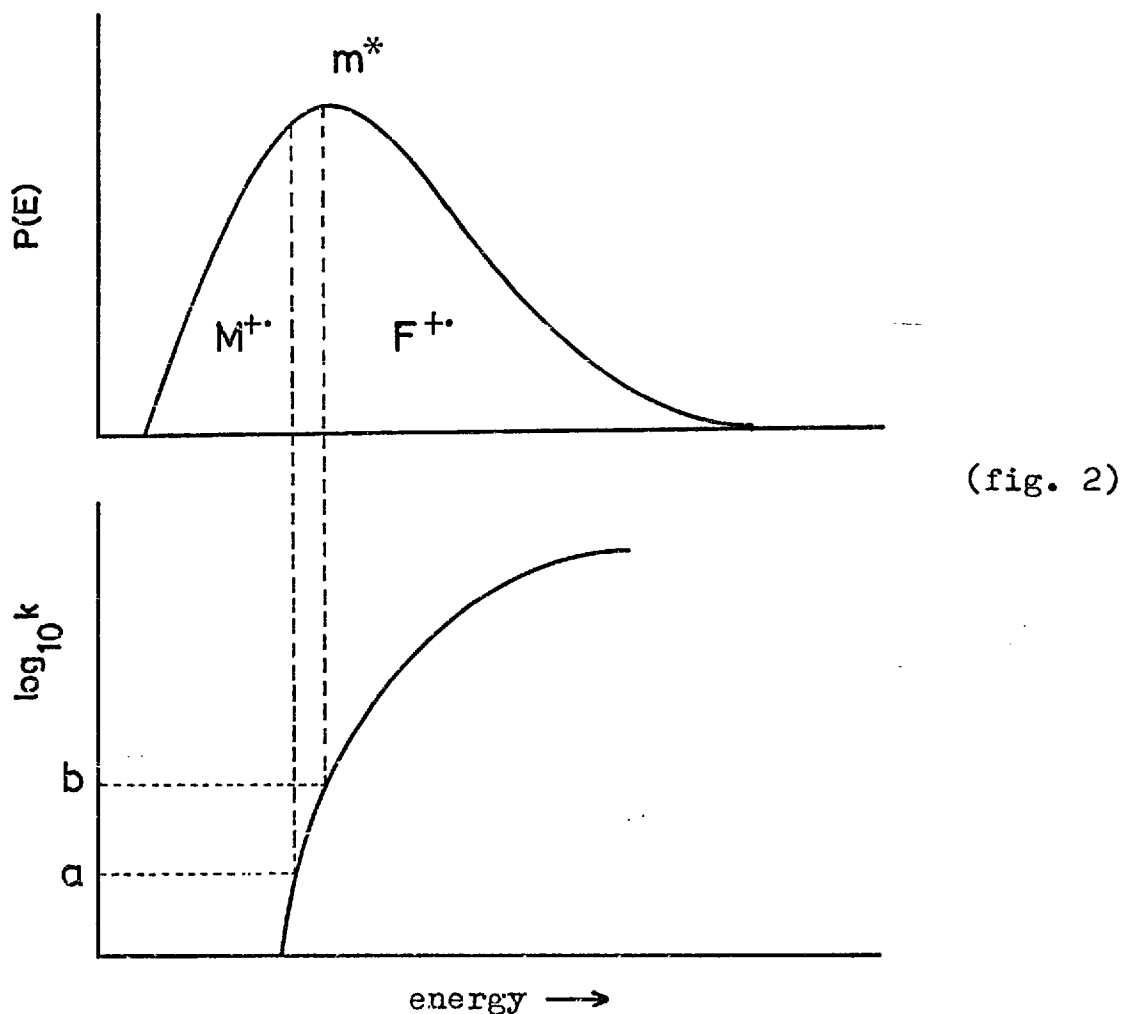


Figure 2 roughly illustrates that different k -values define the molecular ion, metastable ion or the daughter ion for the simple reaction $M + e \longrightarrow M^{\bullet+} + 2e \xrightarrow{m^*} F^{\bullet+}$. The upper half of figure 2 describes the probability of formation of the different ions with respect to the

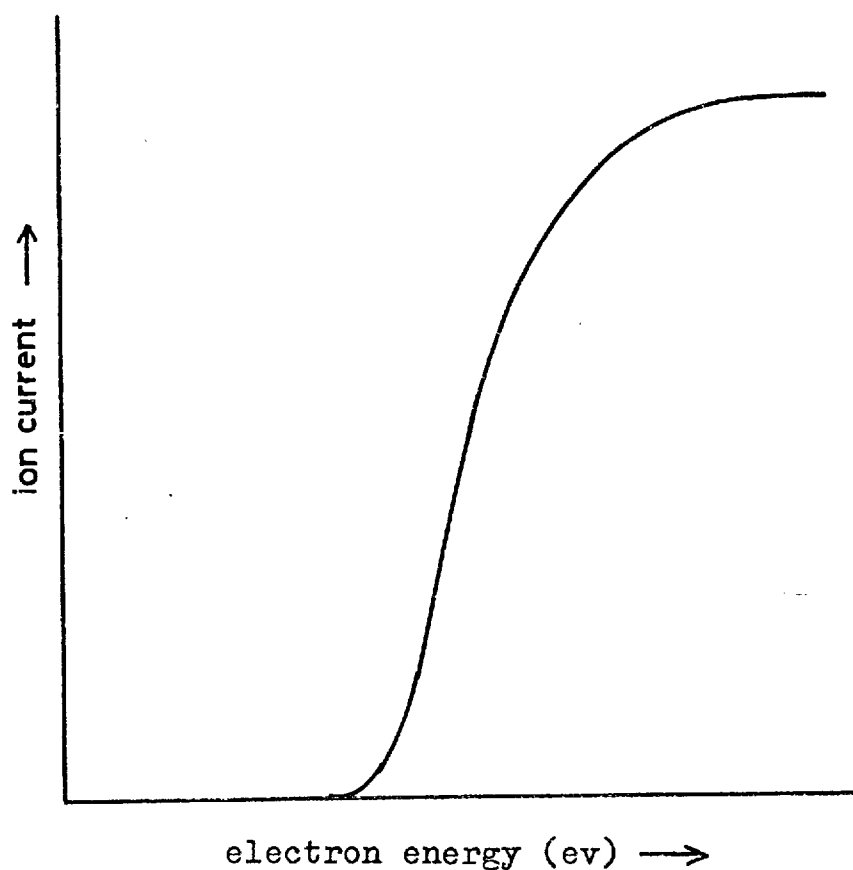
internal energy. The lower half describes the rate of the reaction as a function of internal energy.

Hickling and Jennings ¹² have partially measured the amount of kinetic shift by obtaining the difference between the AP of meta-stable and fragment ions. They have pointed out that the actual value of the measurable part of the kinetic shift appears to be partly dependent on the method by which the data are treated.

Bentley, Johnstone and McMaster ¹³ have shown that in most cases the partial measure of the kinetic shift is the result of crud^eness of the methods employed. They ¹³ have shown that when the IE/EDD method ¹⁴ (see page 15) was used, within experimental error, no significant difference in the AP of meta-stable and normal ions were observable.

METHODS OF "IP" AND "AP" MEASUREMENTS

A plot of ion current for a given m/e as a function of the energy of the ionizing electron beam is called the ionization efficiency curve. (fig. 3). Three distinct regions can be distinguished in this curve. First, the "foot" of the ionization efficiency curve, where the ion current gradually falls to zero. The tailing is caused by the energy spread in the electron beam. Second, the relatively linear rise of ion current with increase of electron energy. Third, the region where the ion current is relatively insensitive to the change in electron energy.



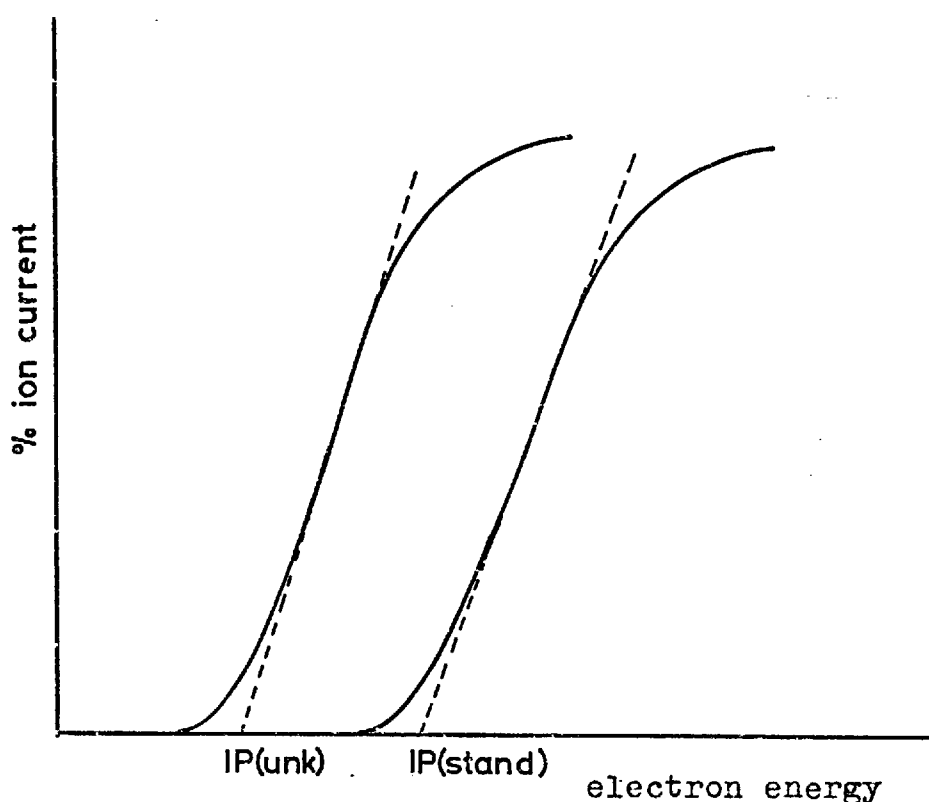
(fig. 3)

It should be noted that the "ionization efficiency" curve could refer to a molecular ion or a daughter ion, since they both result in similarly shaped curves. Obviously this is an improper terminology for the daughter ion, but through common usage such curves have come to be known by this term.

A number of methods have been devised for the measurement of the IP's or AP's.

Linear Extrapolation.

This method was introduced by R.H. Vought ¹⁵. The linear portion of the ionization efficiency curve is extrapolated to zero ion current for both the unknown and a standard substance of accurately known ionization potential (fig. 4). The difference between the two obtained IP's is the increment to be added to (or subtracted from) the ionization potential of the standard.

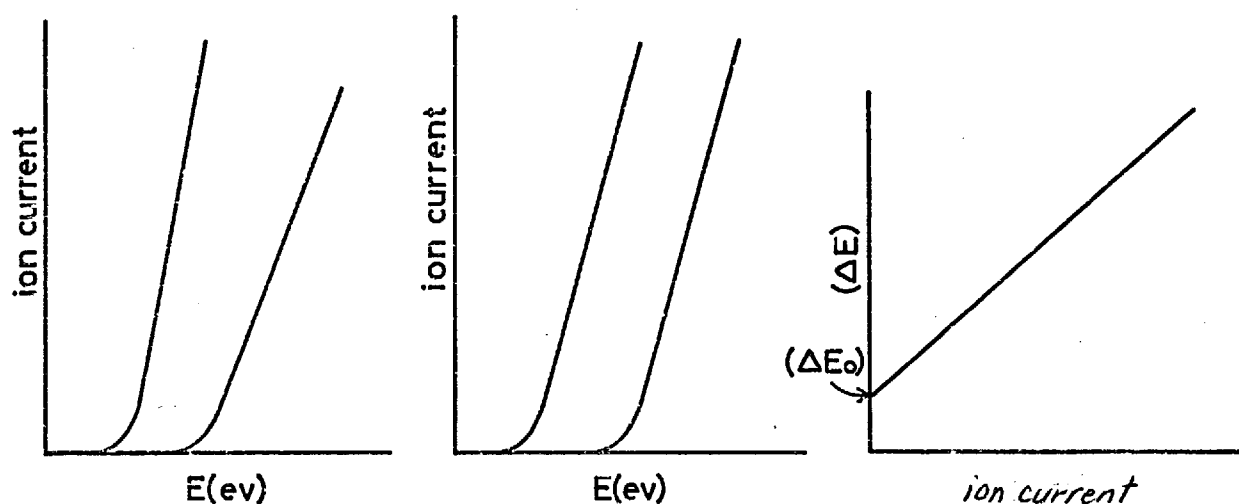


(fig. 4)

The Extrapolated Voltage Difference Method (Warren's Method).

T.W. Warren ¹⁶ plotted the ionization efficiency (IE) curves of the unknown and standard and changed the scale of ion current of either the standard or unknown

so as to make the linear part of the two curves parallel (fig. 5). The separation of the linear part of the two curves is measured at different values of ion current. A new plot of these separations (ΔE) against the ion current is drawn and the curve extrapolated to zero ion current (fig. 6). The value obtained (ΔE_0) represents the difference between the IP's of the unknown and standard.



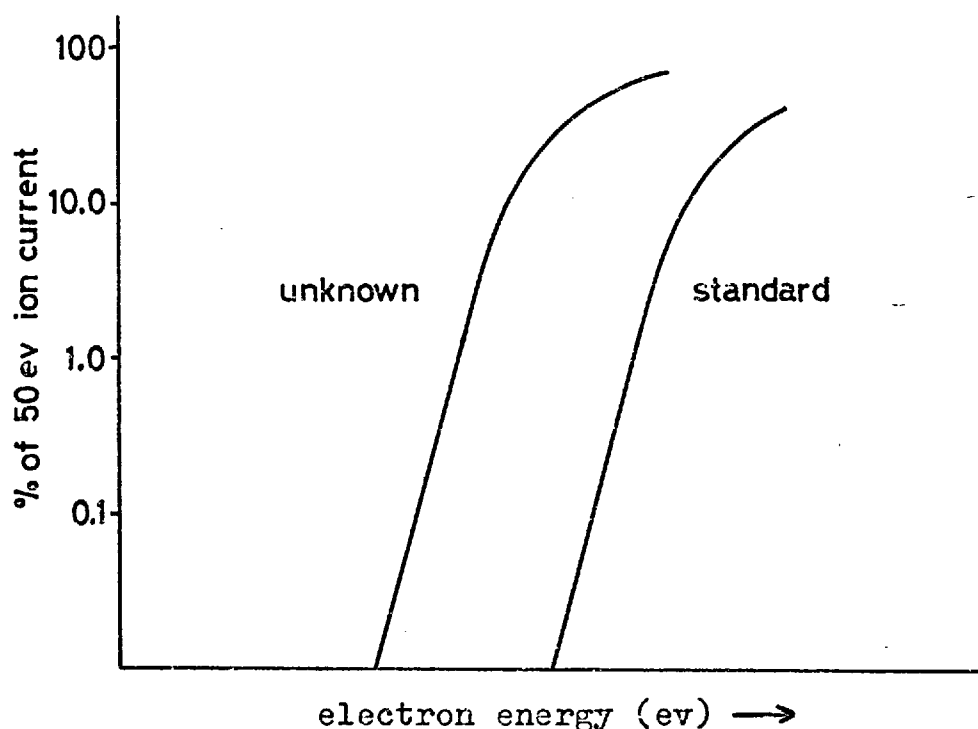
(fig. 5)

(fig. 6)

Semi-Logarithmic Plot Method.

F.P. Lossing *et. al.*¹⁷ proposed the semi-logarithmic plot method. They plotted the logarithm of the ion current expressed as a percentage of the 50 ev ion current versus electron energy for the standard and the unknown. They found that the curves were parallel

in the region of about 1% of the 50 ev ion current and suggested that values obtained were reproducible to within ± 0.01 ev. Kiser¹⁸ found that the curves were parallel in the region of 2 or 3% to about 0.1% of the 50 ev ion current and the reproducibility was of the order of 0.05 - 0.1 ev (fig. 7).



(fig. 7)

The average of the electron energy difference between the two curves in the region where they are parallel represents the difference between the IP's of the standard and the unknown.

Critical Slope Method.

This method was developed by Honig¹⁹ for determining IP and AP values. He assumed that the

probability of ionization is proportional to the square of the excess energy above the IP. He derived the relationship,

$$\ln N(V) = \ln[(V_c - V) + 3kT] - \left(\frac{\phi + V_c - V}{kT} \right) + C$$

where $N(V)$ is the number of ions produced at an energy of V , V_c is the ionization potential, k is the Boltzmann constant, T is the absolute temperature, ϕ is the work function of the filament in the source and C is a constant. A plot of $\ln N(V)$ against electron voltage results in a straight line with the following slope,

$$\text{slope} = \left(\frac{1}{kT} \right) - \left[\frac{1}{(V_c - V + 3kT)} \right]$$

At the ionization potential $V = V_c$, hence

$$\text{slope} = \frac{1}{kT} - \frac{1}{3kT} = \frac{2}{3kT}$$

The IP and AP was then found from a semi-logarithmic plot by determining at what voltage a line of slope $\frac{2}{3kT}$ becomes tangent to the curve.

Barfield and Wahrhaftig²⁰ have mentioned that in the case of large polyatomic molecules the critical slope should be taken as $2/3kT$ while for the calibrant rare gas the slope should be $1/2kT$. This value was used since the ionization efficiency curves for rare gases near the threshold have a linear dependence on the excess energy.

Energy Compensation Technique.

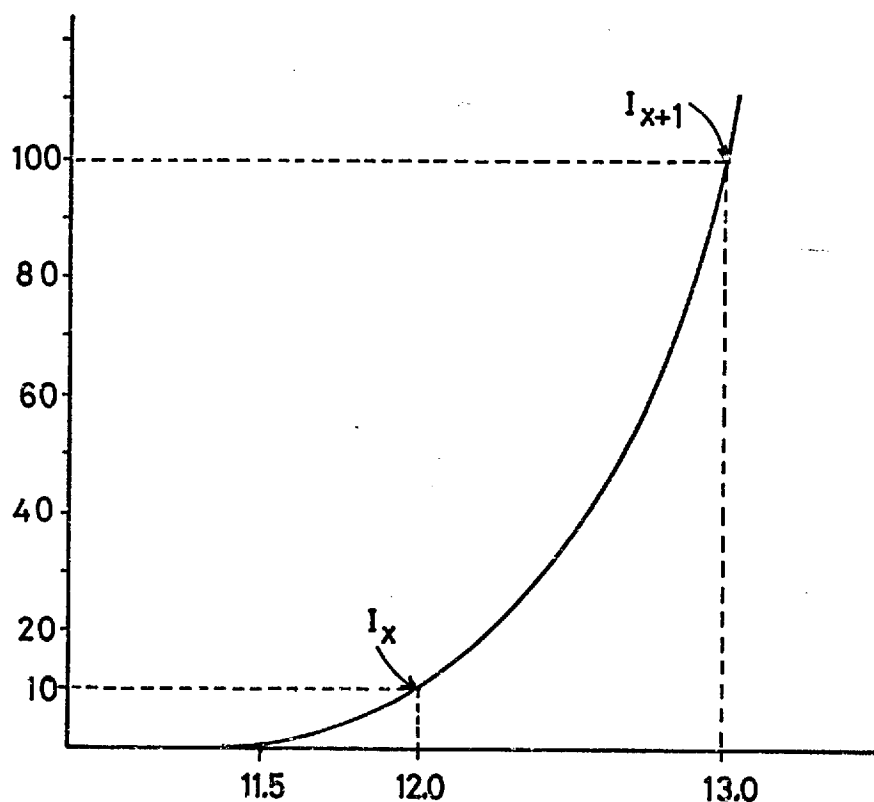
This method was developed by Kiser and Gallegos²¹. In effect this technique follows the concept of the semi-logarithmic plot method¹⁷. In this method the ion current of the standard and the unknown are measured at 50 ev. Then the sensitivities of the ion current recorders (one for each peak) are increased 100 fold. The electron energy is then decreased until the ion currents are the same as they were at 50 ev. The difference between the two electron energies is taken as the difference between the IP's of the standard and the unknown.

The "Times-10" method.

Flesch and Svec²² have described a method in which some unique points in the ionization efficiency curves of the unknown and standard are compared. With slight modification of Warren's method¹⁶, they normalized the ionization efficiency curve so that equal recorded intensity of ion current is obtained at a point about 1.5 - 2.0 ev above the onset potential. In doing so they found that the curves are similarly shaped in this low energy region (fig. 8). One possible unique point is that point on the IE curve such that one ev increase in electron energy results a ten-fold increase in the ion current intensity. That is to say,

$$\frac{I_{x+1}}{I_x} = R ,$$

where I_x and I_{x+1} are the ion currents at electron energy x and $x+1$ respectively and R is the ratio of the ion currents. When $R = 10$, then the value of x represents the value of uncorrected IP of the unknown. By treating the standard in the same way the correct IP is found.



(fig. 8)

The Computer IE/EDD Method ¹⁴.

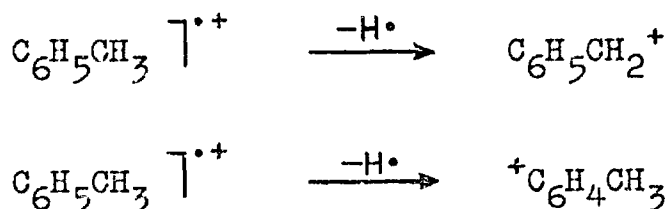
The IE/EDD (Ionization Efficiency by Energy-Distribution Difference) technique is a computer-assisted method for acquisition of ionization efficiency data with mathematical smoothing and analysis of the resulting curves. It has been suggested ²³ that more accurate and reproducible results can be achieved by this method.

Occolwitz, Cerimele and Brown ²⁴ have compared and evaluated a number of methods for measuring ionization and appearance potentials, and have concluded that a slightly modified critical slope method gives the best result. In their measurements the ion currents were plotted as a percentage of the value at 20 ev rather than 50 ev which Honig ¹⁹ used. They ²⁴ have mentioned that the critical slope method provides IP and AP measurements with reasonable accuracy using conventional mass spectrometers without the need for modifications to the instrument. They have concluded that the AP values obtained by the critical slope method are close to the AP's found from the corresponding meta-stable reactions.

TROPYLIUM ION

One of the most important fragment ions in the spectra of aromatic hydrocarbons is the $C_7H_7^+$ ion. The structure and the production of this ion have been the subject of a lot of research. A comprehensive review on this subject has been written by Grubb and Meyerson²⁵ and extended by many publications. In this section, therefore, only a short review will be made on the subject.

The first indication that a tropylium ion might be formed came when the ionization potential of the benzyl-free radical²⁶ was compared with an earlier value²⁷ obtained by measurements of the appearance potential of the $C_7H_7^+$ ion from toluene and bibenzyl. The two values differed by 0.7 ev (16 Kcal/mole) which was too large to be attributed to experimental error. To study this discrepancy Farmer and co-workers²⁸ compared the mass spectra of unlabeled and labeled toluene. In their experiments they found that toluene- α - d_3 loses H and D nearly in the ratio of 5 to 3 as if all the hydrogens were equivalent. They interpreted this result by the two following processes.

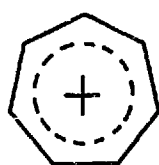


However they failed to distinguish which of the two processes was involved attributing their failure to insufficient isotopic purity. In another experiment ²⁹ it was observed that 66% of hydrogens lost in the spectrum of toluene- α -d₃ are protium which confirmed the ratio of 5:3 observed by Farmer and co-workers ²⁸. Furthermore the spectra of toluene-o-d, -m-d and -p-d were indistinguishable and showed that 10% of the hydrogens lost were deuterium. The spectrum of toluene- α -d showed only slightly greater loss of deuterium relative to protium than the toluene-ring-d compounds. Table I shows partial spectra of the unlabeled and labeled toluenes.

TABLE I : Partial spectra of labeled toluenes

Mass	Unlabeled	α -d	o-d	m-d	p-d	α -d ₃	ring-d ₅
97	-	-	-	-	-	-	100.0
96	-	-	-	-	-	-	76.0
95	-	-	-	-	-	100.0	61.0
94	-	-	-	-	-	92.0	-
93	-	100.0	100.0	100.0	100.0	46.0	-
92	100.0	129.0	132.0	132.0	133.0	-	-
91	148.0	17.2	14.3	14.0	14.7	-	-

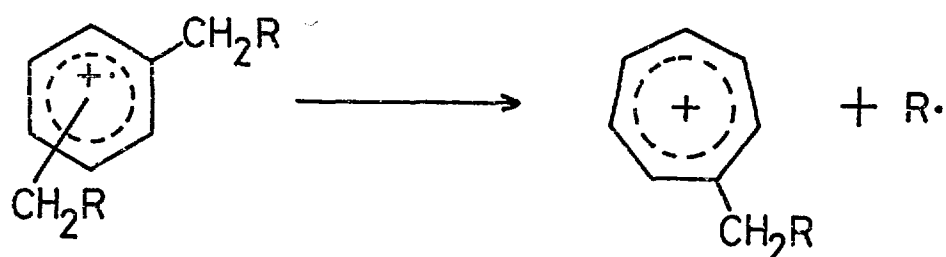
From the above experiments it was seen that, apart from a slight preference for loss from α - over ring-hydrogens and also of protium over deuterium, the hydrogen atoms in toluene have become indistinguishable in the formation of the ion $C_7H_7^+$. As evidenced by metastable peaks the ion $C_7H_7^+$ decomposes further to form the ion $C_5H_5^+$ and C_2H_2 . From labeling studies it was found that the retention of the labeled atom in the ion $C_5H_5^+$ was 69, 77, 77, 77 and 70% for toluene- α -d, - o -d, m -d, p -d and α - C^{13} respectively. These retention values are in good agreement with the 71% retention if complete loss of positional identity of the atoms in the ion $C_7H_7^+$ had occurred. This complete loss of identity of carbon and hydrogen atoms in the ion $C_7H_7^+$ suggested a highly symmetrical structure which led to the proposal of tropylium ion (1) ²⁹



(1)

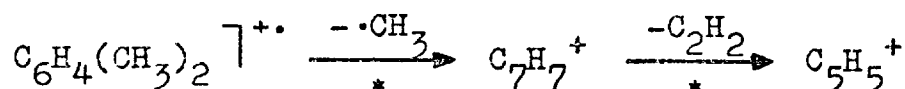
The rearrangement to a seven-membered ring may occur before, during or after the first cleavage. However, the loss of identity of the hydrogen atoms suggested that rearrangement occurs before or during the bond cleavage.

The dissociation of di-alkylbenzenes via tropylium rather than benzyl ions gives a reasonable explanation for the fact that no differences are observed between the mass spectra of ortho, para and meta isomers. The residue of one side chain is incorporated into the ring and only one side chain remains; as a result the products of the three isomers are identical ²⁵.



Further evidence for the structure of the ion C_7H_7^+ in the mass spectrum of toluene was obtained by comparison of the mass spectra of toluene and cycloheptatriene ³⁰. The two spectra were remarkably similar for two compounds with different structure and chemical properties. The similarity of the ions in the lower mass region suggested that they have a common origin. The appearance potential measurements and consequently the heats of formation for a number of alkylbenzenes resulted in values which were remarkably close to the value obtained for cycloheptatriene. These results confirmed the suggestion of a tropylium ion for the ion C_7H_7^+ .

In the mass spectra of xylenes two metastable peaks are observed which are attributed to the following fragmentation paths.



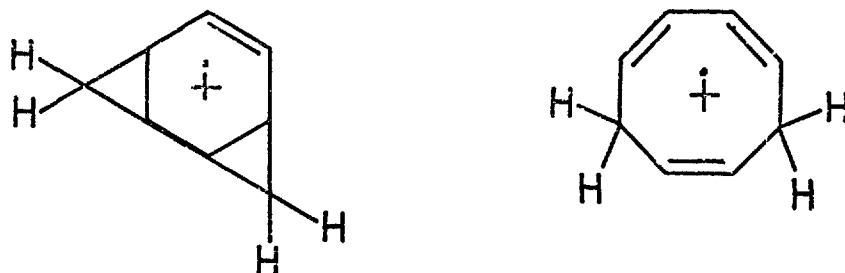
The methyl radical lost had been assumed to be one of the original side chain methyls. However, labeling studies on p-xylene support the formation of a tropylium ion, and also show that the methyl radicals lost are not all original methyl groups ³¹. From the label retention in C_7H_7^+ (table II) it was observed that the values are in good agreement with the retention values calculated on the assumption that the original methyl group lost has had a 50:50 chance of exchanging one hydrogen with the ring.

TABLE II : Label retentions in C_7H_7^+ from p-xylene

Number of labeled atoms	α -d	α, α' -d ₂	o-d	α -C ¹³
	<u>observed</u>			
1	56%	81%	89%	58%
2	-	19%	-	-
	<u>calculated* for α-cleavage preceded by exchange</u>			
1	58%	83%	88%	50%
2	-	17	-	-
	<u>calculated* for α-cleavage with no exchange</u>			
1	50%	100%	100%	50%
2	-	0	-	-

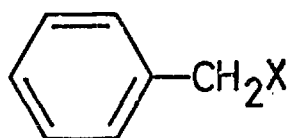
* The calculated values are based on the assumption that only one reaction path is involved. The absence of any changes in the retention values as the ionization voltage is changed from 70 ev to AP supports this assumption.

The models that would meet these requirements are of the following forms:



Each methyl group gives rise to a CH_2 group and the CH_3 group lost may be either of these and a hydrogen from an adjacent CH group. From the yield of labeled C_5H_5^+ relative to labeled C_7H_7^+ derived from singly labeled xylene, it was found that the atoms originally in the ring and side chains are no longer distinguishable. In this experiment, however, Meyerson and Rylander could not account for the 16% of the methyl radicals coming from the ring. Meyerson and E.K. Field³² suggested that the unaccounted fraction could result from two hydrogens from the methyl group rather than one being transferred to the adjacent carbon atom in the ring and consequently the new methylene group is lost with one hydrogen from the adjacent carbon atom.

The generality of formation of the tropylium ion was further studied by the consideration of mass spectra of benzyl compounds of the following type:



In the mass spectra of benzylchloride (2 : X = Cl) and benzylalcohol (2 : X = OH) ³³the ion $C_7H_7^+$ consists of the original atoms in the benzyl group. The metastable peaks in the unlabeled, singly labeled and doubly labeled alcohol and chloride established that the ion $C_7H_7^+$ is the source of the ion $C_5H_5^+$. The label retention values in $C_5H_5^+$ ion implied that the Hydrogen atoms in $C_7H_7^+$ ion intermediate had become equivalent suggesting the tropylium ion structure for the ion $C_7H_7^+$ (Table III).

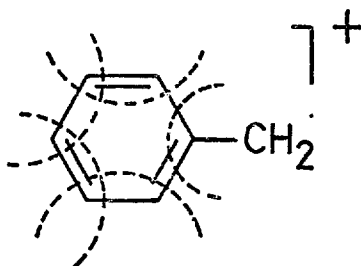
TABLE III

Label retention in $C_5H_5^+$ from benzyl-
chloride and alcohol

		α -d	o -d	m -d	α -d ₂ ^(a)
Observed	Chloride	68%	75%	74%	47%
	Alcohol	68%	72%	69%	45%
Calculated	Symmetrical $C_7H_7^+$	71%	71%	71%	48%
	Benzyl ion (b) $C_6H_5CH_2^+$	60%	80%	60%	80%

(a) Retention of both deuterium atoms.

(b) The calculated values for benzyl ion are based on the assumption that the benzyl ion can lose C_2H_2 in five different ways. (see next page)



The ion $C_7H_7^+$ produced in the mass spectrum of p-chlorotoluene ²⁵ undergoes further decomposition to form the ion $C_5H_5^+$. For the singly labeled p-chlorotoluene the label retention values in the $C_5H_5^+$ ion were found to be 72% which was in very good agreement with the calculated value of 71% if all seven hydrogen atoms in the ion $C_7H_7^+$ had become equivalent, i.e. if the ion $C_7H_7^+$ had the structure of the symmetrical tropylium ion.

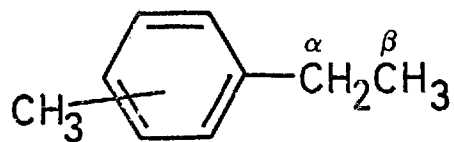
The tropylium ion structure was also assigned to the ion $C_7H_7^+$ produced by electron bombardment of the benzyl and benzyl- α -d₂ free radicals ³⁴ formed by thermal decomposition of the corresponding 1,2-diphenylethanes. Table IV shows partial spectra of the two compounds. The retention value of 47% (retention of both deuterium atoms) in the ion $C_5H_5^+$ is in complete agreement with the calculated value, 48%. This retention value was unchanged by a change in ionization voltage which suggests only one path for the reaction.

TABLE IV

Partial spectra of benzyl radical

Mass	Unlabeled	α -d ₂
93	-	100
92	-	77
91	100	14.6
90	10.7	8.7
89	20.4	2.0
67	-	33.2
66	-	36.5
65	70.9	14.2

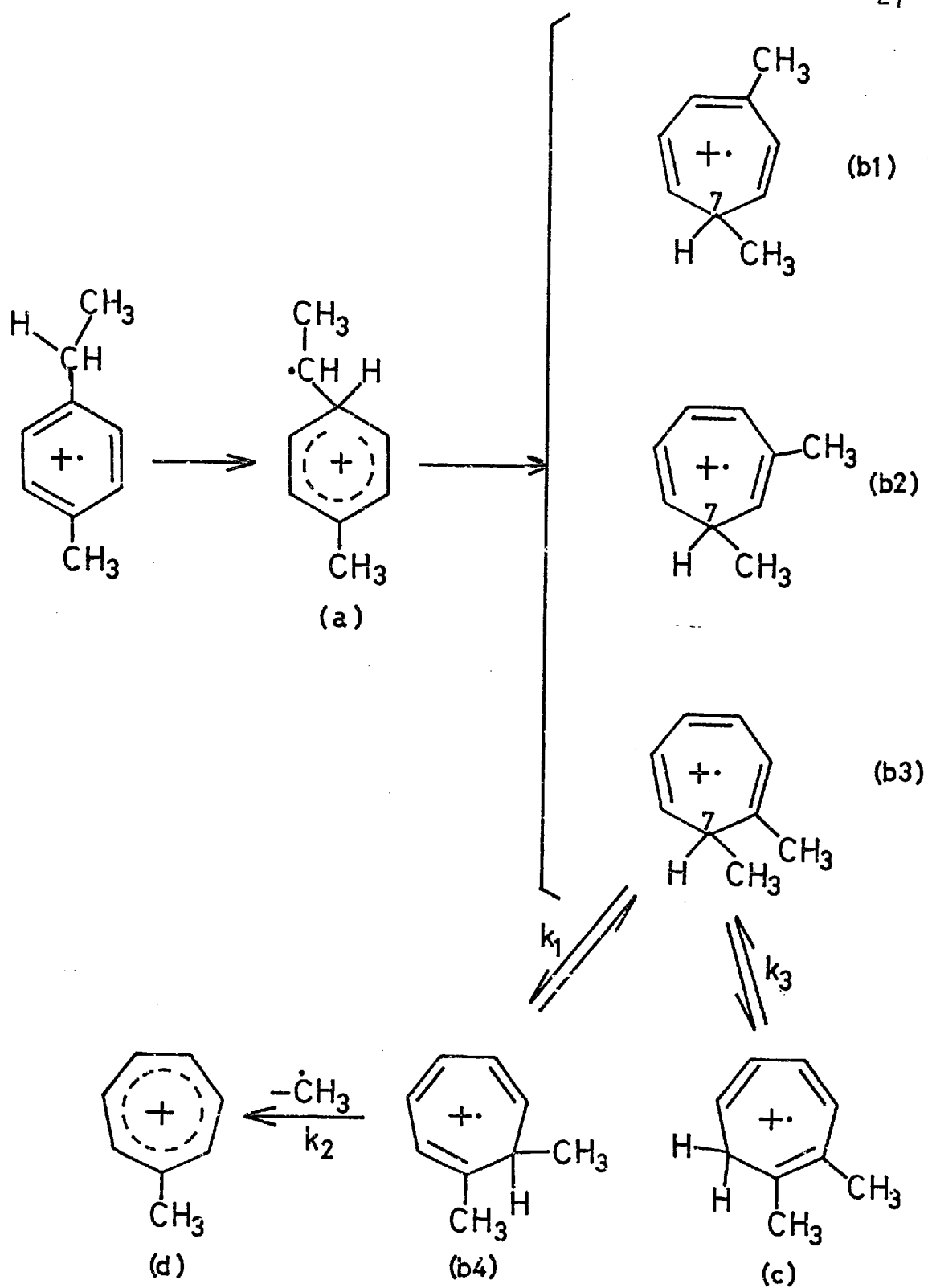
To account for the equivalence of the hydrogens during the formation of tropylium ion Meyer and Harrison ³⁵ did some extensive labeling studies on methylethylbenzene,



and suggested a mechanism for the formation of the tropylium ion. In their studies they found that the β -methyl and ring methyl groups are lost in the ratio of approximately 5 to 1. The appearance potentials for the loss of CH_3 and CD_3 in either methyl-d₃-ethylbenzene or methylethyl- β -d₃-benzene were the same. From the AP value the heat of formation for the ion C_8H_9^+ was found

to be 226 ± 3 kcal/mole. This value was in agreement with the heats of formation found in a similar way for diethylbenzene ³⁶, m-propylmethylbenzene ³⁶ and m- and p-xylene ³⁷ (221 - 226 kcal/mole) suggesting a common structure for the ion $C_8H_9^+$. These results indicated that loss of the ring-methyl and the β -methyl yield the same fragment but the ratio suggested that the two methyls had not become equivalent in the formation of the fragment. The ratio of 5:1 remained constant as the ionizing voltage was decreased from 50 ev to the appearance potential which suggested only one path for the reaction. The following mechanism was proposed to account for the ratio and other observations. (Scheme I)

One of the α -hydrogens is transferred to the ring carbon bearing the ethyl group followed by insertion of the resulting $\text{—}\dot{C}HCH_3$ group between any two carbons of the benzene ring resulting in the three structures b1, b2 and b3 (Scheme I). In the latter intermediate a rapid intramolecular hydrogen transfer occurs resulting in an equilibrium between the structures b3 and b4. This hydrogen transfer causes the relative abundances of the intermediates b1 : b2 : b3 : b4 to be 2:2:1:1. The methyl radical is lost only from the methylene (i.e. position 7) of the intermediates; as a result 5/6 of the methyl radicals lost would be the β -methyl and 1/6 the ring-methyl. These ratios are in agreement within experimental error with the observed ratio of 5:1. In proposing this mechanism Meyer and Harrison made two major assumptions. The first was that the ring expansion



SCHEME I

occurs by the insertion of the side chain with equal probability in any position in the ring. The second assumption was that the rate of hydrogen transfer between adjacent carbons which are equivalent (in this case carbons bearing a methyl group - the b3 and b4 structures, Scheme I) is much faster than it is between non-equivalent carbons. If this were not so then one would expect complete equivalence of the methyls in the intermediates b1 to b3 and hence a ratio of 1:1 for the loss of the two methyls. In other words the rates of hydrogen transfer and the rate of methyl loss are related in the following manner,

$$k_1 \gg k_2 \gg k_3 .$$

To get some insight into the extent to which the α -carbon atom is scrambled into the ring Rinehart and co-workers³⁸ studied the mass spectrum of toluene- α , 1 - $^{13}\text{C}_2$. They calculated the ratio of loss of C_2H_2 from the ion C_7H_7^+ which could be formed by path (a) or (b). In path (a) the α -methyl is inserted between carbon atoms 1 and 2 of the ring giving rise to the structure (3) in which only carbons 1 and 2 are labeled. Path (b) involves the insertion of the α -methyl between any two carbon atoms with equal probability. As a result in structure (4) any two carbon atoms could be labeled.

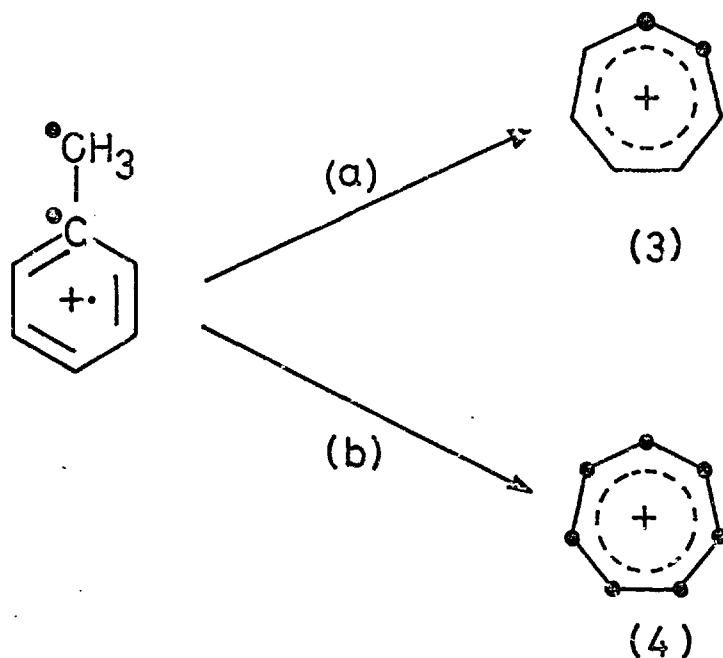


Table V shows the label retention values in C_5H_5^+ calculated on the basis of path (a) or (b).

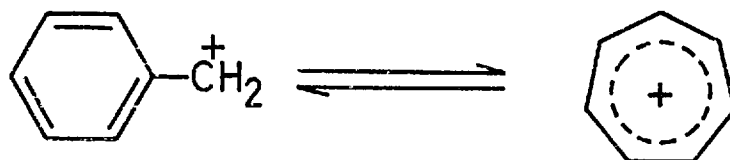
TABLE V : Label retention ratio in the ion C_5H_5^+ of toluene- α , 1 - $^{13}\text{C}_2$.

		C_5H_5 (m/e 65)	$^{13}\text{CC}_4\text{H}_5$ (m/e 66)	$^{13}\text{C}_2\text{C}_3\text{H}_5$ (m/e 67)
Calculated label retention ratios in C_5H_5^+	Path (a)	1/7(0.143)	2/7(0.286)	4/7(0.572)
	Path (b)	1/21(0.048)	10/21(0.476)	10/21(0.476)
Abundance Ratios observed		0.060	0.457	0.483

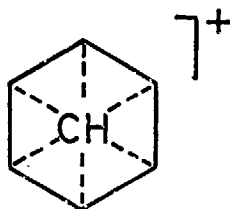
The observed retention values suggest that path (b) is responsible for the scrambling of the carbon atoms. This was in complete support of the mechanism proposed by Meyer and Harrison ³⁵ for the formation of the tropylium ion.

Siegel ³⁹ argued that although the study on toluene- α , 1- $^{13}\text{C}_2$ suggests the formation of a tropylium ion in which the carbon atoms have randomized, it does not differentiate between the two following processes, (a) and (b), by which this randomization occurs.

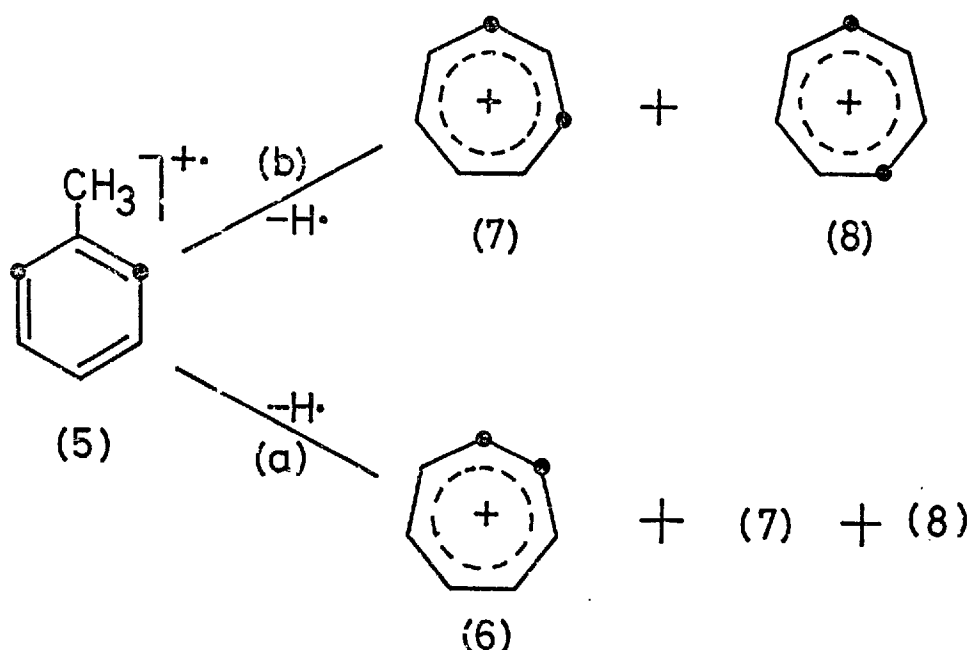
(a) Randomization by a series of rapid benzyl ion-tropylium ion isomerization.



(b) Randomization by insertion of the methyl carbon atom randomly between any two adjacent carbon atoms of the ring.



He studied ³⁹ the mass spectrum of toluene-2,6- $^{13}\text{C}_2$ (5). The tropylium ions that are formed by either processes, (a) or (b), are shown below.



Heavy dots represent labeled atoms.

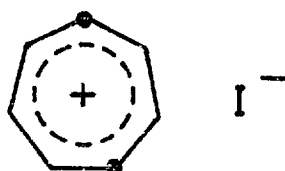
The $C_5H_5^+$ ions produced by loss of C_2H_2 from the ions $C_7H_7^+$ according to path (b) must all be at least singly labeled, since neither of the intermediates (7) and (8) can lose the two labeled atoms as $^{13}C_2H_2$. In fact the observed relative intensity for the production of $C_5H_5^+$ ion by the loss of $^{13}C_2H_2$ was 0.057. Table VI shows the observed relative intensities of the ions at m/e 65, 66 and 67 and the calculated values based on paths (a) and (b). The observed values are in good agreement with the calculated values based on path (a).

TABLE VI : Partial spectra of toluene-2,6- $^{13}C_2$

mass	ion	observed*	calculated*	
			path (a)	path (b)
65	C_5H_5	0.057	0.048	0.000
66	$^{13}CC_4H_5$	0.467	0.476	0.571
67	$^{13}C_2C_3H_5$	0.476	0.476	0.429

* $\sum 65, 66, 67 = 1.000$

Siegel ⁴⁰, in a recent report, examined the mass spectrum of tropylium-1,4-¹³C₂ iodide (9) to determine whether scrambling occurs in those C₇H₇⁺ ions which have sufficient energy to fragment by losing C₂H₂.



(9)

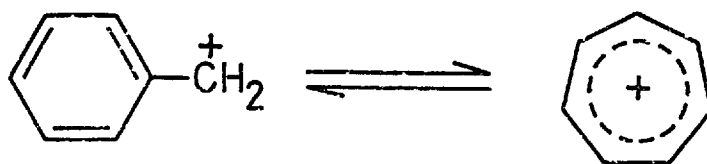
The loss of C₂H₂ from skeletally intact C₇H₇⁺ ions should give only labeled C₅H₅⁺ ions (Case a), whereas skeletally rearranged C₇H₇⁺ ions should produce some unlabeled C₅H₅⁺ ions by losing ¹³C₂H₂ (Case b). Table VII shows the observed relative abundances of the ions at m/e 65, 66 and 67 recorded at 70 ev and 20 ev. The last two columns show the calculated values for the two cases (a) and (b).

TABLE VII : Partial spectra of tropylium-1,4-¹³C₂ iodide.

m/e	ion	observed*		calculated*	
		70 ev	20 ev	case (a)	case (b)
65	C ₅ H ₅	0.029	0.039	0.000	0.048
66	¹³ CC ₄ H ₅	0.549	0.500	0.571	0.476
67	¹³ C ₂ C ₃ H ₅	0.422	0.461	0.429	0.476

* $\sum 65, 66, 67 = 1.000$

As expected the extent of rearrangement increases at lower ionization voltage. Another recent report ⁴¹, referred to by Siegel ⁴⁰, shows that the appearance potentials of the $C_7H_7^+$ ions produced by electron impact from tropylium iodide, bromide and tetrafluoroborate were identical (6.74 eV). This value was close to the spectroscopic ionization potential of the cycloheptatrienyl radical (6.24 eV) and very much closer to the ionization potential of this radical measured under electron impact (6.60 eV), which suggested that the tropylium ion from these salts is first reduced to the radical and then ionized to $C_7H_7^+$ ion, presumably a tropylium ion. As a result the tropylium ion and/or the radical undergo skeletal rearrangement prior to decomposition to the $C_5H_5^+$ ion. These skeletal rearrangements may occur via a tropylium ion - benzyl ion isomerization. The results of Siegel ⁴⁰ and Hvistendahl et al. suggest that the



loss of positional identity of the carbon atoms in toluene does not solely occur during the formation of tropylium ion but also after its formation.

Isotope labeling of the hydrogen and carbon atoms have shown that the ion $C_7H_7^+$ has the symmetrical tropylium ion structure. However the conclusions were based on those $C_7H_7^+$ ions which have enough energy to

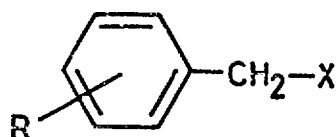
undergo further decomposition to the ion $C_5H_5^+$ and C_2H_2 . Harrison, Kebark and Lossing⁴² measured the ionization potential of a number of meta and para substituted benzyl radicals by the electron impact technique. They observed that a number of substituents showed large differences in the stabilization of the benzyl ion depending on the position of substituent and its capability of conjugation with the positive charge. This result suggested that the substituent effect might be useful in determining the structure of the substituted C_7 ion formed in the dissociative ionization of the molecule.

Tait, Shannon and Harrison³⁷ showed that non-decomposing ions of general formula $RC_7H_6^+$ at the threshold have the symmetrical tropylium ion structure depending on the nature of substituent. They suggested³⁷ that if the ion $RC_7H_6^+$ has the benzyl structure at the threshold one would expect that the appearance potentials of meta and para isomers would differ by the same amount as is found for the ionization potentials of the corresponding benzyl radicals. On the other hand, if rearrangement to the tropylium ion has occurred the orientation of meta and para will be lost and the appearance potentials of the ions $RC_7H_6^+$ from the two isomers would be identical. In the interpretation of their results³⁷ they assumed that during the process of dissociative ionization of benzene derivatives the orientation of substituents is not changed if the central skeletal structure of the ion is maintained. On the basis of their experimental results (Table VIII) they concluded that the ion $RC_7H_6^+$

formed has the symmetrical tropylium ion structure when $R = \text{CH}_3$, F and OH. However the ion RC_7H_6^+ has the benzylic structure when $R = \text{OCH}_3$.

TABLE VIII

Appearance Potential Differences
for meta and para substituent.

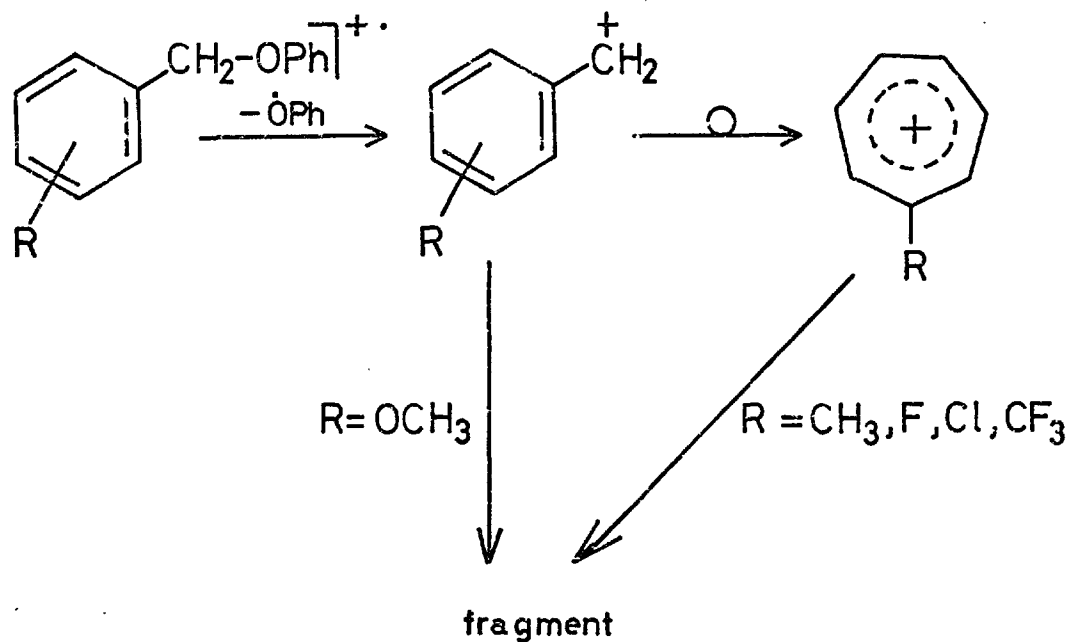


R	X	Experimental AP(meta)-AP(para)	Theoretical* AP(meta)-AP(para)
CH_3	H	-0.02 ± 0.05	0.28
CH_3	Br	0.01 "	0.28
F	H	0.01 "	0.50
F	Br	0.07 "	0.50
OH	H	-0.08 "	0.66
OH	CH_3	-0.03 "	0.66
CH_3O	Cl	1.15 ± 0.1	0.99

* calculated on the basis of benzyl ion formation.

In an attempt to probe the structure of RC_7H_6^+ ion in the transition state in which they are formed Brown⁴³ measured the rate of decomposition of a series of meta and para substituted benzylphenyl ethers at

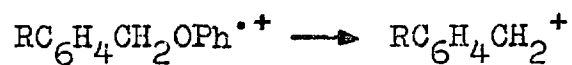
70 ev and 20 ev. A linear relationship was observed when the relative rates were correlated with Hammett's σ^+ constants. This linear relationship suggested that in the transition state for the initial cleavage reaction the potential daughter ion does not have the tropylium ion structure and that the molecular ion has not rearranged prior to cleavage. This means that all isomeric pairs of meta and para substituted benzylphenyl-ethers decompose with different rates which suggests the retention of positional identity of the substituent and the formation of benzylic intermediate (Scheme II). This ion undergoes further decomposition and the metastable ion characteristics⁴⁴ for these transitions were recorded (Table IX). It was observed that the ratio of metastable ion intensity to that of the precursor ion were effectively constant for each pair of meta and para isomers with the exception of the methoxy isomers. This observation suggested that the positional identity of the substituents is lost and that the ion $RC_7H_6^+$ has rearranged to the symmetrical tropylium ion before fragmenting any further. These results can best be explained in the Scheme II.



SCHEME II

TABLE IX

Metastable ion abundance Data for the Reaction



R	Transition	[metastable]/[$\text{RC}_6\text{H}_4\text{CH}_2^+$] $\times 10^3$	
		<u>m</u> -R	<u>p</u> -R
CF_3	159 $\longrightarrow$ 109	0.65	0.61
	159 $\longrightarrow$ 139	0.35	0.31
Cl	125 $\longrightarrow$ 89	0.40	0.28
	125 $\longrightarrow$ 99	0.14	0.12
F	109 $\longrightarrow$ 83	0.35	0.36
CH_3	105 $\longrightarrow$ 77	0.22	0.18
	105 $\longrightarrow$ 78	0.16	0.14
	105 $\longrightarrow$ 79	0.79	0.70
OCH_3	121 $\longrightarrow$ 77	0.27	0.14

In a later paper Brown⁴⁵ reported that the rate differences for the reaction $\text{RC}_6\text{H}_4\text{CH}_2\text{-OPh}^{\bullet+} \longrightarrow \text{RC}_6\text{H}_4\text{CH}_2^+$ between the meta and para-R isomeric pairs did not distinguish the energy differences between the molecular ions and/or the transition states. In a series of experiments he measured the rate of decomposition of the para isomer, Z_p relative to that of meta isomer, Z_m , where:

$$Z_p = \frac{A_p^+}{M_p^{\bullet+}}, \quad Z_m = \frac{A_m^+}{M_m^{\bullet+}}$$

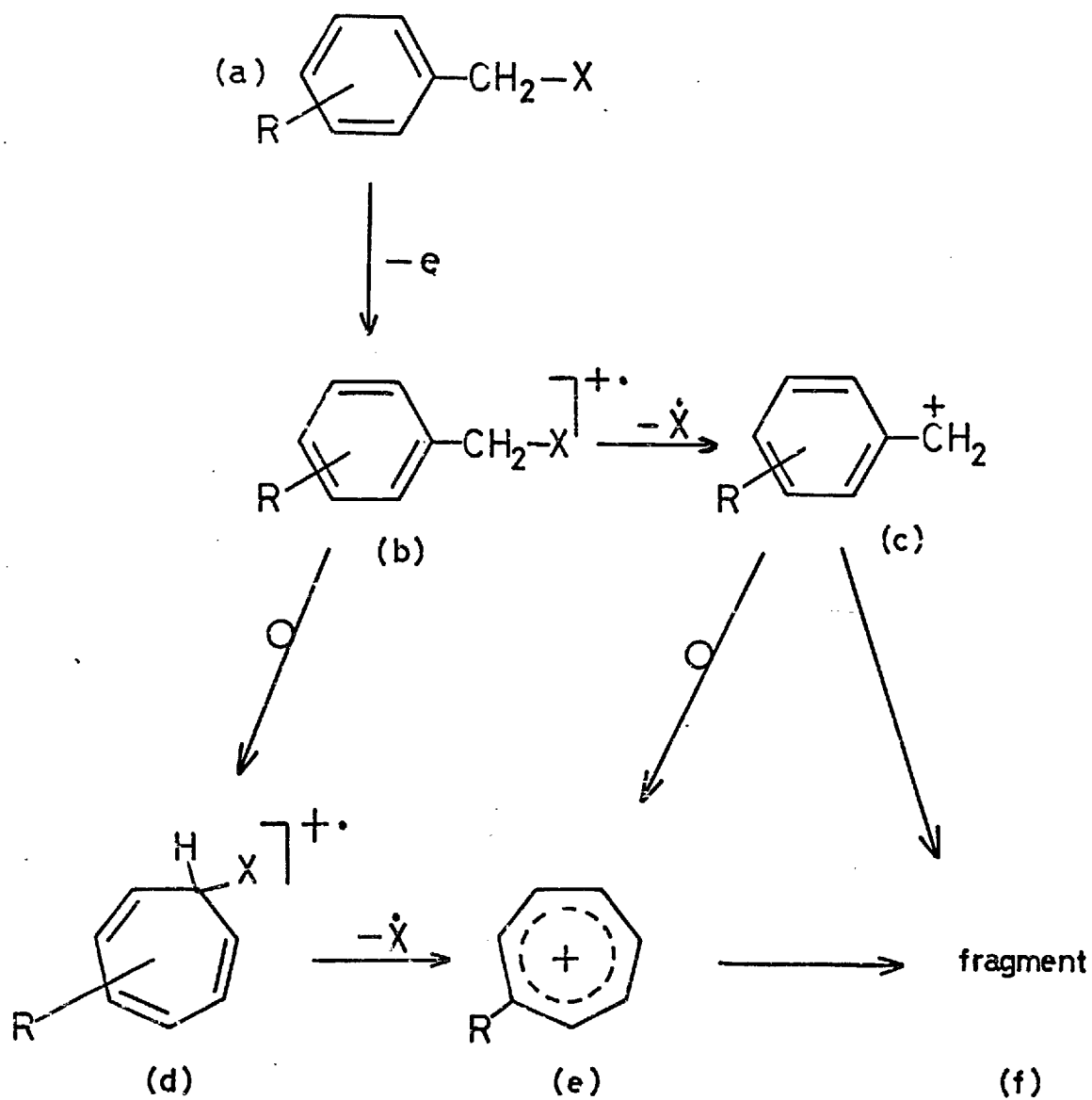


These measurements were made over the electron energy range from 70 ev to the threshold of A^+ formation. Since the ions $\text{CH}_3\text{OC}_7\text{H}_6^+$ ³⁷ and $\text{NO}_2\text{C}_7\text{H}_6^+$ ⁴⁶ seemed to be benzylic in structure, the similar variation in Z_p/Z_m for all the substituent from 70 ev to the threshold suggested that the ion RC_7H_6^+ has the benzylic structure. However, the ion RC_7H_6^+ has been shown³⁷ to have the tropylium ion structure at the threshold when $R = \text{CH}_3$ and F. Therefore, it was concluded that this variation in Z_p/Z_m (which reflects the transition state energy difference) could be because of vibrational energy differences in a common RC_7H_6^+ ion derived from each meta and para substituted isomeric pair of benzylphenyl ethers when $R = \text{CH}_3$, F, Cl, Br and CF_3 . When $R = \text{OCH}_3$ or NO_2 , however, the variations of Z_p/Z_m were attributed

to structural difference in the transition state leading to the ions $\text{CH}_3\text{OC}_6\text{H}_4\text{CH}_2^+$ and $\text{NO}_2\text{C}_6\text{H}_4\text{CH}_2^+$. In other words, in contrast to his previous paper ⁴³, Brown concluded that the molecular ion rearranges to a common intermediate with only vibrational energy differences for each pair of meta and para isomer with the exception of the cases when $\text{R} = \text{OCH}_3$ and NO_2 .

In a similar experiment Brown ⁴⁷ considered the loss of a methyl radical from the molecular ion of a series of meta and para substituted ethylbenzenes. He found that when $\text{R} = \text{NH}_2$ or OCH_3 the positional identity is maintained. However, when $\text{R} = \text{OH}, \text{CH}_3, \text{F}, \text{Cl}, \text{Br}$ and CF_3 the molecular ion rearranged prior to fragmentation. These results are best demonstrated in Scheme III.

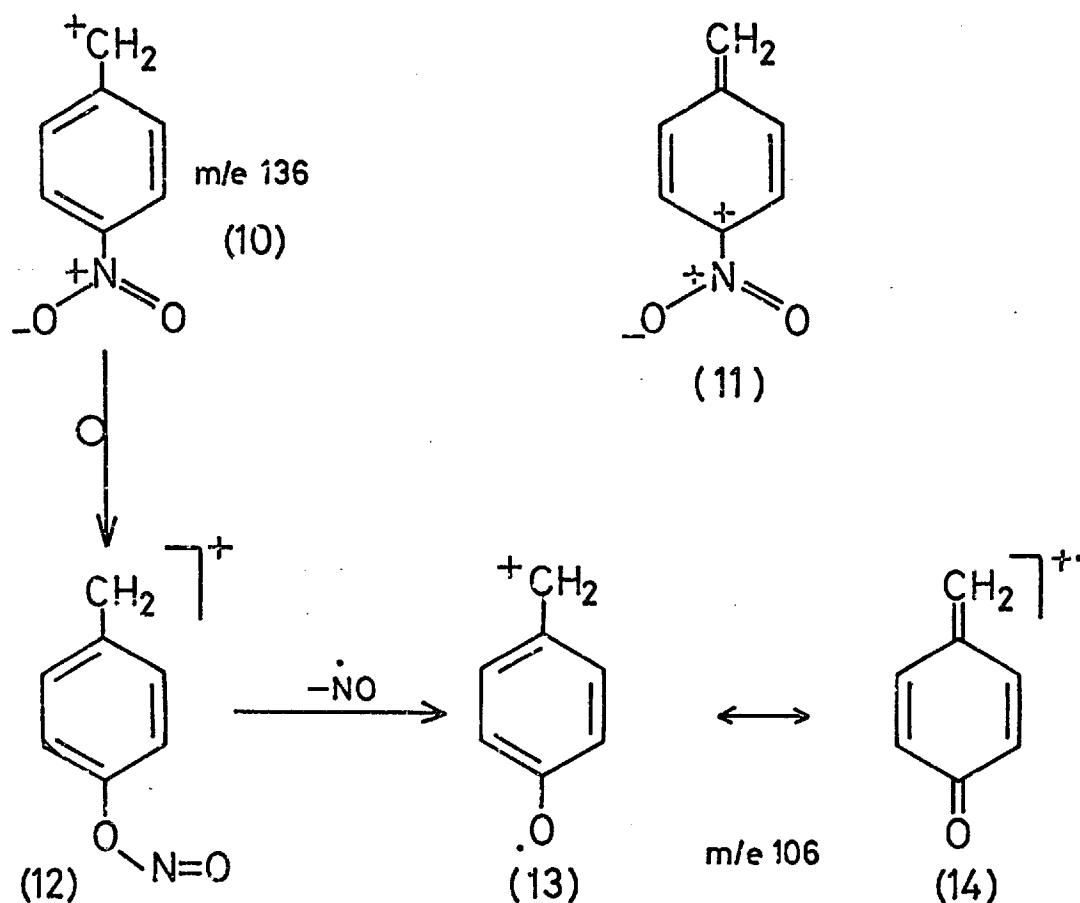
The structure of the ion $\text{NO}_2\text{C}_7\text{H}_6^+$ has been shown to have the benzylic structure. Shapiro and Serum ⁴⁶ studied the mass spectra of meta and para nitrobenzylbromide and phenyl ether. They observed that after the initial cleavage (loss of $\cdot\text{Br}$ or $\cdot\text{OPh}$) the ion at mass m/e 136 behaved differently depending on the position of the nitro group. In the spectrum of the para-nitro substituted isomer metastable peaks were observed for the loss of NO and NO_2 from the M-X ions (where M is the molecular ion and $\text{X} = \text{Br}$ or OPh). In the case of the meta isomer, however, only metastable peaks for the loss of NO_2 were observed. As the ionization voltage was lowered the rearrangement process (i.e. loss of NO) was favoured to a greater extent than



$a \rightarrow b \rightarrow c \rightarrow f$ $a \rightarrow b \rightarrow d \rightarrow e \rightarrow f$
 when $\text{R} = \text{NH}_2, \text{OCH}_3, \text{NO}_2$ when $\text{R} = \text{OH}, \text{CH}_3, \text{F}, \text{Cl}, \text{Br}, \text{CF}_3$

SCHEME III

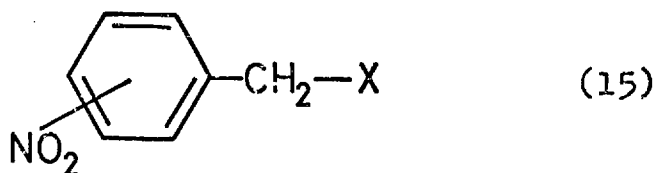
the loss of NO_2 . The loss of NO from the (M-X) ion in the spectrum of the meta isomer although increasing with decreasing ionization voltage does not do so as rapidly as in the case of the para isomer. Shapiro and Serum⁴⁶ interpreted the results to mean that the decomposing ion ($\text{NO}_2\text{C}_6\text{H}_4\text{CH}_2^+$) does not lose positional identity based on the fact that the two isomers behave so differently. In other words this ion must be benzylic in structure. They suggested that the para isomer loses NO with a rearrangement for which there is a strong driving force, whereas the meta isomer predominantly loses NO_2 by direct cleavage and the driving force for the rearrangement reaction is much weaker. (Scheme IV.)



SCHEME IV

This driving force was explained in terms of the electronic effects in the ion, m/e 136. Since the $^+ -CH_2$ group has a strong electron withdrawing effect, the para-nitrobenzyl cation (10) is expected to be highly destabilized because of the contributing structure (11). However, the rearrangement of the nitro to the nitrito group (an electron donating group) will stabilize the ion at m/e 136; the loss of NO is favoured by resonance in the resulting ion (m/e 106) ⁴⁸ (13 $\longleftrightarrow$ 14). In the case of the meta isomer such contributions are not possible and as a result the driving force for rearrangement reaction is very weak.

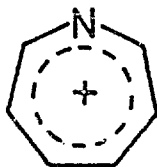
Westwood, Williams and Yeo ⁴⁸ extended the above work and drew essentially the same conclusions when the leaving group "X" was changed to H, CH_3 and C_2H_5 (structure 15)



AZATROPYLIUM ION

An analogue of the tropylium ion intermediate is the azatropylium ion (16) which may be responsible for hydrogen scrambling in nitrogen-containing aromatic compounds.

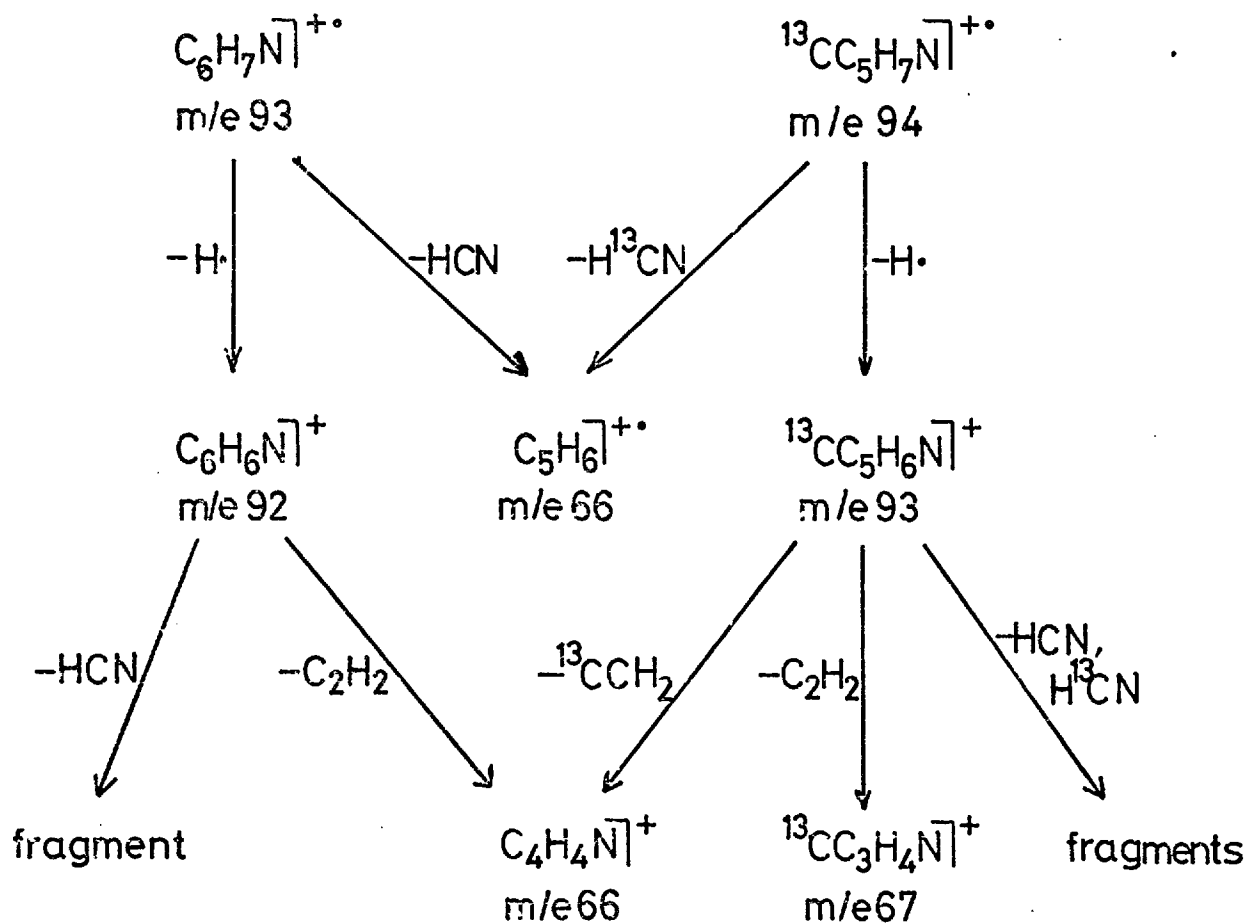
In the mass spectrum of aniline the main fragmentation involves the loss of HCN from the molecular ion.



(16)

It is assumed that if HCN is lost with no rearrangement in the molecular ion, then the carbon atom lost as HCN is the one to which the amino group is originally attached, i.e. carbon 1. In the mass spectrum of 1- ^{13}C -aniline^{49,50} it was found that 90% of the molecular ion fragmented with total loss of the labeled atom as hydrogen cyanide, i.e. no rearrangement occurred. However, an ion $\text{C}_6\text{H}_6\text{N}^+$ is also present which is produced by the loss of a hydrogen atom from the molecular ion as denoted by the corresponding metastable ion. This ion, $\text{C}_6\text{H}_6\text{N}^+$, undergoes further decomposition by losing HCN and C_2H_2 with appropriate metastable ions.

In the spectrum of 1- ^{13}C -aniline the $(\text{M}-\text{H})^+$ ion at m/e 93 loses not only C_2H_2 but also $^{13}\text{CCH}_2$ suggesting that it must have rearranged, presumably to an azatropylium ion, so that the labeled carbon atom could be lost as acetylene. It was concluded that although the molecular ion is nearly all unrearranged, the $(\text{M}-\text{H})^+$ ion is largely rearranged to the azatropylium ion prior to further fragmentation, in a process analogous to the formation of tropylium ion from toluene.

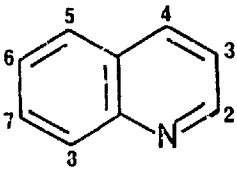
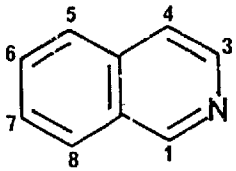


The formation of the azatropylium type of ion was investigated in the mass spectra of quinoline and isoquinoline and their methyl-substituted derivatives ⁵¹. The most important fragmentation in the mass spectra of quinoline and isoquinoline is the loss of HCN from the molecular ion. Introduction of a methyl group in these molecules reduces the importance of this fragmentation in favour of a new process. This new process involves the loss of a hydrogen atom from the molecular ion followed by expulsion of HCN to give rise to the fragment ion $[(M - (H + HCN))]^+$. It was observed that the ratios of peak intensities $[M - (H + HCN)] / (M - H)$ were constant

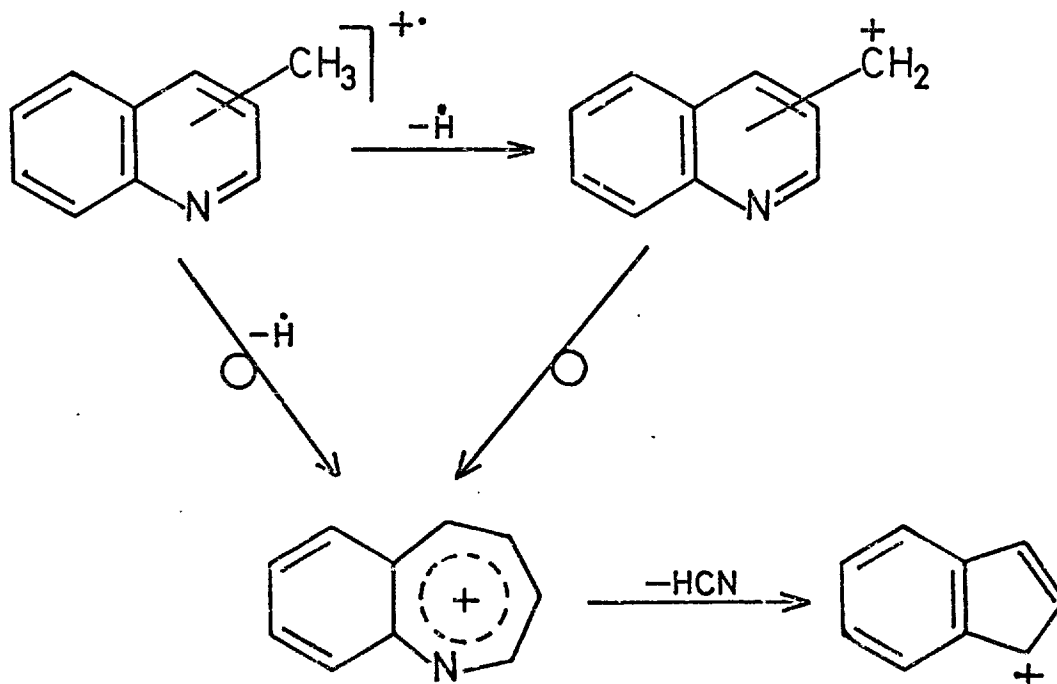
when the methyl group was in any position in the heterocyclic ring (Table X). This constant ratio suggested that the fragment ion (M-H) undergoes rearrangement prior to fragmentation. This rearrangement occurs in such a way that the carbon atom originally in the methyl group becomes identical to the rest of the carbon atoms in the heterocyclic ring, i.e. a common azatropylium ion is formed for the three isomers. Since the hydrogen cyanide is expelled from a common intermediate the position of the methyl group in the heterocyclic ring does not alter the extent of formation of the fragment $[M-(H + HCN)]^+$.

TABLE X

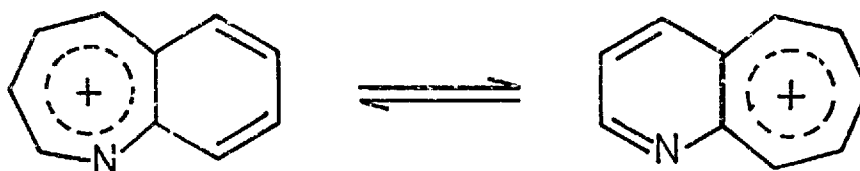
Intensity of peaks of $(M-H)^+$ and $[M-(H+HCN)]^+$ fragments in the spectra of methylquinolines and methylisoquinolines.

Compound	Position of Methyl	Peak intensities		$[M-(H+HCN)]^+$
		(M-H)	$[M-(H+HCN)]$	(M-H)
Quinoline 	2	3.9	5.0	1.28
	3	9.0	11.8	1.32
	4	6.5	9.3	1.32
	5	16.5	5.7	0.34
	6	14.7	4.8	0.32
	7	13.4	4.0	0.31
	8	13.4	4.2	0.31
Isoquinoline 	1	4.9	10.1	2.04
	3	5.5	11.1	2.08

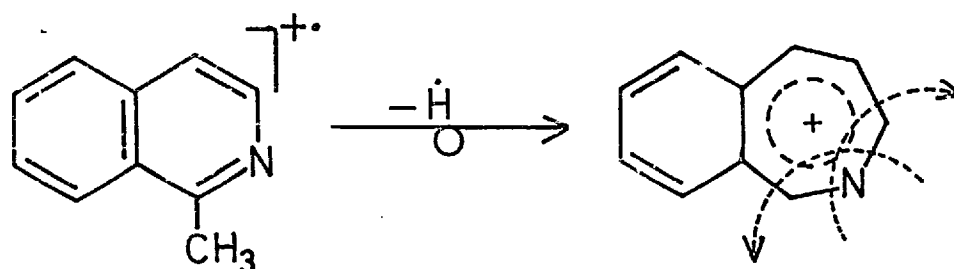
The following mode of fragmentation was proposed for the 2-, 3- and 4-methylquinolines:



For the case when the methyl group is in the benzene ring the ratio $[M-(H + HCN)]/(M - H)$ is also constant but much lower than for the isomers with the methyl group in the heterocyclic ring. The constant ratio suggested a common intermediate for the four isomers namely a tropylium ion. The following equilibrium between the tropylium and azatropylium ions was postulated to account for the extent of loss of HCN from the $(M - H)^+$ ion in the two groups of compounds.

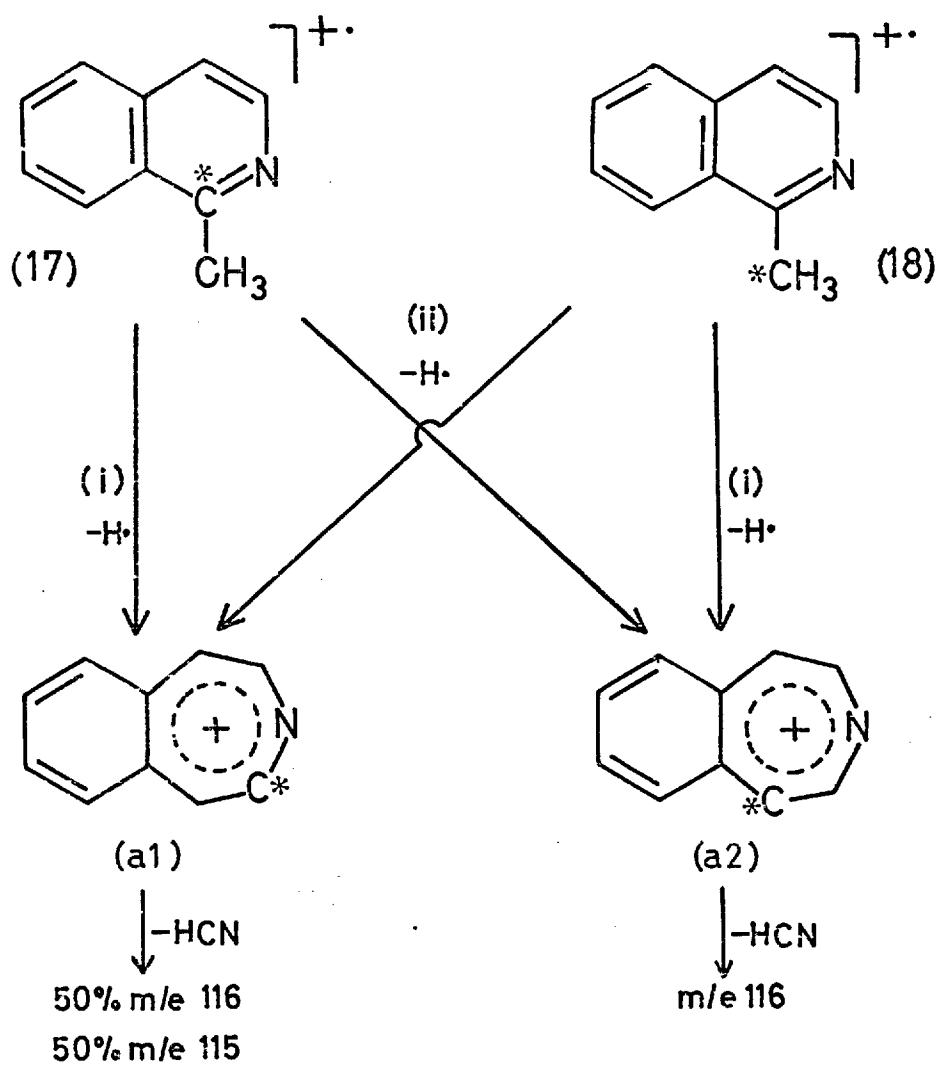


In the mass spectra of the 1- and 3-methylisoquinolines the ratios were nearly twice as large as for 2-methylquinoline (Table X). This high ratio was simply attributed to the fact that the azatropylium intermediate in this case could lose HCN in two different ways, as shown by dotted lines below.



Marx and Djerassi⁵² further investigated the formation of the azatropylium ion by labeling 1-methylisoquinoline at the carbon 1 position (17) and at the methyl group (18) with carbon 13. They suggested that if an azatropylium ion is formed either of the two paths shown in Scheme V are possible. Path (i) involves phenyl migration, whereas path (ii) involves nitrogen migration

For ^{13}C to be lost as H^{13}CN from either of these species the intermediate (al) must be formed. Since this intermediate is symmetrical with respect to the nitrogen the carbon atom lost as HCN can be either of the two adjacent carbon atoms. As a result the observed percentage of labeled atom lost represents only half of maximum loss of labeled carbon atom (Table XI).



SCHEME V

TABLE XI : Percentage of labeled atom lost as HCN
in the two compounds (17) and (18)

Compound	% label lost	m/e
17	26	115
18	14	115

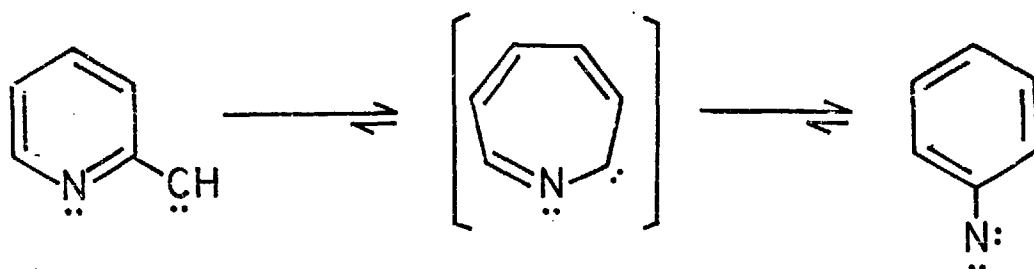
From these results it can be seen that (17) and (18) lose HCN through the intermediate (a1) with a contribution of 52% and 28% respectively. Marx and Djerassi, therefore, concluded that at least 80% of the $[M-(H+HCN)]^+$ ion in the spectrum of 1-methylisoquinoline comes from the rearranged $(M-H)^+$ ion, i.e. the azatropylium ion (a).

The formation of the azatropylium type of ion has been suggested in the fragmentation of the cation radical of phenyl nitrene. Kingston and Henion ⁵³ have studied the mass spectrum of 2,4,6-d₃-phenylazide. They observed that the intensities of the ions resulting from the decomposing $(M-N_2)^+$ ion are in good agreement with the calculated values. The calculated values were based on the assumption that complete scrambling of H and D in the ion $(M-N_2)^+$ had occurred prior to any decomposition.

Woodgate and Djerassi ⁵⁴ looked at the spectrum of 1-¹³C-phenylazide and observed that the molecular ion not only loses labeled HCN but also labeled acetylene. To account for this latter loss the nitrogen must insert into the ring to form the azatropylium type of ion.

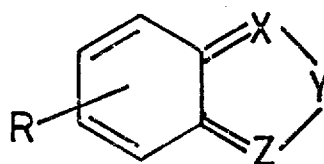
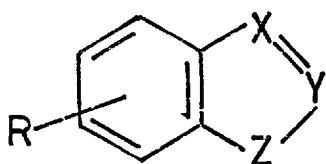
In the mass spectrum of p-tolyl-2,6-d₂-azide it was observed ⁵⁵ that the $(M-N_2)^+$ ion has undergone 60% insertion of the methyl group as deduced from the partial scrambling of the methyl and ring hydrogens. This suggests that the insertion of the methyl to form the tropylium ion is a more favoured process than the formation of azatropylium ion.

In a number of reports the pyrolytic interconversion of phenylnitrene and pyridylcarbene has been mentioned ^{56,57,58,59}. The azatropylium type of structure has been proposed as an intermediate for this interconversion.



BENZOTRIAZOLE

The mass spectra of aromatic heterocyclic compounds of the general formulae shown below, where X, Y and Z are hetero atoms, are not very well known. Although the mass spectra of benzotriazoles (19) and (20) have been recorded ^{60,61,62,63}, not much work has been done on compounds like benzofurazans (23) and benzo-thiadiazoles (21, 22).



(19) : X = Y = N, Z = NH

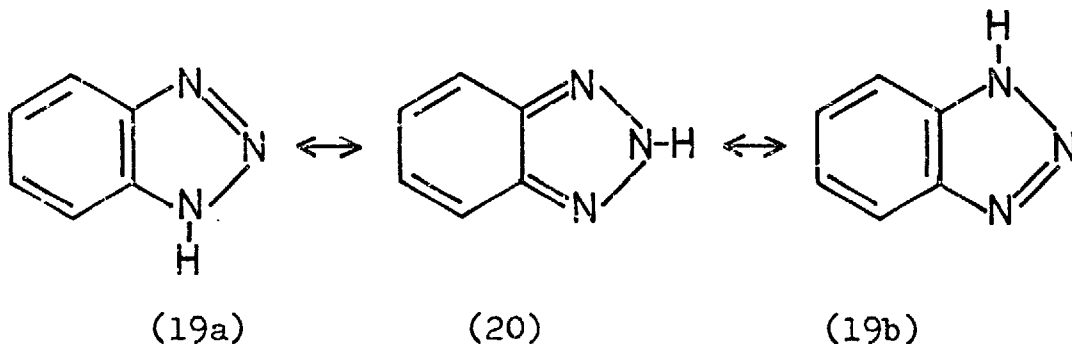
(20) : X = Z = N, Y = NH

(21) : X = Y = N, Z = S

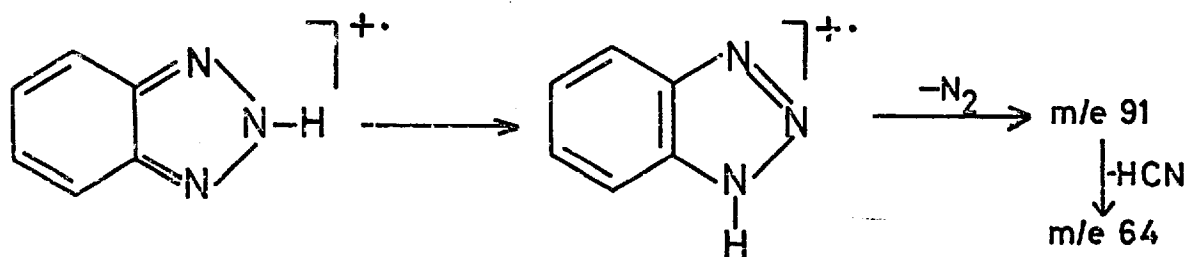
(22) : X = Z = N, Y = S

(23) : X = Z = N, Y = O

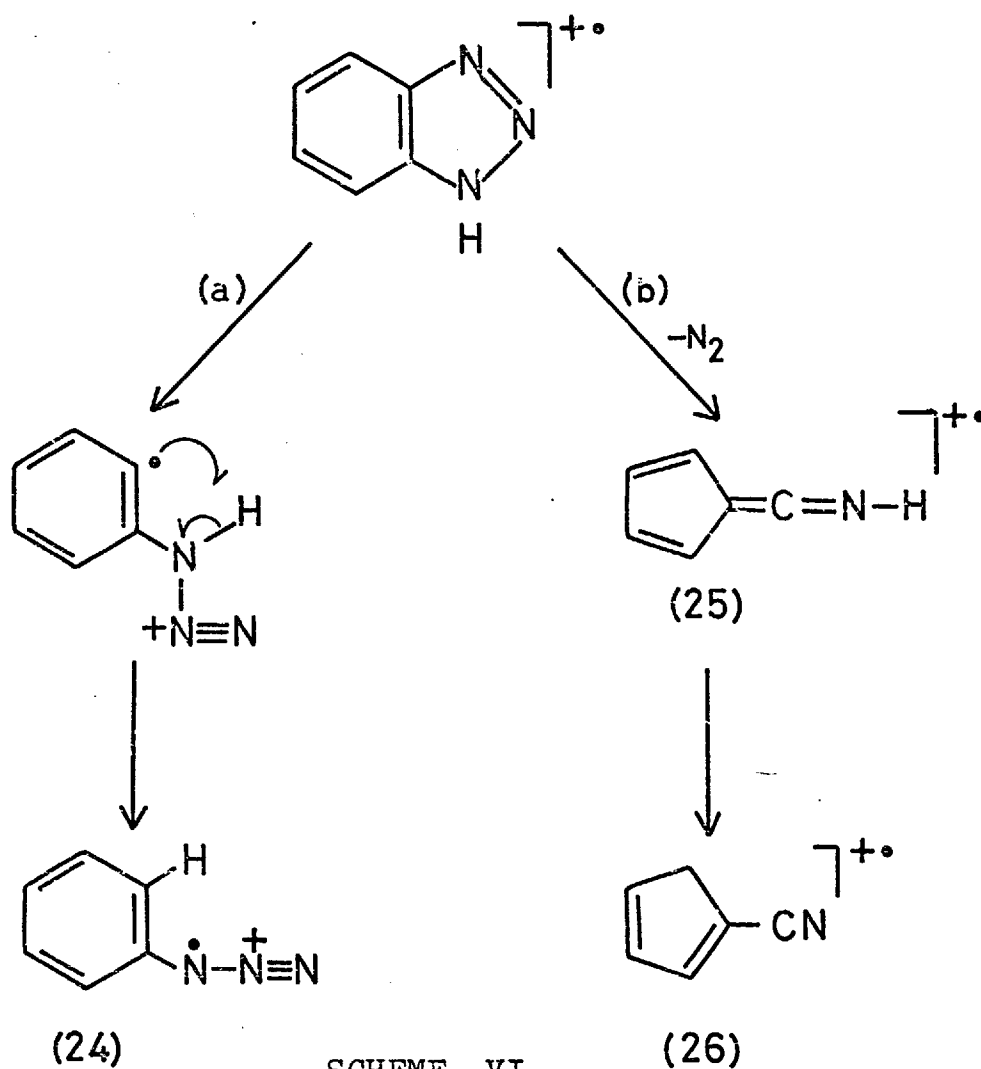
1,2,3-Benzotriazole could have any of the following tautomeric forms.



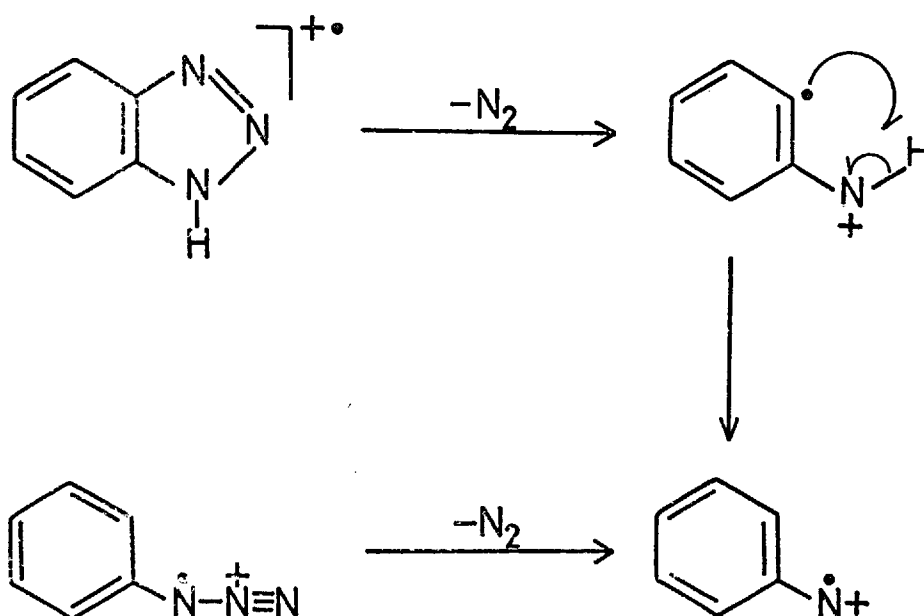
It has been shown that the two structures (19a and b) predominate in solution ⁶⁴. In a recent report Maquestiau and co-workers ⁶³ have shown that in gas phase only the 1-H-benzotriazole exists. They suggested that in the mass spectrometer the 2-H-benzotriazole isomerises to the 1-H-isomer prior to fragmentation.



The main fragmentation of 1-H-benzotriazole under electron impact is the loss of N_2 followed by expulsion of HCN . Lawrence and Waight ⁶¹ proposed two routes for this fragmentation (Scheme VI). The first, route (a), involves the transfer of the aminohydrogen to the ring resulting in the molecular ion of phenylazide (24); they suggested that the similarity of the spectra of phenylazide ⁶⁵ and benzotriazole supports this route. The second, route (b), involves the loss of N_2 and ring contraction to form the ion (25) which rearranges to the molecular ion of cyanocyclopentadiene (26). In fact one of the products obtained from pyrolysis of benzotriazole has been identified as cyanocyclopentadiene ⁶⁵.

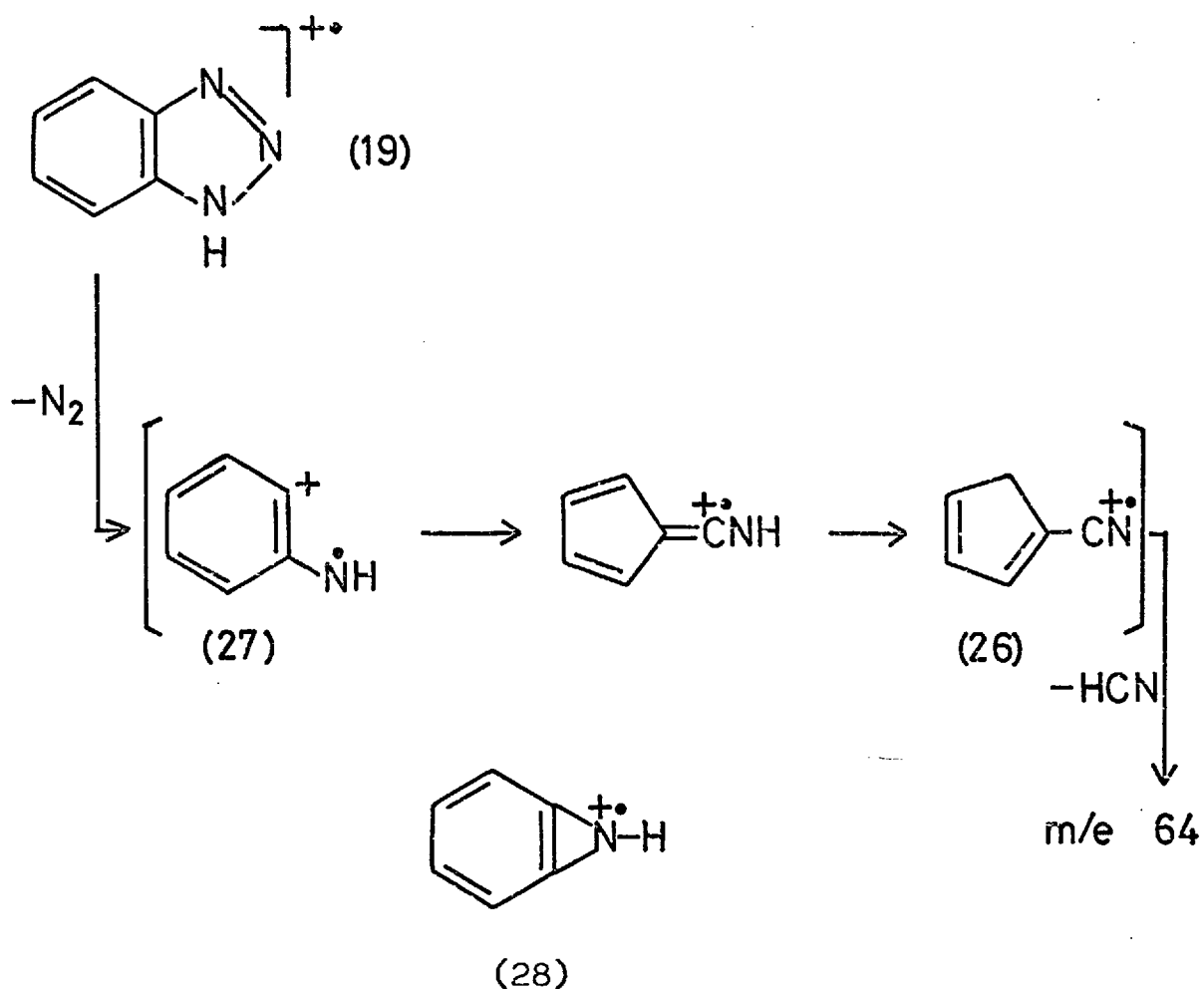


Comparison of the mass spectra of phenylazide and benzotriazole clearly reveals that although the two spectra are quite similar below m/e 92, the intensities of the molecular ion at m/e 119 are quite different. The larger relative intensity of the molecular ion of benzotriazole suggests that this ion is more stable than the molecular ion of phenylazide, i.e. it does not lose N_2 as easily. However, the similarities below m/e 92 indicates that the fragment ion ($M-N_2$) from the two compounds may be similar. In other words the ($M-N_2$) ion in the spectra of benzotriazole may rearrange to form an ion similar to the ($M-N_2$) ion in the spectra of phenylazide.

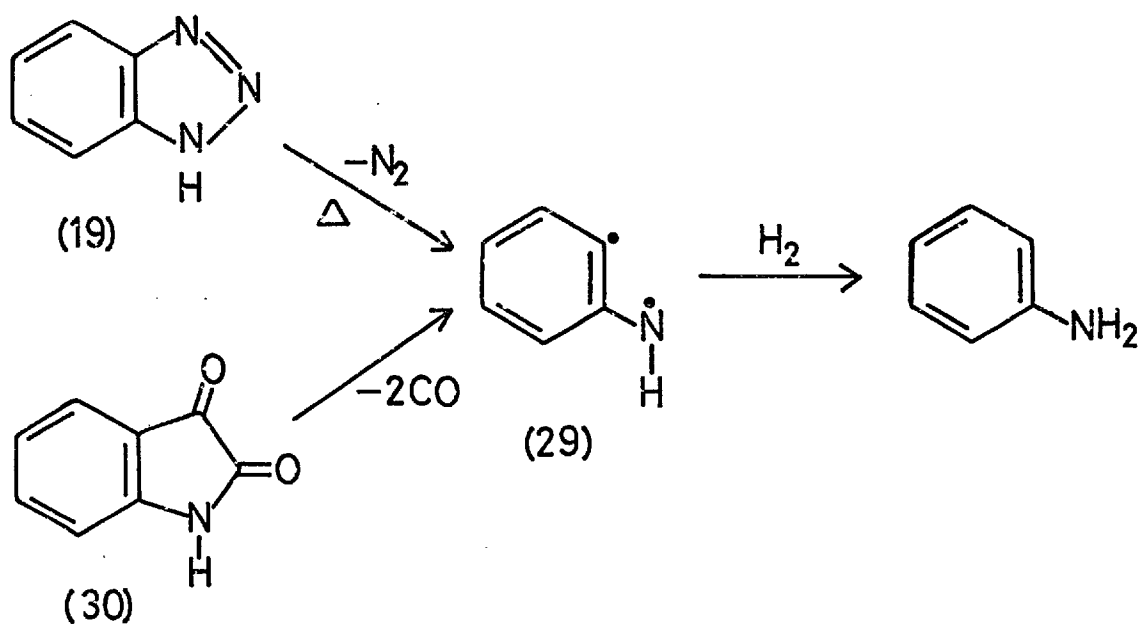


Ohashi and co-workers⁶² have studied the electron impact mass spectra of a number of benzotriazoles and essentially their results on the 1-H-benzotriazole are consistent with those found by Lawrence and Waight⁶¹. They suggested that the molecular ion (19) loses N_2 to form a radical cation (27) which can ring contract followed by hydrogen migration to produce the molecular ion of a pyrolytic fragmentation product, i.e. cyanocyclopentadiene (26).

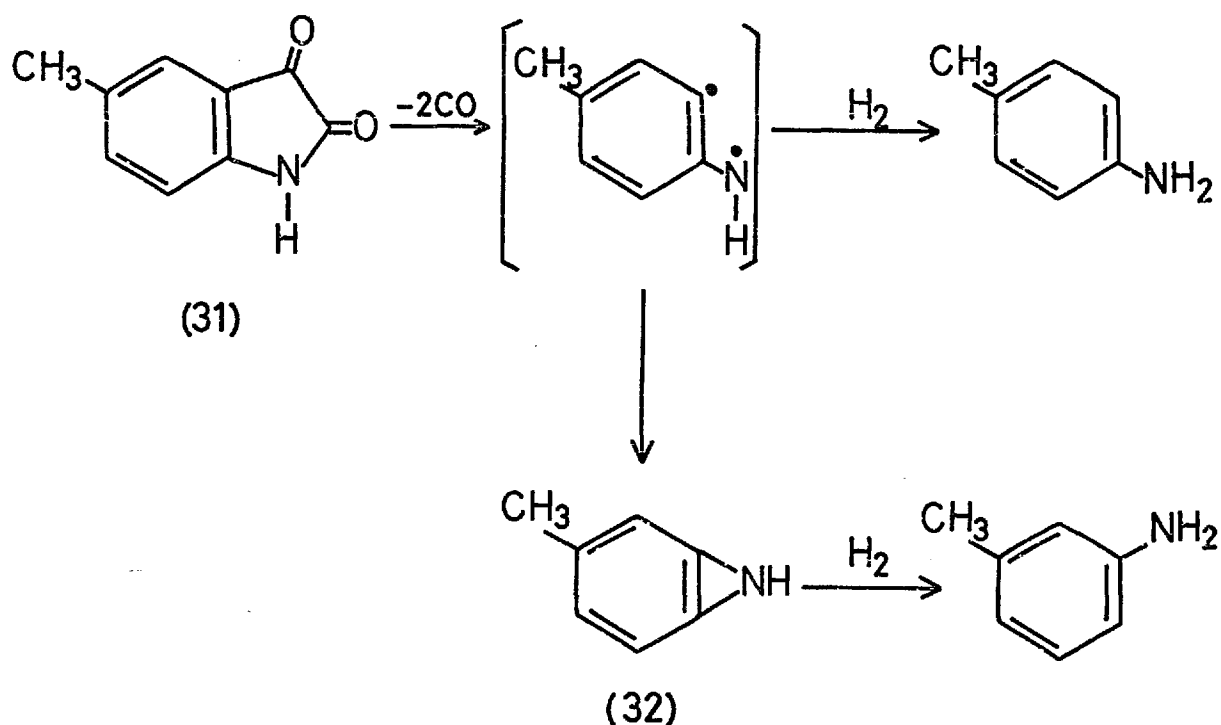
The azirine (28) could be a possible structure for the ion at m/e 91. However, with the help of molecular orbital calculation using the extended Hückel method, Ohashi and co-workers⁶² found out that the azirine ion (28) is less stable than the radical cation (27) by about 1.7 eV. As a result they suggested that the ion (27) is preferred to the structure (28).



It may be of some significance to note that the 1,3-biradical (29) was proposed as an intermediate in the pyrolytic decomposition of benzotriazole (19) ⁶⁶. The evidence which was offered in support of this biradical



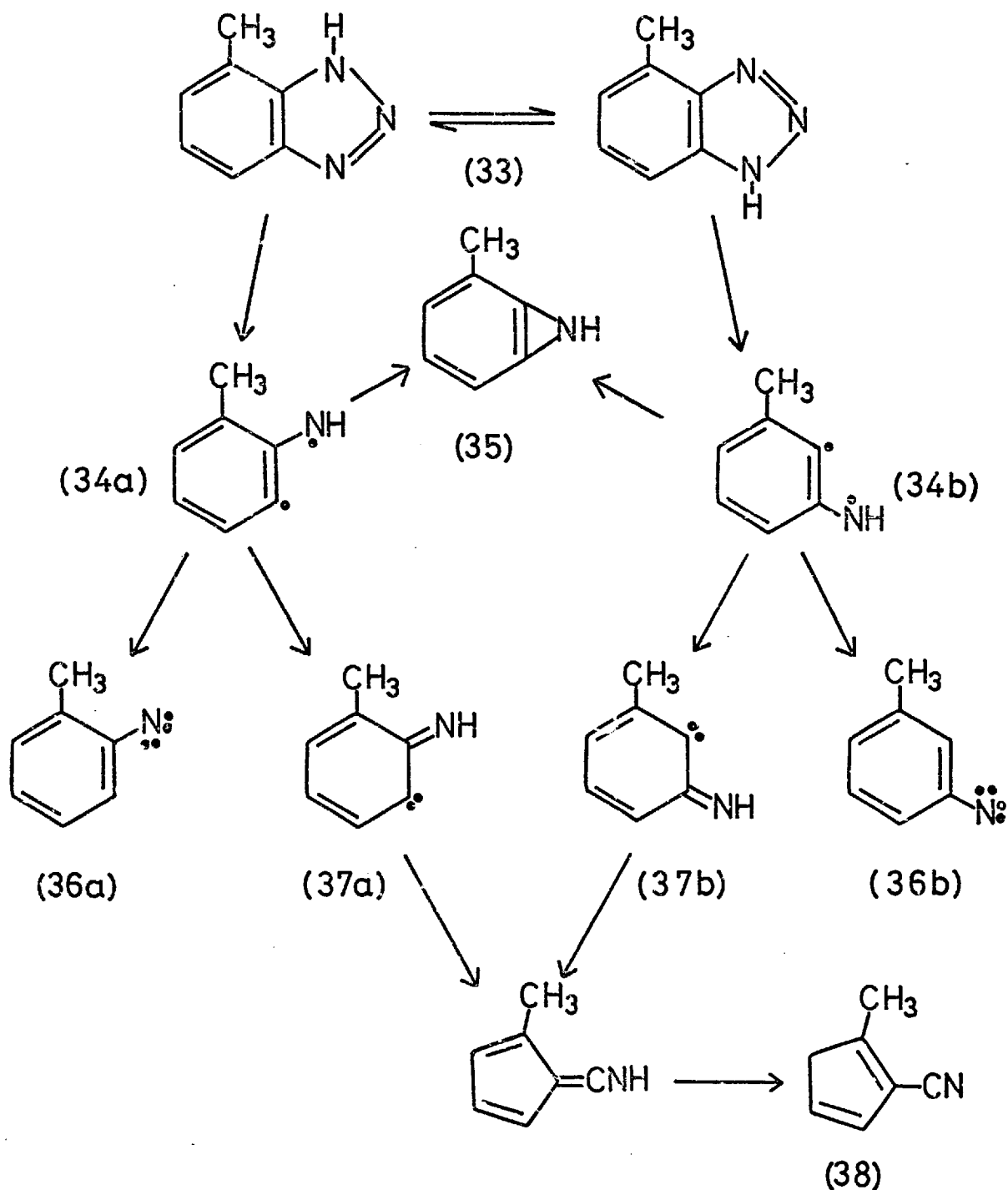
was that it abstracts hydrogen atoms to form aniline in very low yield. The 1,3-biradical (29) was also an intermediate in pyrolysis of isatin (30) ⁶⁶. Pyrolysis of 5-methylisatin (31) below 700° resulted in the formation of p-toluidine in a very low yield but at higher temperature a small amount of m-toluidine was also produced. The production of m-toluidine suggested that the azirine (32) may be an intermediate in this decomposition. Scheme VII.



SCHEME VII

Pyrolysis of 4-methylbenzotriazole (33) has been reported by Wentrup and Crow ⁶⁷ who proposed the following mechanistic paths for the fragmentation, Scheme VIII. Because of tautomerism, either of the biradicals (34 a or b) can be formed. These biradicals may undergo any of the following transformations:

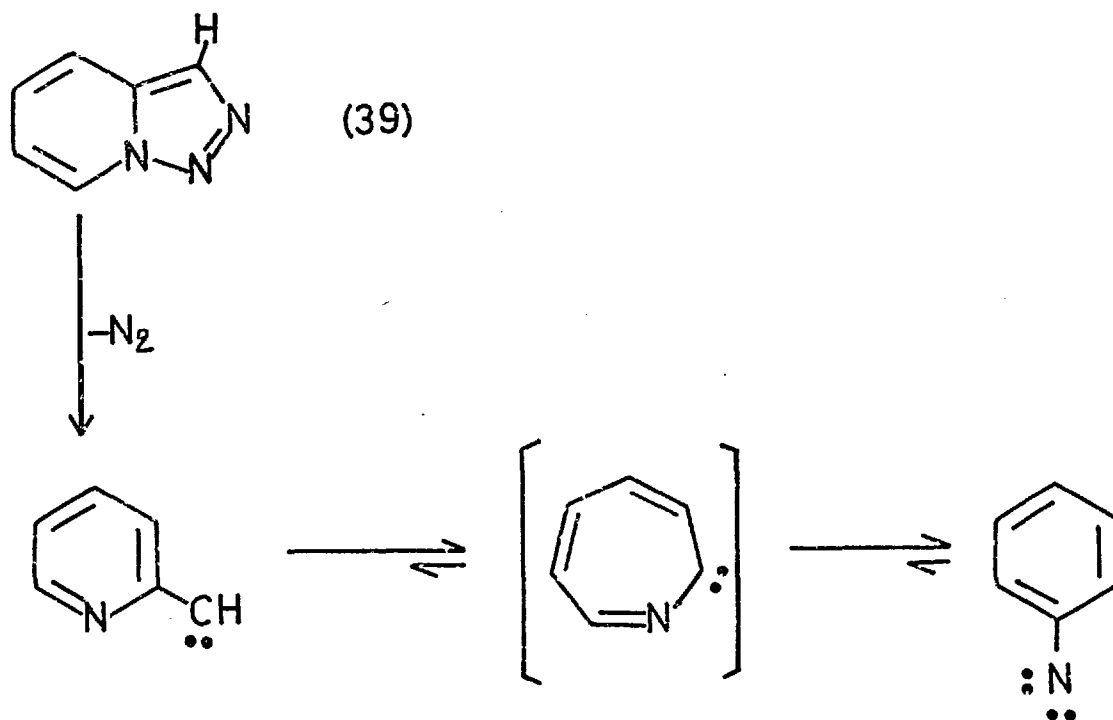
1 - formation of azirine (35); 2 - rearrangement to the nitrenes (36a and b); 3- formation of the iminocarbenes (37a and b). The formation of the azirine (35) is an unlikely but not impossible process.



SCHEME VIII

Rearrangement to nitrene does not occur since no azobenzene derivative (a common product if nitrene is present) was identified in the pyrolysate of benzotriazole. It was also observed ⁶⁷ that pyrolysis of benzotriazole results in the formation of cyanocyclopentadiene in up to 99% yield as compared to about 50% for phenylazide. This suggests that different intermediates are involved for the two compounds. The most probable process is the formation of the iminocarbenes (37 a and b) which undergo a Wolff rearrangement to form the cyanocyclopentadiene (38).

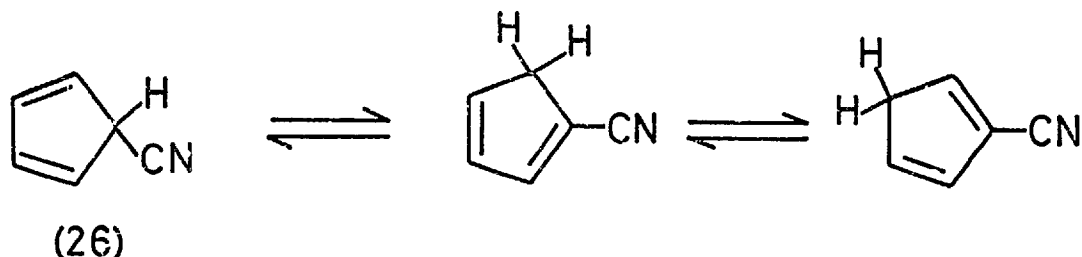
The similarities of mass spectra of phenylazide and vic-triazolo[1,5-a] pyridine (39) suggests that the radical cation of phenylnitrene and 2-pyridylcarbene interconvert by ring expansion ⁵⁵, similar to the pyrolytic interconversion ^{56,57,58,59}.



Comparison of metastable peaks in these spectra and those in the spectrum of cyanocyclopentadiene ⁵⁵, however, suggests that the radical cation of phenylnitrene does not ring contract in the mass spectrometer.

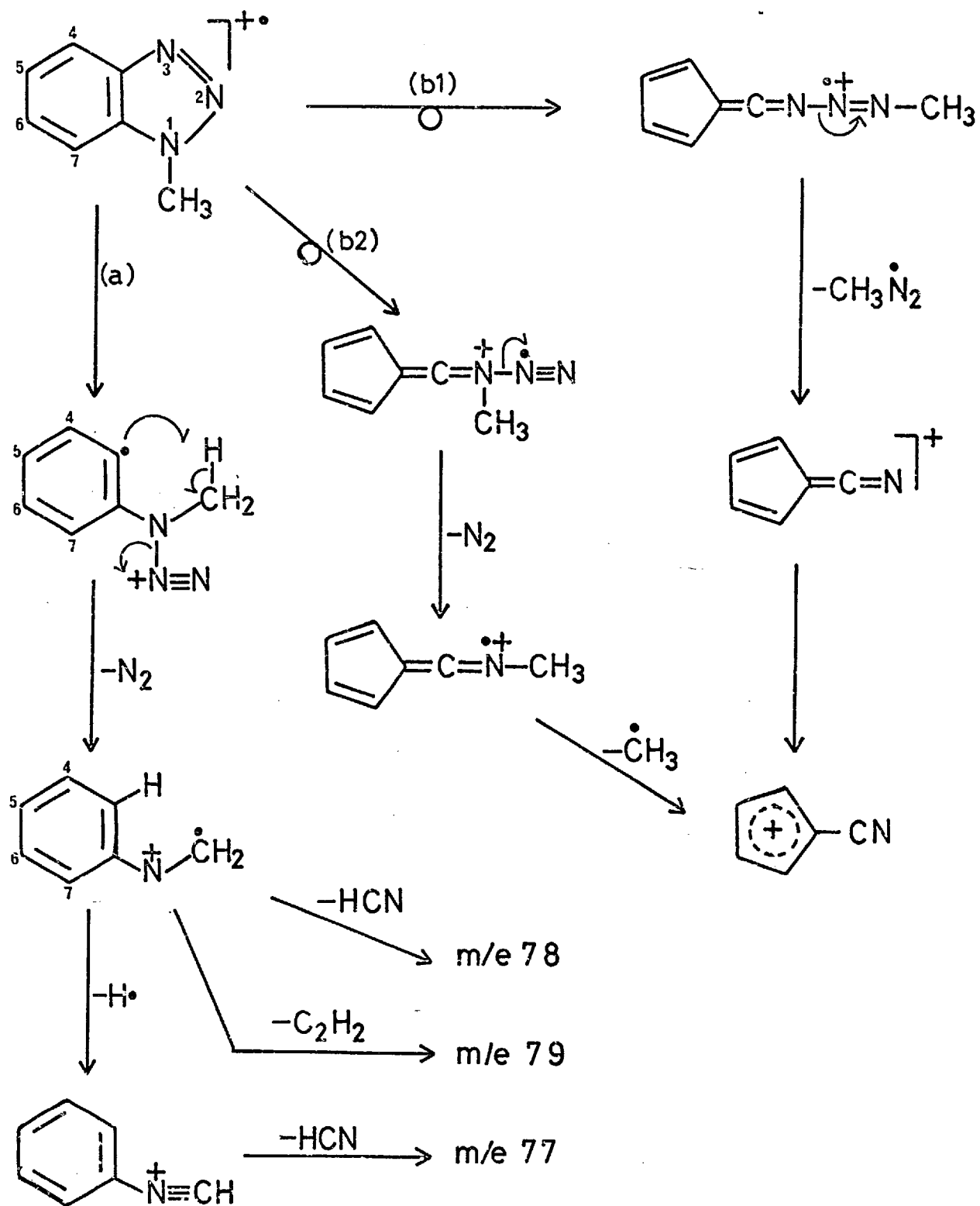
In order to get an insight into the structure of the ion $(M-N_2)^+$ in the spectrum of benzotriazole, Wentrup and co-workers ⁵⁵ looked at the spectrum of 1-d-benzotriazole. They observed that the $(M-28)^+$ ion loses DCN and HCN in the ratio of about 80 : 20. From comparison of this result and the results of Kingston and Henion ⁵³ on deuterated phenylazide, they ⁵⁵ concluded that the $(M-N_2)^+$ ions in the spectra of the two compounds are different.

In a recent investigation by Maquestiau and co-workers it was observed that the $(M-N_2)^+$ ion in the spectrum of 1-d-benzotriazole loses DCN and HCN in the ratio of approximately 1:4. This ratio suggested that complete hydrogen scrambling had occurred in the ion $[C_6H_5N]^+$ prior to any fragmentations. The manner by which this hydrogen scrambling occurs in this ion is not well defined. This hydrogen scrambling does not seem to occur via an intermediate which was responsible for hydrogen scrambling in the isomeric phenylnitrene radical cation. As mentioned above this latter radical cation does not ring contract ⁵⁵. It is possible that this scrambling may occur in the ion $[C_6H_5N]^+$ which has rearranged to the molecular ion of cyanocyclopentadiene (26). Scrambling of hydrogens may be an easy process in this ion since hydrogen shifts have been reported to be very facile in this compound ^{67,68}.

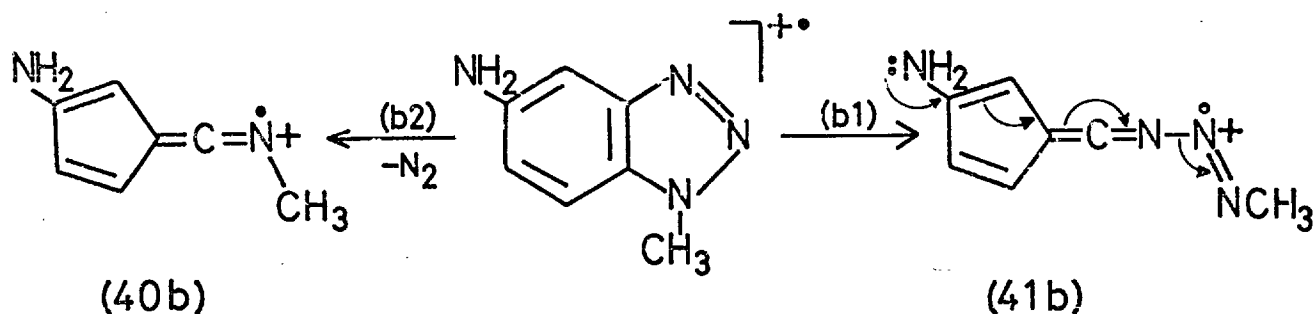
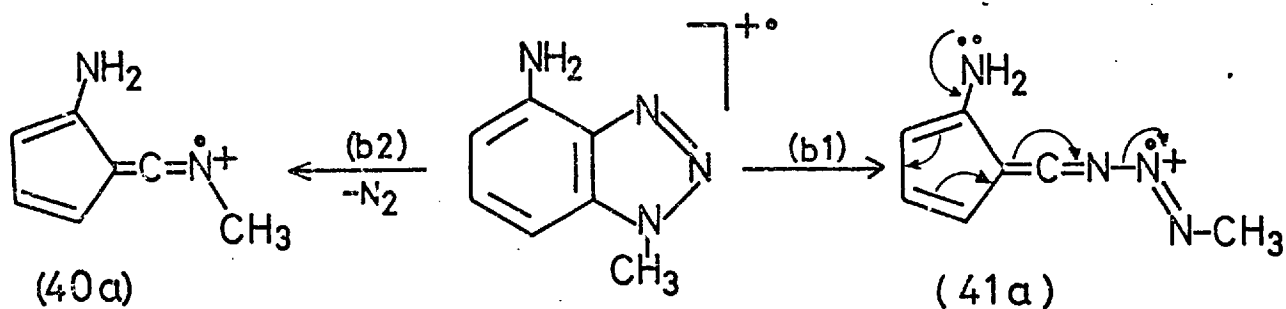


Lawrence ⁶⁰ and Waight ⁶¹ also studied the mass spectra of a number of 1- and 2-methylbenzotriazoles and proposed the following mechanistic routes for their fragmentation, Scheme IX. These routes are essentially the same as those proposed for benzotriazole itself.

They suggested that the molecular ion of the 1-methyl isomer loses both N_2 and N_2CH_3 according to routes (b2) and (b1) respectively. The 2-methylbenzotriazole, however, loses only N_2CH_3 indicating that no rearrangement of the molecular ion to that of the 1-methyl isomer occurs. In support of their mechanism they studied the mass spectra of amino-1-methylbenzotriazoles. Similarities were observed between the mass spectra of 5- and 6-amino compounds and also between the 4- and 7- isomers. These similarities indicated that the fragmentation occurs through route (b) resulting in the ions (40 a and b) and (41 a and b). The ions 40a and 41a are formed from the 4- or 7-amino compound by routes (b2) and (b1) respectively; and the ions 40b and 41b are formed from the 5- or 6-amino isomers by the routes (b2) and (b1) respectively.



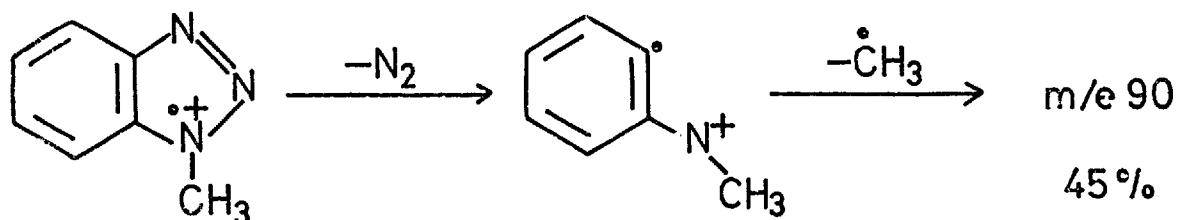
(SCHEME IX)



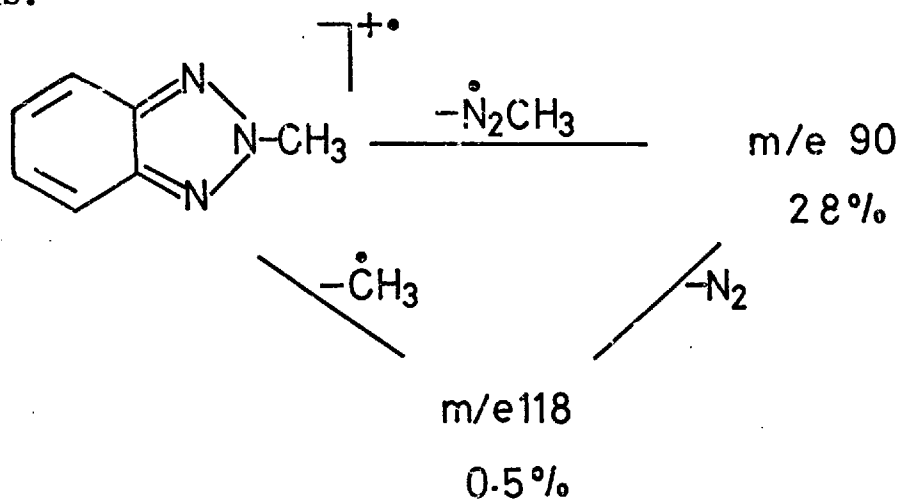
Electron donating groups like NH_2 and OCH_3 tend to assist the expulsion of N_2CH_3 from the ions (41a and b) by the resonance effect. In the case of an electron withdrawing group like NO_2 , however, the $[\text{M}-\text{N}_2\text{CH}_3]^+$ ion is relatively unimportant. In the mass spectra of 4-, 5-, 6- and 7- nitro-1-methylbenzotriazoles it was observed that the fragmentation patterns of the 4- and 6- isomers were similar and were different from those of 5- and 7- isomers. This suggested that the nitro-compounds probably undergo fragmentation via route (a) in which the positions 4 and 6 become identical but 5 and 7 do not.

Maquestiau and co-workers⁶³ also studied the fragmentation of 1- and 2-methylbenzotriazoles. With the help of the metastable refocusing technique, they showed that the molecular ion of 1-methylbenzotriazole

only loses N_2 and not N_2CH_3 as suggested by Lawrence and Waight ⁶¹.

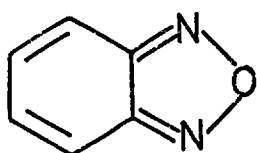


They proposed that the N_2CH_3 lost is the result of a two step process, namely: first, loss of a nitrogen molecule and second, the expulsion of a methyl radical resulting in the ion at m/e 90 with a relative intensity of 45% with respect to the molecular ion (100%). The 2-methyl isomer, being a more stable molecule than the 1- isomer, undergoes fragmentation less easily and the relative intensity of the ion m/e 90 is only 28% with the molecular ion at 100% at m/e 133. This ion (m/e 90) is produced by way of two processes. The first involves the loss of a methyl radical resulting in an ion at m/e 118 with a relative intensity of 0.5% followed by the loss of N_2 . In the second process the molecular ion loses N_2CH_3 radical as shown by the appropriate metastable transitions.

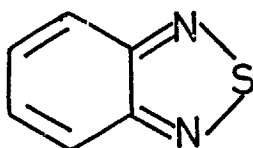


BENZOFURAZANS AND BENZOTHIADIAZOLES

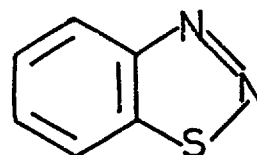
Very little work has been done on the mass spectra of benzofurazans and benzothiadiazoles. It has been shown^{60,61} that when two atoms of nitrogen are adjacent to each other in these compounds, the loss of N_2 is relatively an easy process. While benzofurazan (23) loses NO with relative ease, the sulphur analogue (benzothiadiazole) (22) does not expel NS to any appreciable extent.



(23)



(22)



(21)

Both NO and NS are odd electron species. However NO is a much more stable molecule than NS. It appears, therefore, that the ease of fragmentation of the two compounds (22) and (23) depends on the stability of the neutral fragment expelled⁶¹. Table XII shows the percentage of the total ion current carried by the ion $(M - X)^+$, where $X = N_2$, NO or NS depending on the compound.

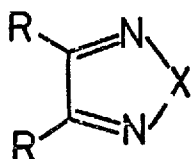
TABLE XII

Loss of neutral fragment from the molecular ion of compound (23), (22), (21) and benzotriazole.

<u>Compound</u>	<u>X</u>	<u>M-X*</u>
2,1,3-benzoxadiazole	NO	26.6
2,1,3-benzothiadiazole	NS	3.92
1,2,3-benzothiadiazole	N ₂	37.7
	NS	0
1,2,3-benzotriazole	N ₂	19.0

* percent total ion current carried by this ion.

Cantrell and Haller⁶⁹ have studied the photochemical behaviour of some five-membered ring aromatic heterocyclic compounds.



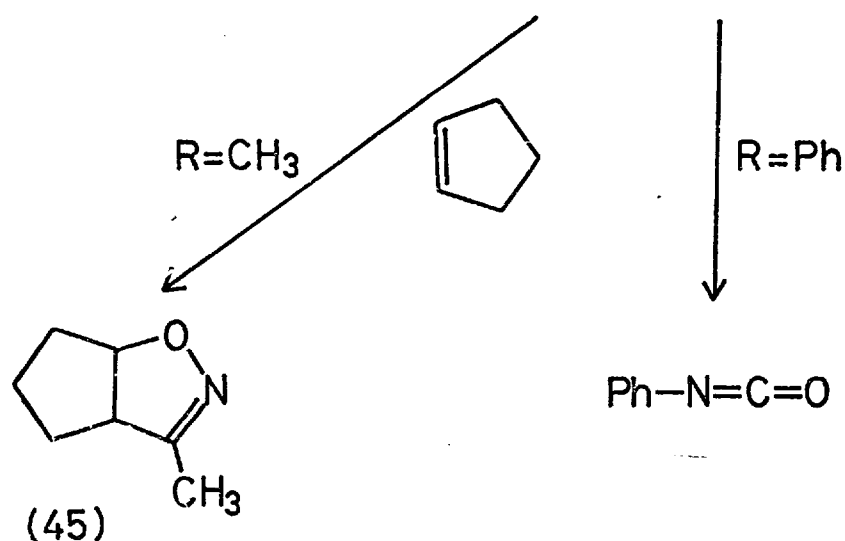
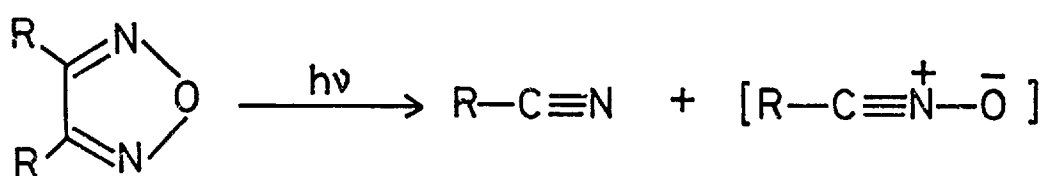
(42) : X = O

(43) : X = S

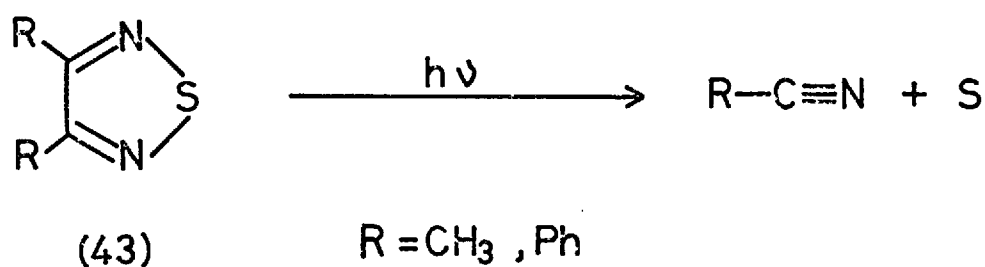
(44) : X = N-R

R = CH₃, Ph

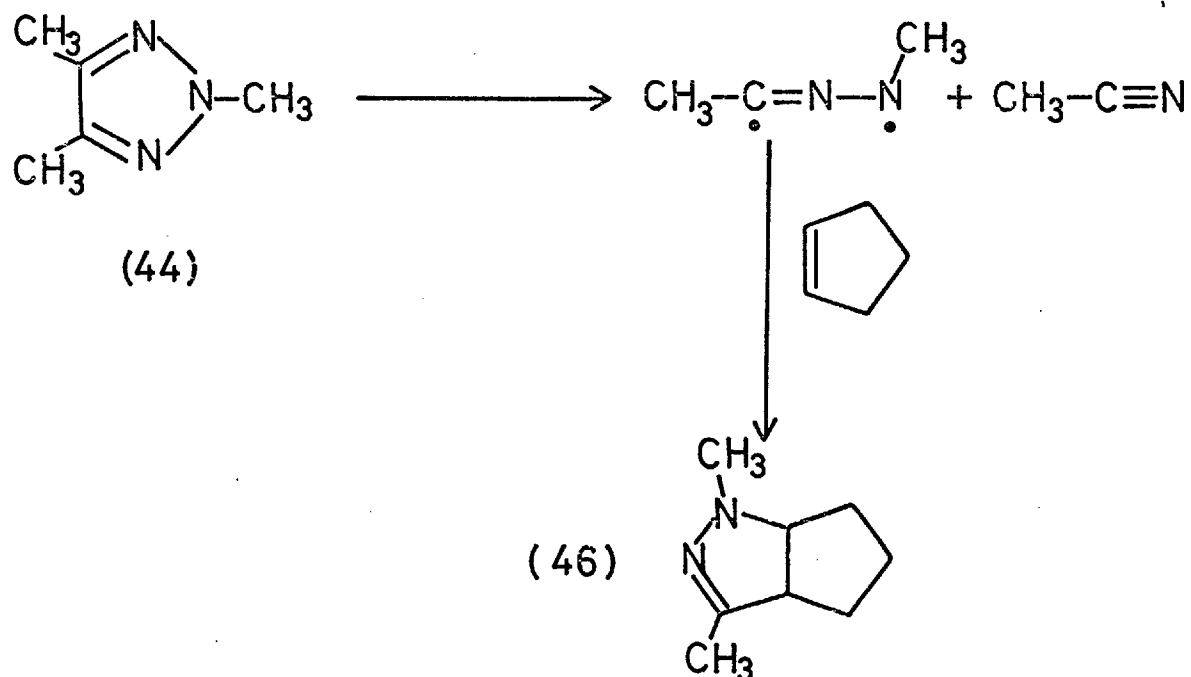
Irradiation of 42 (R = Ph) in ether resulted in the formation of benzonitrile (82%) and phenylisocyanate (48%). Irradiation of 42(R = CH₃) in the same manner resulted in acetonitrile and some tar. However, photolysis of 42 (R = CH₃) in the presence of a large amount of cyclopentene produced, besides acetonitrile, the adduct of acetonitrile and cyclopentene (45).



Photolysis of 43 ($\text{R}=\text{CH}_3, \text{Ph}$) always resulted in the formation of the corresponding nitriles and elemental sulfur.

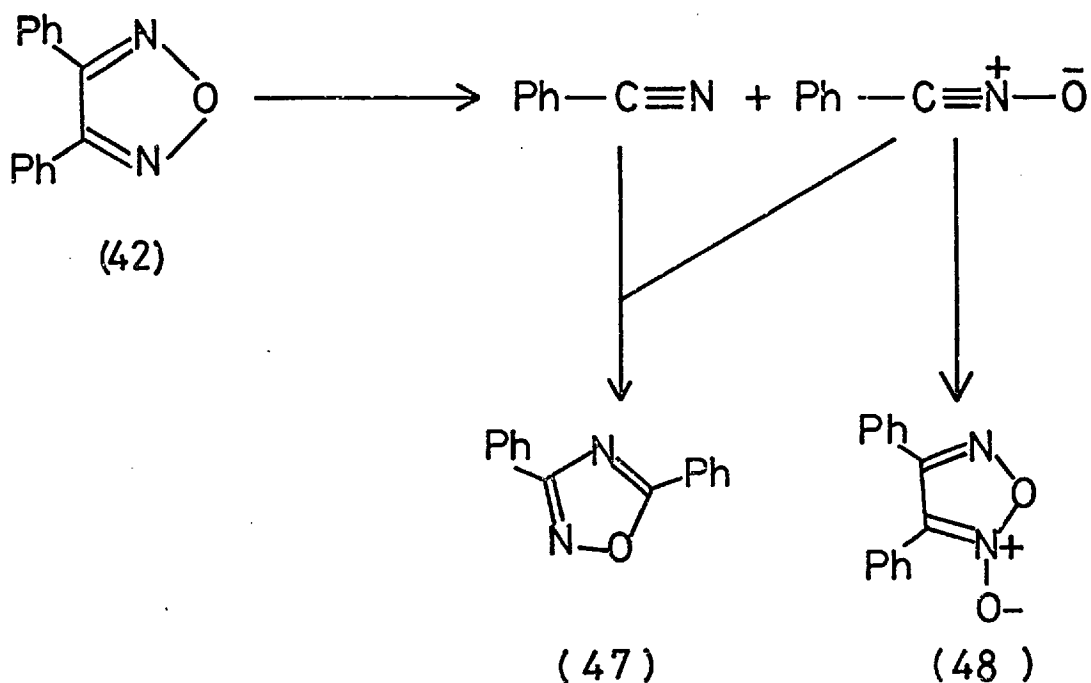


While irradiation of 2,4,5-triphenyl-2H-1,2,3-triazole resulted in no reaction, the photolysis of 44 ($\text{R}=\text{CH}_3$) in the presence of an excess of cyclopentene resulted in the formation of acetonitrile and the compound (46).



These results indicate the particularly interesting double fragmentation of the 1,2,5-oxadiazole resulting in the corresponding nitrile and nitrile oxide ⁶⁹.

Mukai and co-workers ⁷⁰ have also studied the photochemical behaviour of 3,4-diphenyl-1,2,5-oxadiazole 42 (R=Ph). They observed the formation of the two compounds (47) and (48).



The formation of these two products (47 and 48) can be explained by the double fragmentation process proposed by Cantrell and Haller ⁶⁹. In other words, the oxadiazole (47) is product of recombination of benzonitrile and benzonitrileoxide, and the compound (48) is the result of recombination of two molecules of benzonitrile oxide.

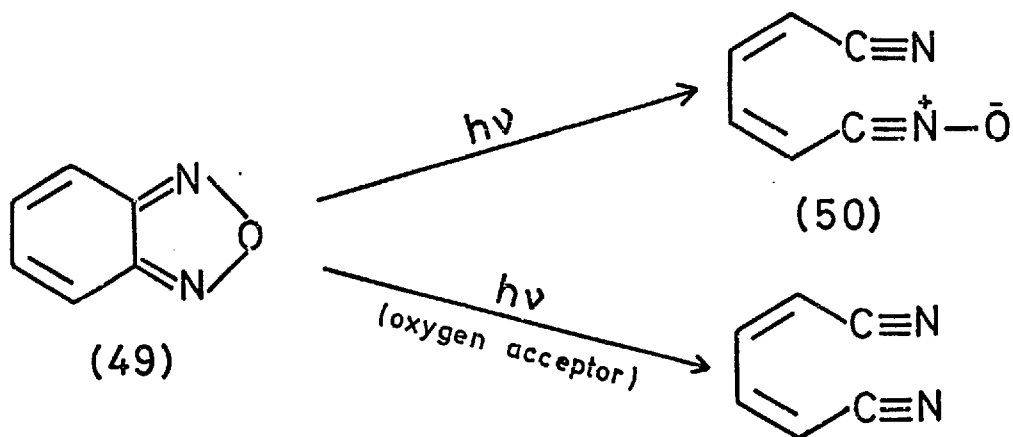
The electron impact mass spectrum of 42(R=Ph) was studied and peaks corresponding to the molecular ions of benzonitrile, m/e 103, and benzonitrile oxide (or phenylisocyanate) m/e 119 were observed.

TABLE XIII : Partial spectra of (42,R=Ph)

<u>fragment</u>	<u>mass</u>	<u>relative intensity (%)</u>
$M^{+\bullet}$	222	95
$M-NO^+$	192	85
	151	17
$Ph-CN-O^{+\bullet}$	119	86
$Ph-N=C=O^{+\bullet}$		
$Ph-CN^{+\bullet}$	103	10
$Ph-N^{+\bullet}$	91	34
$Ph-C^+$	89	100

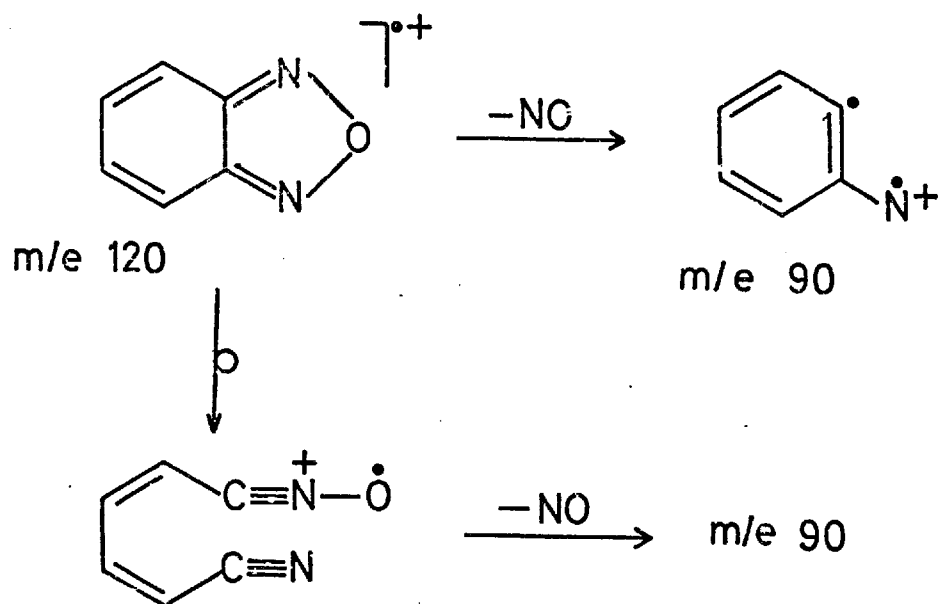
This result suggested that the double fragmentation process observed in photolysis also occurs in electron impact.

Mukai and Nitta ⁷¹, in an attempt to synthesize 1,4-dinitriles from furazans, irradiated benzofurazans (49) and obtained a complex mixture of products. The complexity of the mixture was explained in terms of the production of a reactive intermediate, a nitrile-oxide (50).



However, when the photolysis was carried out in the presence of an oxygen acceptor (e.g. triethylphosphite) the expected dinitrile was produced very cleanly in high yield (80%).

If parallelism can be drawn between photolytic and electron impact fragmentations, then benzofurazans may undergo the same sort of fragmentation under electron impact as they do on photolysis. As a result it may be that benzofurazans, 2,1,3-benzothiadiazoles and 1,2,3-benzothiadiazoles decompose in the mass spectrometer by at least two processes, namely:



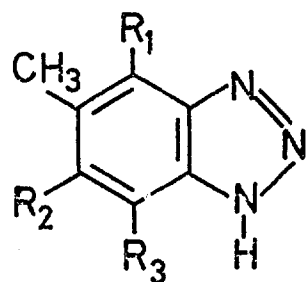
CHAPTER TWO

RESULTS AND DISCUSSION
OF SYNTHETIC WORK

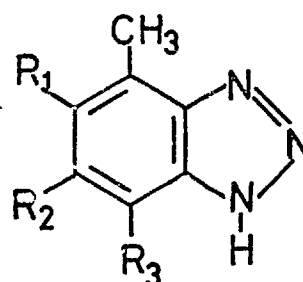
BENZOTRIAZOLES

Benzotriazole and its derivatives are commonly obtained by diazotization of *o*-phenylenediamine or an appropriately substituted derivative ^{71a}. Most of the benzotriazoles synthesized in this work (Table I) were already known and in general the literature procedures were followed for their synthesis. In the following pages the synthetic routes are shown schematically. The starting materials in each case were easily available and for each reaction a brief description of the conditions used is mentioned.

TABLE I



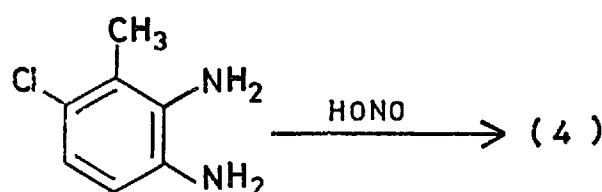
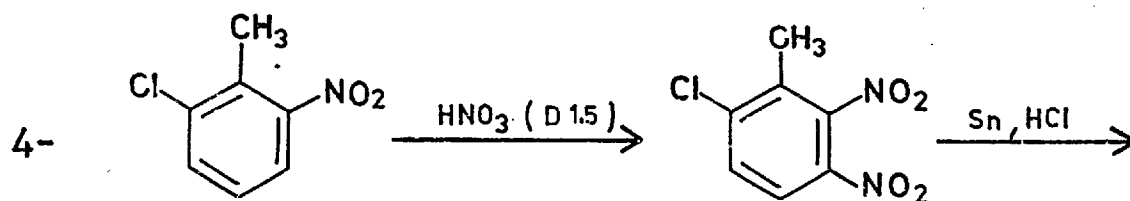
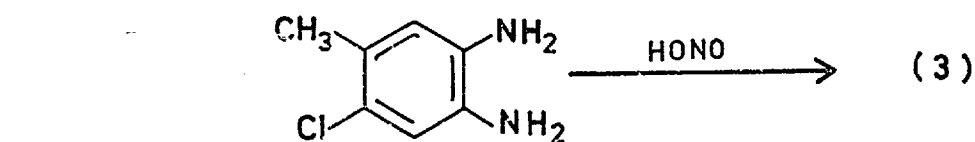
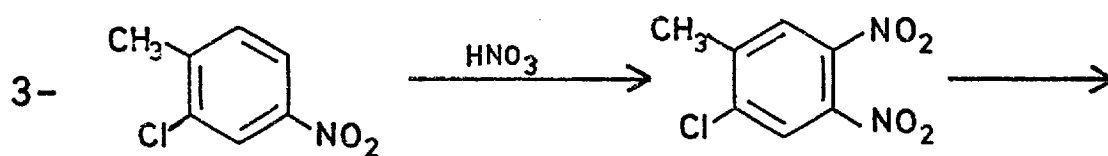
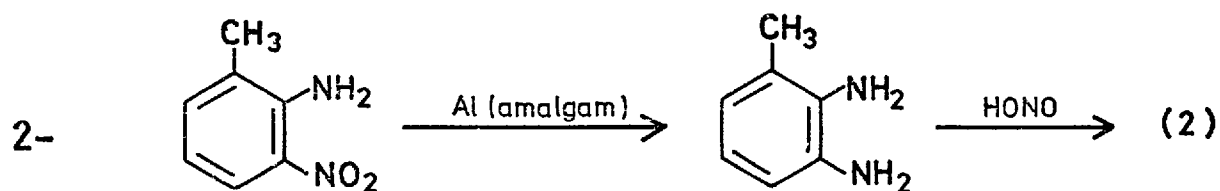
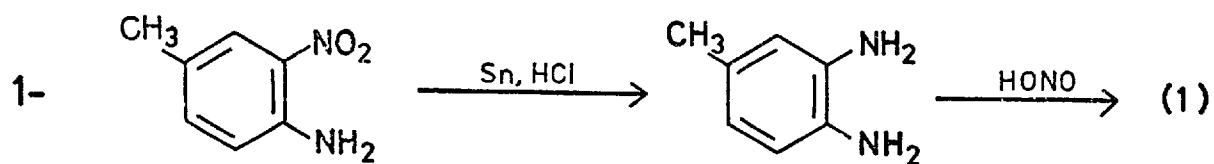
(a)

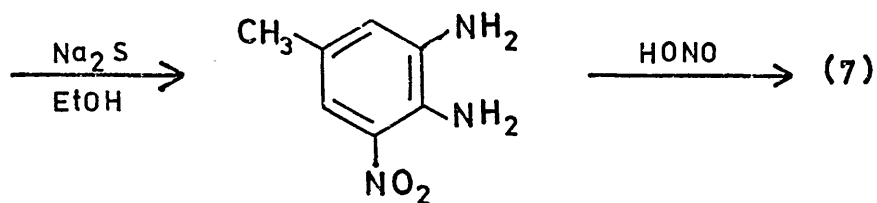
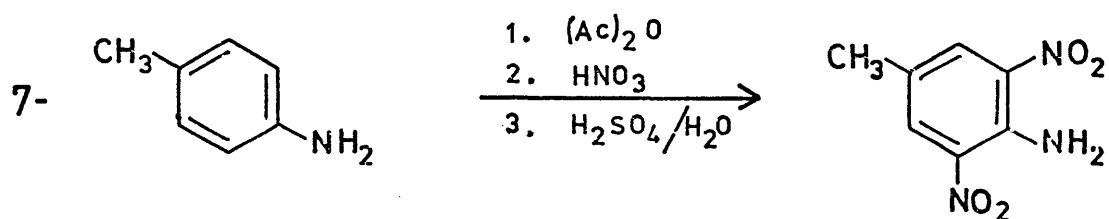
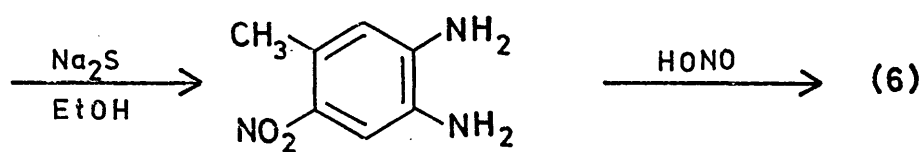
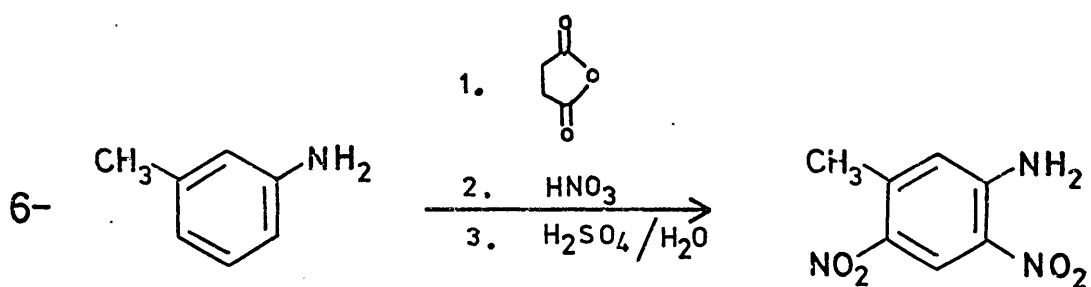
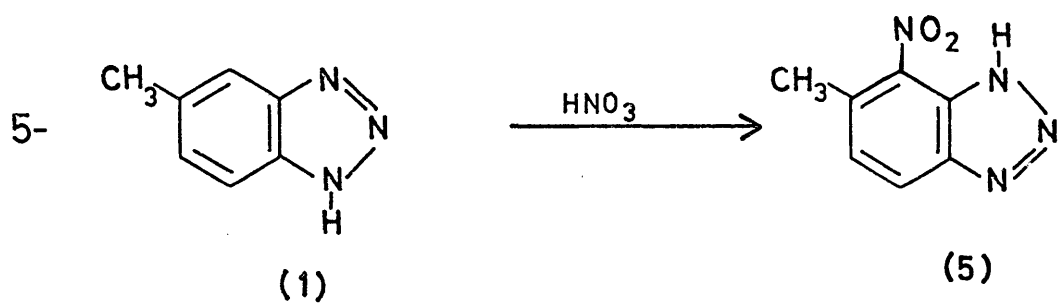


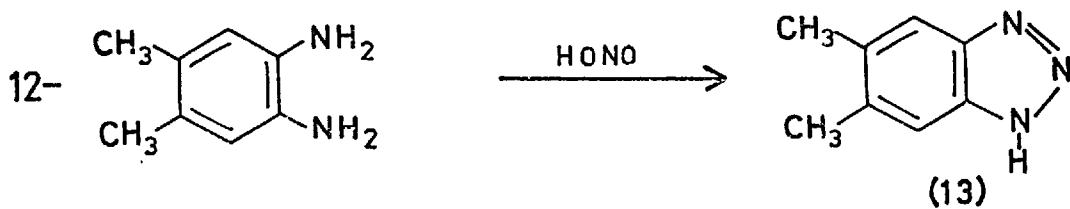
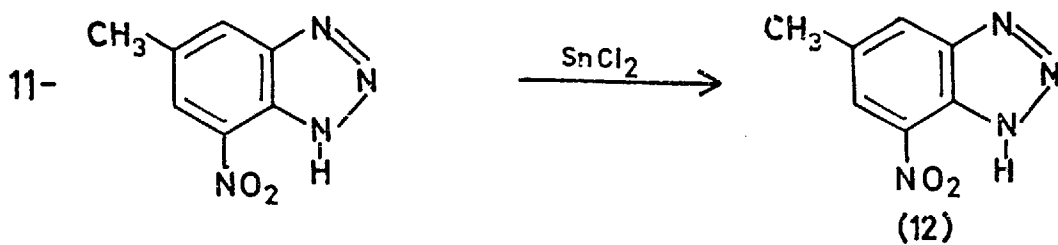
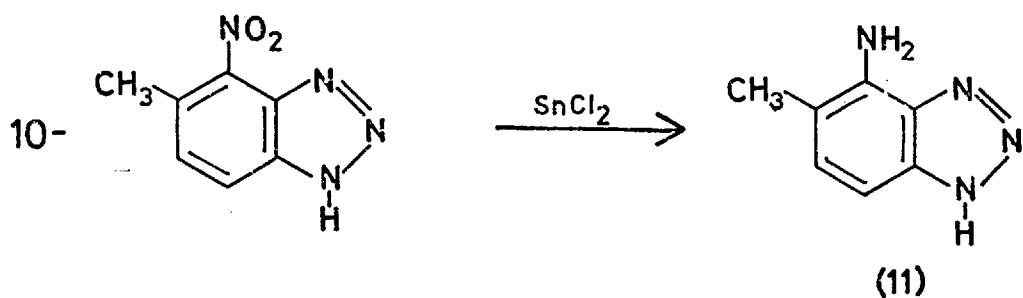
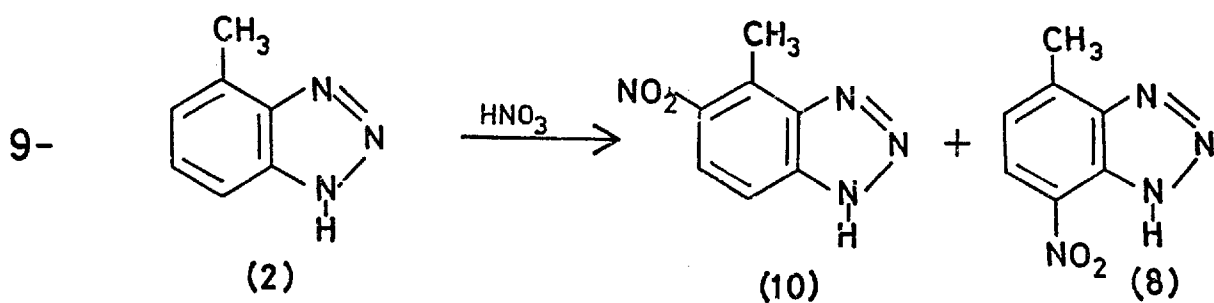
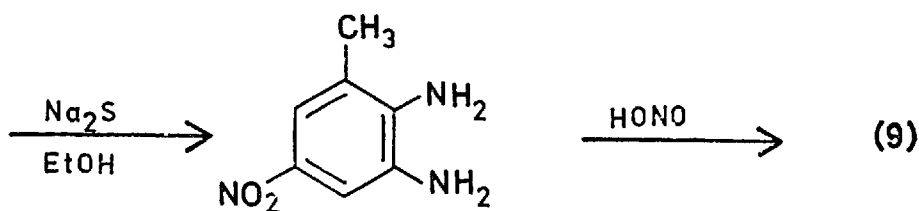
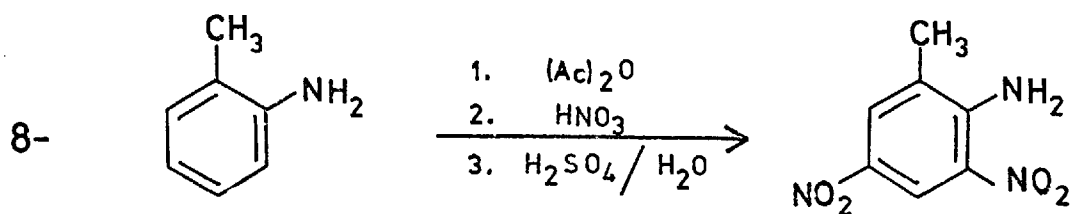
(b)

compound number	reaction route	structure	R ₁	R ₂	R ₃	ref.
(1)	1	a	H	H	H	72
(2)	2	b	H	H	H	73
(3)	3	a	H	Cl	H	74
(4)	4	b	Cl	H	H	74
(5)	5	a	NO ₂ [*]	H	H	75
(6)	6	a	H	NO ₂	H	
(7)	7	a	H	H	NO ₂	76
(8)	9	b	H	H	NO ₂	
(9)	8	b	H	NO ₂	H	77
(10)	9	b	NO ₂	H	H	
(11)	10	a	NH ₂	H	H	
(12)	11	a	H	H	NH ₂	76
(13)	12	a	H	CH ₃	H	78

* The preferred tautomer of this compound is the 6-methyl-7-nitrobenzotriazole (see page 112).







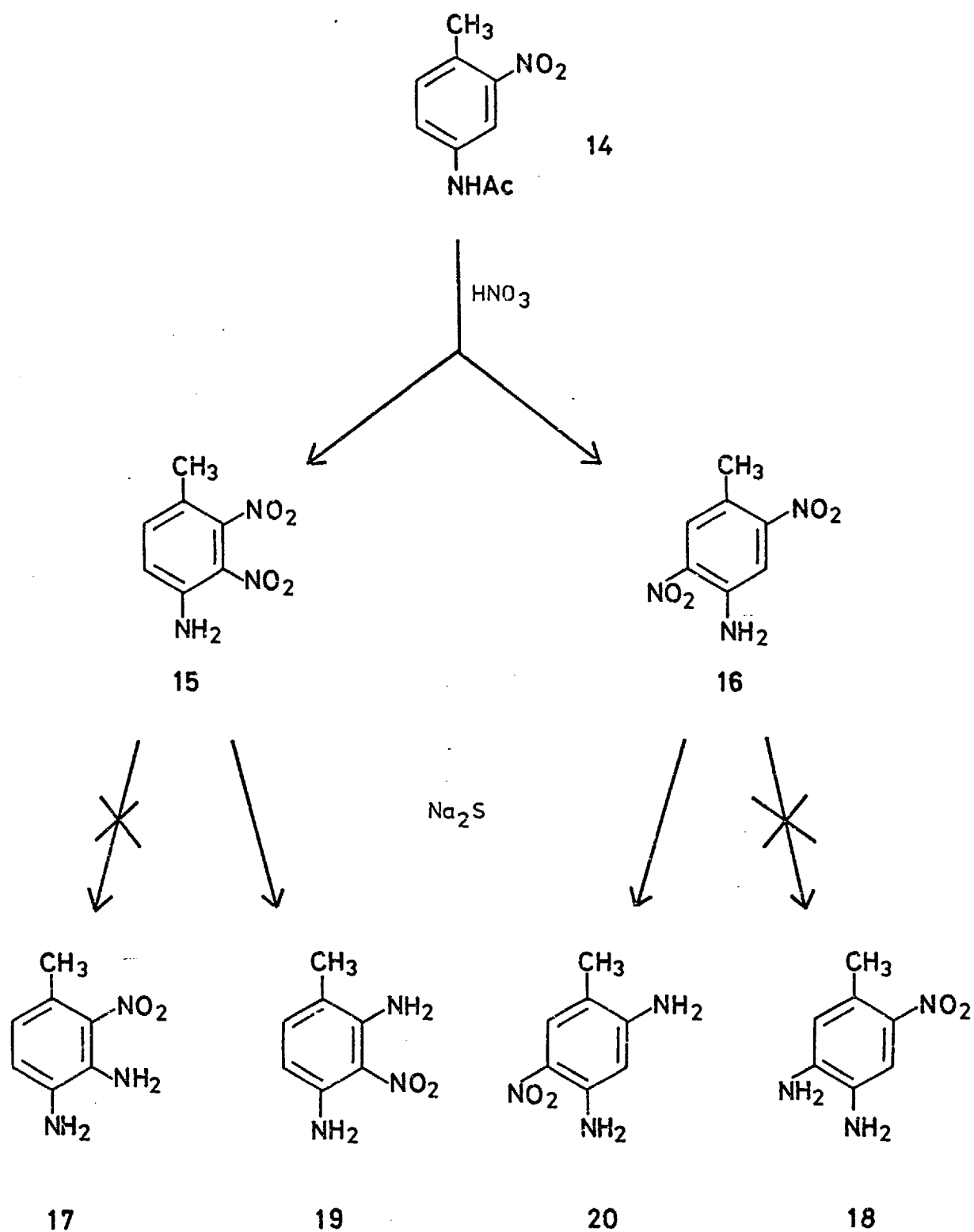
With the exception of (5), (8 and 10), (11) and (12) obtained by routes 5, 9, 10 and 11 respectively, the rest of benzotriazoles were synthesized from the corresponding *o*-phenylenediamines.

Attempts had been made to synthesize the compound (5) from the appropriately substituted phenylenediamine. Nitration of 2-nitro-N-acetyl-*p*-toluidine (14) followed by hydrolysis results in the formation of two isomeric dinitrotoluidines (15) and (16) ^{79,80}. However the reduction of these two products with sodium sulfide failed to produce the ortho-phenylenediamines (17 and 18) but instead gave the diamino products (19 and 20) respectively, (Scheme I).

The sodium sulfide reduction of dinitrotoluidene was quite successful in some cases ⁷⁶ (routes 6, 7 and 8). The mechanism by which this reduction occurs is not clear. However the above results suggest that the reduction is specific and dependent on the position of the nitro group with respect to the amino group. In the two dinitrotoluidines (15 and 16) the nitro group reduced was meta to the amino group. In the other cases, however, no nitro-group was present in the meta positions and therefore the nitro ortho to the amino-group was reduced (routes 6, 7 and 8). As a result it may be possible to generalize the ease of reduction in the following manner,

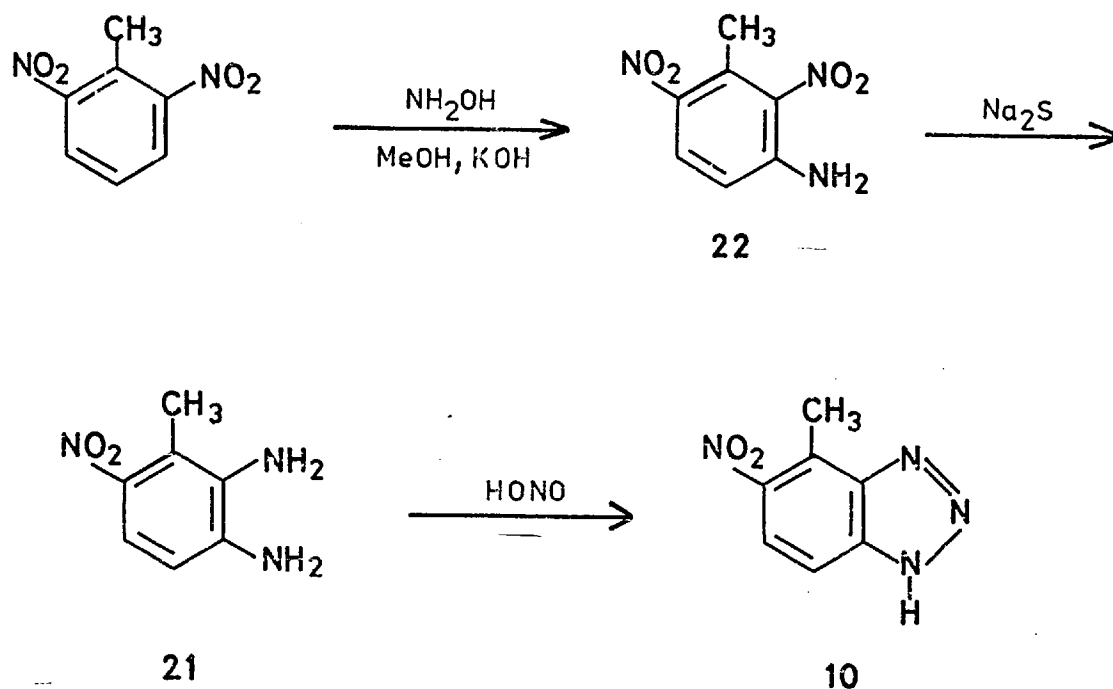
meta-nitro > ortho-nitro > para-nitro ,

where the meta-, ortho- and para- refer to the position of the nitro- with respect to the amino- group.



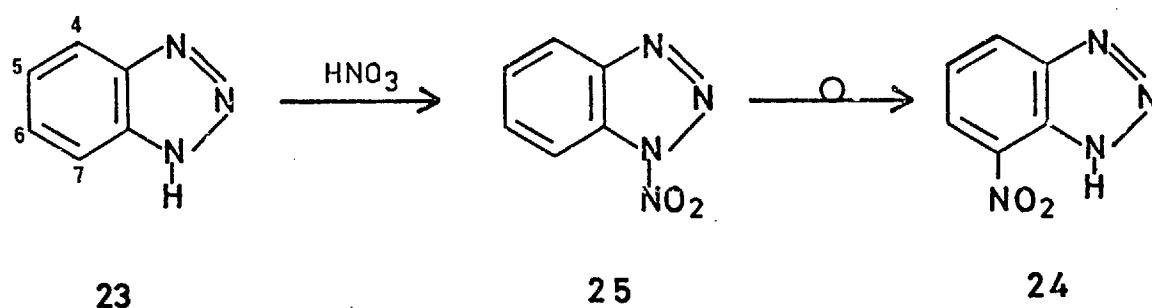
(SCHEME I)

In an attempt to synthesize the benzotriazole(10) from the corresponding diamine (21), Meisenheimer's⁸¹ procedure was followed to synthesize the dinitro-m-toluidine (22) which was expected to produce the diamine(21) under sodium sulfide reduction. However, an extremely low yield in the synthesis of (22) made it necessary to abandon this procedure (Scheme II).

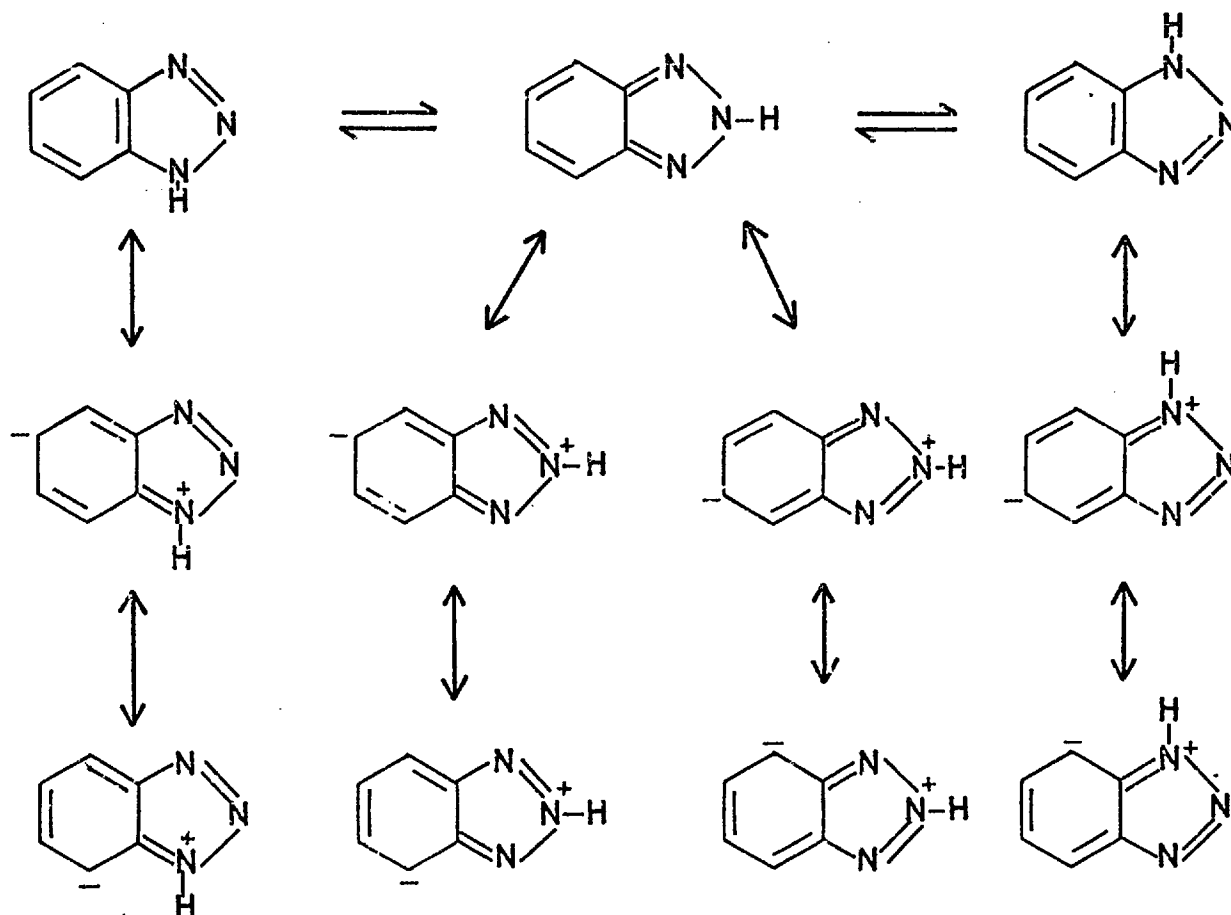


(SCHEME II)

Failures to synthesize the nitrobenzotriazoles (5) and (10) from the corresponding o-phenylenediamines prompted the investigation of other synthetic routes for these compounds. Nitration of benzotriazole (23) has been shown to result in the formation of 4(7)-nitro-derivatives (24) predominantly⁸². The reason for the predominance of this compound may be the production of an N-nitro derivative (25) followed by rearrangement of the nitro group to the ortho-position.



It may also be that, since the triazolo-ring is an electron rich center, positions 4 and 7 of benzotriazole are more susceptible to nitration than positions 5 and 6. The resonance effect does not seem to be very important in this nitration, since if one considers the canonical forms contributing to the three tautomeric structures, one finds all four positions in the benzene ring to be equally activated. (Scheme III).



(SCHEME III)

It seems, therefore, that the important factors influencing nitration are the production of the N-nitro intermediate and the inductive effect of the triazolo-ring.

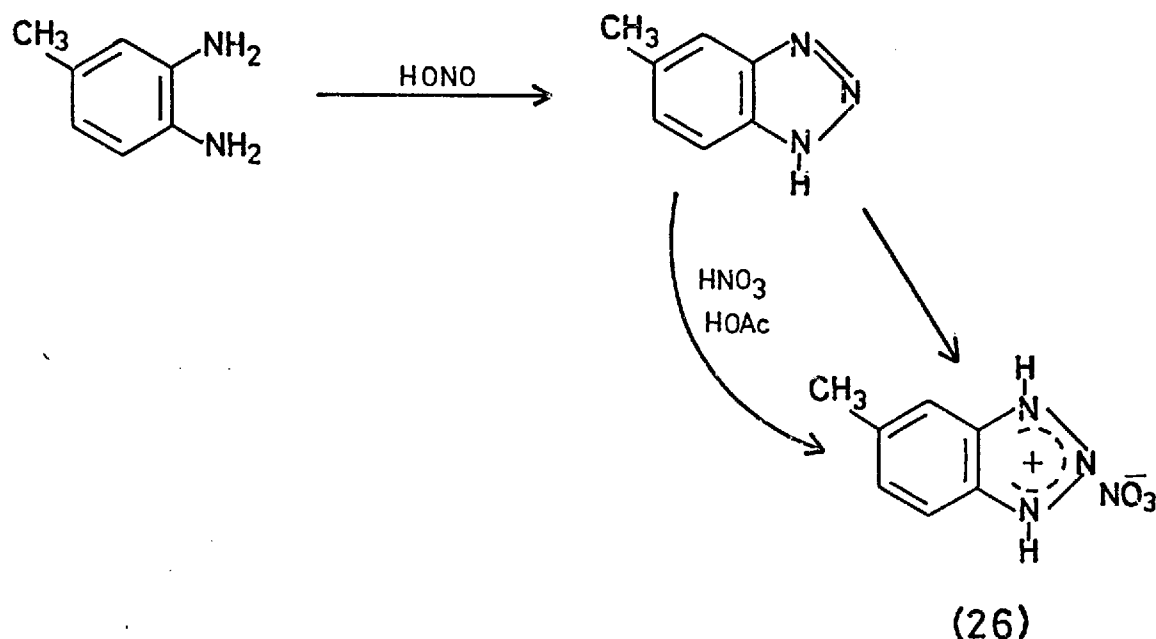
Nitration of 5-methylbenzotriazole resulted in the formation of 4-nitro-5-methylbenzotriazole (5) (see footnote to table I, and page 112) almost quantitatively (route 5). The exclusive production of this compound suggests that the nitration is controlled by the methyl-group. The position four, being influenced by both the methyl group and the triazolo-ring is, therefore, the only position nitrated.

The influence of the methyl-group is better observed in the nitration of the 4-methylbenzotriazole (2) (route 9). Two main products are obtained in this reaction, the 7-nitro-4-methyl- and the 5-nitro-4-methylbenzotriazoles (8) and (10) respectively. The production of the 7-nitro-derivative (8), as expected, is the result of the ortho-para directive effect of the methyl group and the inductive effect of the triazolo-ring. However, the 5-nitro-derivative (10) is solely the result of the former effect in the electrophilic aromatic substitution reaction.

For obvious reasons the amino-benzotriazoles were not synthesized by diazotization of the corresponding amino-*o*-phenylenediamine. These compounds (11 and 12) were produced by reducing the corresponding nitro-derivatives with stannouschloride ⁷⁶ (routes 10 and 11).

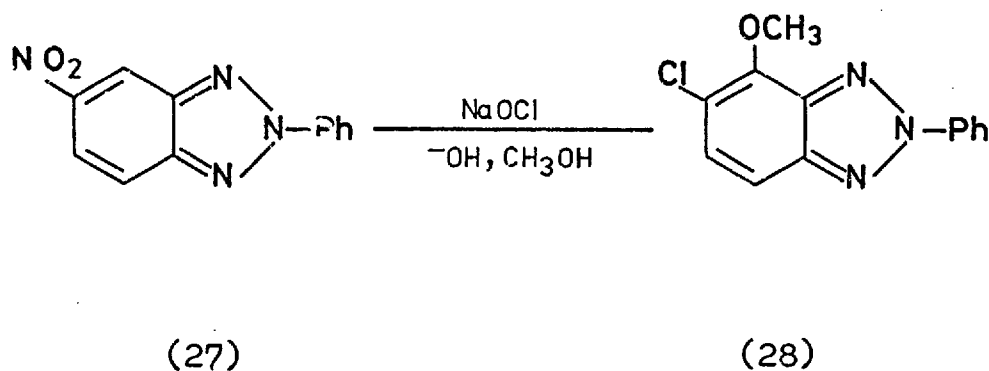
The synthesis of 5-methylbenzotriazole was carried out in the usual manner, i.e. by diazotization

of the corresponding *o*-phenylenediamine with nitrous acid. In the presence of excess nitrous acid, however, the product obtained was not the expected 5-methylbenzotriazole (1). The infrared spectrum of this compound showed a broad absorption around 1900 cm^{-1} which suggested the presence of a salt (NH^+ stretching vibration $2200\text{--}1800\text{ cm}^{-1}$). The proton magnetic resonance spectrum showed, besides the normal peaks for the 5-methylbenzotriazole, two exchangeable protons. The mass spectra of 5-methylbenzotriazole and this product were identical with the exception of a peak at m/e 46 for the latter. Failure to purify this salt (the impurity was the 5-methylbenzotriazole) made it impossible to find out the exact molecular formula by microanalysis; however the data strongly suggest the presence of a nitrate anion. The production of the same salt by treatment of 5-methylbenzotriazole (1) with an equivalent amount of nitric acid in acetic acid suggested that in the original reaction the benzotriazole (1) is formed followed by the production of the salt (26).

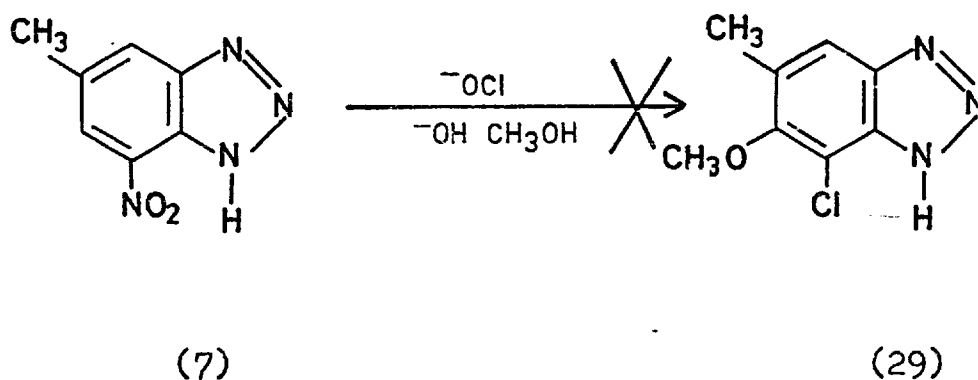


Treatment of this salt (26) with concentrated sulfuric acid resulted in the formation of 4-nitro-5-methylbenzotriazole (5) in very high yield.

The above results suggest that benzotriazole is slightly basic. In fact the production of benzotriazole-hydrochloride has been reported ⁸³. The basicity of benzotriazole is largely dependent on the nature of the substituent in the benzene ring. The presence of an alkyl group probably increases the basicity of the benzotriazole and hence enhances the production of the nitrate (26). The presence of an electron withdrawing group like a nitro- or chloro- group in the ring causes the hydrogen on the nitrogen to become slightly acidic. It has been shown that in a reaction of 5-nitro-2-phenylbenzotriazole (27) with sodiumhypochlorite in alkaline methanol the methoxy-chloro-derivative (28) is produced.⁸⁴ The mechanism of this reaction and reactions similar to it will be discussed later in this section (pages 89-92).



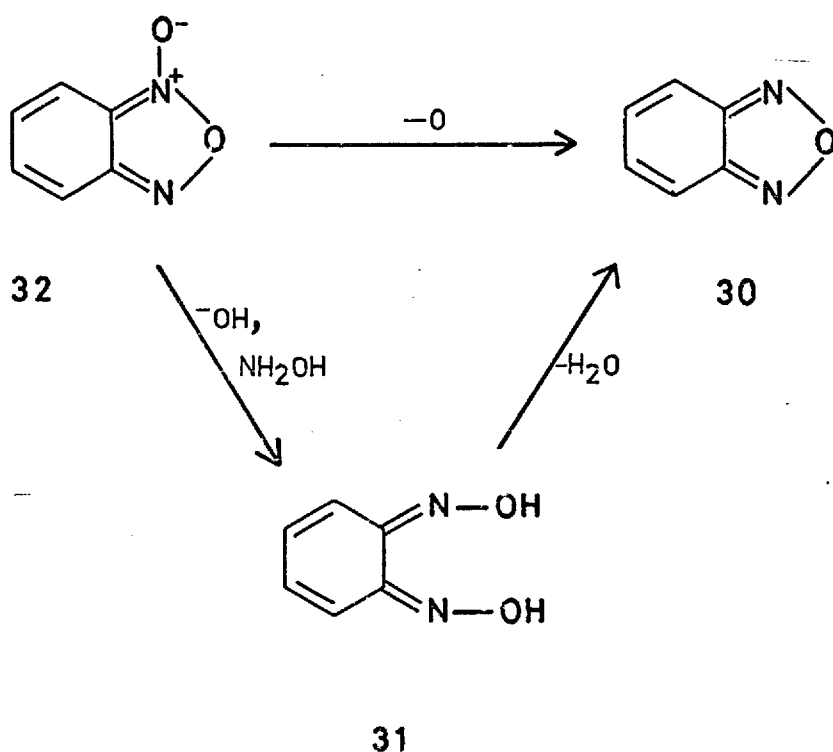
When this reaction was carried out on 5-methyl-7-nitrobenzotriazole (7), however, the chloro-methoxy compound (29) was not produced. Neutralization of the reaction mixture with hydrochloric acid afforded quantitative recovery of the starting material.



The failure of this reaction may be due to the acidity of the benzotriazole (7). This compound in the presence of the hydroxide may form the corresponding anion making the molecule quite electron rich and as a result prevent the approach of the anion CH_3O^- to the reaction site.

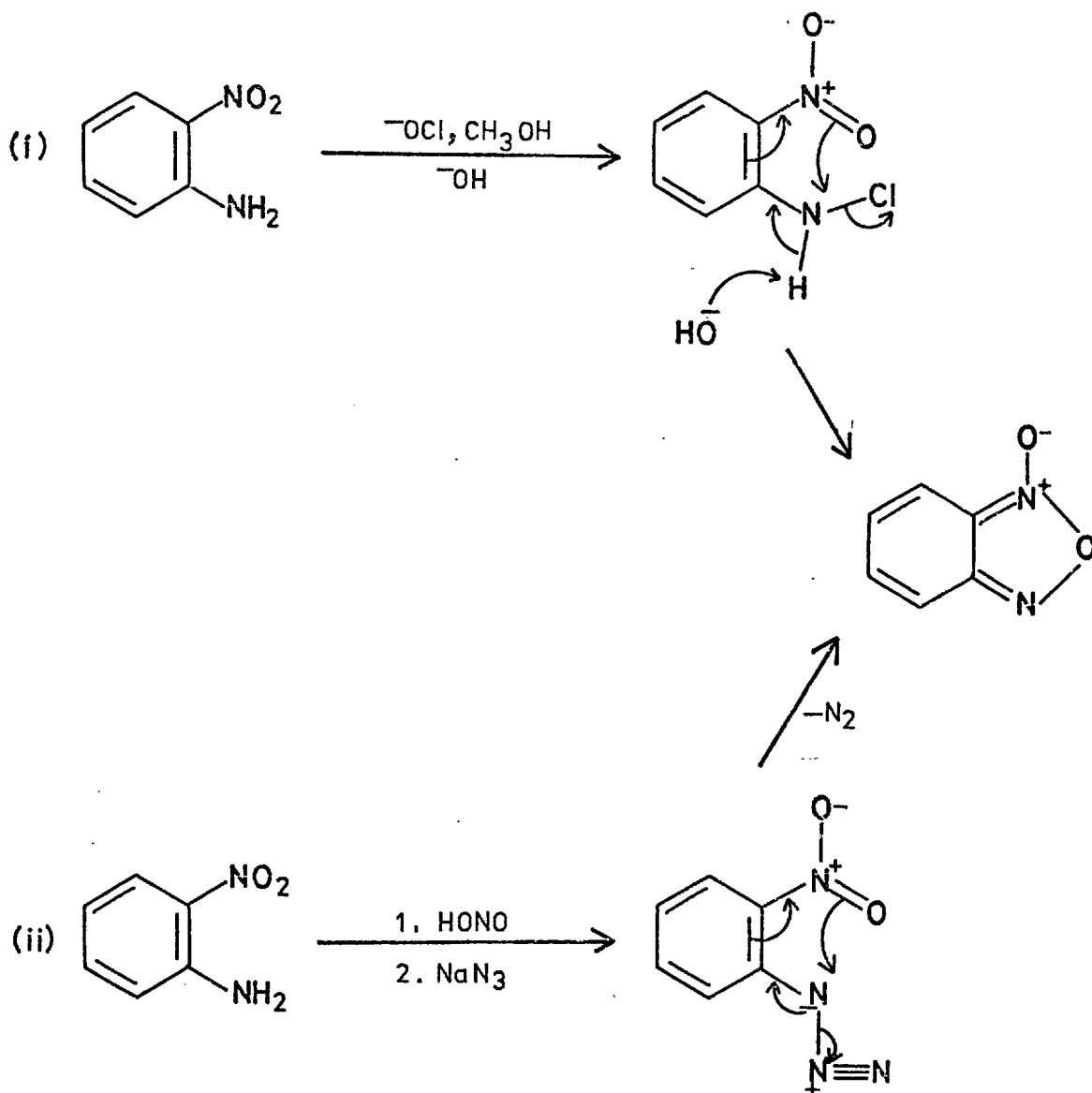
BENZOFURAZANS AND BENZOFUROXANS

The most common method for synthesis of benzofurazan (30) is by dehydration of ortho-quinonedioxime (31) ^{85,86} or by deoxygenation of the corresponding N-oxide (32) ⁸⁷. Most of the benzofuroxans are easily reduced to the corresponding dioximes in alkaline solutions of hydroxylamine. As a result for the synthesis of the



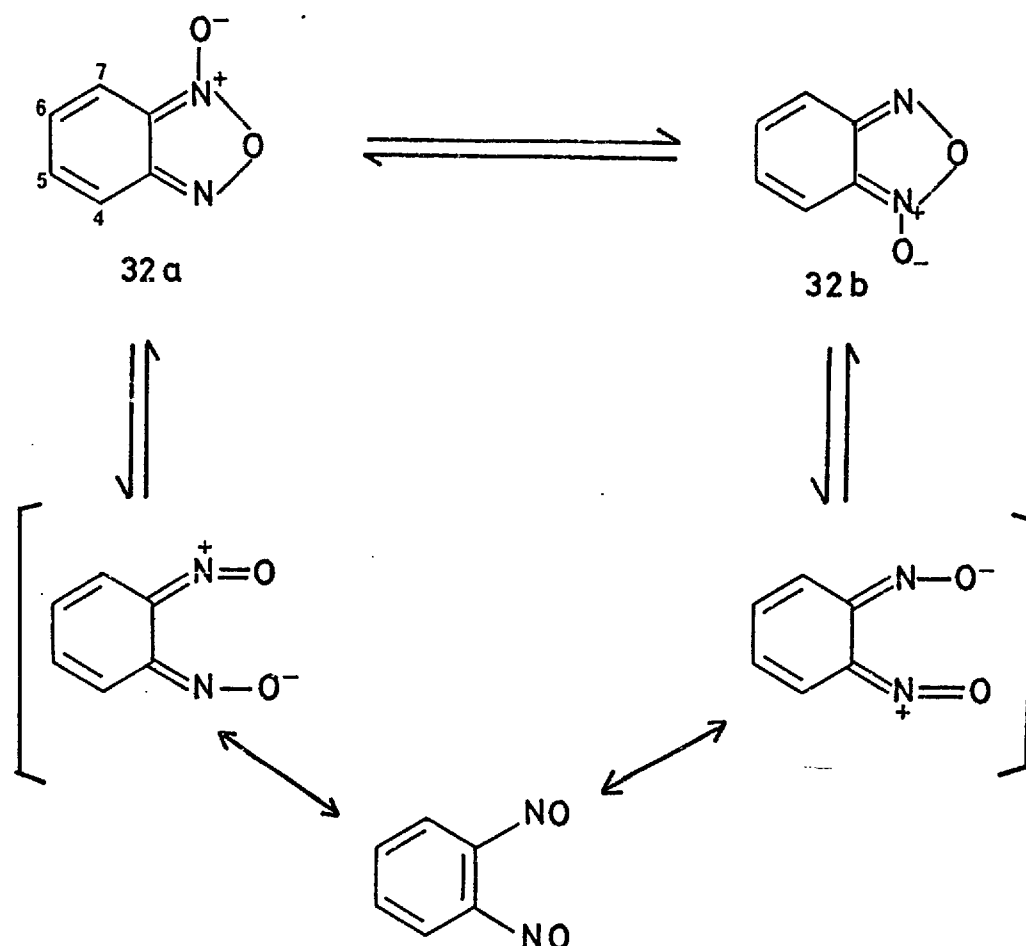
benzofurazans it was found most economical to prepare the corresponding N-oxides.

The two most common methods for the synthesis of these compounds are (i) alkaline hypochlorite oxidation of *o*-nitroanilines ⁸⁸ and (ii) pyrolysis of *o*-nitroaromatic azides.



Possible mechanisms for these synthetic routes are shown above.

The structure of benzofuroxan has been reviewed by Boyer⁸⁹ and the generally accepted forms (32 a and b, Scheme IV) for these compounds have been suggested by Green and Rowe⁸⁸. The appropriate intermediates for the interconversion of these two forms were also proposed by Boyer et al.⁹⁰.

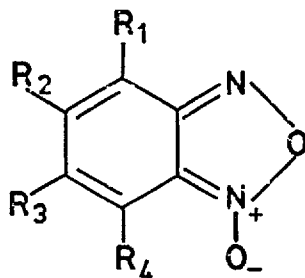


(SCHEME IV)

This 1,3-oxygen shift has been suggested ⁹¹ to be quite rapid when no 4 or 7-substituents are present. In the presence of such substituents this equilibration becomes slower in favour of the less sterically hindered isomer, i.e. the 4-isomer. However, since this equilibrium appears to be quite rapid at room temperatures or above (even for the 4 or 7-isomers), unless otherwise stated, the benzofuroxans in this thesis can take either of the forms (32 a or b).

In table II the benzofuroxans prepared are listed. In most cases the literature procedure was followed for their synthesis.

TABLE II



Compound number	Synthetic route	R ₁	R ₂	R ₃	R ₄	ref.
(32)	(i)	H	H	H	H	86
(33)	(i)	H	CH ₃	H	H	85
(34)	(i)	H	Cl	H	H	86
(35)	(ii)	CH ₃	H	H	H	85
(36)	(ii)	CH ₃	H	NO ₂	H	92
(37)	(ii)	H	CH ₃	NO ₂	H	93
(38)	(ii)	NO ₂	H	CH ₃	H	92
(39)	(ii)	H	H	NO ₂	H	94,95,96
(40)	(ii)	H	OCH ₃	H	H	95
(41)	(ii)	H	CH ₃	Cl	H	
(42)	a	OCH ₃	H	CH ₃	H	
(43)	a	OCH ₃	Cl	CH ₃	H	
(44)	a	Cl	OCH ₃	CH ₃	H	
(45)	b	NO ₂	H	H	CH ₃	92

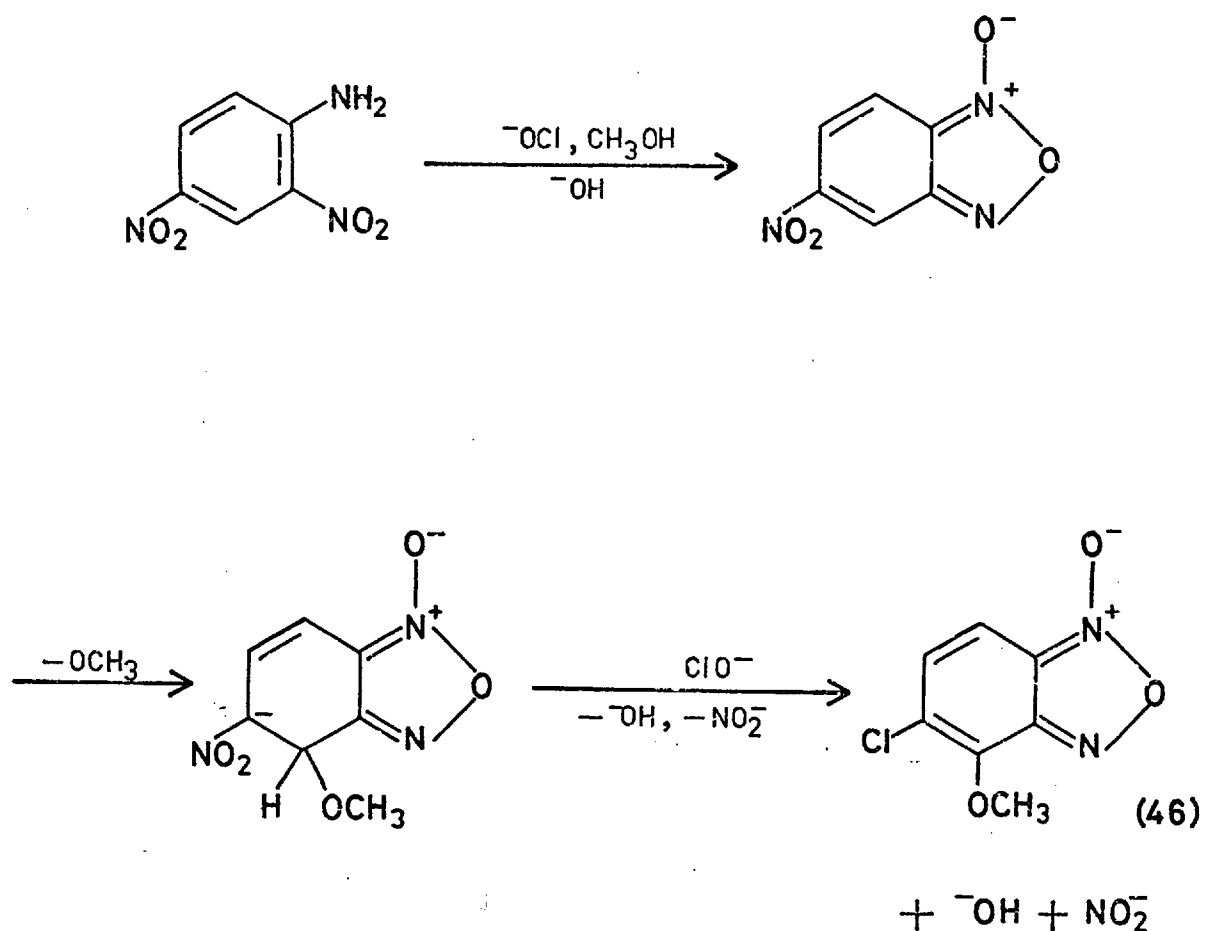
a - see pages 89-92

b - see pages 93-94

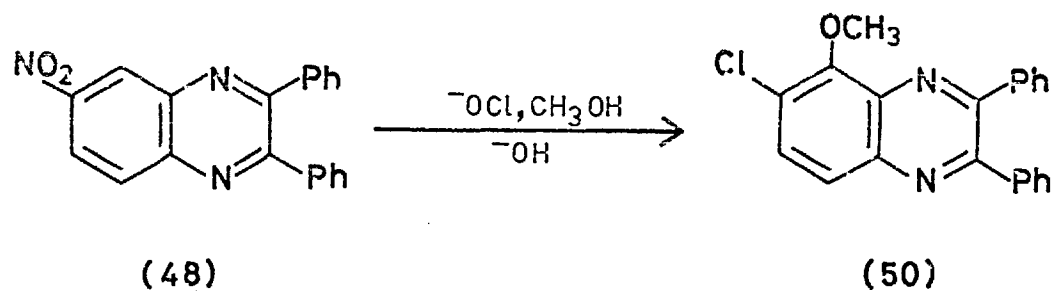
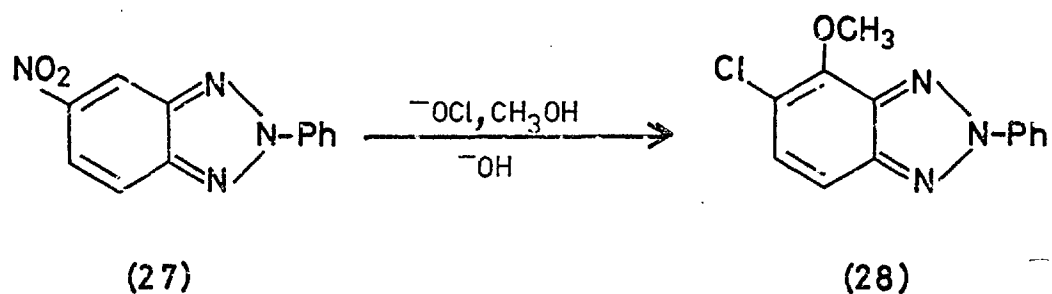
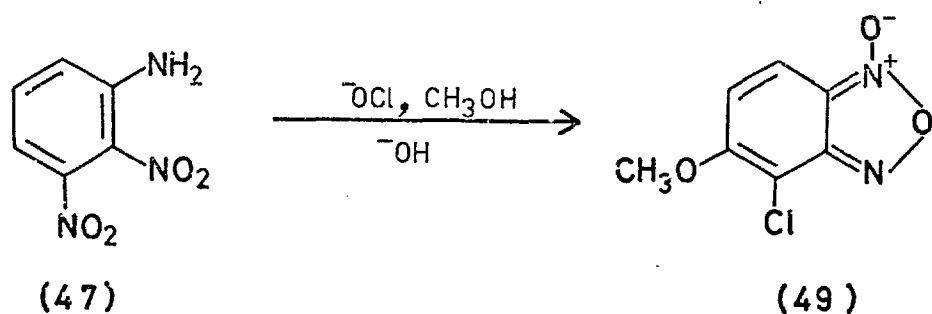
Compounds (32) to (34) were synthesized by the alkaline hypochlorite oxidation of the appropriately substituted o-nitroanilines, route (i). Compounds (35) to (41) were obtained by pyrolysing the corresponding ortho-nitro-aromatic azide, route (ii). Attempts were made to produce the benzofuroxans (35), (40) and (41) by route (i); however, these reactions resulted in very low yield of the desired product and large amount of tar. The same observations were made by Dyal and Pausacker⁹⁷ when they tried the above reactions.

The first attempt to synthesize nitro-substituted benzofuroxans was the treatment of the appropriately substituted o-nitroanilines with alkaline hypochlorite. However the product of these reactions was a chloromethoxy-substituted benzofuroxan rather than the expected nitro-derivative.

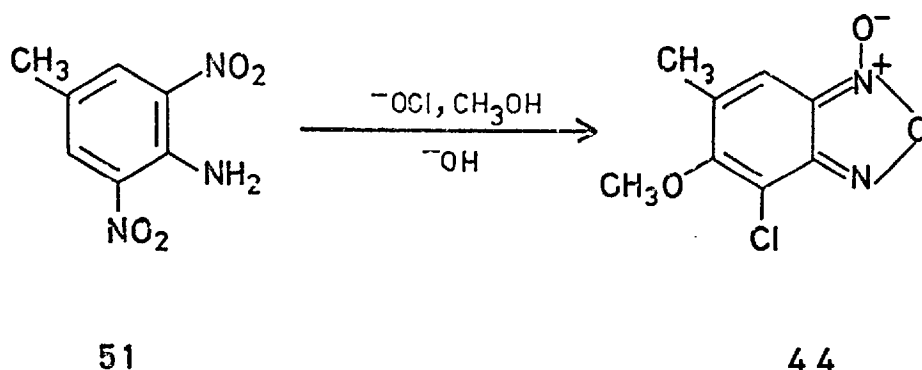
This curious reaction was first reported by Green and Rowe⁸⁸ when they treated 2, 4-dinitroaniline in alkaline methanol with sodium hypochlorite solution. Mallory and Varimbi⁹⁸ repeated the same reaction and established the true structure of the product to be 5-chloro-4-methoxy-benzofuroxan (46) and proposed the following mechanism for the reaction.



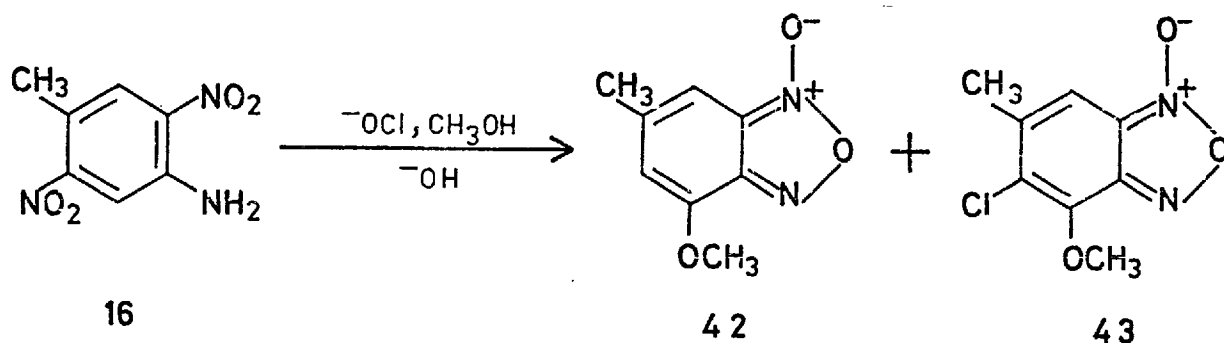
In support of their mechanism 2, 3-dinitroaniline (47) ⁹⁸, 2-phenyl-5-nitrobenzotriazole (27) ⁸⁴ (see page 83) and the diphenylquinoxaline (48) ⁸⁴ were treated in the same fashion and the expected products (49), (28) and (50), respectively were obtained.



Analogous to the above reaction, treatment of 2,6-dinitro-p-toluidine (51) with sodium hypochlorite solution in methanolic potassium hydroxide resulted in the formation of the chloro-methoxy-derivative (44) presumably by the same mechanism.

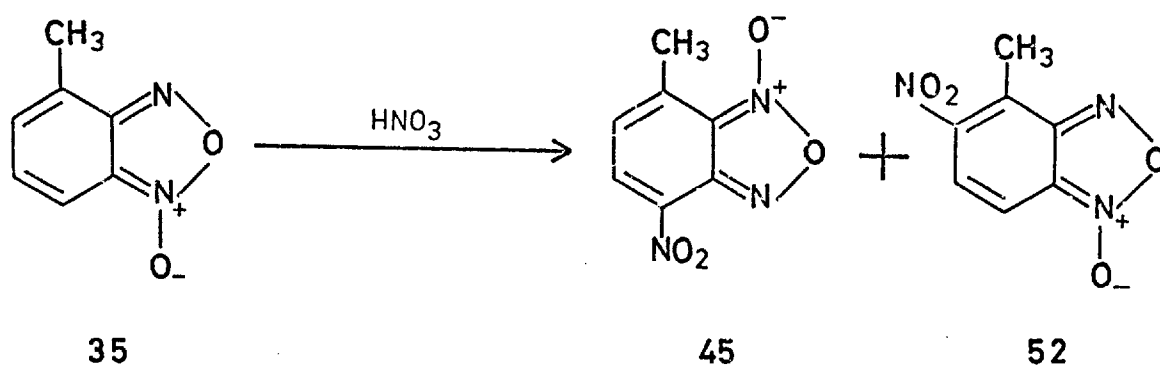


Treatment of 2,5-dinitro-p-toluidine (16) in the same manner, however, resulted in the formation of two products (42) and (43).

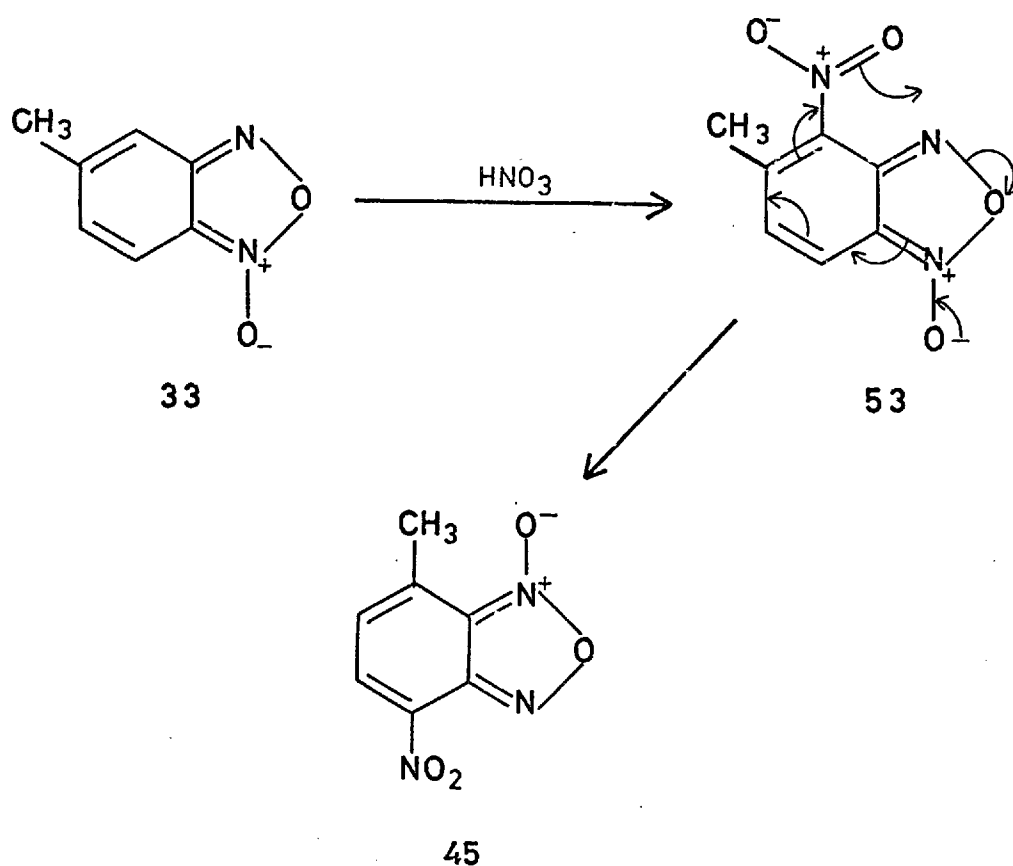


Further investigation in this reaction revealed that in the presence of a large excess of sodiumhypochlorite the latter compound (43) predominates.

Analogous to the benzotriazoles (pages 79-81), benzofuroxans undergo nitration reactions with the production of the 4(7) nitro-derivatives ^{95,96}. The nitration of 4-methylbenzofuroxan (35) resulted in the formation of two nitro-derivatives (45) and (52) with the former predominating.

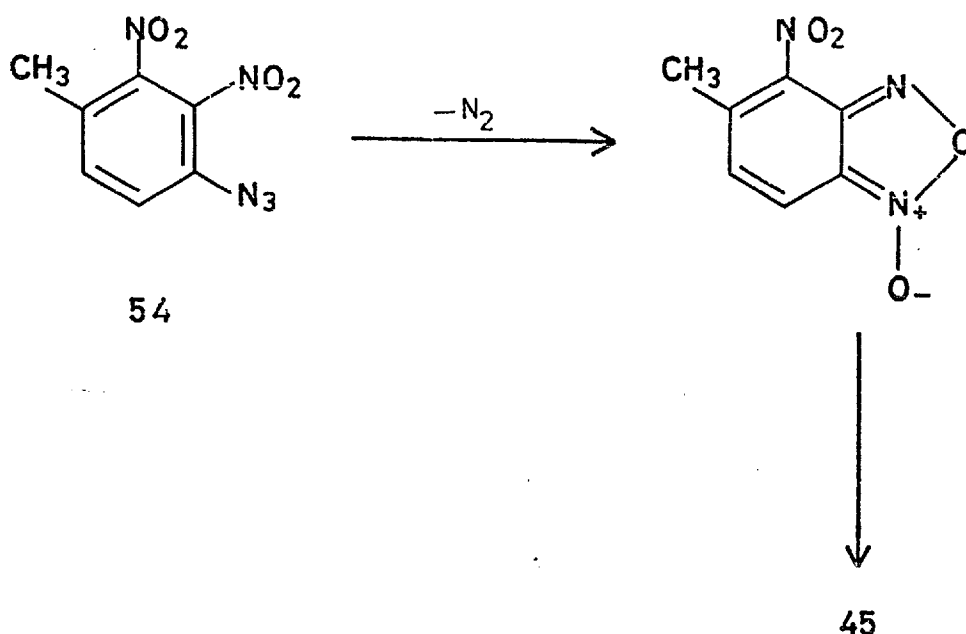


The compound (45) was also produced by nitration of 5-methylbenzofuroxan (33). This nitration originally results in only one product, the 4-nitro-5-methylbenzofuroxan (53)⁹². This product, however, undergoes a rearrangement to form the less sterically hindered isomer, i.e. the nitro-derivative (45). As a result the product of the above nitration was a mixture of the two nitro-derivatives (53) and (45).



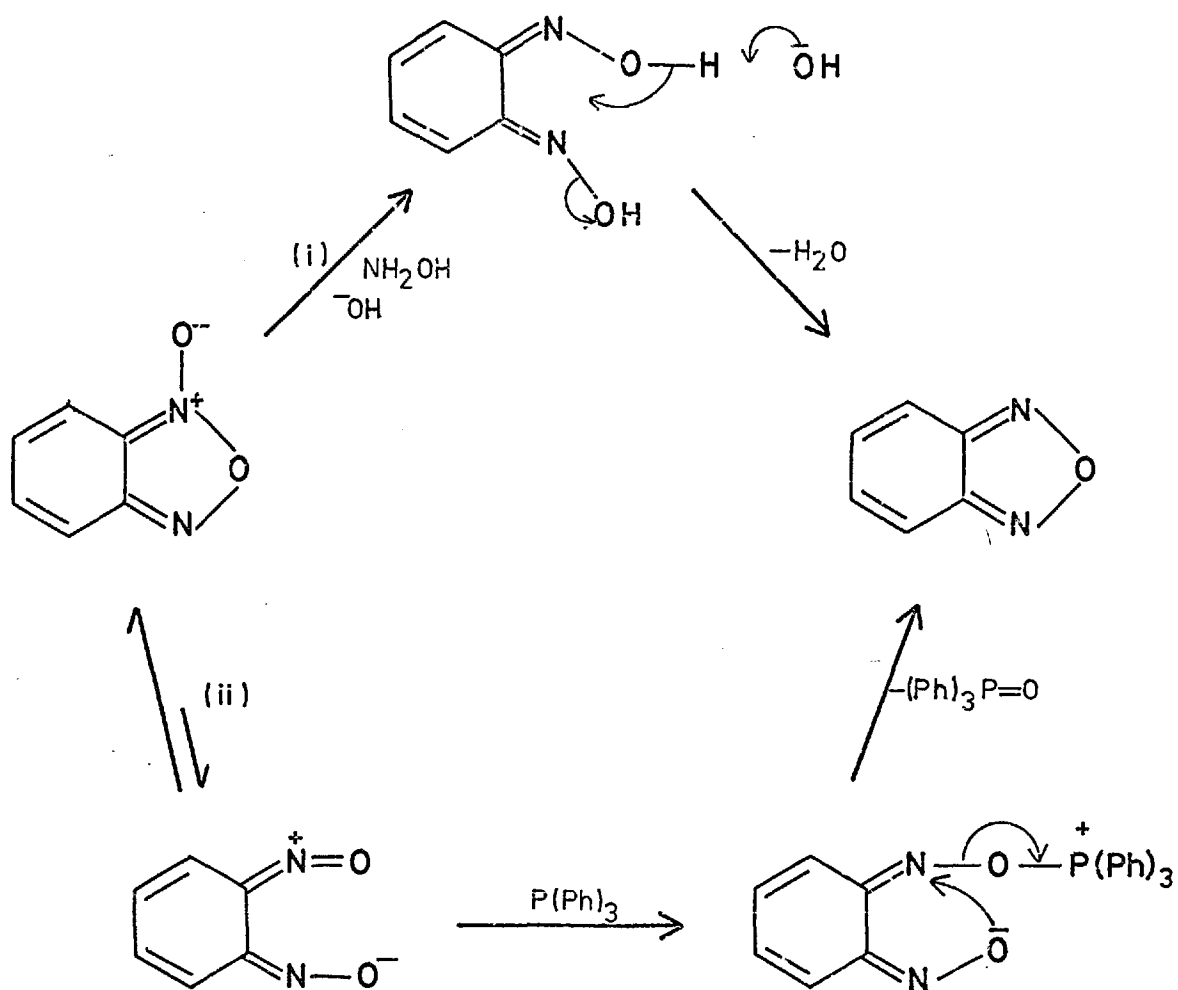
This type of rearrangement was first reported by Boulton and Katritzky⁹⁹ (The Boulton-Katritzky Rearrangement) and they suggested that refluxing the derivative (53) in acetic acid resulted in quantitative yield of the more stable isomer (45). Hence reflux of the above mixture of isomers afforded the isolation of the isomer (45) as the sole product of nitration.

The Boulton-Katritzky rearrangement⁹⁹ is also responsible for the formation of (45) in the pyrolysis of 2,3-dinitro-4-azide-toluene (54).

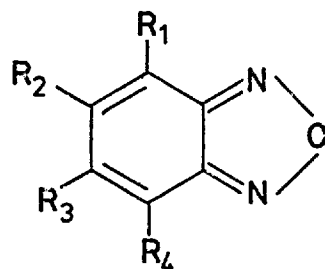


With the exception of nitrosubstituted derivatives most of the benzofurazans were prepared from the corresponding benzofuroxans. The two methods used were mentioned at the beginning of this section and

a possible mechanism for these are shown below.



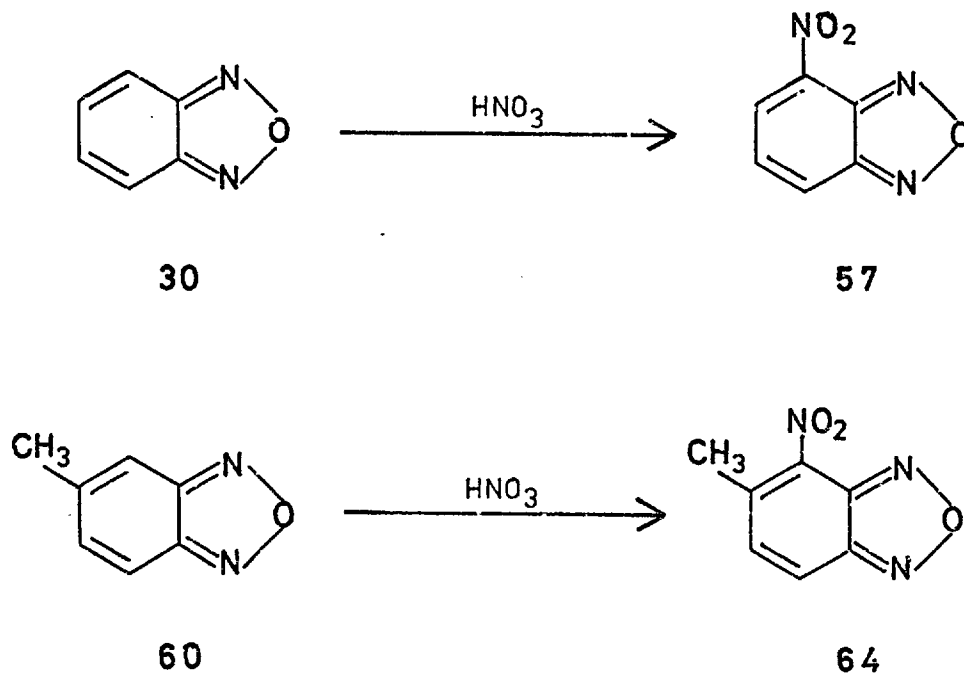
In table III the benzofurazans prepared are listed. Column 2 shows the route by which the highest yield was obtained.

TABLE III

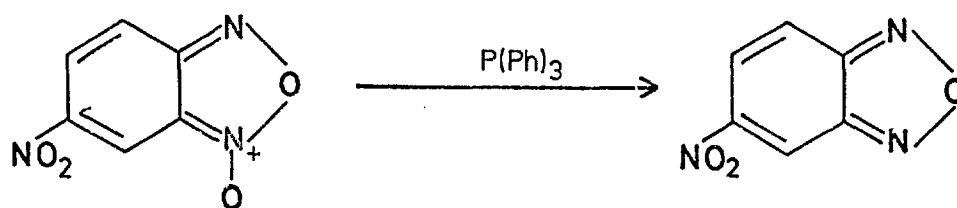
Compound number	Synthetic route	R ₁	R ₂	R ₃	R ₄	ref.
30	(i)	H	H	H	H	88
55	(ii)	Cl	H	H	H	86
56	(i)	H	OCH ₃	H	H	95
57	a	NO ₂	H	H	H	94
58	(ii)	H	NO ₂	H	H	103
59	(i)	CH ₃	H	H	H	85
60	(i)	H	CH ₃	H	H	85
61	(i)	H	CH ₃	Cl	H	
62	(i)	H	CH ₃	OCH ₃	Cl	
63	(i)	H	CH ₃	H	OCH ₃	
64	a	NO ₂	CH ₃	H	H	92

a - Nitration.

Analogous to benzotriazoles and benzofuroxans, the benzofurazans undergo specific nitration reactions ⁹⁴. As a result the nitro-derivatives (57) and (64) were synthesized by direct nitration of the corresponding benzofurazans (30) and (60), respectively.

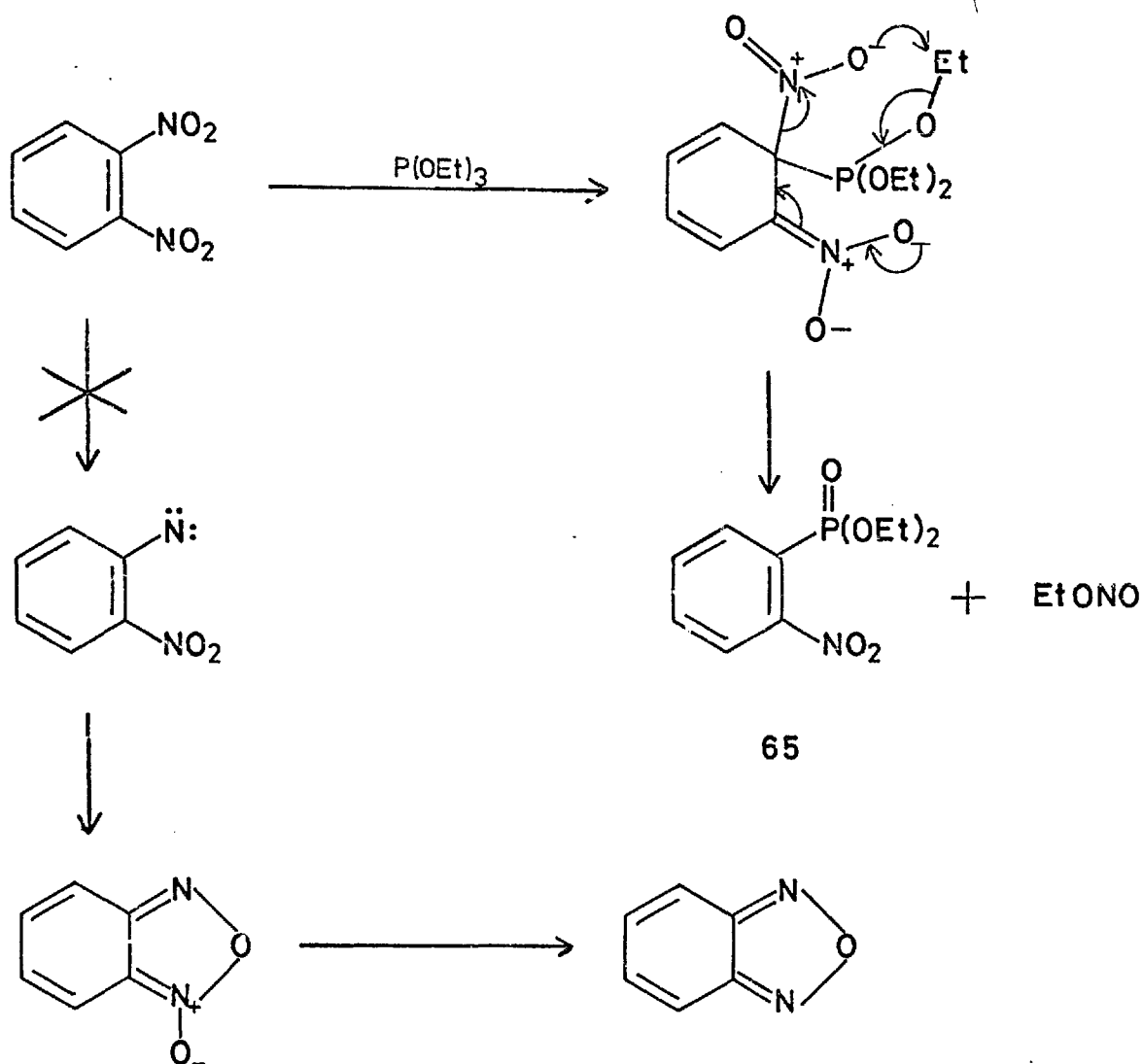


Attempts were made to prepare other nitro-derivatives by deoxygenation of the corresponding N-oxides with triphenylphosphine. The failure of these attempts was attributed to the fact that triethylphosphite and probably triphenylphosphine tend to react with nitro-aromatic compounds forming the corresponding nitrene. The only exception to these failures was the synthesis of 5-nitro-benzofurazan (58) by treatment of the corresponding N-oxide with an equivalent amount of triphenylphosphine.



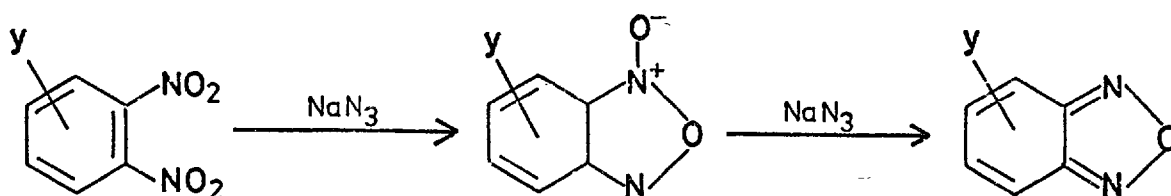
58

The production of nitrene in the reaction of nitroaromatic compounds and triethylphosphite prompted Cadogan et al.¹⁰⁰ to carry out this reaction on o-dinitrobenzene in the hope of obtaining the corresponding benzo-furazan. However the product obtained was (65) and

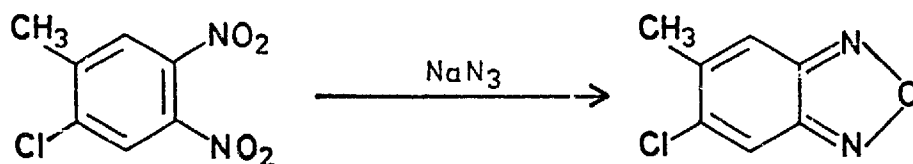


not the desired benzofurazan. In a similar reaction Boyer and Ellzey⁸⁷ used triphenylphosphine with negative results.

Recently Di-Nunno and Florio¹⁰¹ have developed a synthetic route for the synthesis of these compounds by refluxing one equivalent of substituted ortho-dinitrobenzenes with 2 equivalents of sodiumazide in dimethylsulfoxide or ethyleneglycol.



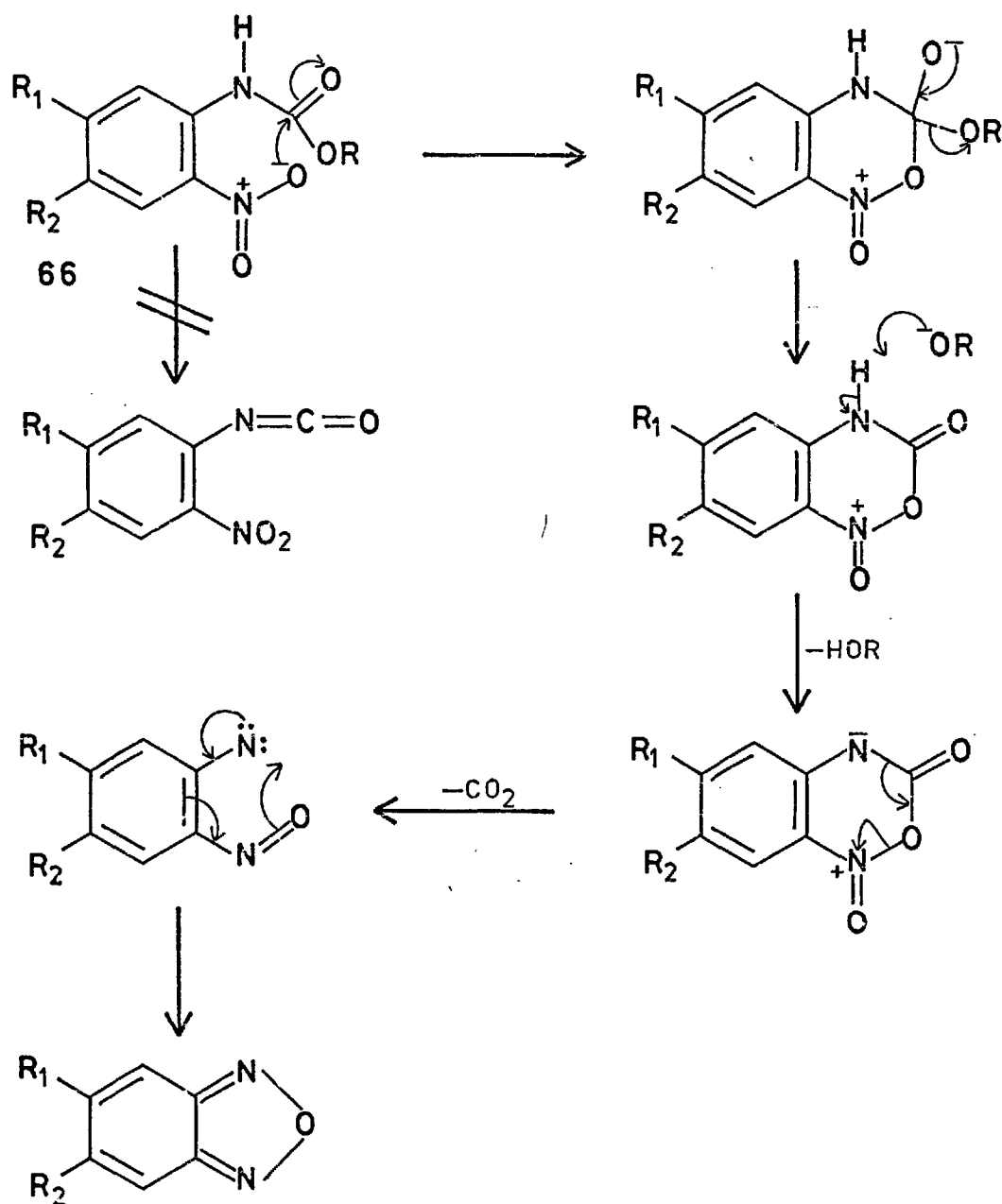
They report successful results when $y = \text{Br}$, Cl , I or OCH_3 , and failure when $y = \text{NO}_2$. The mechanism by which the benzofuroxan is deoxygenated by sodiumazide is not clear. The compound (61) was synthesized by this method in very low yield. However, attempts to prepare the 4-methyl-5-chlorofurazan from the corresponding dinitro-derivative failed.



61

In a procedure described by Prokipcak, et al.^{102,103} some benzofurazans were prepared by pyrolysis of ortho-nitro carbamates (66). Originally it was thought that

the carbamate decomposes to the corresponding isocyanate followed by loss of carbon dioxide to form the desired benzofurazans. However failure to obtain these compounds by pyrolyses of the corresponding isocyanates suggested a more complex mechanism (Scheme V). In general the yields in this reaction were very low, the best result being achieved when $R = \text{CH}_3$.

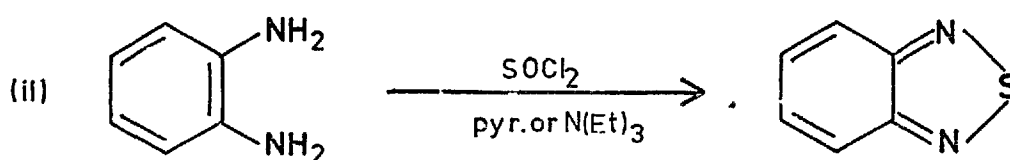
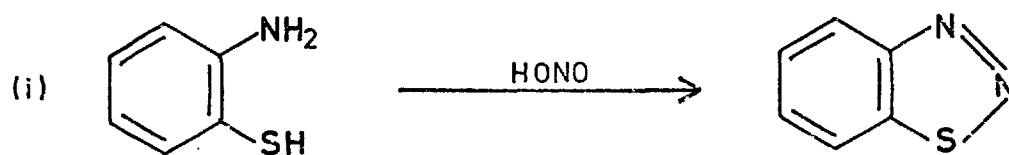


(SCHEME V)

By this method the benzofurans (30), (55), (56), (58), (59) and (60) were prepared^{102,103}. The compound (58) was synthesized from the carbamate (66, $R_1 = \text{NO}_2$, $R_2 = \text{H}$). However, all attempts to prepare the same compound from the carbamate 66 ($R_1 = \text{H}$, $R_2 = \text{NO}_2$) failed.

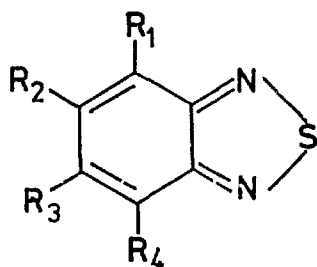
BENZOTHIADIAZOLES

The third group of compounds synthesized for the purpose of mass spectral studies consists of the benzothiadiazoles. The 1,2,3- and 2,1,3- benzothiadiazoles are commonly synthesized from the corresponding ortho-aminothiophenols¹⁰⁴ and ortho-phenylenediamine¹⁰⁵ respectively.



In tables (IV) and (V) the 2,1,3- and the 1,2,3-benzothiadiazoles prepared are listed. Most of these compounds were synthesized by literature procedures and the synthetic routes of some of these are shown schematically in the following pages.

TABLE IV

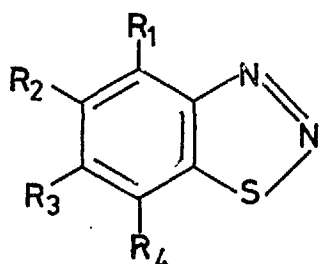


Compound number	Synthetic route	R ₁	R ₂	R ₃	R ₄	ref.
67	(ii)	H	H	H	H	105
68	(ii)	H	CH ₃	H	H	105,106
69	(ii)	H	CH ₃	H	NO ₂	107
70	a	NO ₂	CH ₃	H	H	108
71	b	NH ₂	CH ₃	H	H	-
72	b	H	CH ₃	H	NH ₂	-

a - Nitration

b - Reduction

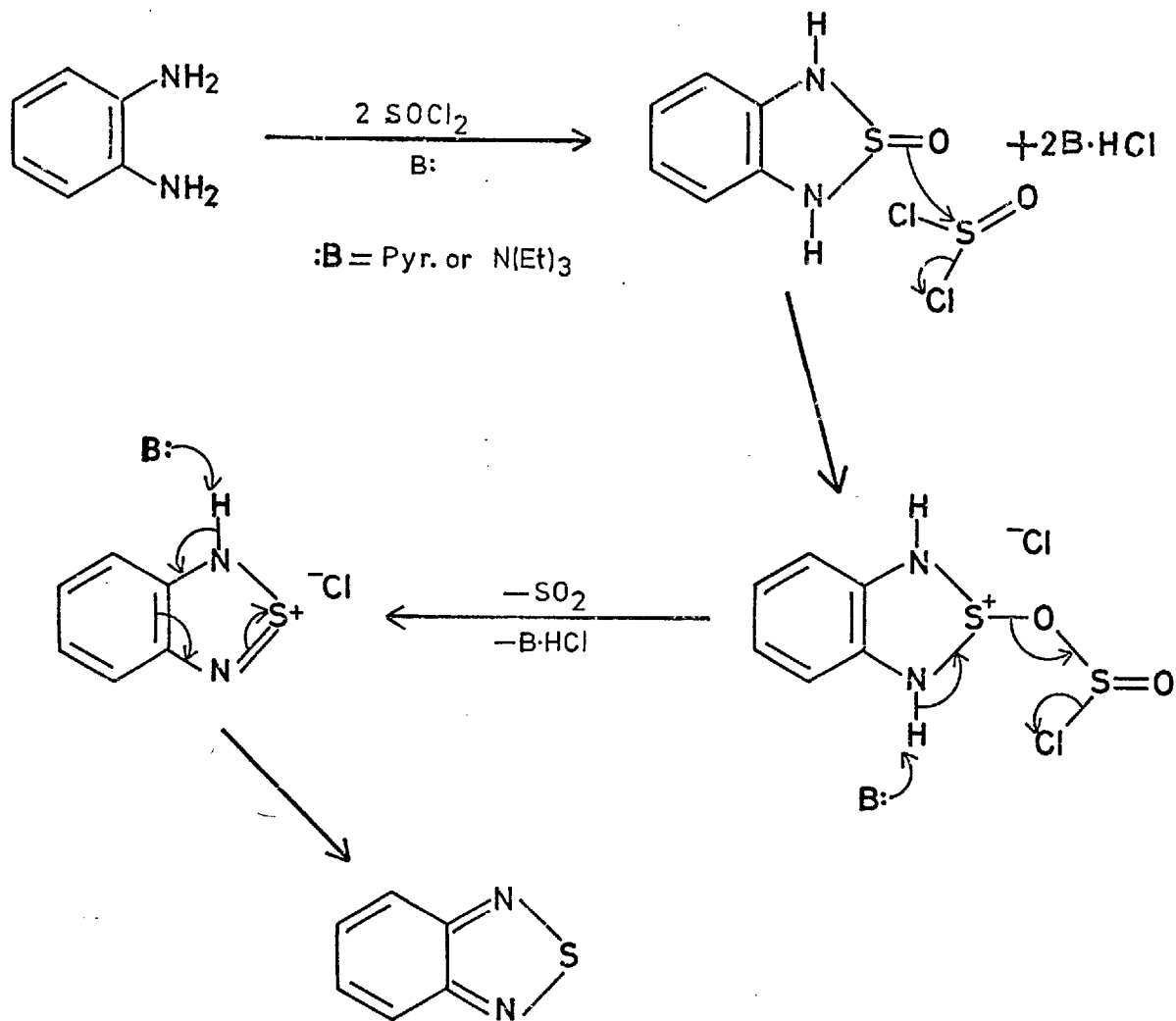
TABLE V



Compound number	Synthetic route	R ₁	R ₂	R ₃	R ₄	ref.
73	(i)	H	H	H	H	104,109
74	(i)	H	CH ₃	H	H	137
75	(i)	H	H	CH ₃	H	110,111
76	(i)	CH ₃	H	Cl	H	114
77	a	NO ₂	CH ₃	H	H	-
78	a	H	H	CH ₃	NO ₂	-
79	b	NH ₂	CH ₃	H	H	-
80	b	H	H	CH ₃	NH ₂	-

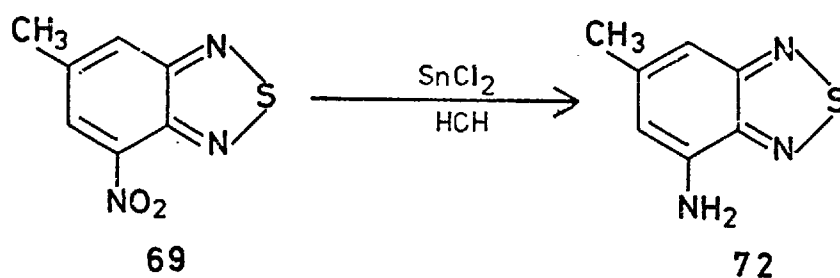
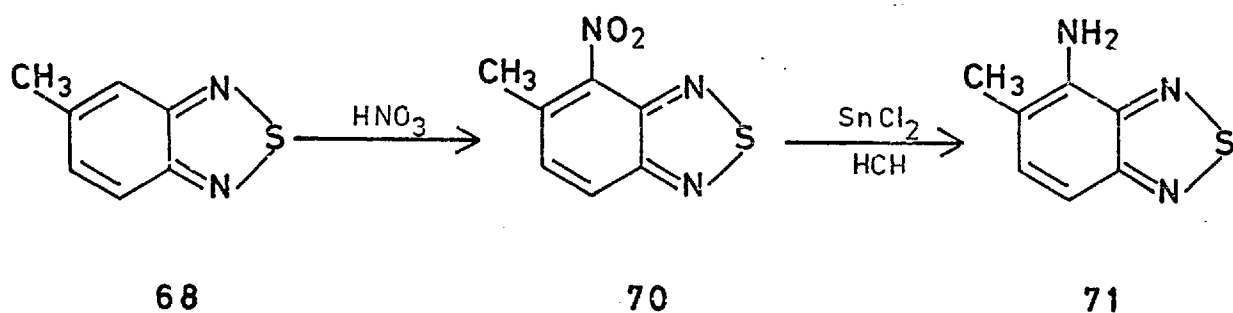
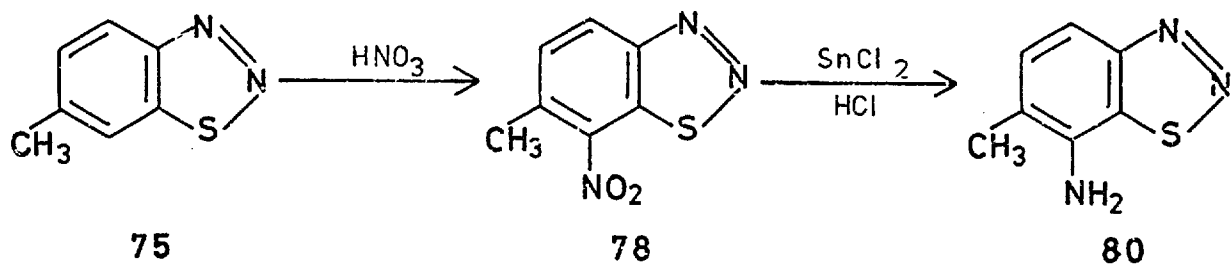
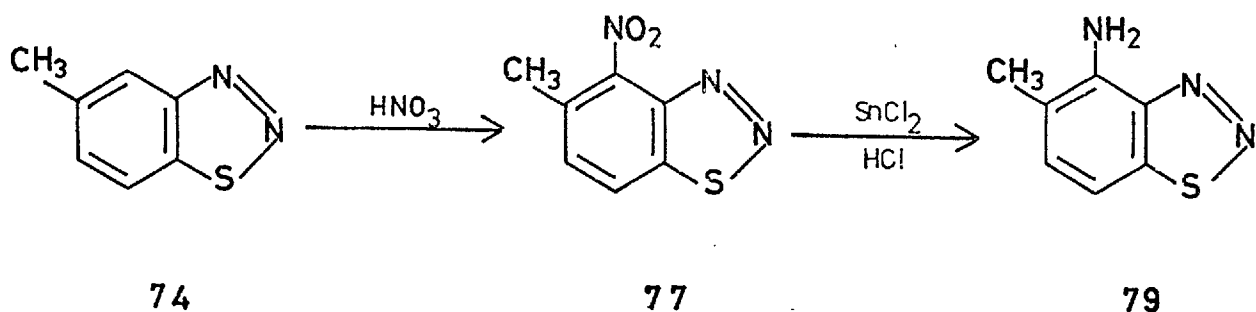
a - Nitration; b - Reduction.

The derivatives (67) to (69) were prepared from the corresponding ortho-phenylenediamines in the usual way. A possible mechanism for these reactions is shown in Scheme VI.



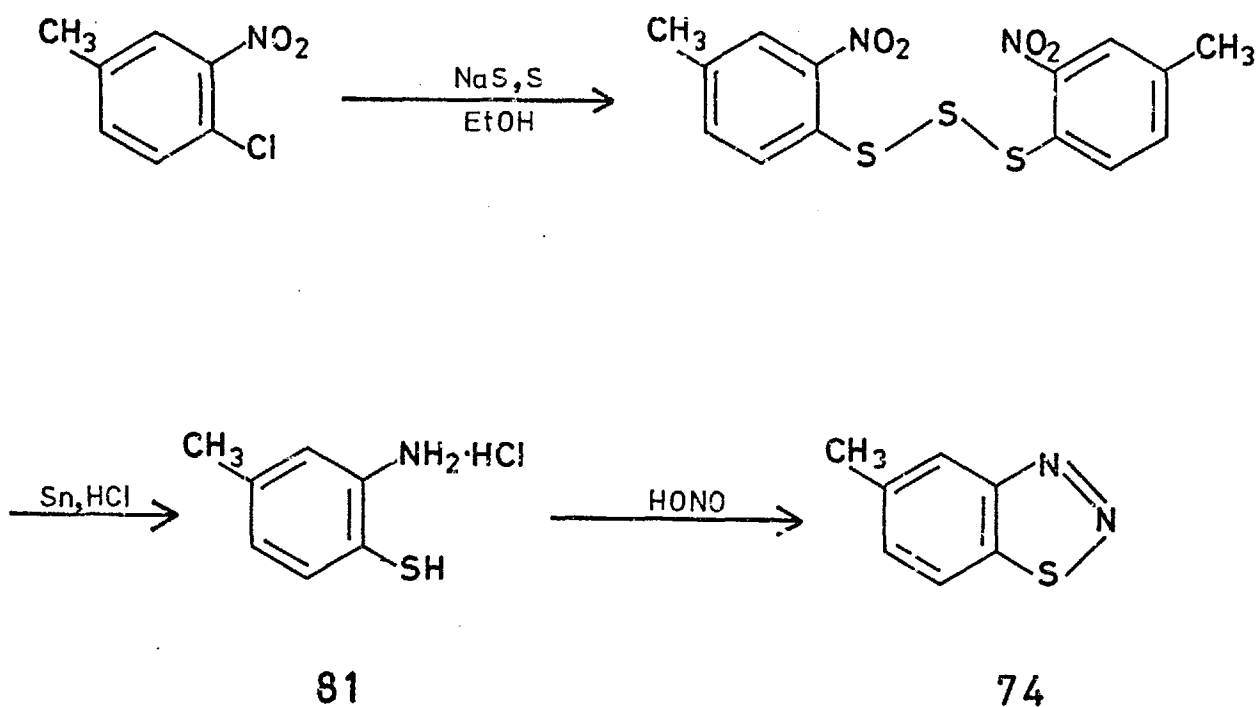
SCHEME VI

Analogous to the benzo-triazoles and -oxadiazoles, the nitro derivatives (70), (77) and (78) were synthesized by nitration of (68), (74) and (75) respectively. Reduction of the nitro-derivatives with anhydrous stannouschloride resulted in the formation of the corresponding amino-derivatives (71, 72, 79 and 80).

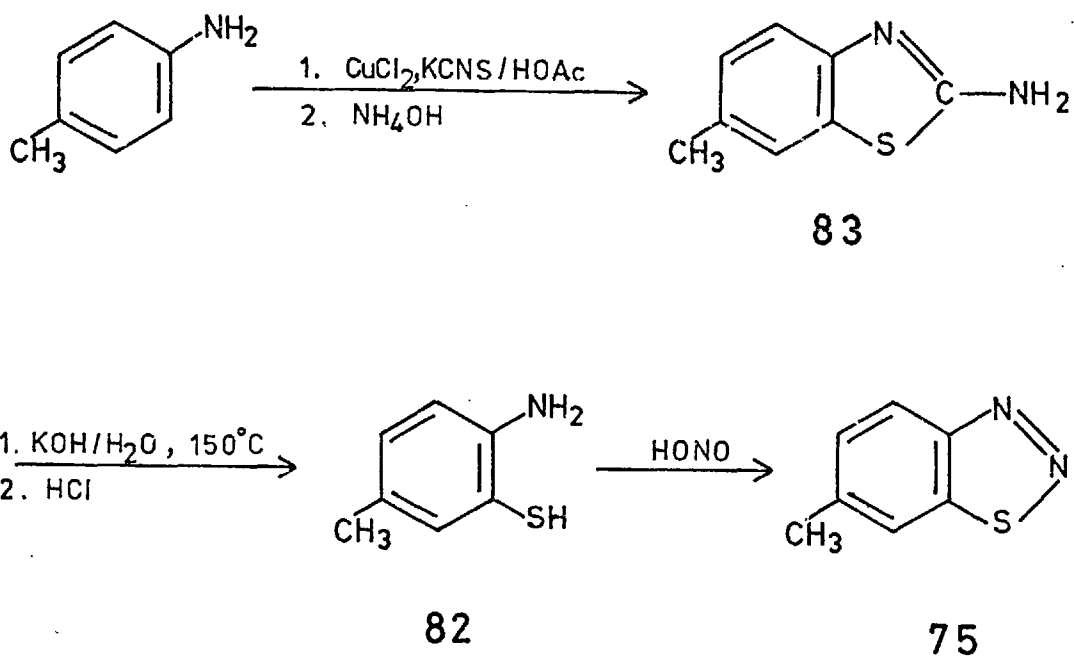


The 1,2,3-benzothiadiazoles (73) to (76) were easily synthesized by diazotization of the corresponding ortho-aminothiophenols. The synthetic routes for the appropriately substituted thiophenols for the above reaction are described in the following pages.

The 4-methyl-orthoaminothiophenol (81) was synthesized from 3-nitro-4-chlorotoluene according to a procedure described by Dannley and Zazaris ¹¹².

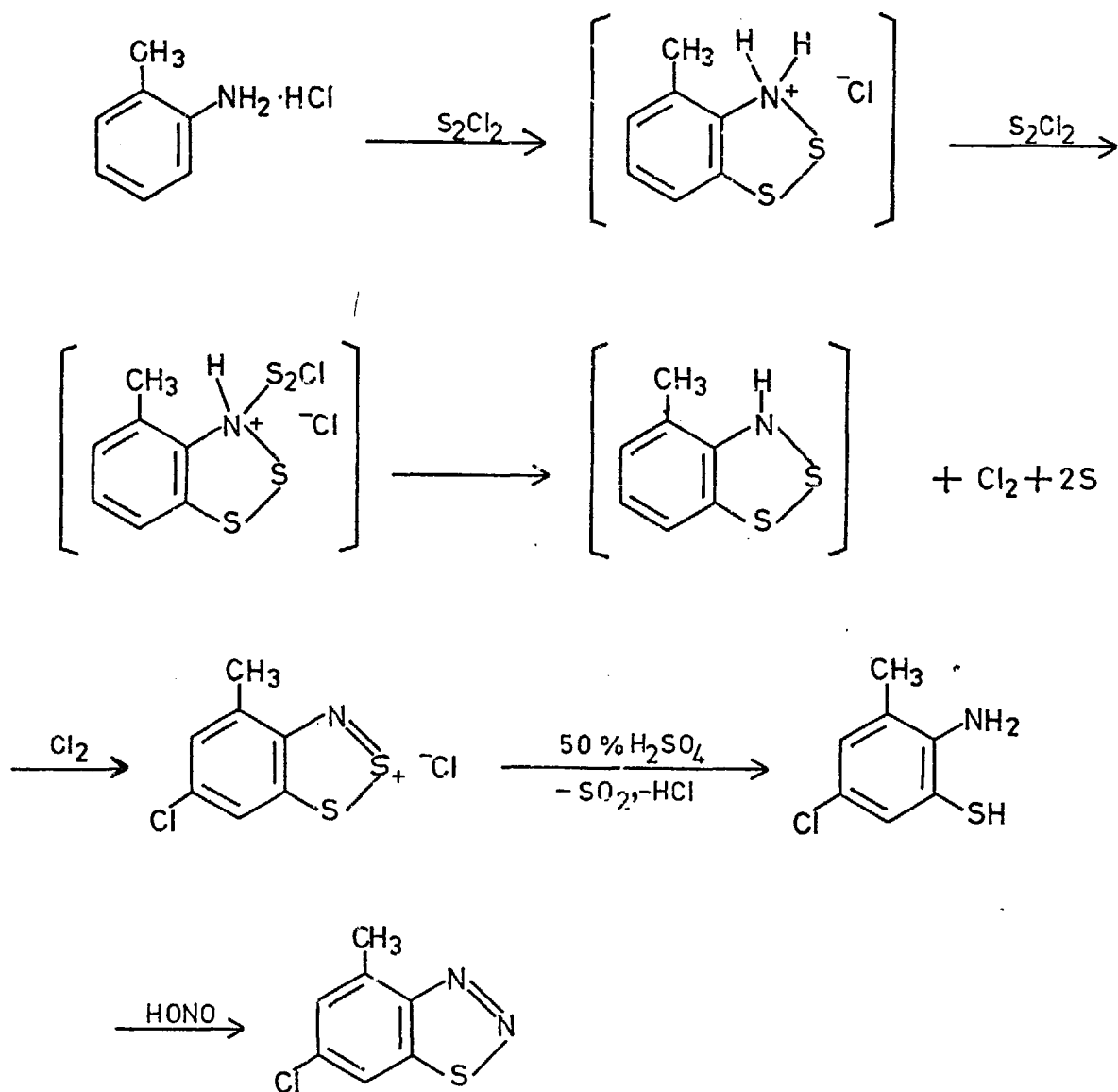


In a procedure described by Fridman ¹¹³,



2-amino-5-methylthiophenol (82) was prepared by base hydrolysis of 6-methyl-2-amino-benzothiazole (83) followed by neutralization with hydrochloric acid. The thiazole (83) was synthesized by treating *p*-toluidine with cupricchloride and potassiumthiocyanate.

6-Chloro-4-methylbenzothiadiaazole (76) was prepared by treatment of *o*-toluidine with sulphur monochloride according to a procedure described by Kirby et al. ¹¹⁴. A mechanism for this reaction has been proposed by Hope and Wiles ¹¹⁵, Scheme VII.

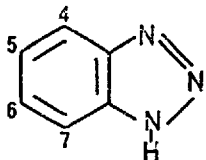
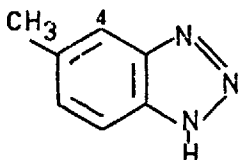
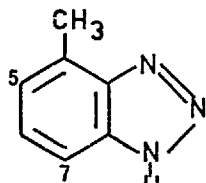


SCHEME VII

ELECTROPHILIC SUBSTITUTION

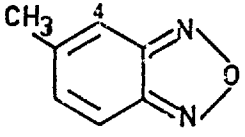
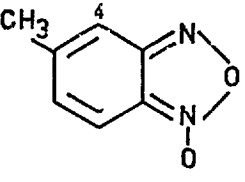
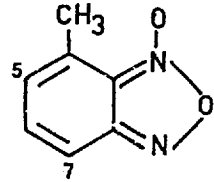
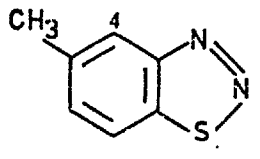
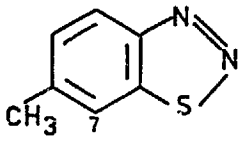
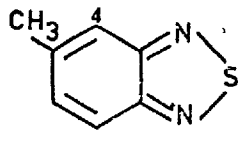
The susceptibility of benzo-triazoles, -oxadiazoles and -thiadiazoles towards electrophilic substitution in the benzenoid ring has been noted and made use of in the synthesis of nitro derivatives. In order to obtain a more quantitative theoretical explanation of the relative reactivities of the various positions in the ring systems Dr. L. Phillips and Mr. Kinns have calculated the total electron density on the carbon atoms using the CNDO/2 method (Complete Neglect of Differential Overlap), the results are shown in Table VI.

TABLE VI

<u>Compound</u>	<u>Total electron density</u>			
	4	5	6	7
	4.023	4.011	3.994	* 4.031
	4.*040	3.974	4.010	4.025
	3.982	4.*031	3.988	4.*042

(Continued)

TABLE VI (Contd.)

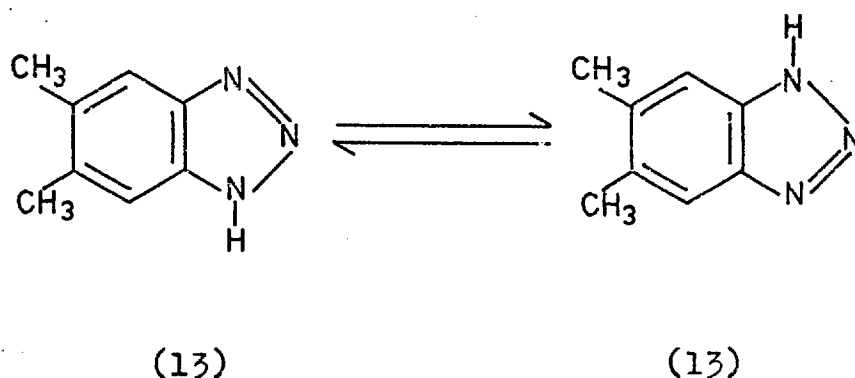
<u>Compound</u>	<u>Total electron density</u>			
	4	5	6	7
	4*.036	3.959	4.014	4.005
	4*.011	3.995	3.963	4.006
	3.971	4*.006	3.999	3*.993
	4*.0211	3.9456	4.0134	3.9583
	3.995	3.9954	3.9636	3*.9795
	4*.0336	3.9494	3.9908	4.0132

* the star shows the position nitrated.

In general it can be seen that the carbon atom nitrated in each compound in fact has the highest electron density in agreement with previous discussions on these reactions.

NUCLEAR MAGNETIC RESONANCE STUDIES

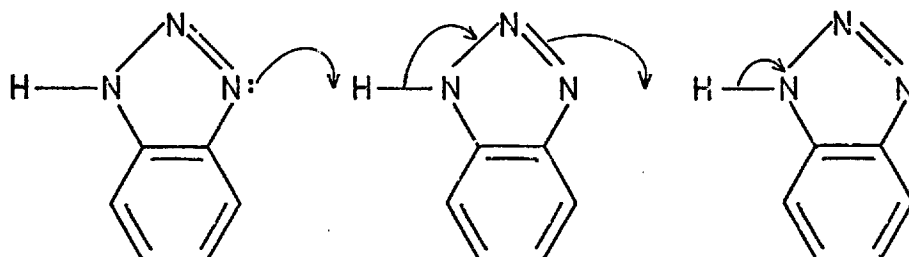
In order to get better insight into the fine structure of the compounds under investigation, a detailed study of their NMR spectra has either been made ^{91,118,119} or is currently being carried out by Mr. A.M. Ahmad and Dr. L. Phillips ¹¹⁷. These results are briefly discussed in this section. One of the compounds which has already been partially studied ¹¹⁷ is the 5,6-dimethylbenzotriazole (13). This compound, although not symmetrical, appears to be so because of the following equilibrium.



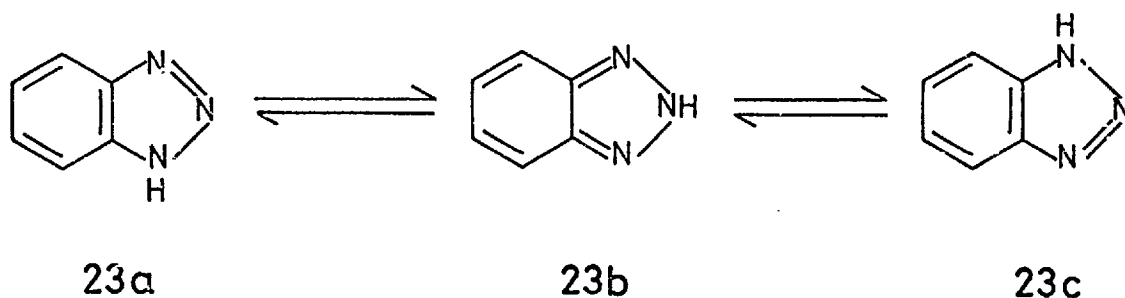
As a result the NMR spectrum of this compound shows a singlet for the six methyl protons (τ 7.65) and also a singlet for the two aromatic protons (τ 2.38). At low temperature however the aromatic singlet is resolved into two separate singlets suggesting the freezing of the above equilibrium.

There are indications that the above transformation is base catalysed. Phillips and Ahmad ¹¹⁷ observed that the coalescence temperature was lowered as

the basicity of the solvent increased. The amphoteric character of benzotriazoles (page 83) may also contribute to this transformation by self-catalysis.

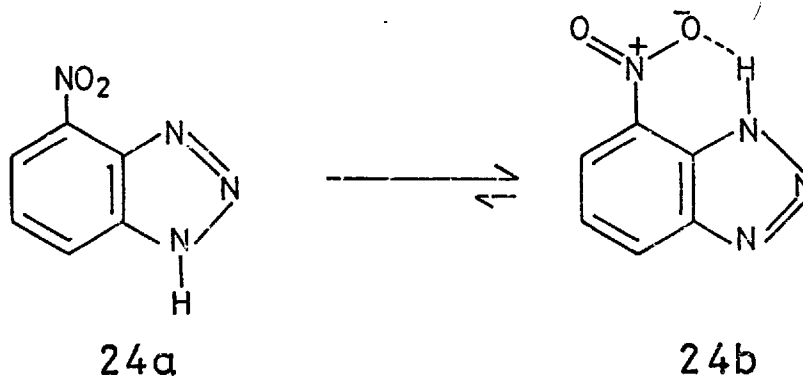


In the review it was mentioned that the N-substituted benzotriazoles have only one structure whereas in the absence of such a substituent three tautomeric structures are possible for these compounds.

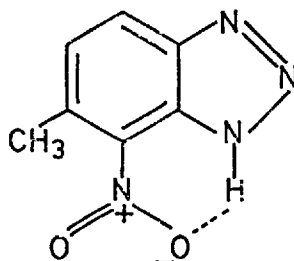


Because they have higher delocalization energy the benzenoid structures (23a and c) are to be preferred to the quinoid form (23b). In the case of substituted benzotriazoles other factors like resonance effects, steric hindrance and the possibility of intramolecular hydrogen bonding may affect the relative stability of the benzenoid forms (23a) and (23c). It has been shown ⁸²

that of the two tautomeric forms of 4(7)-nitrobenzotriazole (24a and b) the structure (24b) is the more stable form because of hydrogen bonding.

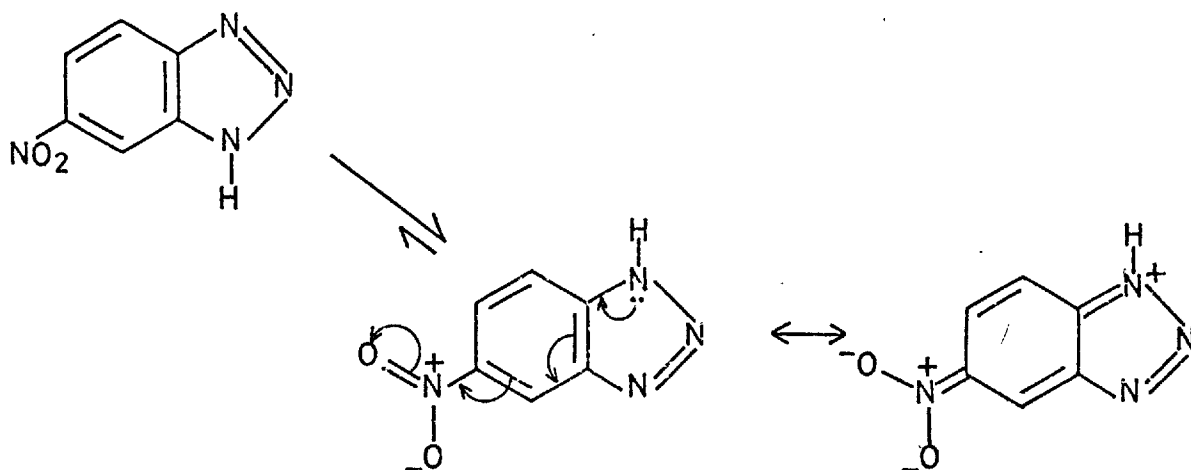


Attempts were made to study this hydrogen bonding by investigating the infrared spectrum of 6-methyl-7-nitrobenzotriazole (5). However no suitable solvents could be found.

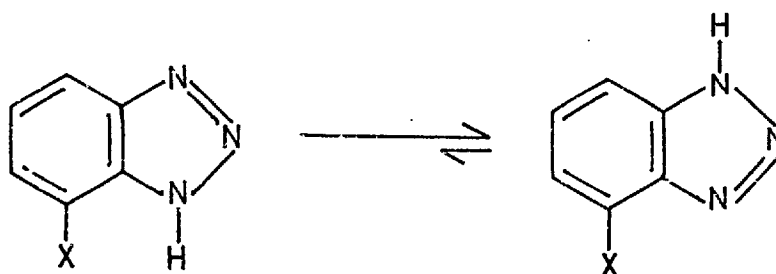


5

The resonance effect is most pronounced when the substituent is an electron withdrawing group. The preferred tautomer in such cases is that which can be stabilized by a quinoid type of resonance structure. As an example for the two 5- or 6-nitrobenzotriazoles, the 5-nitro-derivative would be the more stable form.



In the presence of other substituents like methyl-, chlorine or an amino-group it would be more difficult to visualize any preference for either of the two isomeric structures. However, when one of the substituents is ortho to the heterocyclic ring steric factors drive the equilibrium in favour of the 4-derivative. This steric hindrance, of course, does not apply to the nitro derivatives in which hydrogen bonding is possible.



where $X = \text{Cl}, \text{NH}_2, \text{CH}_3$.

Based on the preceding argument concerning the benzotriazole equilibrium the preferred tautomers have been tabulated with their NMR data, (table VII).

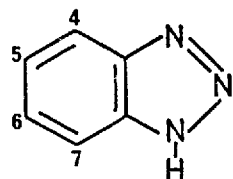
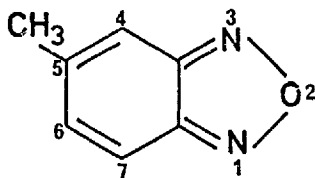


TABLE VII : NMR SPECTRA OF BENZOTRIAZOLES

Compound	Chemical shifts (τ)					Coupling constants c/s	
	H ₄	H ₅	H ₆	H ₇	CH ₃	ring-ring	methyl-ring
4-methyl-	multiplet (2.20-2.85)				7.24		
5-methyl-	2.30	-	2.80	2.12	7.48	H ₆ H ₇ : 8.5; H ₄ H ₆ : 1.5	MeH ₄ :0.8; MeH ₆ & MeH ₇ :0.4
4-methyl-5-chloro-	-	-	2.25	2.60	7.25	H ₆ H ₇ : 8.5	MeH ₆ :0.6; MeH ₇ :0.5
5-methyl-6-chloro-	2.26	-	-	2.06	7.47	-	MeH ₄ :0.8; MeH ₇ :0.9
5,6-dimethyl-	2.38	-	-	2.38	7.65*	-	-
5-methyl-6-nitro-	2.26	-	-	1.35	7.28	-	MeH ₄ :0.85; MeH ₇ :0.3
5-methyl-7-nitro-	1.76	-	1.76	-	7.40	H ₄ H ₆ : 1.3	MeH ₄ :0.85; MeH ₆ :0.5
6-methyl-7-nitro-	1.80	2.60	-	-	7.16	H ₄ H ₅ : 8.5	MeH ₄ :0.45; MeH ₅ :0.55
4-methyl-7-nitro-	-	2.67	1.64	-	7.06	H ₅ H ₆ : 8.3	-
4-methyl-6-nitro-	-	1.82	-	1.21	7.12	H ₅ H ₇ : 2.0	MeH ₅ :1.0; MeH ₇ :0.7
5-methyl-7-amino-	3.71	-	3.37	-	7.73	H ₄ H ₆ : 0.8	MeH ₄ :0.9; MeH ₆ :0.5
5-methyl-4-amino-	-	-	2.96	3.18	7.79	H ₆ H ₇ : 8.1	MeH ₆ :0.5

* The two methyl signals appear at the same τ value.

The NMR spectra of a number of benzofurazans and benzofuroxans have been reported ^{91, 118, 119}. It has been pointed out ^{118, 119} that the coupling constants across the 4-5 and 6-7 positions are larger than those for the 5-6 positions, i.e. 9.0 - 9.3 Hz and 6.5 Hz respectively. This observation has also been made between the methyl and the ring protons in the methyl-substituted benzofuroxans ¹¹⁹ (1.0 - 1.4 Hz across the 4-5 and 6-7 positions, and 0.3 Hz across the 5-6 positions). These large coupling constants for the methyl-ring protons appear to be more of an allylic type, in other words the double bonds in these compounds may be partially fixed ¹²⁰ between the carbon atoms 4-5 and 6-7.



This type of coupling was also observed in the methyl-benzofurazans and their sulfur analogues. The chemical shifts and coupling constants of the benzofuroxans, -furazans and thiadiazoles are listed in tables (VIII), (IX) and (X) respectively.

The structure of these compounds is best represented by the form (a), whereas form (b) need only be invoked to explain their aromaticity.

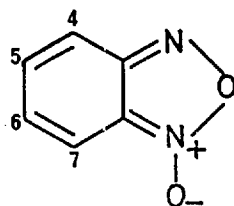


TABLE VIII : NMR SPECTRA OF BENZOFUROXANS

Compound	Chemical shifts (τ)					Coupling constants (c/s)	
	H ₄	H ₅	H ₆	H ₇	CH ₃	ring-ring	methyl-ring
4-methyl-	multiplet (2.7 - 3.1)				7.44	-	MeH ₅ : 0.8
5-methyl-	multiplet (2.5 - 3.1)				7.61	-	MeH ₄ : 1.2
5-chloro-	multiplet (2.25- 3.05)				-	-	-
5-methoxy-	multiplet (2.65- 3.55)				-	-	-
5-nitro-	multiplet (1.45- 2.45)				-	-	-
5-methyl-6-chloro	2.67	-	-	2.47	7.55	-	MeH ₄ : 1.3
6-methyl-4-methoxy	-	2.80	-	3.46	7.72	-	MeH ₇ : 1.2
5-methyl-6-nitro	2.50	-	-	1.87	7.44	-	MeH ₄ : 1.3
4-methyl-6-nitro	-	2.1	-	1.65	7.28	-	MeH ₅ : 0.9
7-methyl-4-nitro	-	1.45	2.65	-	7.29	H ₅ H ₆ : 7.5	MeH ₆ : 1.3
6-methyl-4-nitro	-	1.67	-	2.40	7.40	-	MeH ₇ : 1.3
6-methyl-5-methoxy-4-chloro-	-	-	-	2.94	7.71	-	MeH ₇ : 1.3
5-methyl-4-nitro	-	-	2.82	2.40	7.34	H ₆ H ₇ : 9.2	-

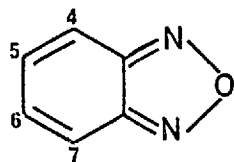


TABLE IX : NMR OF BENZOFURAZANS

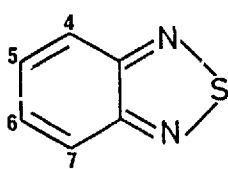
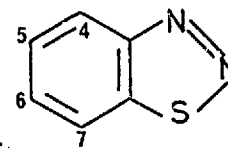
Compound	Chemical shifts (τ)					Coupling constants c/s	
	H ₄	H ₅	H ₆	H ₇	CH ₃	ring-ring	Methyl-ring
4-methyl-	multiplet (2.2 - 3.0)				7.35		CH ₃ -H ₅ :1.27; CH ₃ -H ₆ :0.9
5-methyl-	2.44	-	2.73	2.24	7.53	H ₆ H ₇ :9.0; H ₄ H ₆ :1.1	CH ₃ -H ₄ :1.3; CH ₃ -H ₆ :0.4; CH ₃ H ₇ :0.2
5-methoxy-*	3.16	-	2.92	2.30	-	H ₆ H ₇ :9.5; H ₄ H ₆ :2.0	-
5-chloro-	multiplet (2.0 - 2.8)				-	-	-
5-nitro-	multiplet (1.0 - 2.6)				-	-	-
4-nitro-	multiplet (1.2 - 2.4)				-	-	-
5-methyl-6-chloro-	2.30	-	-	2.11	7.49	H ₄ H ₇ : 0.9	MeH ₄ : 1.4; MeH ₇ : 0.5
5-methyl-7-methoxy-†	2.48	-	3.18	-	7.68	H ₄ H ₆ : 0.8	MeH ₄ : 1.3; MeH ₆ : 0.5
5-methyl-4-nitro	-	-	2.46	1.87	7.25	H ₆ H ₇ : 9.0	-
5-methyl-6-methoxy-‡	2.50	-	-	-	7.60	-	MeH ₄ : 1.3
7-chloro							

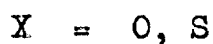
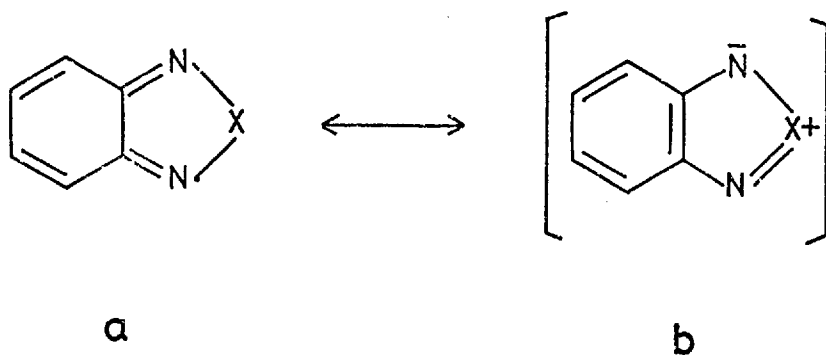
* The methoxy signal is at 6.08 τ

† The methoxy signal is at 6.05 τ

‡ The methoxy signal is at 5.93 τ

TABLE X : NMR SPECTRA OF BENZOTHIADIAZOLES

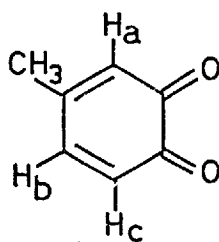
Compound 	Chemical shift (τ)					Coupling constants (c/s)	
	H ₄	H ₅	H ₆	H ₇	CH ₃	ring-ring	Methyl-ring
5-methyl-	2.28	-	2.62	2.14	7.48	H ₆ H ₇ :9.0; H ₄ H ₆ :1.5	MeH ₄ :1.1
5-methyl-7-nitro-	1.83	-	1.56	-	7.14	H ₄ H ₆ :1.6	MeH ₄ :1.1
5-methyl-4-nitro-	-	-	2.42	1.90	7.35	H ₆ H ₇ :9.0	-
5-methyl-4-amino-	-	-	2.83	2.83	7.77	-	-
5-methyl-7-amino-	3.04	-	3.74	-	7.66	H ₄ H ₆ :1.2	MeH ₄ :1.1
							
5-methyl-	1.78	-	2.67	2.15	7.53	H ₆ H ₇ :8.5; H ₄ H ₆ :1.5	MeH ₄ :0.9; MeH ₆ :0.4; MeH ₇ :0.2
6-methyl-	1.50	2.57	-	2.15	7.42	H ₄ H ₅ :9.0; H ₅ H ₇ :1.4	-
4-methyl-6-chloro-	-	2.65	-	2.14	7.00	H ₅ H ₇ :1.5	-
5-methyl-4-nitro-	-	-	2.34	1.83	7.35	H ₆ H ₇ :8.5	-
6-methyl-7-nitro-	1.20	2.27	-	-	6.97	H ₄ H ₅ :8.5	-
5-methyl-4-amino-	-	-	2.73	2.84	7.73	H ₆ H ₇ :8.2	-
6-methyl-7-amino-	2.74	2.21	-	-	7.68	H ₄ H ₅ :8.4	-



The lone pair of electrons on the oxygen or sulfur is used to fulfil the $(4n + 2)\pi$ rule of aromaticity. Delocalization of these electrons can result in benzenoid structures like (b). However these are expected to be unimportant because of charge separation.

Recently the NMR spectrum of 4-methylbenzoquinone (84) (a nonaromatic compound) has been investigated¹²¹. In table (XI) the relevant data are listed.

TABLE XI



Chemical shift τ	Coupling constants c/s			
H_a : 3.77	H_a-H_b	2.1	CH_3-H_a	1.7
H_b : 3.06	H_a-H_c	0.9	CH_3-H_b	0.3
H_c : 3.65	H_b-H_c	10.0	CH_3-H_c	0.5
CH_3 : 7.80				

The similarities of the coupling constants between the $\text{CH}_3 - \text{H}_a$ protons in this compound and those observed for the benzo-furazans, -furoxans and 2,1,3-benzothiadiazoles support the quinoid type of structure in the latter compounds.

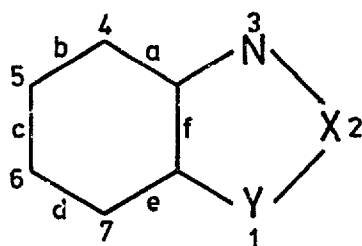
In a series of molecular orbital calculations using the CNDO/2 method, Dr. L. Phillips and Mr. M. Kinns^{11.6} have calculated the π -bond order for the substituted benzo-triazoles, -furoxans, -furazans and thiadiazoles. In table XII the values for the benzenoid ring of a number of these compounds are listed.

The values in Table XII indicate that the π -electrons are partially localized in the bonds (b and d) between carbon atoms 4-5 and 6-7 in the benzo-furoxans, -furazans and 2,1,3-benzothiadiazoles in agreement with the quinoid type of structure and the observed coupling constants.

The π -bond orders for the 1,2,3-benzothiadiazoles however, are very much closer to each other suggesting a more complete delocalization of the π -electrons which is expected for benzenoid type of structures.

The benzotriazoles appear to be in an intermediate position indicating that these compounds can have either of the two structural forms, namely benzenoid and/or the quinoid forms, in agreement with the previously discussed tautomerism.

TABLE XII



Benzofurazan: X=O, Y=N

1,2,3-Benzothiadiazaole: X=N, Y=S

Benzofuroxan: X=O, Y=N $\rightarrow$ O

Benzotriazole: X=N, Y=NH

2,1,3-Benzothiadiazaole: X=S, Y=N

Compound	π -bond order					
	a	b	c	d	e	f
Benzofurazan	.5115	.7643	.5566	.7650	.5090	.5183
5-methyl- "	.5144	.7459	.5422	.7680	.5079	.5165
4-methyl- "	.4979	.7442	.5623	.7620	.5062	.5192
Benzofuroxan	.5036	.7661	.5548	.7623	.5204	.5126
5-methyl- "	.5016	.7703	.5398	.7446	.5229	.5123
4-methyl- "	.4898	.7481	.5581	.7349	.5143	.5167
2,1,3-Benzothiadiazaole	.3889	.8694	.3924	.8697	.3876	.5591
5-methyl- "	.3956	.8494	.3836	.8715	.3864	.5570
1,2,3-Benzothiadiazaole	.6553	.6790	.6395	.6811	.6453	.5838
5-methyl- "	.6625	.6610	.6258	.6830	.6442	.5789
6-methyl- "	.6545	.6805	.6270	.6635	.6522	.5797
Benzotriazole	.5698	.7179	.6123	.7117	.5856	.5631
5-methyl- "	.5693	.7042	.5962	.7163	.5838	.5630
4-methyl- "	.5569	.6989	.6177	.7089	.5823	.5645

CHAPTER THREE

RESULTS AND DISCUSSION OF

MASS SPECTRA

INTRODUCTION

It has been shown that in benzotriazoles, benzoxadiazoles and benzothiadiazoles where a heteroatom like N, O or S is adjacent to a nitrogen atom one of the main fragmentation processes of the molecular ions under electron impact involves the expulsion of a molecule of N_2 , NO or NS. The production of these molecules is largely dependent on their stability (see review) and also on the stability of the product and the parent ions. In this chapter the mass spectral fragmentation patterns of these compounds are studied and the effect of substituents in the benzene ring on the fragmentation investigated.

BENZOTRIAZOLES

The electron impact induced fragmentations of benzotriazole have already been discussed in the review. The main fragmentation of the molecular ion is the loss of N_2 followed by expulsion of hydrogen cyanide. Although the mass spectra of benzotriazoles with a methyl group in the heterocyclic ring have been investigated ^{60,61,63} no mention concerning the fragmentation of benzotriazoles with a methyl substituent in the benzene ring has been made.

The molecular ions of the 4- and 5-methyl-benzotriazoles like the parent compound, undergo facile loss of N_2 followed by expulsion of HCN resulting in the ions m/e 105 and m/e 78 respectively. Metastable ions at m/e 82.9 and m/e 57.9 confirm these losses in the mass spectra of these compounds (MS-2 and -3, respectively). A striking difference between the mass spectra of these compounds and that of the parent compound, however, is that the molecular ion and also the $(M-N_2)^+$ ion of the 4- and 5- methyl-benzotriazoles show a loss of a hydrogen atom. This loss from the molecular ion occurs only to a small extent, whereas the $(M-N_2)^{•+}$ ion loses a hydrogen atom resulting in the most abundant peak at m/e 104 in the spectrum. Sharp metastable ions at m/e 131.0 and 103.0 confirm these losses. Metastable defocusing reveals that the ion m/e 104 also results by the loss of N_2 from the $(M-1)^+$ ion.

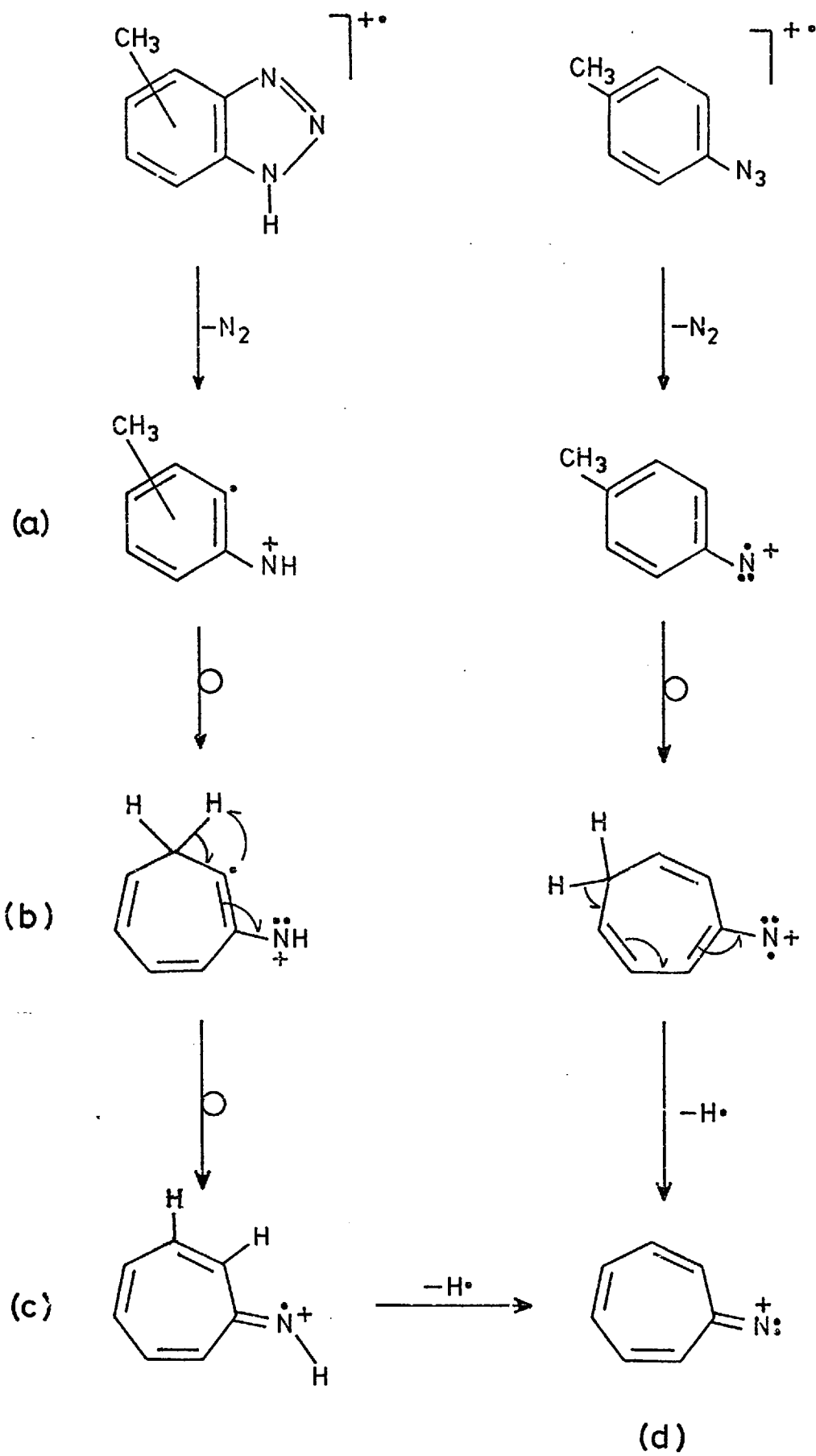
The absence of such a hydrogen atom loss in the mass spectrum of benzotriazole (MS-1) strongly suggests the involvement of the methyl group in this fragmentation.

Analogous to the substituted toluenes the hydrogen elimination may involve either the tropylium intermediate or the benzylic intermediate depending on the nature of the substituent.

In order to get some insight into the fragmentation mechanism of the methyl-substituted-benzotriazoles it is, perhaps, of some significance to compare the mass spectra of these compounds with that of p-tolylazide (MS-5).

The molecular ion of the azide shows three main fragmentations. The most significant of these is the loss of N_2 . The other two fragmentations involve the losses of C_2H_2 and HCN resulting in the ions m/e 107 and m/e 106, respectively. These latter losses are not observed in the mass spectra of the methyl-benzotriazoles. Furthermore the molecular ion of the tolyl-azide does not show any loss of a hydrogen atom. The differences in the fragmentation pattern of these compounds imply that the molecular ions of the benzotriazoles do not rearrange to that of the tolyl azide.

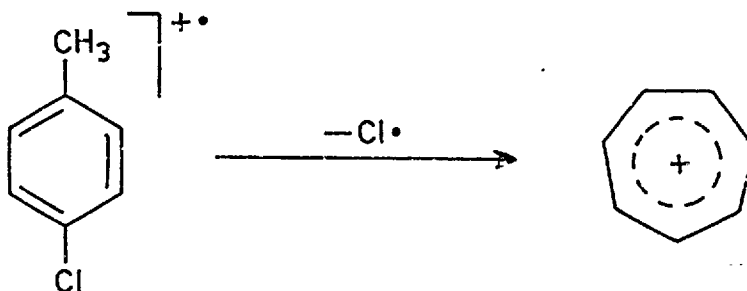
The $(M-N_2)^{+}$ ions in both compounds show the loss of a hydrogen atom resulting in the ion m/e 104 (Scheme I). This loss in the case of the tolylazide predominantly occurs via a tropylium ion ⁵⁵. If the $(M-N_2)^{+}$ ion (a) in the spectra of the 4- and 5- methyl-benzotriazoles loses a hydrogen atom via a ring expanded



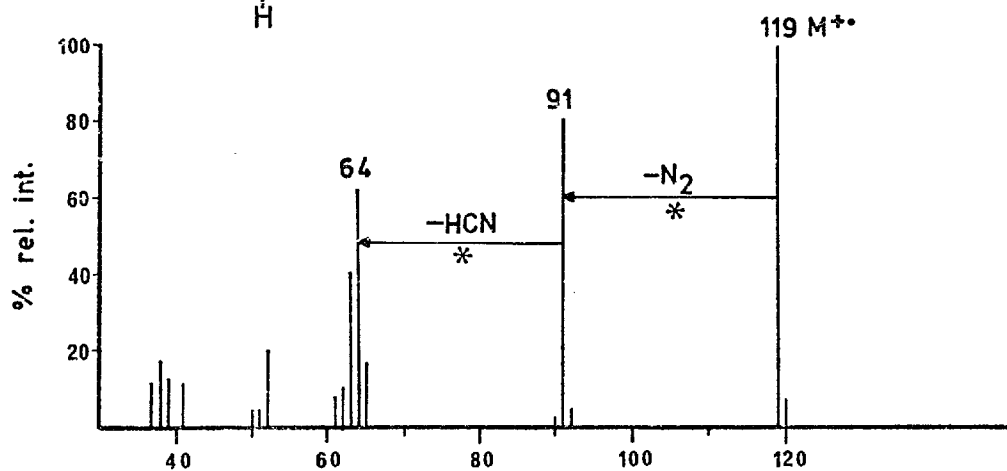
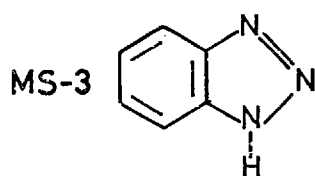
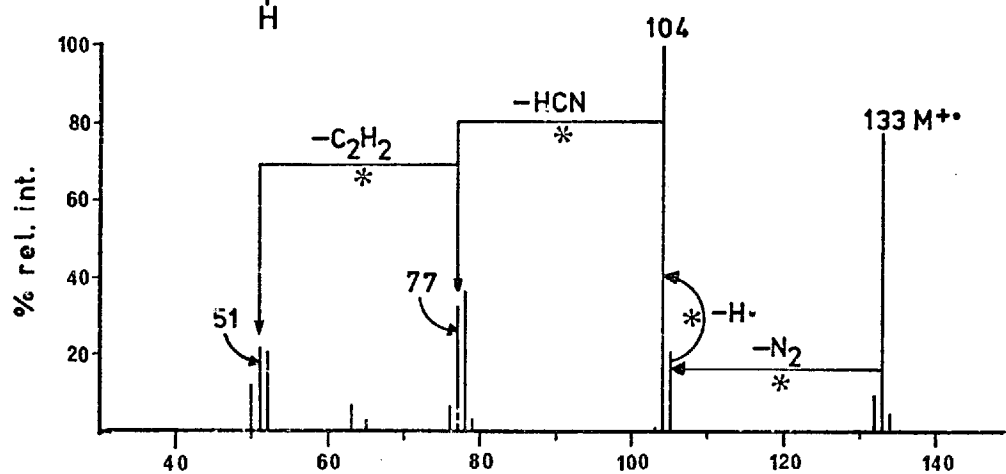
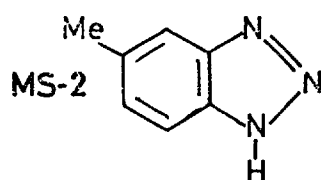
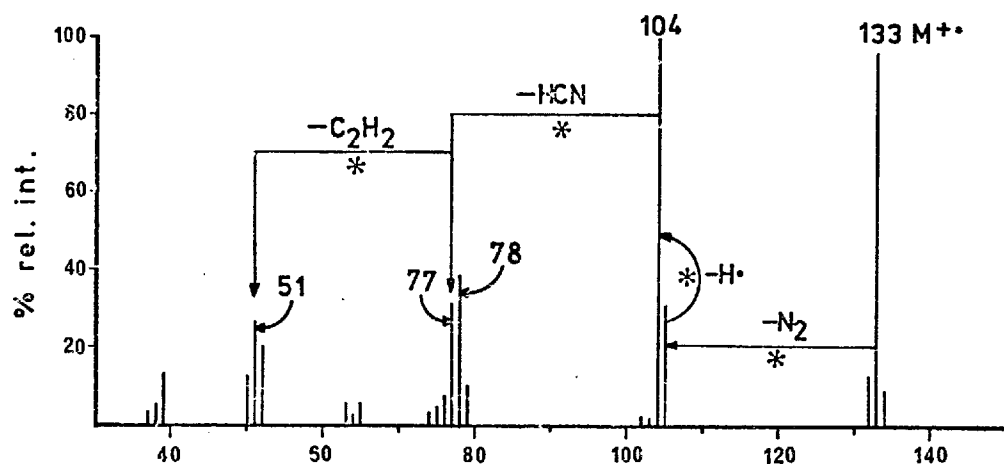
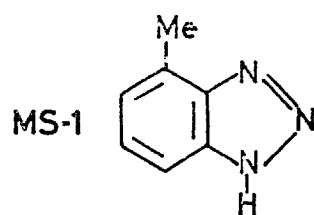
Scheme I

intermediate (b and c), then one would expect the resulting ion to have the same structure as the m/e 104 ion (d) in the spectrum of tolyl azide.

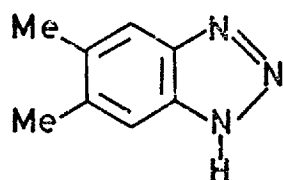
The rearrangement step (b $\rightarrow$ c) is justified since similar hydrogen shifts are responsible for the production of tropylium ion in the spectrum of p-chlorotoluene ²⁵ (see review page 24).



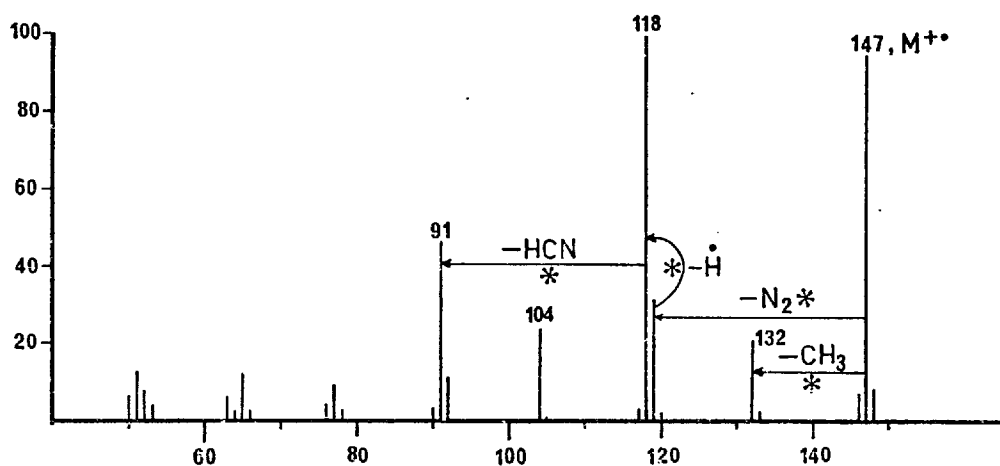
The ion m/e 104, $(C_7H_6N)^+$, in both spectra undergoes a metastable fragmentation by expulsion of HCN resulting in the ion m/e 77. However, comparison of the relative intensities of the ions m/e 104, m/e 77 and the corresponding metastable ion m/e 57.0 strongly suggests that the ions m/e 104 in the spectra of these compounds do not have the same structure. Table I shows the ratios (m/e 57.0)/(m/e 104), (m/e 77)/(m/e 104), (m/e 78)/(m/e 105) and (m/e 104)/(m/e 105).



MS-4



m^*	transition	loss
118.5 : 147	$\longrightarrow$ 132	(CH ₃)
117.0 : 119	$\longrightarrow$ 118	(H)
96.3 : 147	$\longrightarrow$ 119	(N ₂)
70.2 : 118	$\longrightarrow$ 91	(HCN)
46.4 : 91	$\longrightarrow$ 65	(C ₂ H ₂)



MS-5

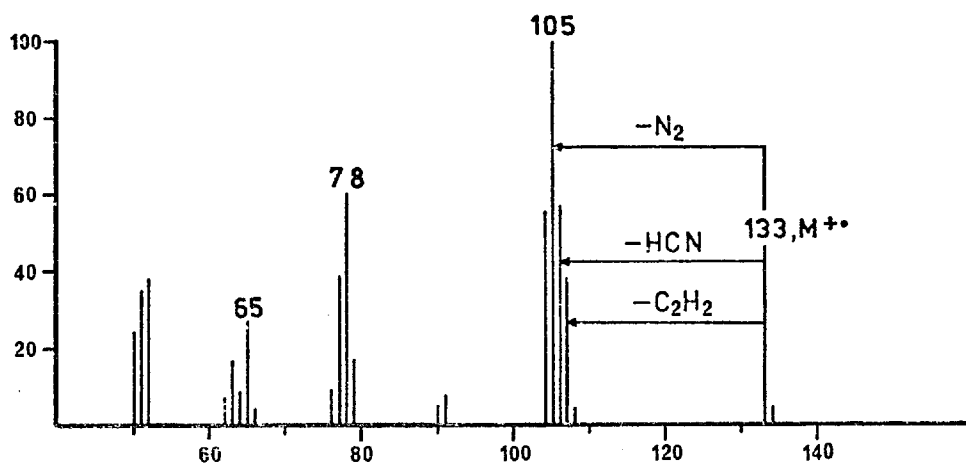
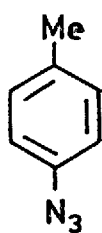
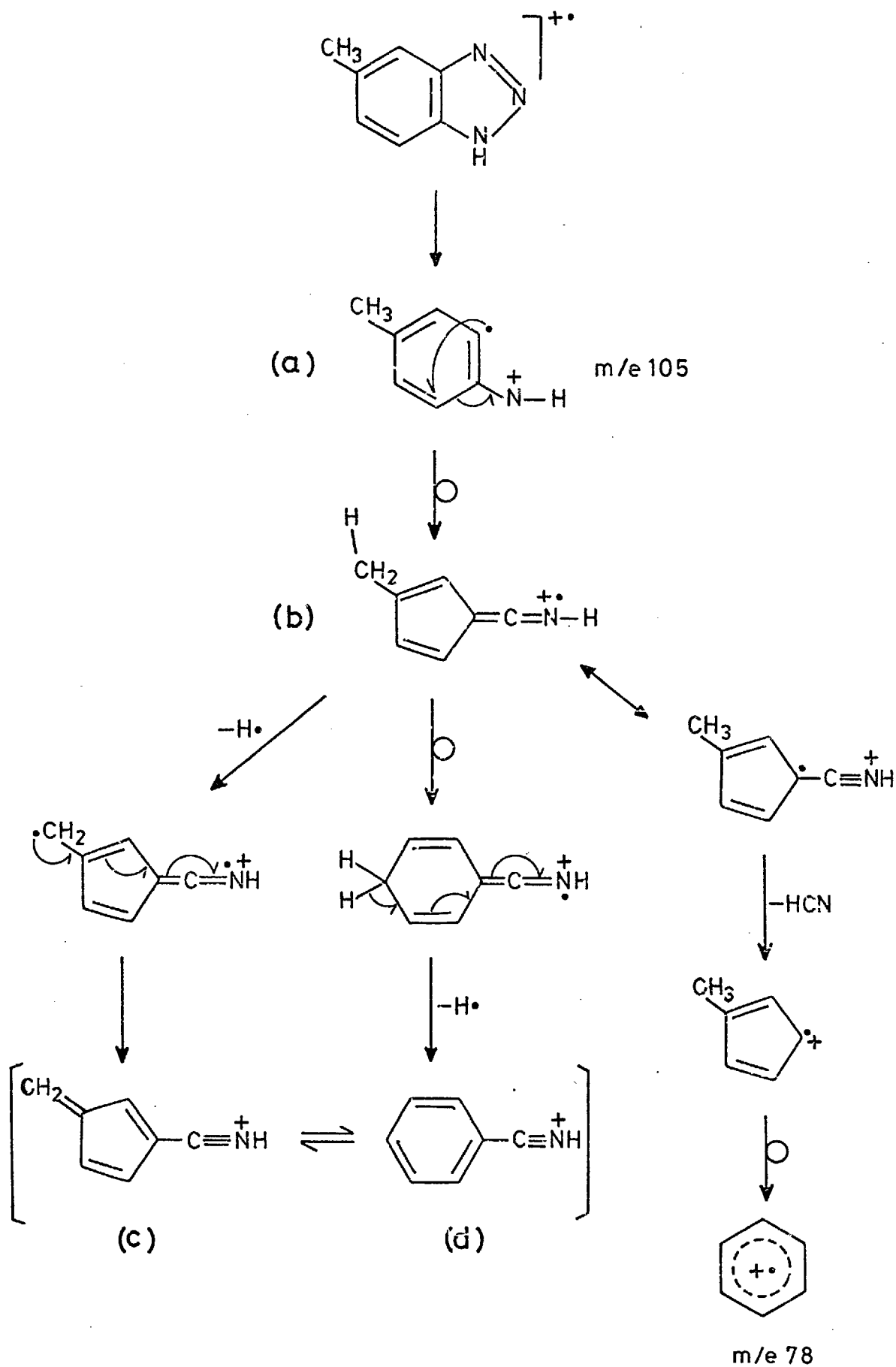


TABLE I

Compound	Ratio of relative intensities			
	$\frac{m/e\ 57.0}{m/e\ 104}$	$\frac{m/e\ 77}{m/e\ 104}$	$\frac{m/e\ 78}{m/e\ 105}$	$\frac{m/e\ 104}{m/e\ 105}$
4-methyl-Benzotriazole	8.1×10^{-4}	0.32	1.3	3.21
5-methyl-Benzotriazole	11.1×10^{-4}	0.31	1.7	4.76
p-tolylazide	15.5×10^{-4}	0.66	0.78	0.56

The ratios in the first two columns clearly indicate that the loss of HCN from the ion $m/e\ 104$ is more favoured in the case of the azide. The third column, on the other hand, shows that this loss from the $(M-N_2)^{+}$ ions is more pronounced for the benzotriazoles. Furthermore the loss of a hydrogen atom from the ion $m/e\ 105$ is a more favourable process in the case of the benzotriazoles as evidenced by the ratios in the last column of table I. These results are in agreement with the suggestion that the fragmentation of methyl-benzotriazoles does not involve tropylium type of ions as intermediates.

A more probable mechanism for the fragmentation of the 4- and 5-methylbenzotriazoles is shown in Scheme II. This involves the production of the radical cation (a) which, analogous to the previously reported fragmentation mechanism of the parent compound^{61, 62} (see review, pp 52 - 55) undergoes ring contraction to the structure (b).



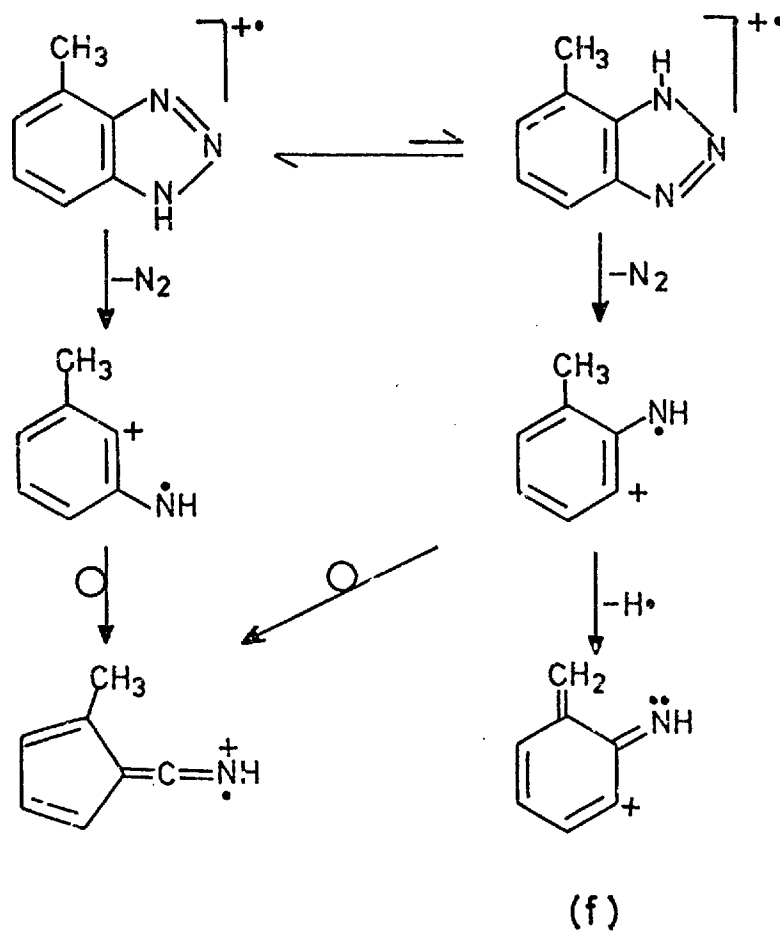
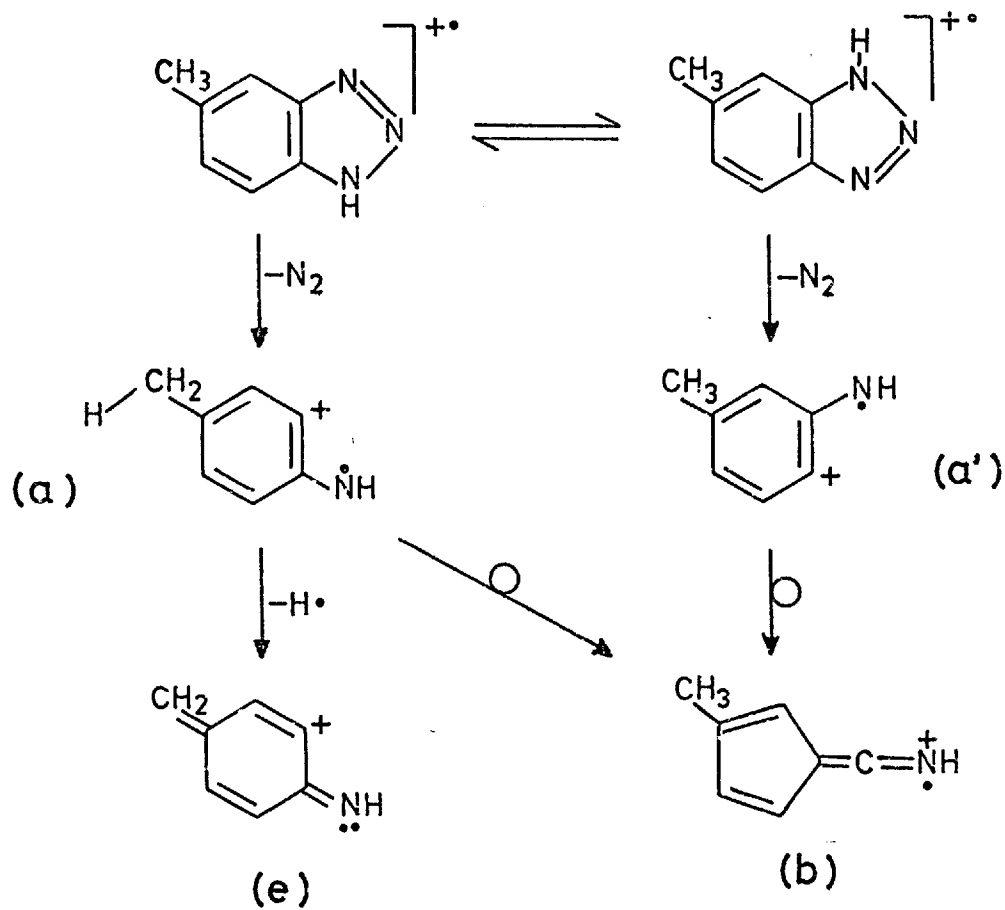
NOTE: The 4-methyl-benzotriazole undergoes the same type of fragmentations.

SCHEME II

The species (b) can then undergo two processes, namely losses of a hydrogen atom or HCN resulting in the ions m/e 104 and m/e 78. The loss of a hydrogen atom from (b) is a favourable process since the resulting biradical can probably be stabilized by a structure like (c). A second process which contributes to the stability of the ion m/e 104 is the ring expansion of the ion (b) followed by the loss of H. and the formation of the stable benzenoid structure (d). The relative magnitude of the loss of HCN from the ion m/e 104 may be related to the stability of the ion m/e 104. The greater the stability of this ion the less the extent of loss of HCN. The relative stability of structures (c) and (d) may therefore account for the lesser loss of HCN from the ion m/e 104 in the spectra of the methyl-benzotriazoles. The greater loss of HCN from the ion m/e 105 in the case of benzotriazoles can also be explained via the ring-contracted mechanism. The HCN moiety already present in this structure can be lost via a direct cleavage, whereas in the case of tolyl-azide the loss of HCN must be preceded by a rearrangement.

A second mechanism that could account for the greater stability of the ion m/e 104 in the methylbenzotriazole is shown in Scheme III.

With the consideration of the equilibrium between the two tautomeric forms of the 5-methylbenzotriazoles the ion m/e 105 $(M-N_2)^{+}$ can have either of the structures (a) or (a'). Ring contraction on either of these structures results in the formation of the ion (b) in Scheme II.

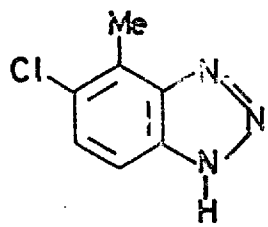


SCHEME III

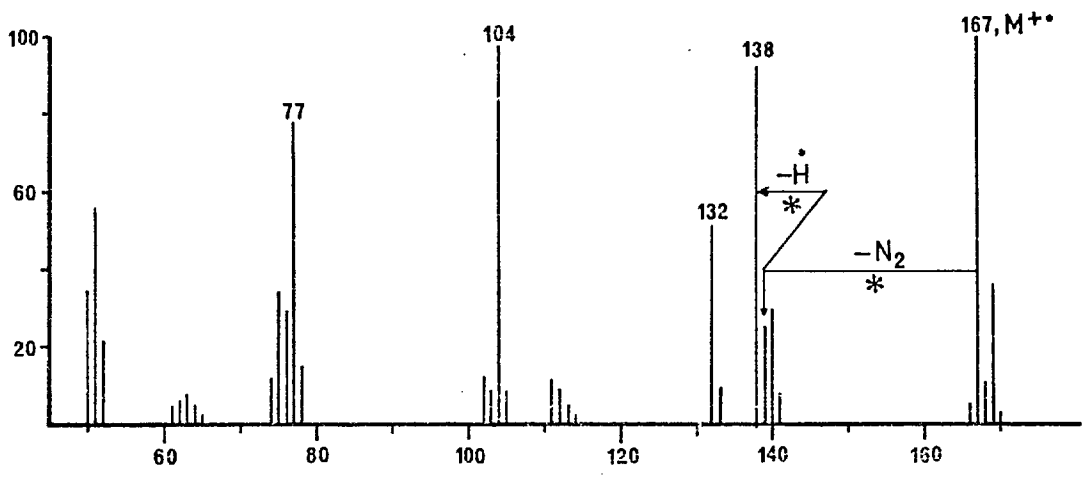
However, another pathway open to the ion (a) is the loss of H• with the production of the stable quinoid type of ion (e). In the case of the 4-methylbenzotriazoles because of steric factors the equilibrium between the two tautomeric forms will be shifted in favour of the 4-isomer and not the 7-isomer. As a result the fragmentation by the quinoid type of intermediate (f) would be of little importance. This additional fragmentation pathway for the 5-methylbenzotriazole accounts for the slightly greater stability, and ease of production of the ion m/e 104 in the mass spectra of the two methylbenzotriazoles. This is evidenced from the ratios in the first and last columns of table I.

The main fragmentation of the molecular ion of 4-methyl-5-chlorobenzotriazole (MS-6) and 5-methyl-6-chlorobenzotriazole (MS-7), analogous to the corresponding methylbenzotriazoles, is the loss of N₂ resulting in the ion m/e 139. Metastable ions at m/e 115.7 in the spectra of both compounds confirm this fragmentation. The (M-N₂)⁺ ion in the spectrum of the 4-methyl-5-chlorobenzotriazole undergoes two competitive metastable transitions. These involve losses of a hydrogen atom and a chlorine atom resulting in the ions m/e 138 and m/e 104. Metastable ions at m/e 137.0 and m/e 77.8 confirm these losses. In the spectrum of the 5-methyl-6-chloro-benzotriazole (MS-7), however, only the metastable ion at m/e 137.0 is observed suggesting that the loss of the hydrogen atom is more favoured in this compound. The metastable defocusing technique was employed to confirm the loss of the chlorine atom from the (M-N₂)⁺ in this compound.

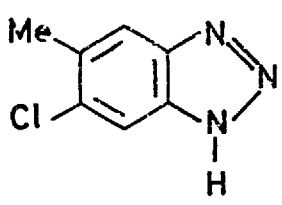
MS-6



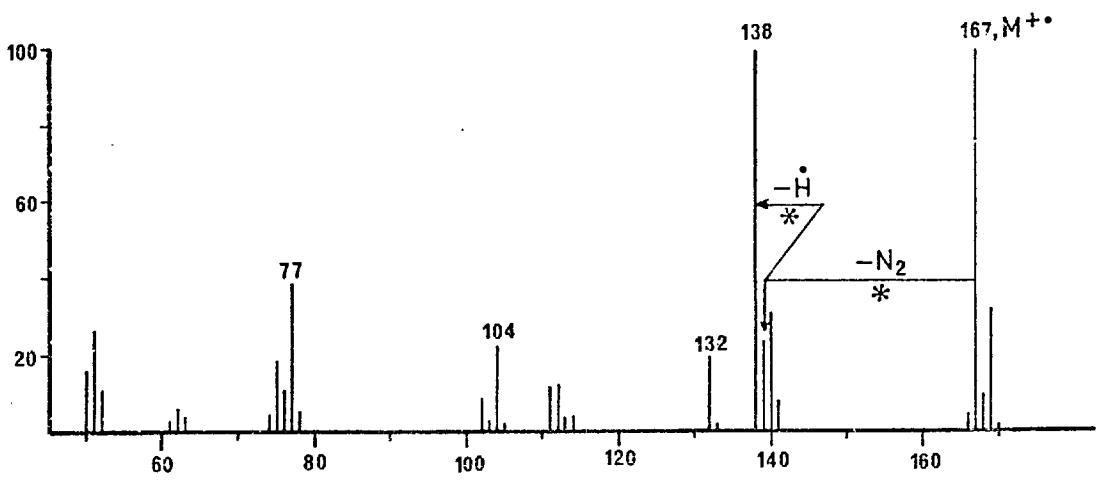
<u>m*</u>	<u>transition</u>	<u>loss</u>
137.0 :	139 $\longrightarrow$ 138	(H)
115.7 :	167 $\longrightarrow$ 139	(N ₂)
104.3 :	167 $\longrightarrow$ 132	(Cl)
89.3 :	133 $\longrightarrow$ 111	(HCN)
77.8 :	139 $\longrightarrow$ 104	(Cl)
75.4 :	138 $\longrightarrow$ 102	(HCl)
57.0 :	104 $\longrightarrow$ 77	(HCN)
55.1 :	102 $\longrightarrow$ 75	(HCN)



MS-7

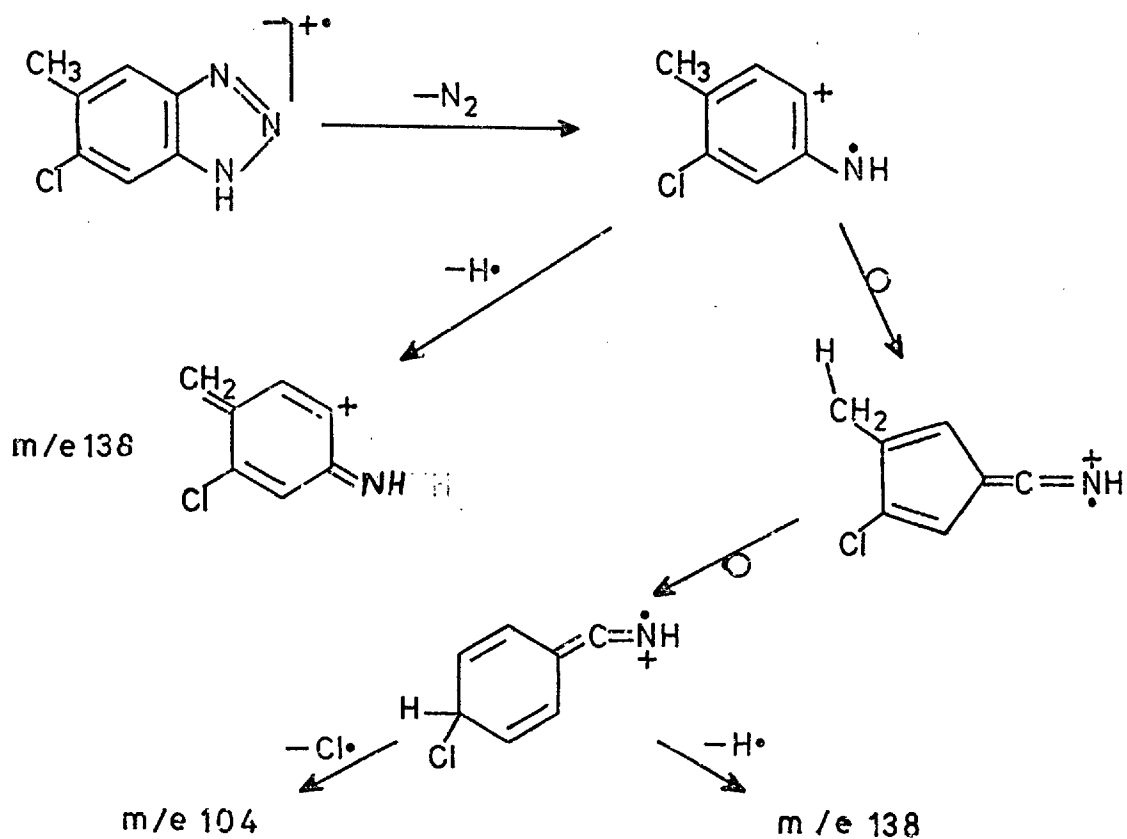


137.0 :	139 $\longrightarrow$ 138	(H)
115.3 :	167 $\longrightarrow$ 139	(N ₂)
104.3 :	167 $\longrightarrow$ 132	(Cl)
89.3 :	138 $\longrightarrow$ 111	(HCN)

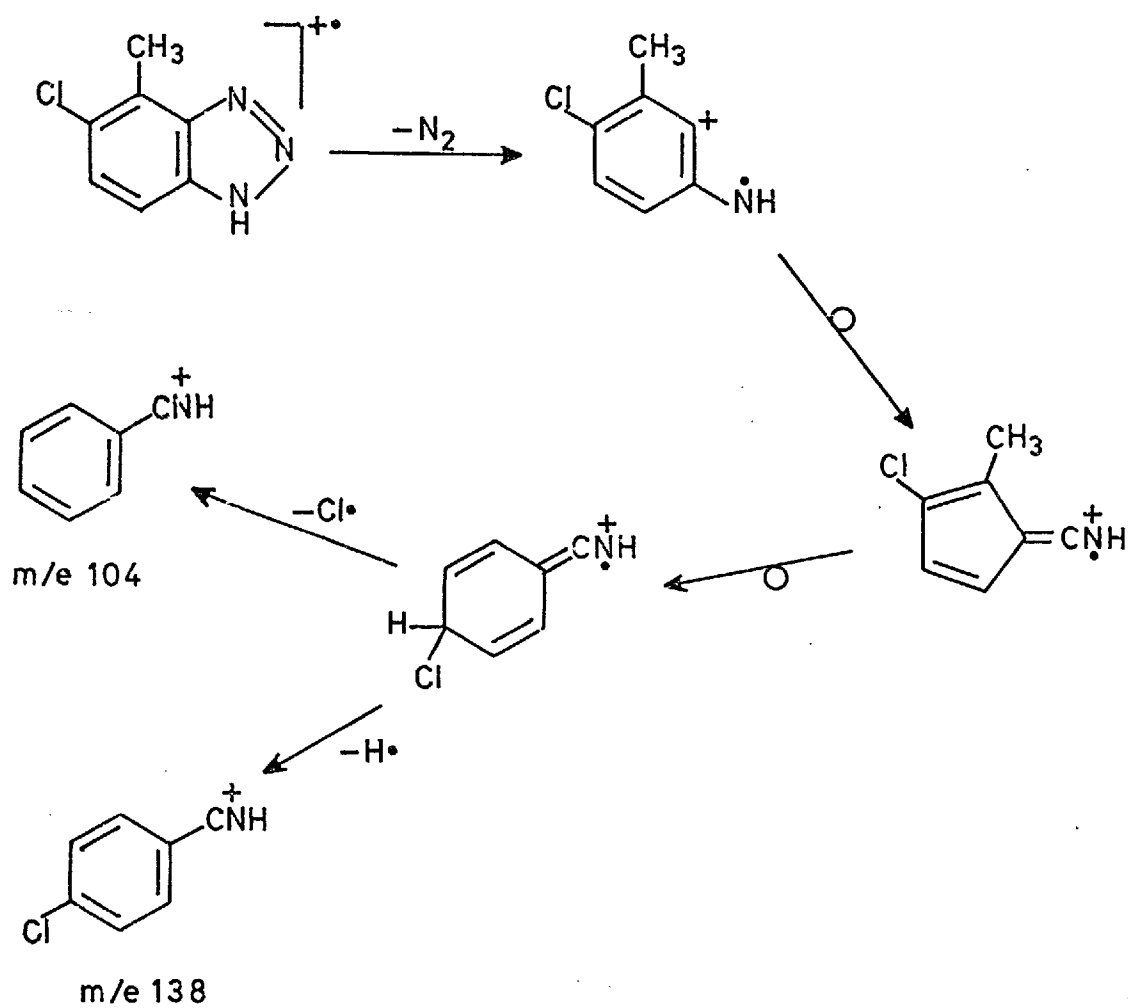


It has been shown that aromatic chlorides undergo facile loss of the halogen resulting in the most abundant fragment ion ¹²². The same is true for aromatic chlorides with a methyl group on the ring. However in the presence of alkyl groups larger than methyl the usual alkylbenzene β -cleavage starts to prevail. In other words the loss of a chlorine atom relative to the β -cleavage becomes unimportant. By analogy one would expect, therefore, in the mass spectra of the two chloromethyl-substituted benzotriazoles, the $(M-N_2)^{+}$ ion to lose a chlorine atom predominantly. The fact that the $(M-N_2)^{+}$ behaves differently in the spectra of the two methyl-chloro-benzotriazoles and also in contrast to the aromatic chloro compounds suggests that different mechanisms are involved.

By analogy to the fragmentation mechanism of 5-methyl-benzotriazole the $(M-N_2)^{+}$ ion in the case of the 5-methyl-6-chlorobenzotriazole loses a hydrogen atom by two mechanisms namely the ring contracted mechanism (Scheme II) (The chlorine atom is more likely to be lost through this mechanism; see below) and the quinoid mechanism (Scheme III). From the relative intensities of the ions m/e 138 and m/e 104 Table II, it is apparent that the latter mechanism prevails (Scheme IV). Because of steric hindrance the loss of $H\cdot$ from the $(M-N_2)^{+}$ in the spectrum of the 4-methyl-5-chlorobenzotriazole predominately occurs via the ring contracted mechanism; this mechanism also accounts for the approximately equal loss of the $H\cdot$ and $Cl\cdot$ (Scheme V).



SCHEME IV



SCHEME V

TABLE II

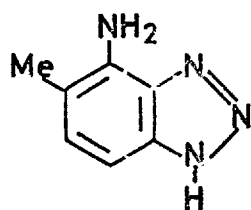
Partial spectra of 4-methyl-5-chloro- and
5-methyl-6-chloro-benzotriazoles

Compounds	Relative intensities % *		
	m/e 139	m/e 138	m/e 104
4-methyl-5-chloro-benzotriazole	26	93	98
5-methyl-6-chloro-benzotriazole	24	100	22

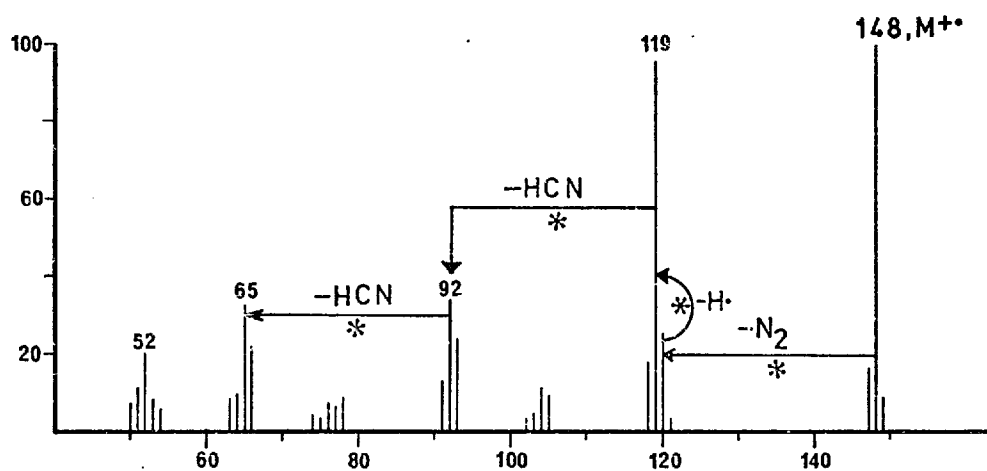
* The base peak is the molecular ion.

The mass spectra of the amino-methyl-benzotriazoles show the same type of fragmentation patterns described for the methylbenzotriazoles. The molecular ions in both the 4-amino-5-methyl (MS-8) and 4-amino-6-methyl-benzotriazoles (MS-9) show the loss of N_2 followed by elimination of a hydrogen atom resulting in the ions m/e 120 and m/e 119 respectively. Both these ions undergo consecutive metastable fragmentations of two molecules of HCN resulting in the ions m/e 93, m/e 92, m/e 66 and m/e 65. The metastable fragmentations and the corresponding metastable ions for both amino-derivatives are listed in table III.

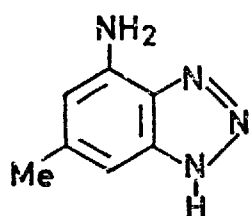
MS-8



m^+	transition	loss
118.0	: 120 $\longrightarrow$ 119	(H)
97.3	: 148 $\longrightarrow$ 120	(N ₂)
72.1	: 120 $\longrightarrow$ 93	(HCN)
71.1	: 119 $\longrightarrow$ 92	(HCN)
46.8	: 93 $\longrightarrow$ 66	(HCN)
45.9	: 92 $\longrightarrow$ 65	(HCN)



MS-9



118.0	: 120 $\longrightarrow$ 119	(H)
97.3	: 148 $\longrightarrow$ 120	(N ₂)
72.1	: 120 $\longrightarrow$ 93	(HCN)
71.1	: 119 $\longrightarrow$ 92	(HCN)
46.8	: 93 $\longrightarrow$ 66	(HCN)
45.9	: 92 $\longrightarrow$ 65	(HCN)

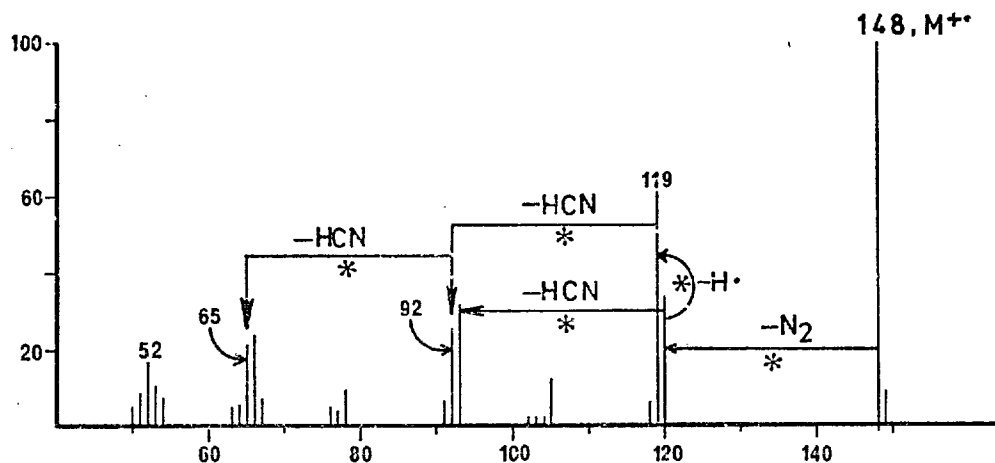
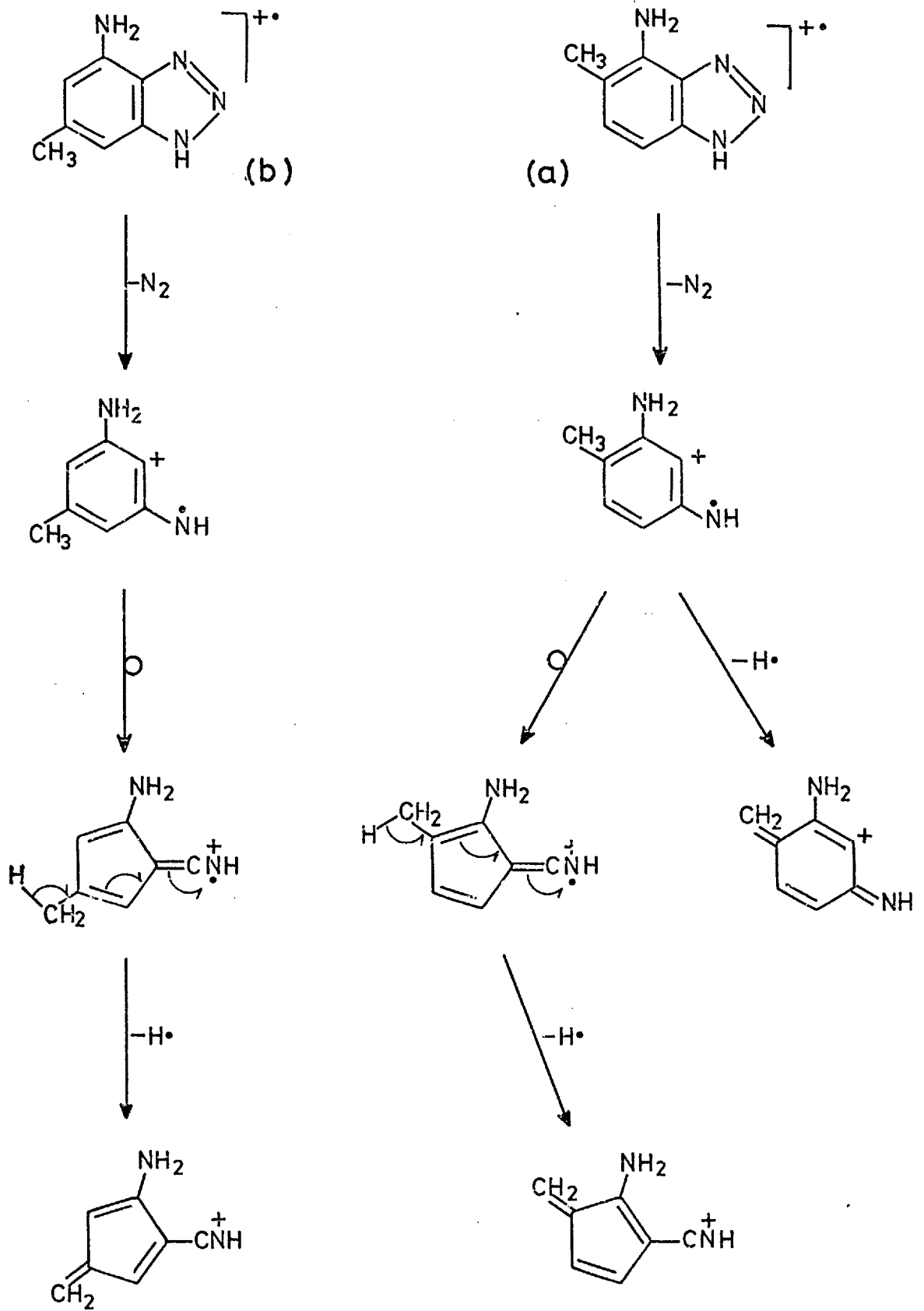


TABLE III

Metastable fragmentation	Fragment lost	Metastable ion m/e
$M^{+\bullet} \longrightarrow m/e\ 120$	N_2	97.3
$m/e\ 120 \longrightarrow m/e\ 119$	H	118.0
$m/e\ 120 \longrightarrow m/e\ 93$	HCN	72.1
$m/e\ 119 \longrightarrow m/e\ 92$	HCN	71.1
$m/e\ 93 \longrightarrow m/e\ 66$	HCN	46.8
$m/e\ 92 \longrightarrow m/e\ 65$	HCN	45.9

Comparison of the relative intensities of the ions $m/e\ 119$ and $m/e\ 120$ in the two spectra suggests that the loss of hydrogen from the $(M-N_2)^{+\bullet}$ ion does not follow the same course. Another difference in the two spectra is that the molecular ion of 4-amino-5-methylbenzotriazole shows a loss of a hydrogen atom whereas the 4-amino-6-methyl-derivative does not.

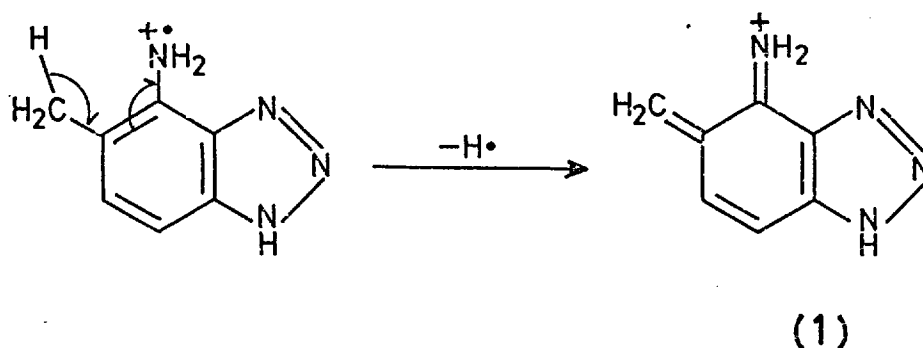
The larger relative intensity of the ion $m/e\ 119$ in the spectrum of 4-amino-5-methylbenzotriazole can be explained using the same argument which accounted for a similar observation in the spectra of 5-methyl- and 5-methyl-6-chloro-benzotriazoles. Because of steric hindrance the preferred tautomers of the 4-amino-5-methyl- and 4-amino-6-methyl-benzotriazoles would be the structures (a) and (b) respectively. The structure (a) can lose a hydrogen atom via the ring contracted mechanism or the quinoid mechanism,



SCHEME VI

whereas the structure (b) loses H• only via the ring contracted mechanism Scheme VI.

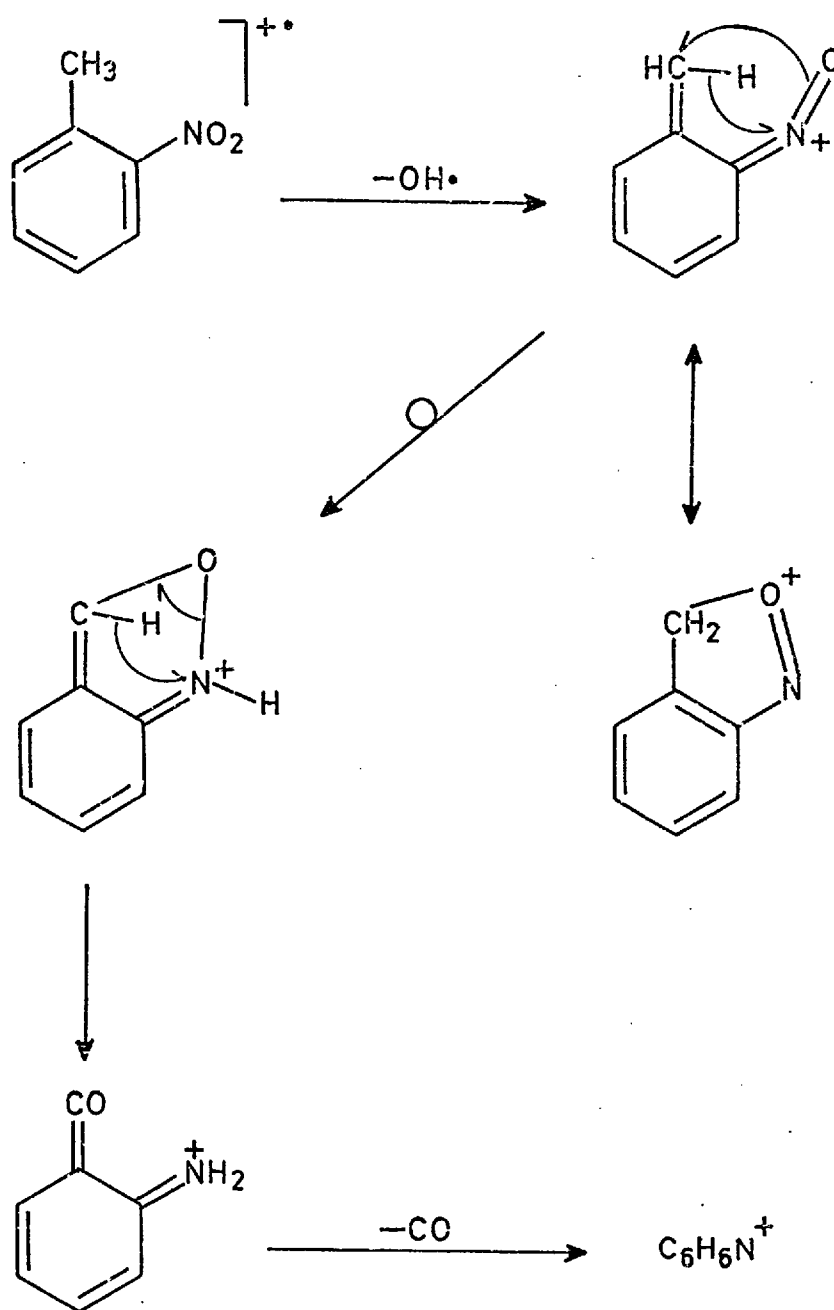
The fact that the molecular ion of 4-amino-5-methyl-benzotriazole shows a loss of a hydrogen atom may be justified since such a loss is accompanied by stabilization of the product ion by the following quinoid type of structure (1)



Since no such stabilization of product ion is possible for the (M-1)⁺ ion in the case of 4-amino-6-methylbenzotriazole, the molecular ion does not undergo this fragmentation.

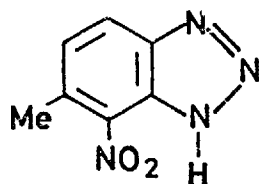
The mass spectra of the methyl-nitro-substituted benzotriazoles are generally complicated. This complication arises from a number of factors. Nitro aromatic compounds undergo a number of competitive fragmentations; namely the losses of oxygen, NO and NO₂ from the molecular ion. When the methyl and the nitro groups are ortho to each other the molecular ion shows mainly the loss of a hydroxyl radical followed by expulsion of carbon monoxide. By ¹³C labeling it has been shown ¹²³ that the carbon atom lost as CO is the original methyl carbon. The

mechanism in scheme VII has been suggested for this fragmentation¹²⁴.

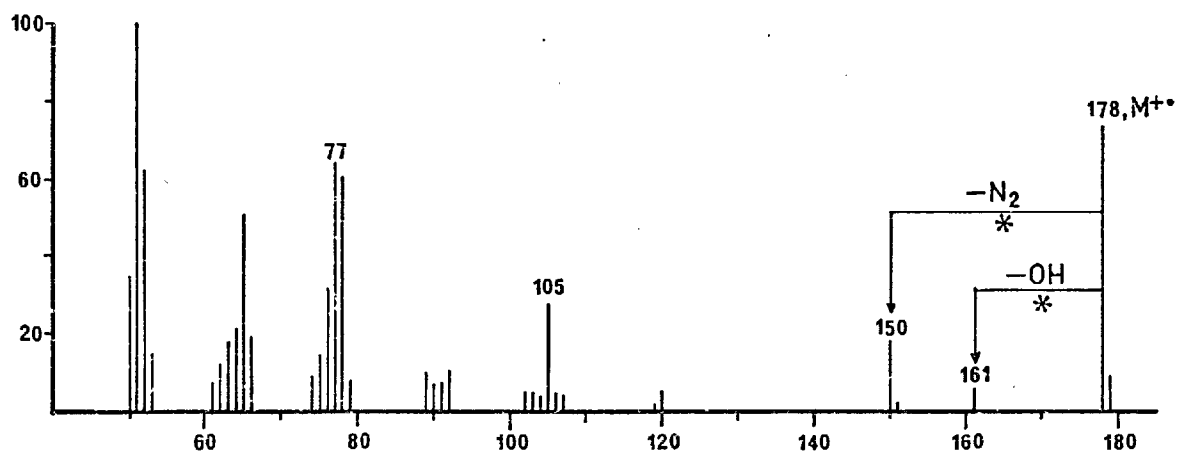


SCHEME VII

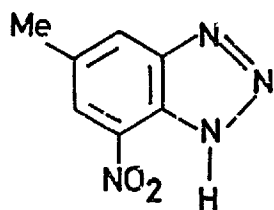
MS-10



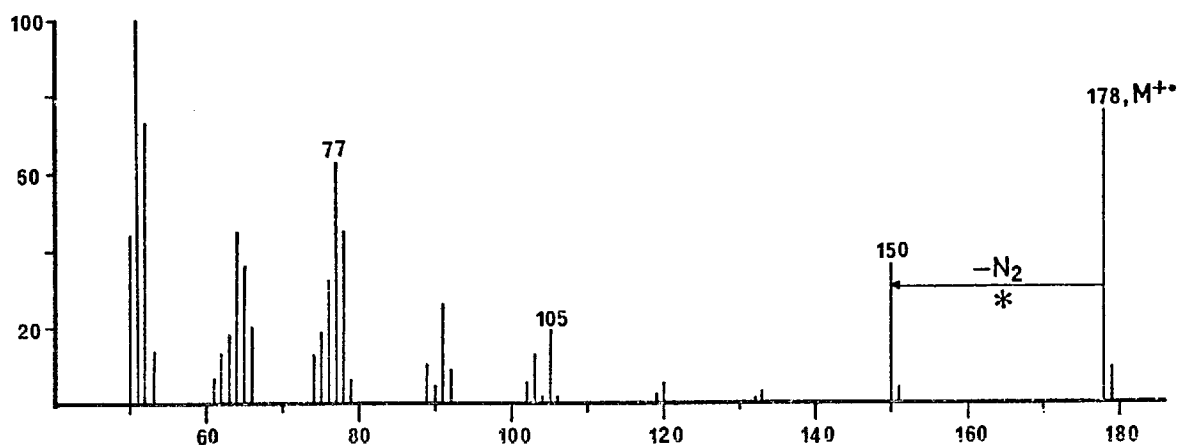
<u>m*</u>	<u>transition</u>	<u>loss</u>
145.6	: 178 → 161	(OH)
126.4	: 178 → 150	(N ₂)
57.9	: 105 → 78	(HCN)
45.9	: 92 → 65	(HCN)
33.8	: 77 → 51	(C ₂ H ₂)
33.3	: 78 → 51	(HCN)



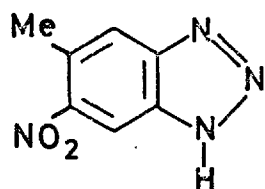
MS-11



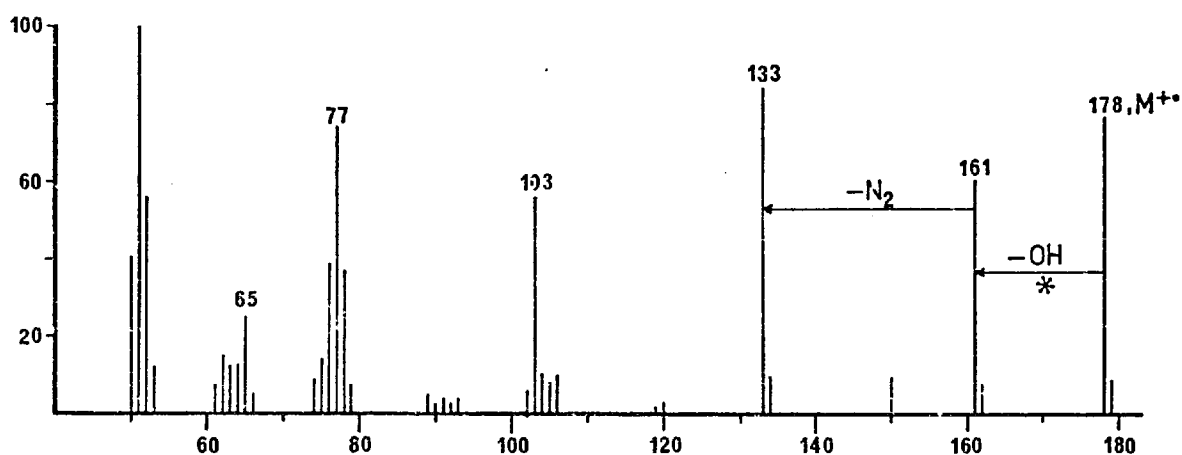
126.4	: 178 → 150	(N ₂)
57.9	: 105 → 78	(HCN)
56.1	: 103 → 76	(HCN)
33.8	: 77 → 51	(C ₂ H ₂)
33.3	: 78 → 51	(HCN)
32.9	: 76 → 50	(C ₂ H ₂)



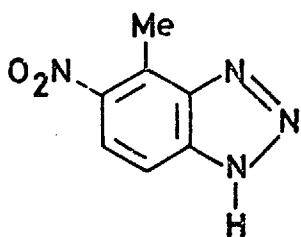
MS-12



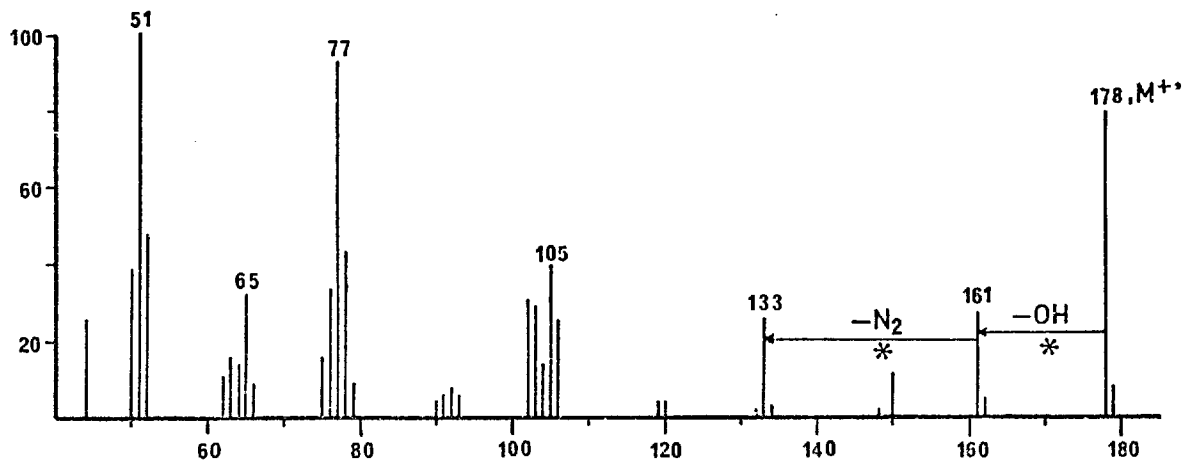
<u>m*</u>	<u>transition</u>	<u>loss</u>
145.6	: 178 → 161	(OH)
126.4	: 178 → 150	(N ₂)
56.1	: 103 → 76	(HCN)
45.9	: 92 → 65	(HCN)
33.8	: 77 → 51	(C ₂ H ₂)
33.3	: 78 → 51	(HCN)
32.9	: 76 → 50	(C ₂ H ₂)



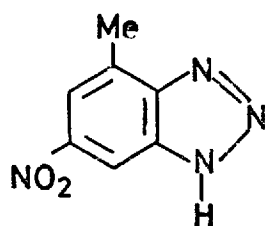
MS-13



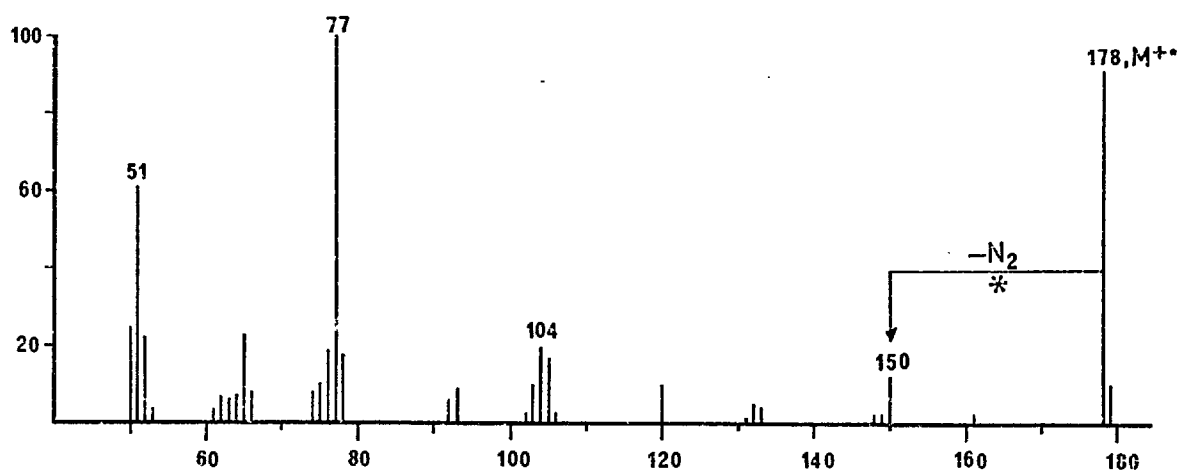
145.6	: 178 → 161	(OH)
126.4	: 178 → 150	(N ₂)
109.9	: 161 → 133	(N ₂)
33.8	: 77 → 51	(C ₂ H ₂)
33.3	: 78 → 51	(HCN)



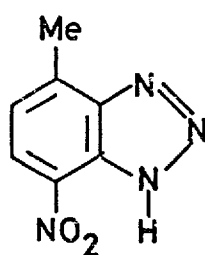
MS - 14



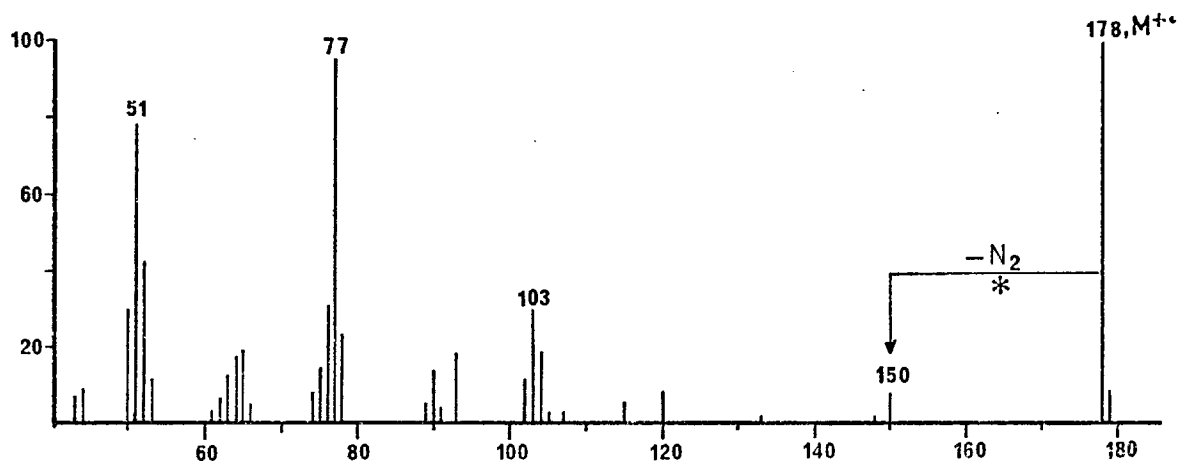
<u>m*</u>	<u>transition</u>	<u>loss</u>
126.4 : 178	→ 150	(N ₂)
123.1 : 178	→ 148	(NO)
80.9 : 178	→ 120	(NO ₂)
57.9 : 105	→ 78	(HCN)
57.0 : 104	→ 77	(HCN)
56.1 : 103	→ 76	(HCN)
33.8 : 77	→ 51	(C ₂ H ₂)
33.3 : 78	→ 51	(HCN)



MS - 15



126.4 : 178	→ 150	(N ₂)
72.1 : 120	→ 93	(HCN)
57.0 : 104	→ 77	(HCN)
56.1 : 103	→ 76	(HCN)
33.8 : 77	→ 51	(C ₂ H ₂)
33.3 : 78	→ 51	(HCN)
32.9 : 76	→ 50	(C ₂ H ₂)



The mass spectra of some nitro-benzotriazoles have already been investigated⁶¹ (see review, page 62). Like nitro aromatic compounds introduction of a methyl group in the benzene ring complicates the fragmentation pattern. In the high mass region, however, some generalizations can be made in regard to the primary fragmentation of the molecular ion of the nitro-methyl-benzotriazoles.

The molecular ions in all these compounds lose N_2 resulting in the ion m/e 150. The extent of this loss is very much dependent on the position of the nitro group relative to the methyl group and the triazolo ring. When the nitro group is ortho to the methyl group the molecular ion, besides the loss of N_2 , undergoes the competitive loss of a hydroxyl radical. In the mass spectrum of ortho-nitroaniline analogous to o-nitrotoluene the molecular ion shows a loss of a hydroxyl radical presumably via an analogous mechanism¹²⁵. As a result it might be anticipated that when the nitro group is in the ortho position to the triazolo ring the molecular ion should show a loss of $\cdot OH$. However this loss is not observed in the mass spectra of 4-methyl-7-nitro- and 5-methyl-7-nitro-benzotriazoles (MS-15 and MS-11, respectively) suggesting that the loss of N_2 is a more favourable process.

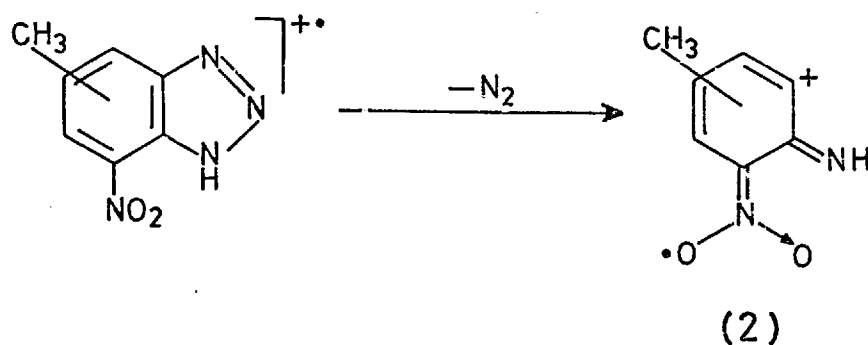
The loss of N_2 from the molecular ion in all the methyl-nitro-benzotriazoles is accompanied by a sharp metastable ion at m/e 126.4. Comparison of the ratio of the metastable ion to precursor ion intensities for the loss of N_2 from the molecular ion (Table IV) shows that when the ortho-nitro-methyl moiety is present the loss of N_2 relative to $\cdot OH$ becomes less pronounced.

TABLE IV

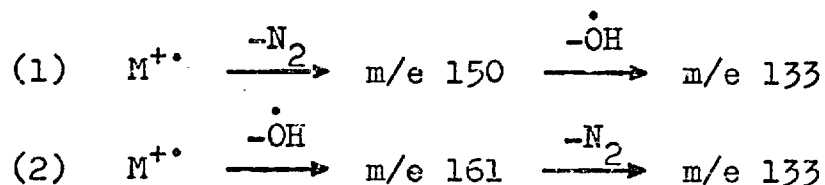
Metastable ion to precursor ion intensity ratio
for the reaction $M^{+\bullet} \longrightarrow (M-N_2)^{+\bullet}$ in
methyl-nitro-benzotriazoles

Compound	Mass spectrum number	$m^*/M^{+\bullet}$
4-methyl-5-nitro	MS - 13	6.55×10^{-4}
6-methyl-5-nitro	MS - 12	6.04×10^{-4}
6-methyl-7-nitro	MS - 10	7.05×10^{-4}
4-methyl-6-nitro	MS - 14	11.08×10^{-4}
5-methyl-7-nitro	MS - 11	13.6×10^{-4}
4-methyl-7-nitro	MS - 15	18.9×10^{-4}

The ratios in table IV also show that when the nitro group is ortho to the triazolo ring (i.e. position 7) the loss of N_2 from the molecular ion becomes relatively more facile. This may be justified since the product ion in such cases can be stabilized by a quinoid type of structure (2).

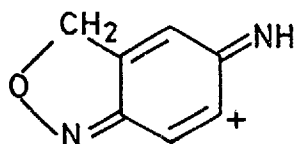


The mass spectra of the methyl-nitrobenzotriazoles exhibit an ion at m/e 133. Mass measurement has shown that this ion is $(C_7H_5N_2O)^+$. Metastable defocusing indicates that this ion is produced by one or both of the following processes.

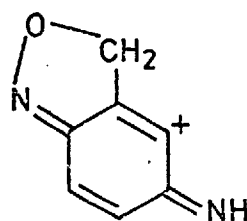


In the cases of 6-methyl-5-nitro-, 4-methyl-5-nitro- and 6-methyl-7-nitro-benzotriazoles (MS-12, MS-13 and MS-10 respectively) both processes contribute to the production of the ion m/e 133. Whereas in the cases of 5-methyl-7-nitro- and 4-methyl-7-nitro-benzotriazoles (MS-11 and MS-15 respectively) only process (1) is responsible.

The larger relative intensity of the ion m/e 133 in the spectra of 6-methyl-5-nitro- and 4-methyl-5-nitro-benzotriazoles may be attributed to the stabilization of the product ion through structures like (3 and 4).

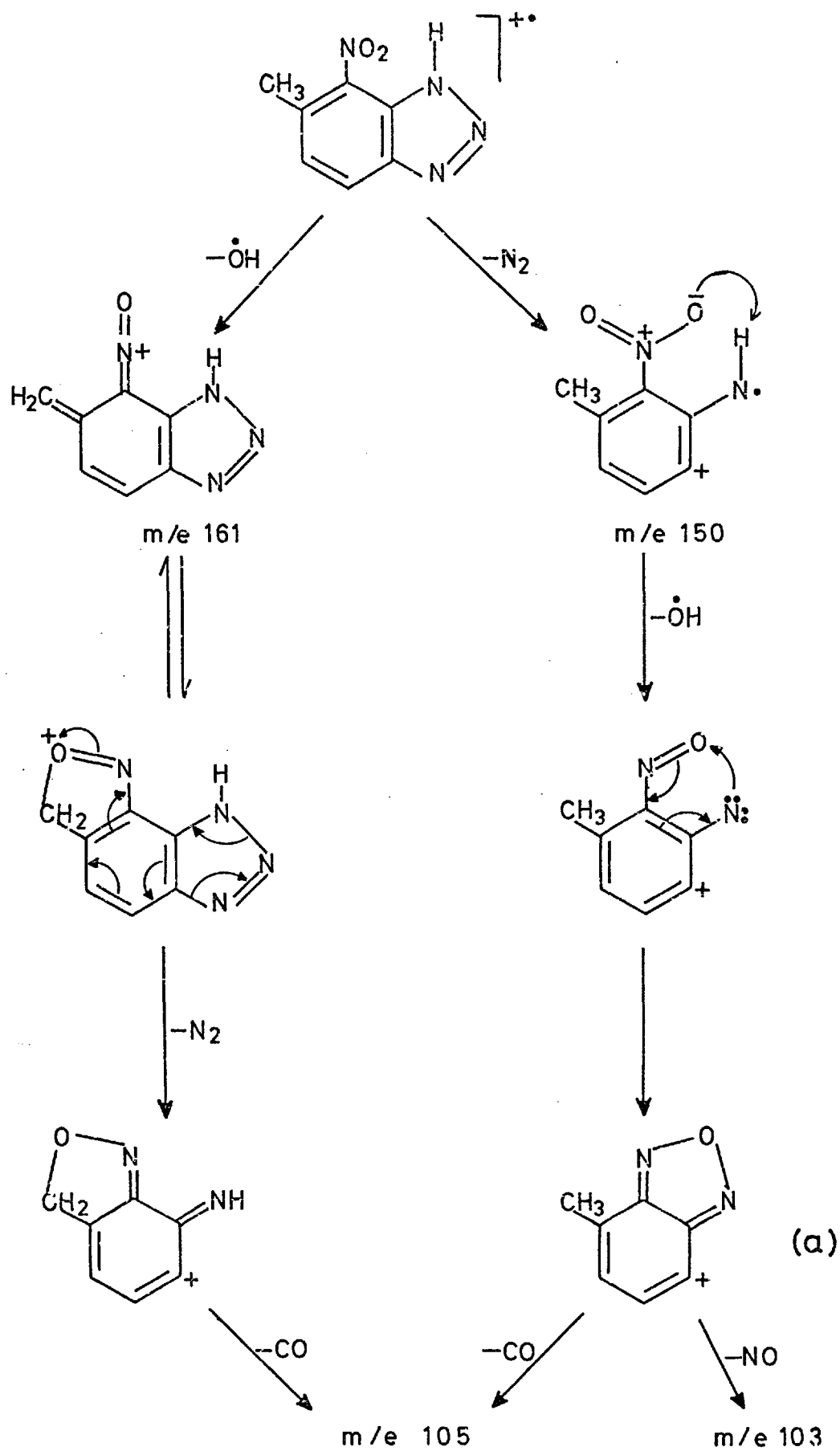


(3)



(4)

The loss of $\dot{O}H$ from the ion m/e 150 in the spectrum of 6-methyl-7-nitro-benzotriazole may result from analogous processes suggested for the loss of $\cdot OH$ from ortho-nitro-toluene¹²⁵ and ortho-nitro-aniline¹²⁵. The



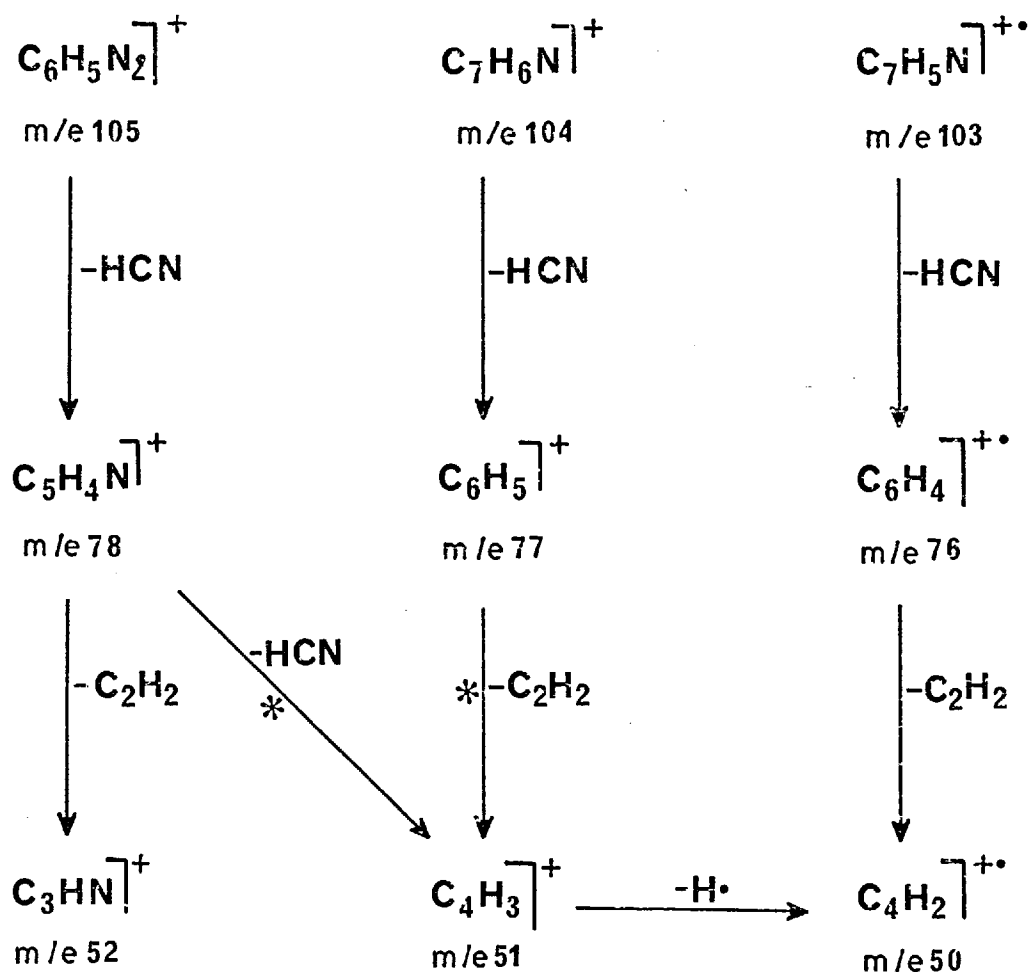
SCHEME VIII

loss of CO from the ion m/e 133 may be accounted for if the loss of $\cdot\text{OH}$ follows the course of ortho-nitrotoluene. Whereas the loss of NO from the ion m/e 133 would prevail if the hydroxyl radical is lost via the mechanism suggested for the ortho-nitroaniline. It may be that this latter process, i.e. consecutive loss of OH and NO, is responsible for the low relative intensity of the ion m/e 133 in this compound. Scheme VIII.

An analogous mechanism to that described in scheme VIII may account for the low intensity of the ion m/e 133 and also the production of the ions m/e 105 and m/e 103 by losses of CO and NO respectively in the mass spectrum of 5-methyl-7-nitrobenzotriazole. The peculiar loss of CO from the benzofurazan structure (a) in scheme VIII will be discussed in connection with the mass spectra of benzofurazans.

Metastable defocusing has shown the ion m/e 103 in the spectra of 6-methyl-5-nitro- (MS-12) and 4-methyl-5-nitro-benzotriazoles (MS-13) to originate from the ion m/e 150. Mass measurements have confirmed this loss to correspond to HNO_2 . In the spectra of the 4-methyl-7-nitro- (MS-15) and 4-methyl-6-nitro-benzotriazoles (MS-14) this loss is observed as a loss of $\text{H}\cdot$ followed by $\text{NO}_2^\bullet$. The m/e 150 ion in the latter two compounds also shows a loss of NO_2 resulting in the peak m/e 104, in other words a typical aromatic-nitro-fragmentation, suggesting that the nitro group does not get involved in rearrangements as much as in the other isomeric compounds.

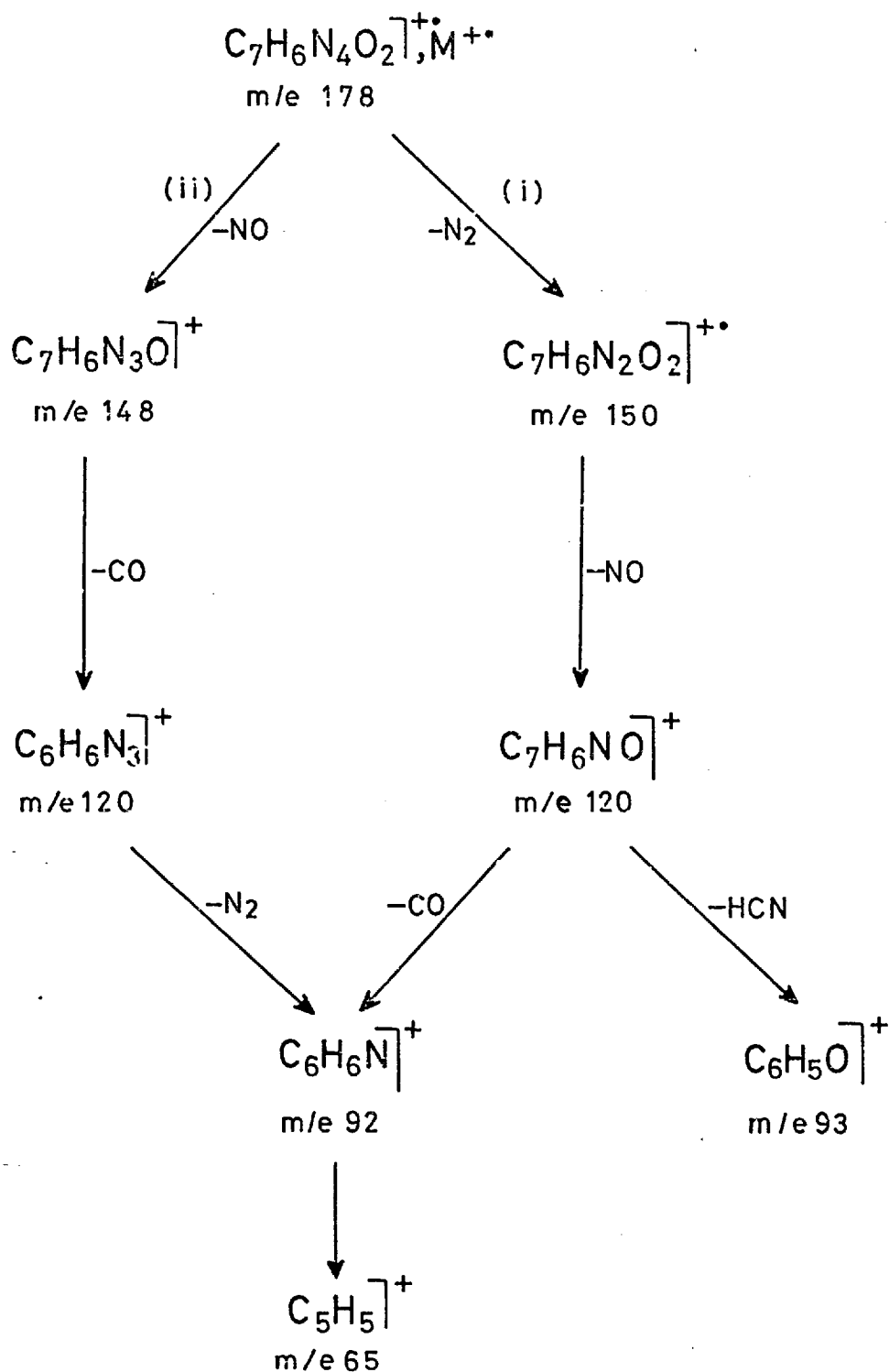
The fragmentation sequences which are in common in the lower mass region of the mass spectra of the methyl-nitro-benzotriazoles are shown in scheme IX. These fragmentations were confirmed by metastable defocusing technique.



* metastable transition

SCHEME IX

Finally, all methyl-nitro-benzotriazoles show a combination of losses which are observed in nitro-aromatic compounds and benzotriazoles. These are best illustrated in Scheme X. All the processes were confirmed by metastable defocusing.



SCHEME X

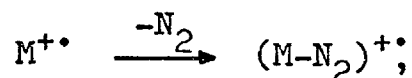
The fragmentation sequence (ii) in scheme X is observed only in the mass spectrum of 4-methyl-6-nitro-benzotriazole. This is in agreement with the previous suggestion that the nitro group in this compound, being

away from both the methyl group and the triazolo ring, does not get involved with rearrangement reactions through ortho-effects.

The ionization potential of a substituted benzo-triazole is largely dependent on the nature of the substituent. It is known that electron withdrawing groups increase the value of I.P. whereas electron donating groups decrease the value of IP of a molecule ¹²⁶.

The IP and AP values for the production of the molecular ion and the $(M-N_2)^+$ ion, respectively, were found using the critical slope method and are listed in table V. As expected the IP values are largest for benzotriazoles with a nitro group in the benzene ring whereas lowest values were found for the compounds with amino group in the benzene ring.

The energies of activation (E_a) for the reaction,



are also listed in table V. The values of (E_a) are calculated by subtracting the IP values from the corresponding AP values. The (E_a) values calculated in this way only roughly represent the true values (see review pp 4-8) however, for the purpose of comparison these values may be considered as good approximations.

The approximately equal values of E_a (within experimental error) for the substituted benzotriazoles (with the exception of amino derivatives) strongly suggest that the energy required for the loss of N_2 is independent of the substituent. The large (E_a) values for the amino

derivatives however indicate that the activation energy for the loss of N_2 in these compounds is dependent on the stability of the molecular ion. Therefore the high value of (E_a) in the case of the amino derivatives is probably not surprising if one considers that the aromatic amines generally have high intensity, stable molecular ions because of the stabilization of the radical by delocalization in the ring ¹²⁷ (structures 6-7).

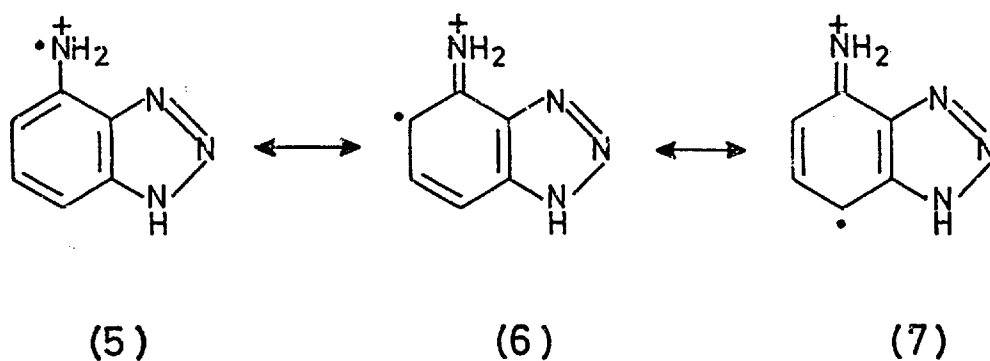
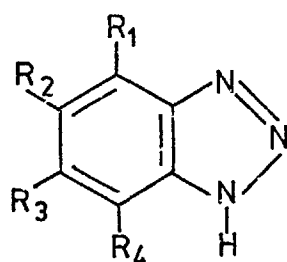


TABLE V

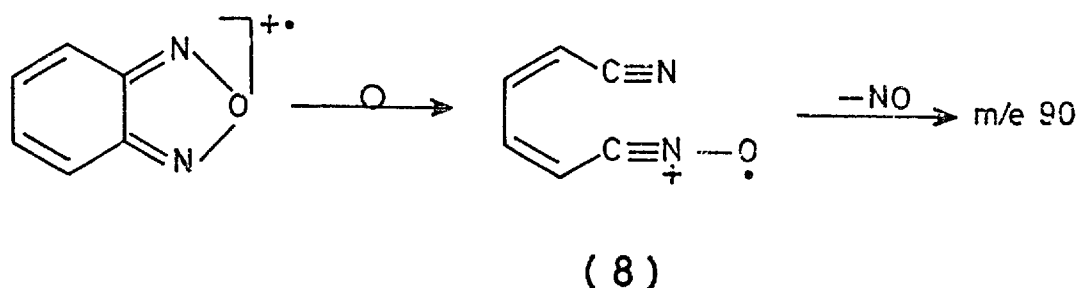


Compound				(ev)			
R ₁	R ₂	R ₃	R ₄	IP(M) ⁺⁺	AP(M-N ₂) ⁺⁺	E _a	AP(M-N ₂ -H) ⁺
-	-	-	-	9.04	10.54	1.50	-
CH ₃	-	-	-	8.63	9.93	1.30	11.53
-	CH ₃	-	-	8.98	10.23	1.25	11.83
CH ₃	Cl	-	-	8.53	9.98	1.45	11.23
-	CH ₃	Cl	-	8.83	10.13	1.30	11.53
-	CH ₃	CH ₃	-	8.44	9.54	1.10	11.44
CH ₃	NO ₂	-	-	9.43	10.88	1.45	-
CH ₃	-	NO ₂	-	9.58	10.73	1.15	-
CH ₃	-	-	NO ₂	9.73	11.03	1.30	-
-	-	CH ₃	NO ₂	9.53	10.68	1.15	-
-	CH ₃	NO ₂	-	9.58	10.73	1.15	-
NH ₂	CH ₃	-	-	7.14	9.84	2.70	10.28
-	CH ₃	-	NH ₂	7.60	10.25	2.65	11.80

BENZOFURAZANS

The mass spectra of benzofurazans have not been discussed to any detail. Although the mass spectrum of the parent compound has been reported^{60,61} no fragmentation mechanisms have been proposed.

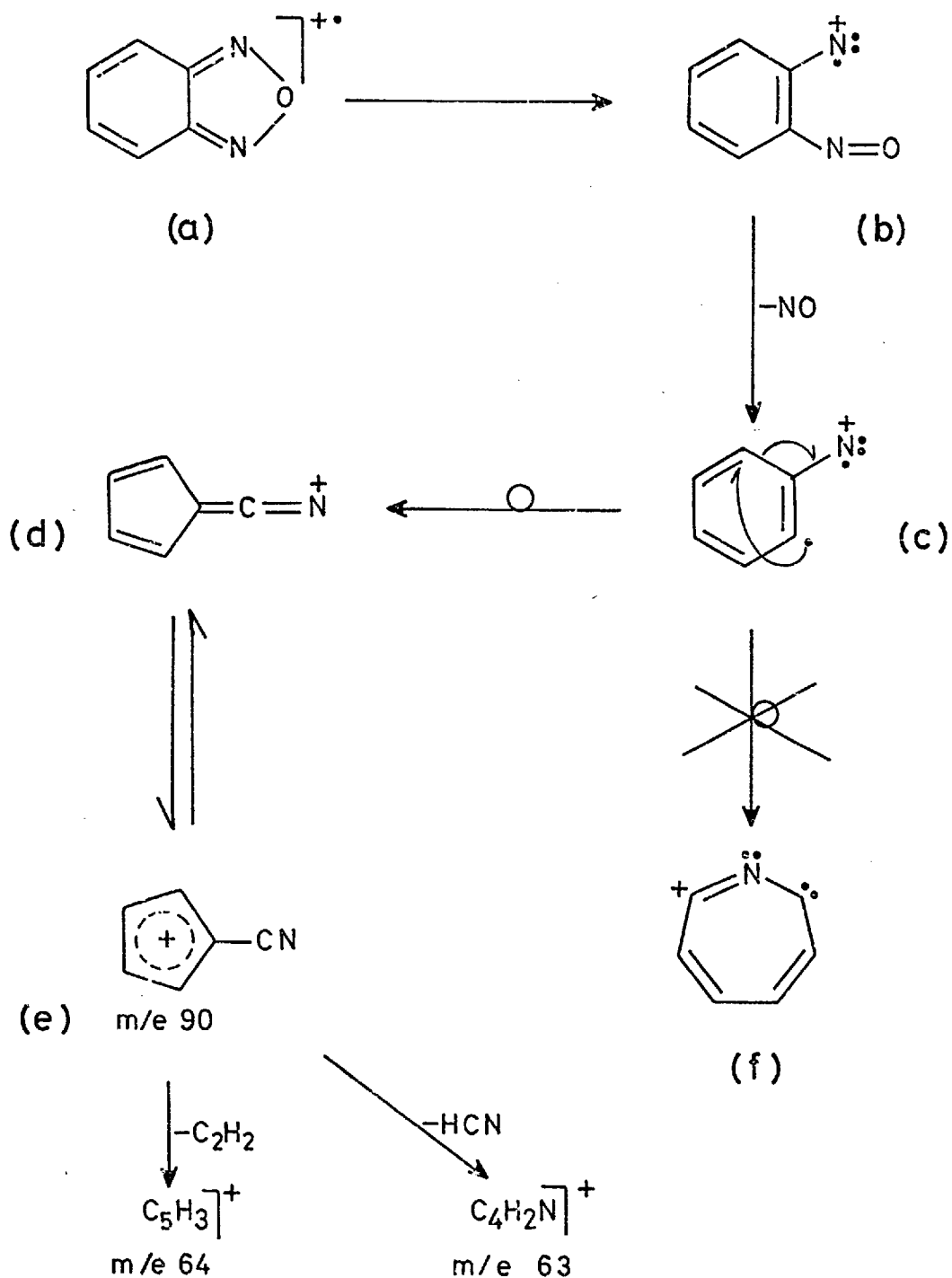
The main fragmentation of these compounds under electron impact involves the facile loss of NO from the molecular ion. By analogy to the photolytic cleavage⁷¹ the first step in the fragmentation may involve the formation of a nitrile oxide (8) which could then lose nitric oxide.



The mass spectra of nitrile oxides are not known. However, it is reasonable to assume that like other N-oxides they would lose an oxygen atom. Since no loss of oxygen is observed in the mass spectrum of benzofurazan, even if the nitrile oxide intermediate is involved in the loss of NO its contribution is probably very small.

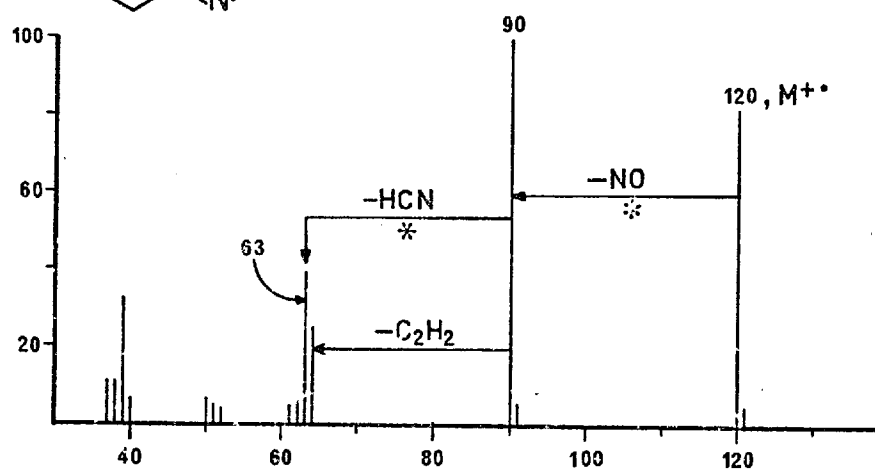
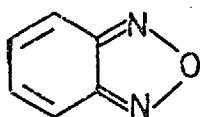
The loss of NO from the molecular ion is accompanied by a metastable ion at m/e 67.5. The sharpness of this metastable ion suggests that the loss of NO from the molecular ion is not accompanied by release of kinetic

energy. In other words the ion m/e 90 in the spectrum of benzofurazan (MS-16) is produced with excess energy. A possible mechanism for the fragmentation of benzofurazan under electron impact is shown in Scheme XI.

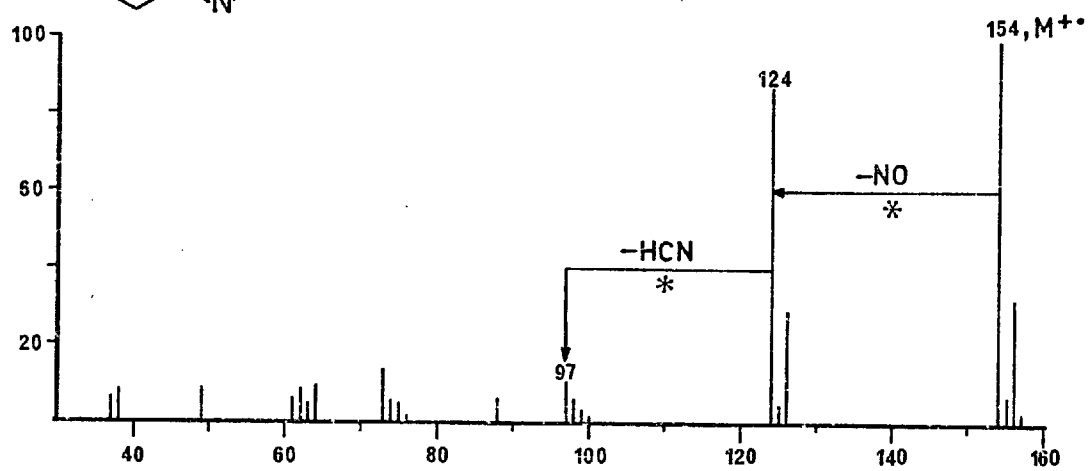
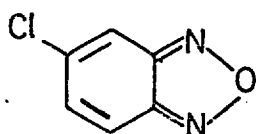


SCHEME XI

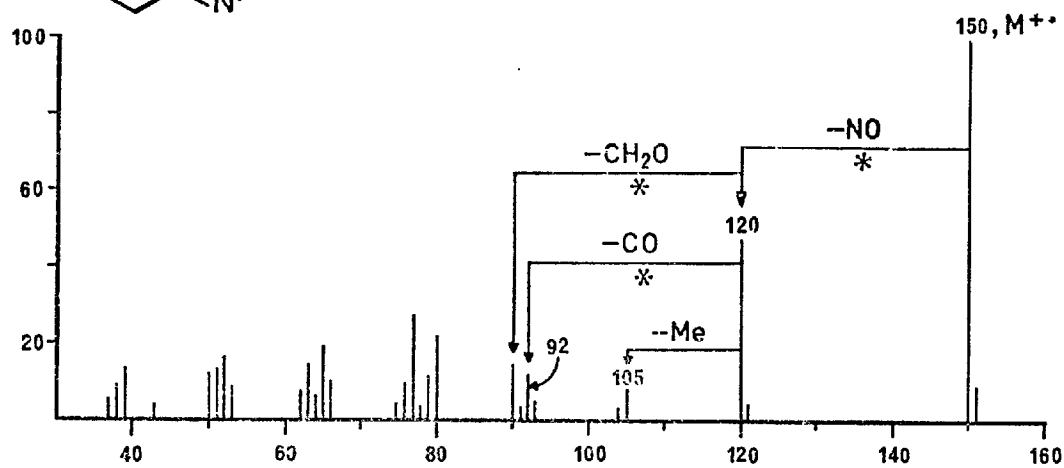
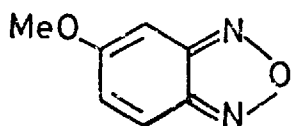
MS-16



MS-17



MS-18



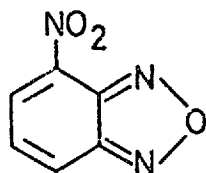
It has been suggested that aromatic nitrenes undergo not ring contraction, but ring expansion with resultant stabilization through an azatropylium ion⁵⁵. However the ion (c) is not isoelectronic with phenyl-nitrene and therefore it is not expected to behave like it. This ion is however isoelectronic with the (M-H)⁺ ion of the cyanocyclopentadiene (e) which may justify the rearrangement process (c) $\rightarrow$ (d) in scheme XI.

Introduction of a simple substituent like a chlorine atom into the benzene ring does not alter the fragmentation pattern to any appreciable extent. In other words the molecular ion of 5-chlorobenzofurazan (MS-17) undergoes facile loss of NO followed by expulsion of HCN and/or C₂H₂.

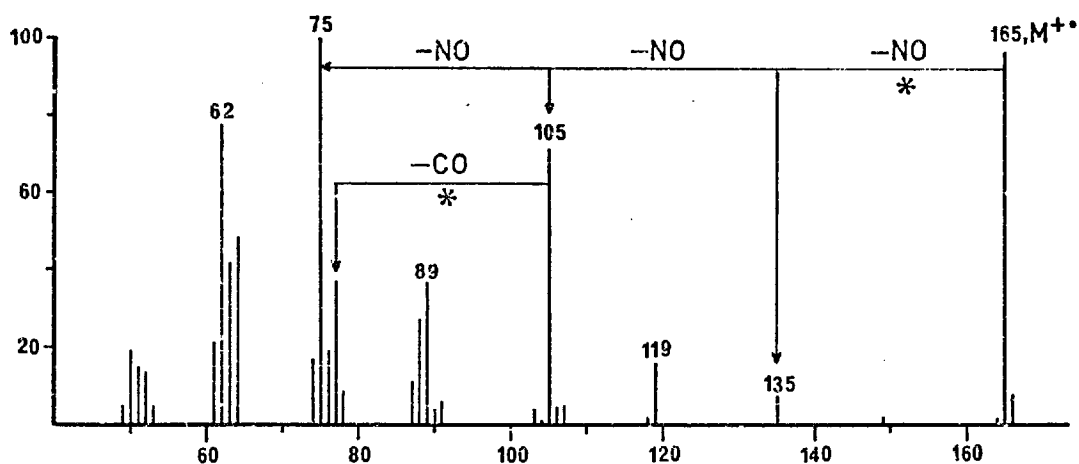
The most intense peak in the spectrum of 5-methoxybenzofurazan (MS-18) is the molecular ion. This ion shows a metastable loss of NO resulting in the ion m/e 120 (C₇H₆NO)⁺ which undergoes fragmentation typical of aromatic methoxides¹²⁹, namely losses of CO, CH₂O and CH₃ resulting in the ions at m/e 92, m/e 90 and m/e 105, respectively.

The mass spectra of nitro-substituted benzofurazans are more complicated. The complication arises because of the number of competitive fragmentations due to aromatic nitro-compounds and the benzofurazan itself. Both 4- and 5-nitrobenzofurazans (MS-19 and MS-20 respectively) show loss of an oxygen atom resulting in the ion m/e 149 (relative intensities of approximately 2%). The molecular ions in both compounds also show losses of NO and NO₂ giving rise to the ions m/e 135 and m/e 119.

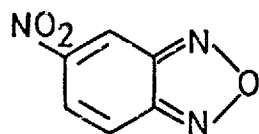
MS-19



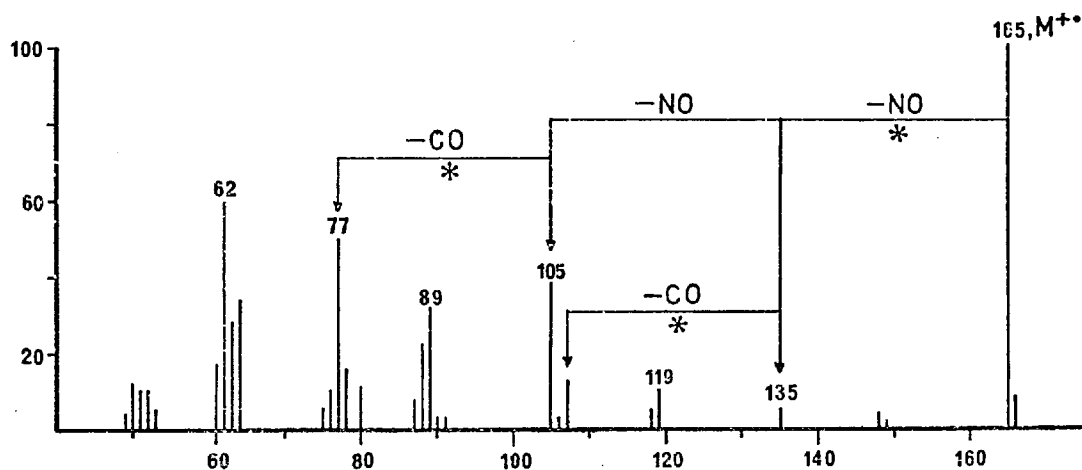
<u>m*</u>	<u>transition</u>	<u>loss</u>
110.4	: 165 → 135	(NO)
69.6	: 119 → 91	(CO)
52.5	: 105 → 77	(CO)
43.2	: 89 → 62	(HCN)
32.5	: 77 → 50	(HCN)

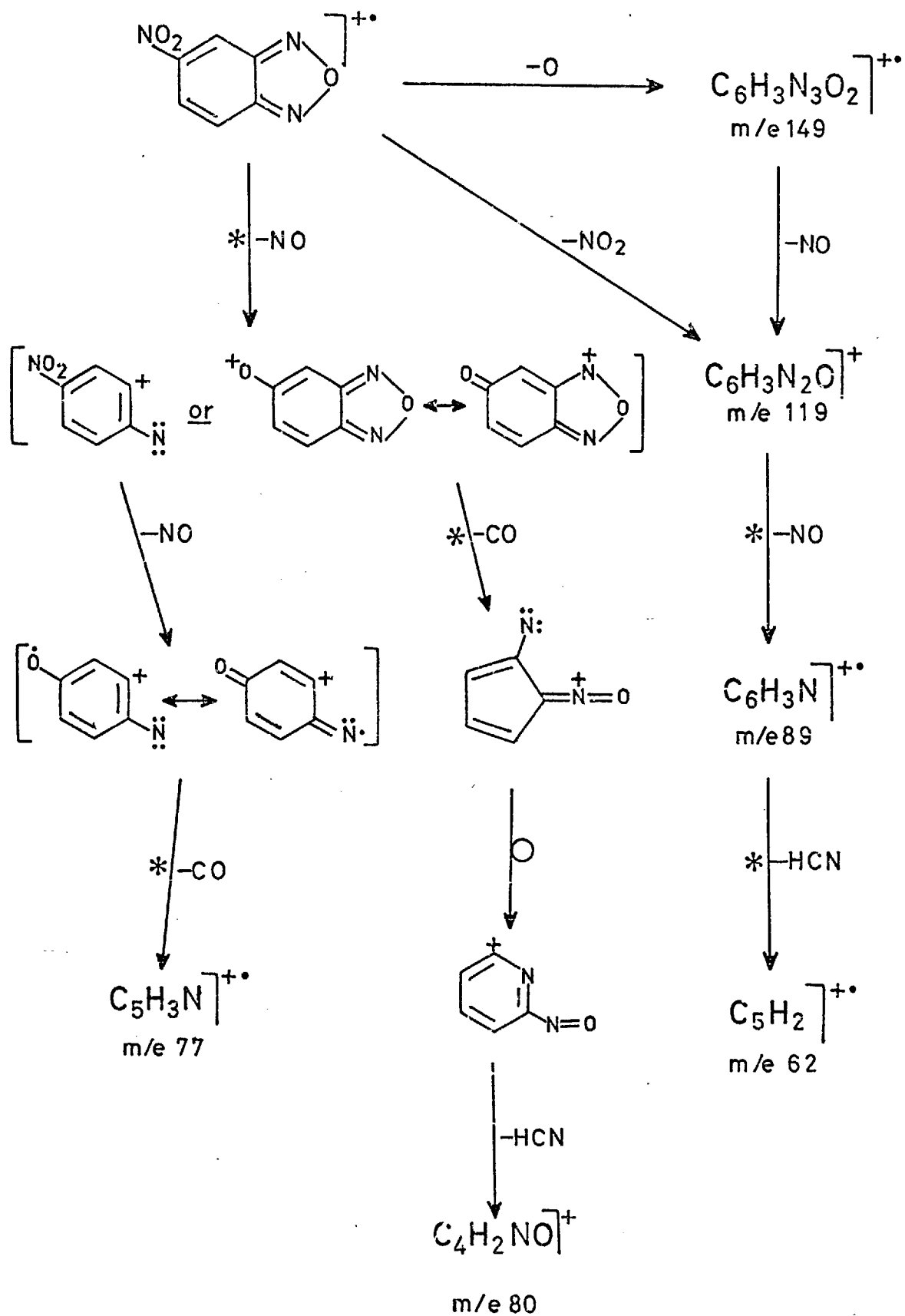


MS-20



110.4	: 165 → 135	(NO)
84.8	: 135 → 107	(CO)
69.6	: 119 → 91	(CO)
66.6	: 119 → 89	(NO)
56.5	: 105 → 77	(CO)
43.2	: 89 → 62	(HCN)
42.3	: 88 → 61	(HCN)





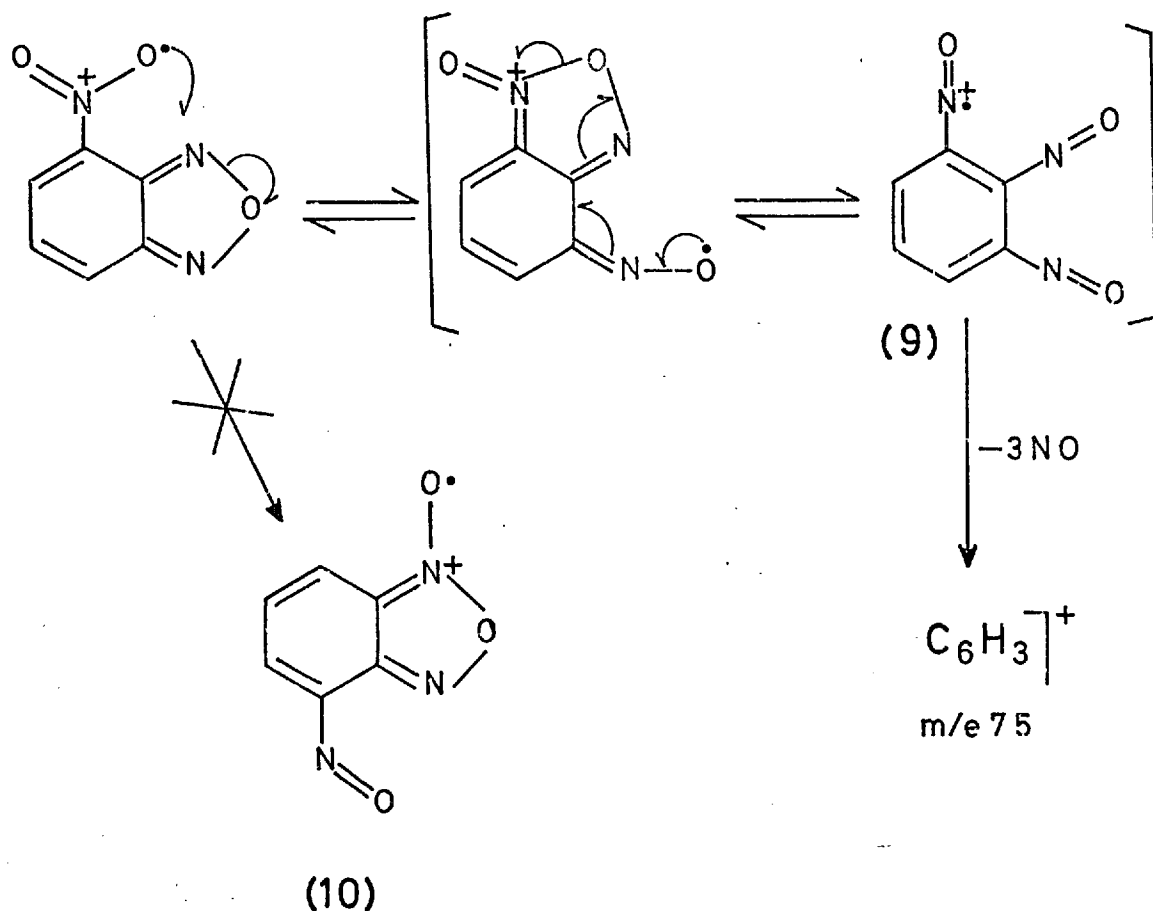
*: metastable fragmentations.

SCHEME XII

In the mass spectrum of the 5-nitro-derivative (MS-20) the $(M-NO)^+$ undergoes two major fragmentations namely the losses of NO and CO resulting in the ions m/e 105 (C_6H_3NO) and m/e 107 ($C_5H_3N_2O$) respectively. The latter fragmentation is accompanied by a metastable ion at m/e 84.8, whereas the former loss was confirmed by the metastable defocusing technique. The above fragmentations and the subsequent decomposition of the product ions are best demonstrated in scheme XII.

The fact that the ion m/e 135 loses both nitric oxide and carbon monoxide indicates that the loss of NO from the molecular ion follows two mechanistic routes. In other words the first molecule of nitric oxide lost may originate from either the nitro group or the furazan ring.

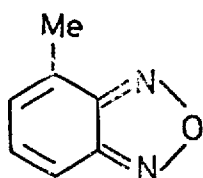
Two main differences are observed between the mass spectra of 4- and 5-nitrobenzofurazans. First, the ion m/e 135 in the spectrum of 4-nitrobenzofurazan does not show any loss of carbonmonoxide. This suggests that the first loss of NO from the molecular ion originates solely from the furazan ring. The second main difference in the two spectra is the presence of the base peak at m/e 75 in the spectrum of 4-nitrobenzofurazan. Mass measurement has shown this ion to be (C_6H_3) which corresponds to consecutive loss of three NO molecules from the molecular ion. These losses may be explained through an ortho-effect and the production of a tri-nitroso intermediate (9).



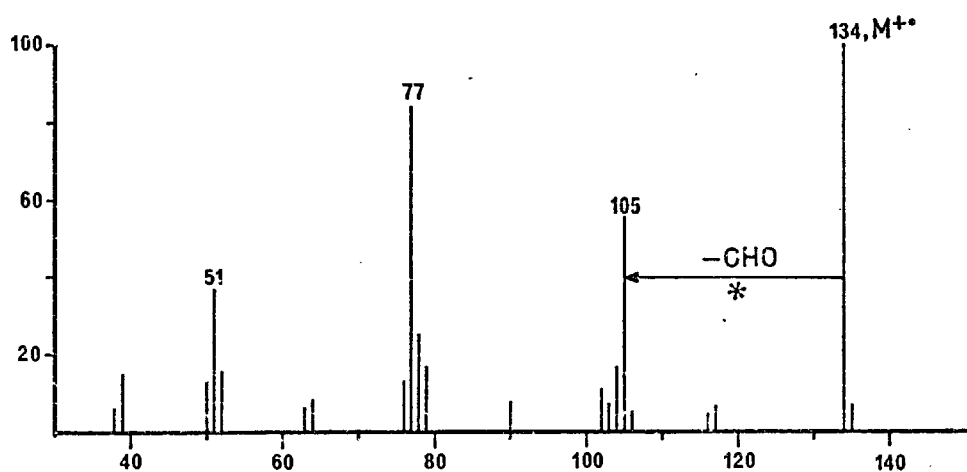
Another possibility is the rearrangement of the molecular ion to that of nitroso-benzofuroxan (10) followed by expulsion of 3 NO molecules. However the molecular ions of benzofuroxans exhibit a consecutive loss of two atoms of oxygen resulting in the ions $(M-O)^{+\bullet}$ and $(M-O_2)^{+\bullet}$. Since such ions are not present in the spectrum of 4-nitrobenzofurazan the contribution of this latter intermediate for the three consecutive losses of nitric oxide is negligible.

Introduction of a methyl group in the benzene ring of benzofurazan alters the fragmentation pattern considerably. The molecular ions of 4- and 5-methylbenzofurazans (MS-21 and MS-22 respectively) besides the usual loss of NO also exhibit a peculiar metastable loss of 29 a.m.u. resulting in the ion m/e 105. Mass measurements showed the ion $(M-29)^+$ to be $(C_6H_5N_2)^+$ which means

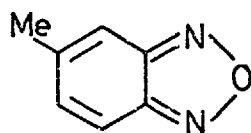
MS - 21



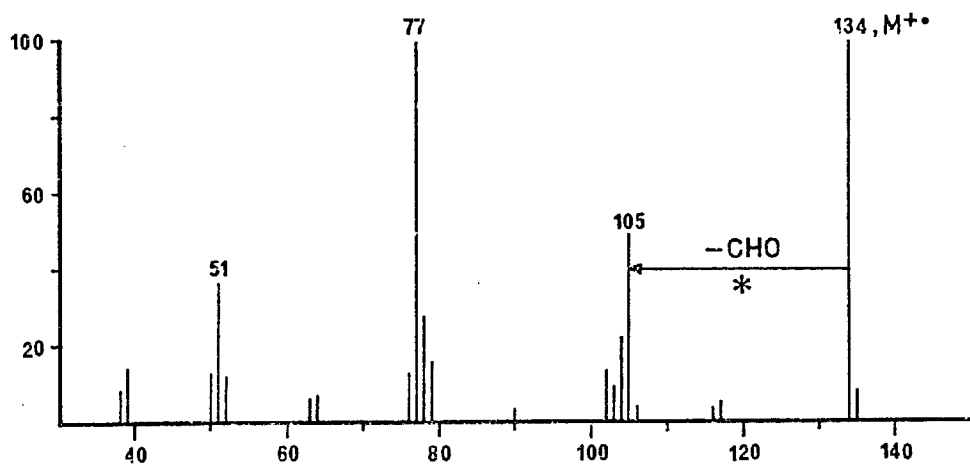
<u>m*</u>	<u>transition</u>	<u>loss</u>
82.2	134 $\longrightarrow$ 105	(H+CO)
57.9	105 $\longrightarrow$ 78	(HCN)
57.0	104 $\longrightarrow$ 77	(HCN)
55.8	77 $\longrightarrow$ 51	(C ₂ H ₂)
33.3	78 $\longrightarrow$ 51	(HCN)



MS - 22

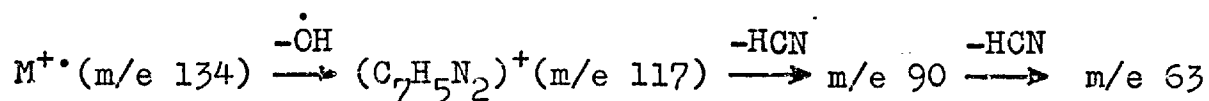


82.2	134 $\longrightarrow$ 105	(H+CO)
57.0	104 $\longrightarrow$ 77	(HCN)
33.8	77 $\longrightarrow$ 51	(C ₂ H ₂)
33.3	78 $\longrightarrow$ 51	(HCN)



the 29 a.m.u. corresponds to CHO. A metastable ion at m/e 83.2 confirms this loss. A second peculiar fragmentation of the molecular ion of these compounds corresponds to a loss of $\cdot\text{OH}$. Metastable defocusing confirms this loss of 17 a.m.u. from $\text{M}^{+\cdot}$. However, the relatively low intensity of the product ion at m/e 117 and of the subsequent fragment ions at m/e 90 and m/e 63 suggest that this fragmentation is not very important (Table VI).

TABLE VI



ions	Relative intensity	
	4-methylbenzofurazan	5-methylbenzofurazan
$\text{M}^{+\cdot}(\text{m/e } 134)$	100	100
$(\text{M}-\text{OH})^+(\text{m/e } 117)$	7	5
$(\text{C}_6\text{H}_4\text{N})^+(\text{m/e } 90)$	7	3
$(\text{C}_5\text{H}_3)^+(\text{m/e } 63)$	6	6

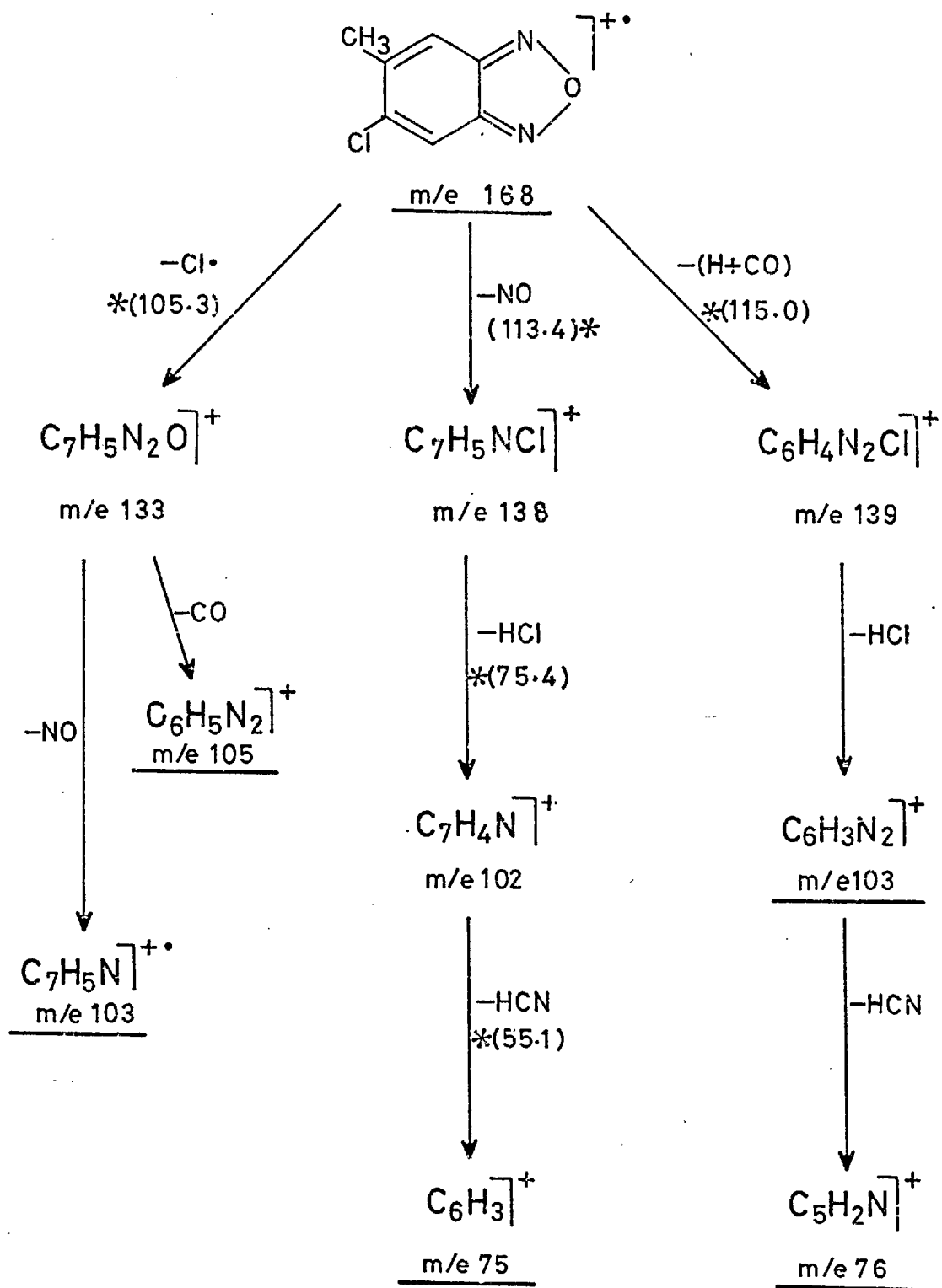
Since the losses of CHO and OH are not observed in the mass spectra of benzofurazans without a methyl group it is reasonable to assume that the methyl group is responsible for the above-mentioned losses from the molecular ion of 4- and 5-methylbenzofurazans. This assumption, however,

does not prove that the carbon and hydrogen atoms lost are from the original methyl group. The explanation for the loss of OH and CHO in the case of 4-methylbenzofurazan may be simpler since such losses may be attributed to ortho effects similar to the one observed in ortho-nitrotoluene. However the remarkably similar fragmentation pattern in the mass spectra of 4- and 5-methylbenzofurazans (MS-21 and MS-22 respectively) strongly suggests a common fragmentation mechanism.

It has been reported¹³⁰ that in the mass spectrum of o-nitrosotoluene the molecular ion shows a loss of CO. However, the true nature of this loss has not been established.

Perhaps it is worth considering the possibility of a two step metastable process for the loss of CHO; in other words the loss of a hydrogen atom followed by a very rapid decomposition of the (M-1) with the expulsion of CO. Another possibility for the combined loss of H + CO is the occurrence of two fragmentation reactions with the same rate at different sites of the molecular ion, i.e. a concerted loss of H. + CO.

The mass spectral fragmentation pathway for the 5-methyl-6-chlorobenzofurazan is shown in scheme XIII. The molecular ion shows metastable losses of H + CO, NO and Cl resulting in the ions m/e 139, m/e 138 and m/e 133 respectively. The base peak in the spectrum appears at m/e 102 which corresponds to the loss of HCl from the ion (M-NO)⁺.



* The figures in parentheses correspond to the metastable ions. The identity of the underlined ions have been established by accurate mass measurements.

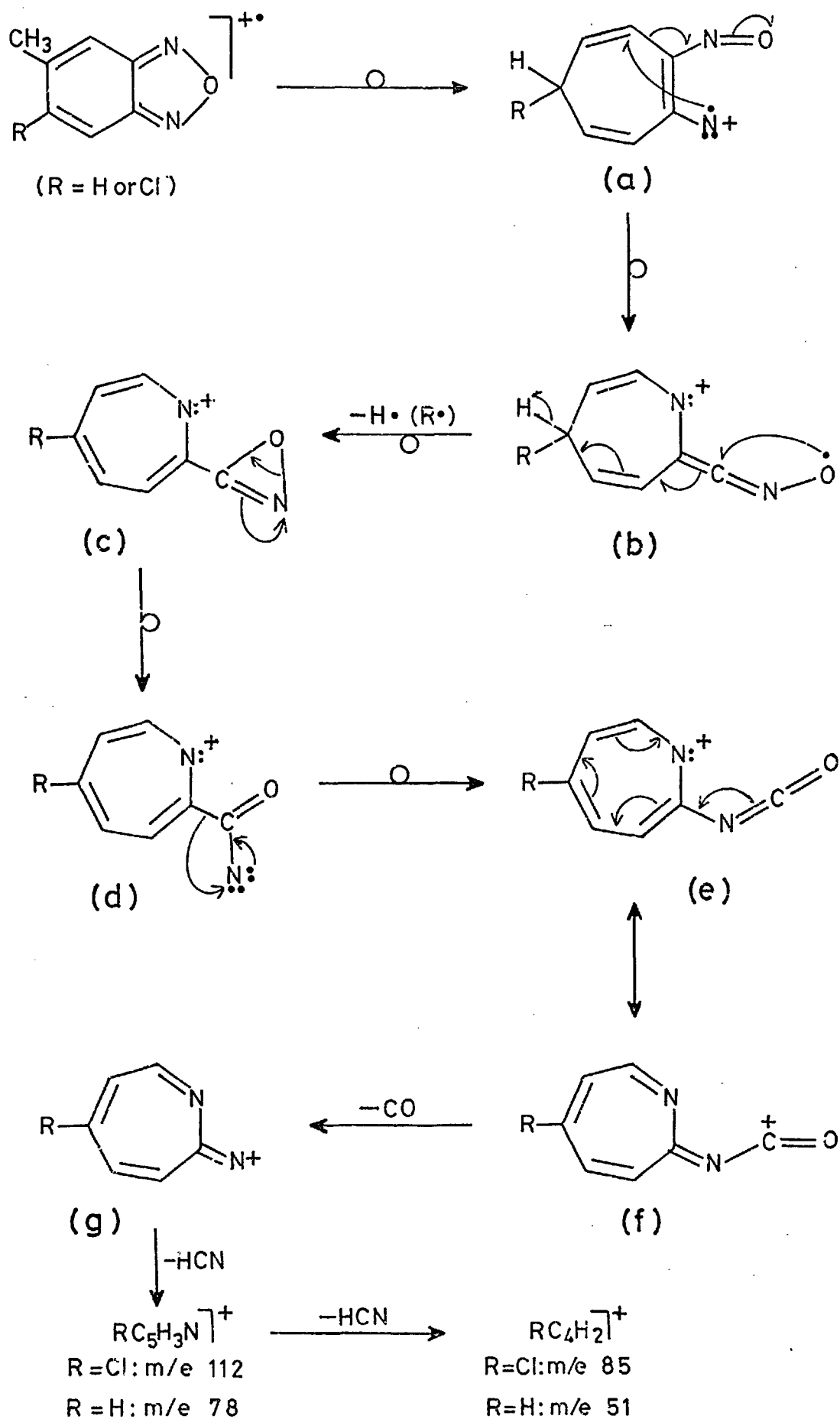
SCHEME XIII

The most interesting fragmentation in the mass spectrum of 5-methyl-6-chlorobenzofurazan (MS-23) is the loss of CO from the ion $(M-Cl)^+$ resulting in the ion $(C_6H_5N_2)^+$ at m/e 105. This consecutive loss of Cl + CO from the molecular ion is in support of the analogous two step loss of 29 a.m.u., i.e. H + CO, from the molecular ion of 4- and 5-methylbenzofurazans. In other words the molecular ion of 5-methyl-6-chlorobenzofurazan undergoes a fast loss of H. followed very rapidly by expulsion of CO; or it can undergo a metastable loss of Cl. followed by a slower loss of CO.

It is impossible to deduce the true nature of this fragmentation without carrying out labeling experiments. However because of very high cost of the required labeled compounds no attempts at further investigations were made.

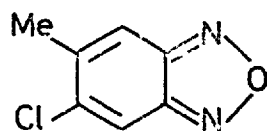
From the results at hand, however, it may be possible to draw some conclusions. Since the loss of CHO is only observed in the mass spectra of methyl-substituted benzofurazans, the first step in this fragmentation may involve a ring expansion to a seven-membered ring intermediate. It is obvious that extensive rearrangement processes must occur before the molecular ion can lose the elements of H + CO (and/or Cl + CO for the chloro-methyl-derivative). One such rearrangement process is shown in scheme XIV.

The rearrangement of (a) $\longrightarrow$ (b) may be justified since similar process is responsible for the inter-conversion of pyridylcarbene and phenylnitrene (see

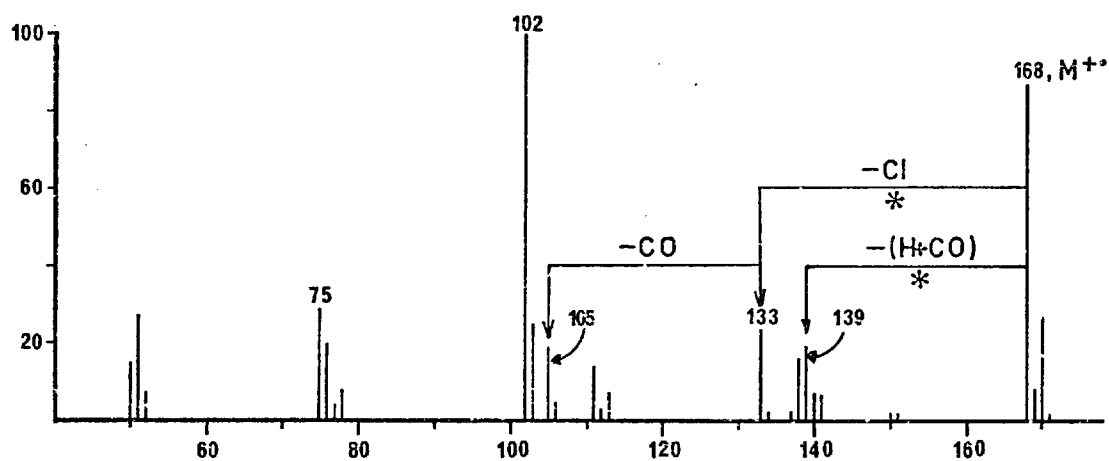


SCHEME XIV

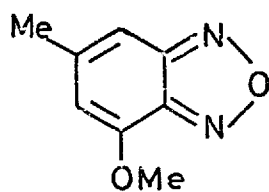
MS-23



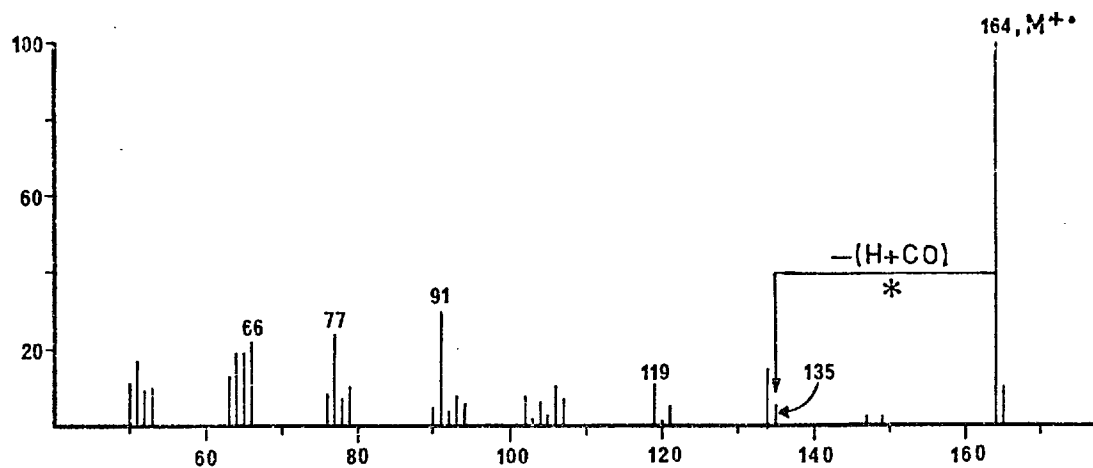
<u>m*</u>	<u>transition</u>	<u>loss</u>
115.0	: 168 $\longrightarrow$ 139	(H+CO)
113.4	: 168 $\longrightarrow$ 138	(NO)
105.3	: 168 $\longrightarrow$ 133	(Cl)
75.4	: 138 $\longrightarrow$ 102	(HCl)
55.1	: 102 $\longrightarrow$ 75	(HCN)
50.7	: 111 $\longrightarrow$ 75	(HCl)



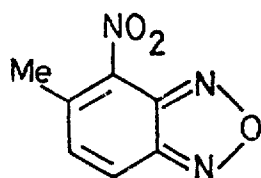
MS-24



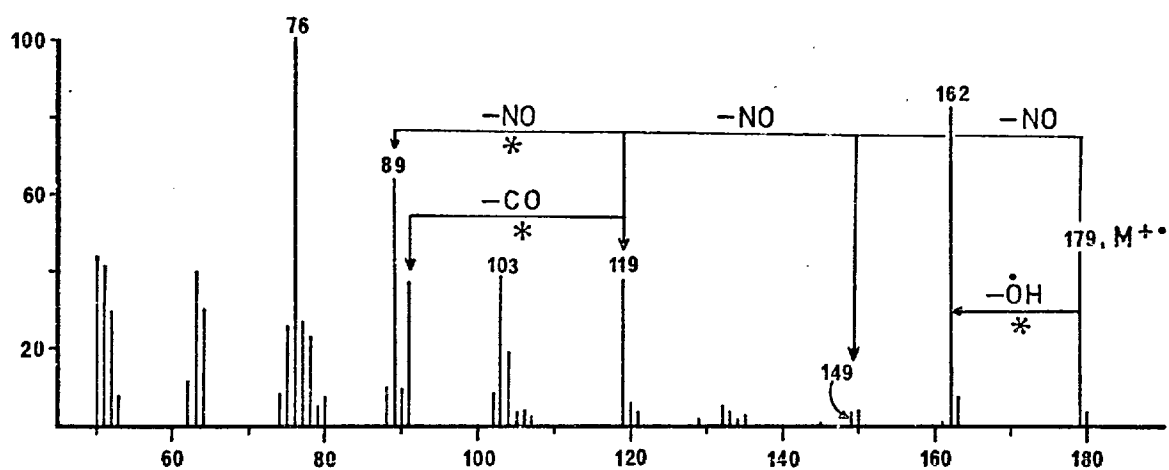
111.1	: 164 $\longrightarrow$ 135	(H+CO)
109.5	: 164 $\longrightarrow$ 134	(NO)
115.7	: 134 $\longrightarrow$ 119	(CH ₃)



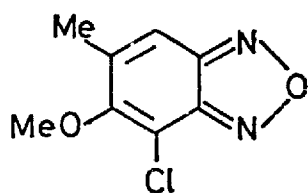
MS-25



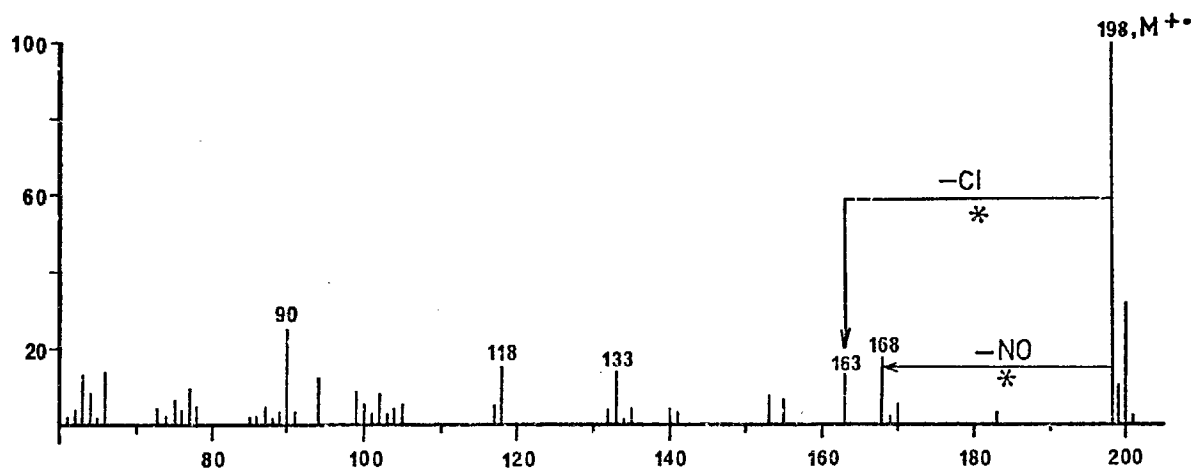
m^*	transition	loss
146.6 : 179	$\longrightarrow$ 162	(OH)
112.5 : 162	$\longrightarrow$ 135	(HCN)
69.6 : 119	$\longrightarrow$ 91	(CO)
66.7 : 119	$\longrightarrow$ 89	(NO)
56.1 : 103	$\longrightarrow$ 76	(HCN)
45.0 : 91	$\longrightarrow$ 64	(HCN)
44.6 : 89	$\longrightarrow$ 63	(C ₂ H ₂)
33.3 : 78	$\longrightarrow$ 51	(HCN)



MS-26

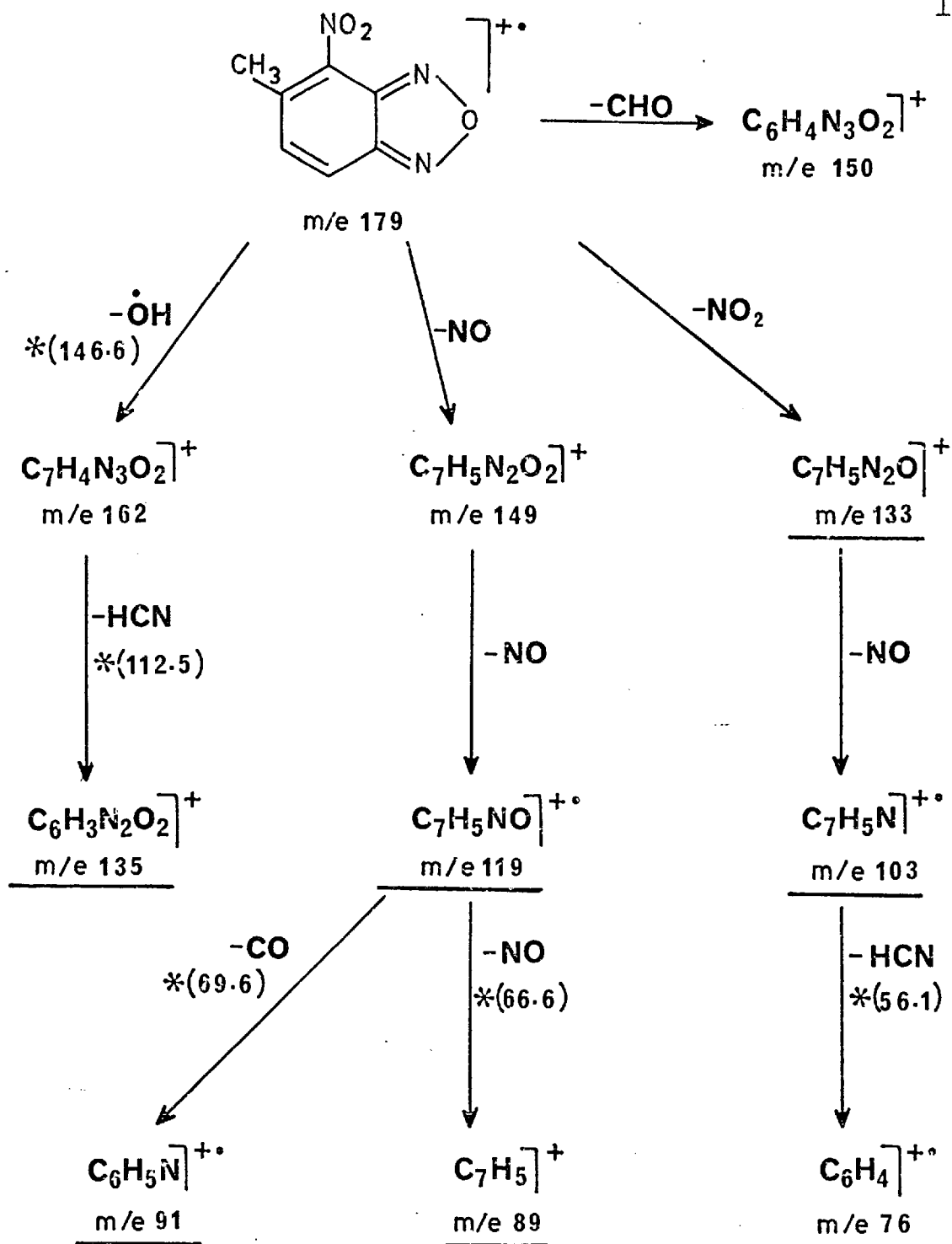


142.5 : 198	$\longrightarrow$ 168	(NO)
134.2 : 198	$\longrightarrow$ 163	(Cl)
105.3 : 168	$\longrightarrow$ 133	(Cl)
68.6 : 118	$\longrightarrow$ 90	(CO)
44.1 : 90	$\longrightarrow$ 63	(HCN)



review page 50). The structure (b) can then undergo a Beckmann type of rearrangement accompanied by the loss of hydrogen atom resulting in the acylnitrene (d) via the structure (c). A Curtius rearrangement of (d) results in the isocyanate (e) which can undergo a facile loss of CO via the structure (f) resulting in the ion (g). Expulsion of two molecules of hydrogen-cyanide from (g) results in the ion m/e 78 and m/e 51 in the spectra of 4- and 5-methylbenzotriazoles.

The mass spectrum of 4-nitro-5-methyl-benzofurazan (MS-25) is very complicated; however three main fragmentation sequences are observed in the spectrum. The first involves the ortho effect observed in the spectra of ortho-nitrotoluenes¹²⁵. This ortho effect seems to be prevailing in this compound and as a result the main fragmentation of the molecular ion is the loss of a hydroxyl radical resulting in the ion m/e 162. The second fragmentation sequence is the consecutive loss of three nitric oxide molecules resulting in the ions m/e 149, m/e 119 and m/e 89. Like 4-nitrobenzofurazan (MS-19) it is only after the second loss of nitric oxide that the resulting ion at m/e 119 shows the loss of CO. This suggests that the first molecule of nitric oxide lost originated solely from the furazan ring. Finally the most important fragmentation sequence is the loss of NO_2 followed by expulsion of NO resulting in the ions m/e 133 and 103 respectively. The latter ion undergoes further decomposition by losing HCN giving rise to the base peak at m/e 76 in the spectrum of 4-nitro-5-methylbenzofurazan (MS-25). In addition to the above fragmentations the



All the transformations were confirmed by metastable defocusing.

*Figures in parentheses correspond to the relevant metastable ion.

The underlined ions were confirmed by accurate mass measurements.

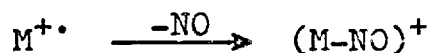
molecular ion also shows the peculiar loss of H + CO; however, this fragmentation occurs only to a very small extent.

The fragmentations described for 4-nitro-5-methylbenzofurazan are best represented in scheme XV.

The methoxy-derivatives of the methyl-benzofurazans have stable molecular ions. In the mass spectrum of 4-methoxy-6-methyl-benzofurazan (MS-24) ions of relatively low intensity corresponding to the loss of CH₃, CHO and NO are observed at m/e 149 (rel.int.2%), m/e 135 (rel. int. 5%) and m/e 134 (rel. int. 15%) respectively. The molecular ion of 4-chloro-5-methoxy-6-methylbenzafurazan (MS-26) undergoes the same type of fragmentations. The ion (M-Cl)⁺ in the spectrum of this compound shows the losses of NO and CO analogous to the fragmentations of the chloro-methylbenzofurazan.

As expected the ionization potential values are dependent on the substituents. The benzofurazans with a methoxy group in the benzene ring have the lowest IP values which is not surprising considering the electron donating property of the methoxy group (Table VII).

The energy of activation for the loss of NO from the molecular ion was calculated by subtracting the IP value from the appropriate appearance potential value of the (M-NO)⁺ ion formation.



$$E_a = AP(M-NO)^+ - IP(M)^{+\bullet}$$

The energy of activation for this reaction is lowest in the case of the parent compound whereas the highest value is obtained for the methoxy-derivatives.

The high value of E_a for the methoxy-derivatives can be explained through the stability of the molecular ion. Like aromatic amino compounds the molecular ion is generally the base peak and its stability comes about because of delocalization of the free electron in the ring (structures 12 - 14). As a result a greater amount of energy is necessary to reach the transition state for the loss of NO.

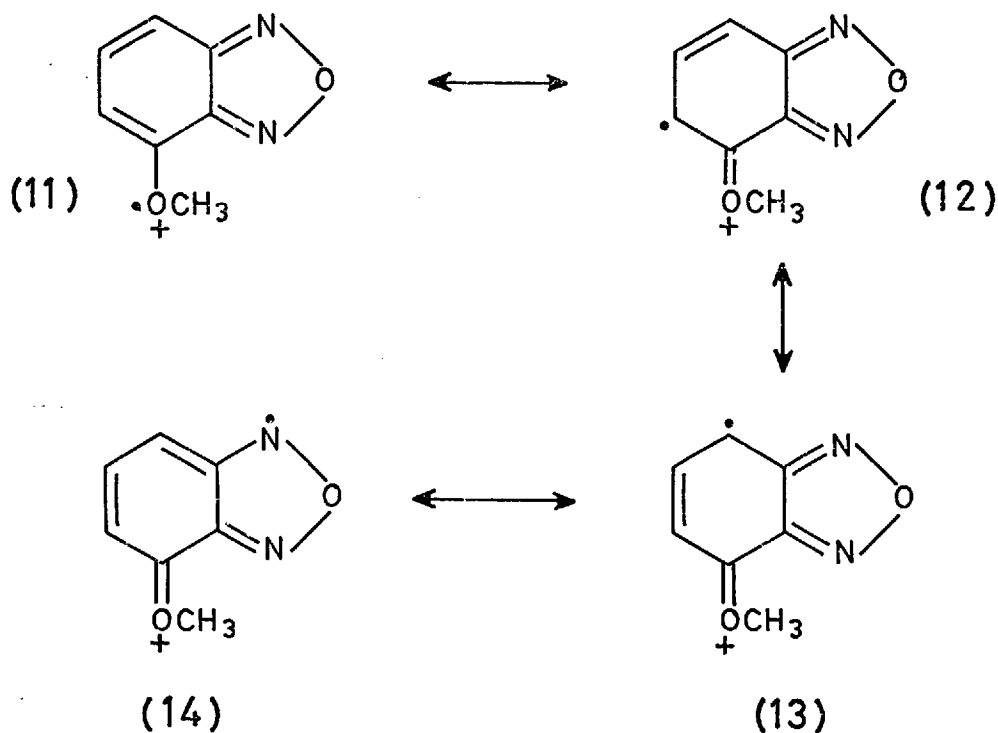
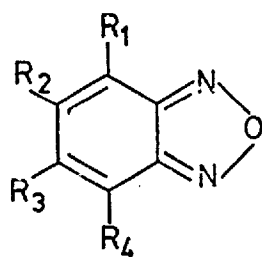


TABLE VII



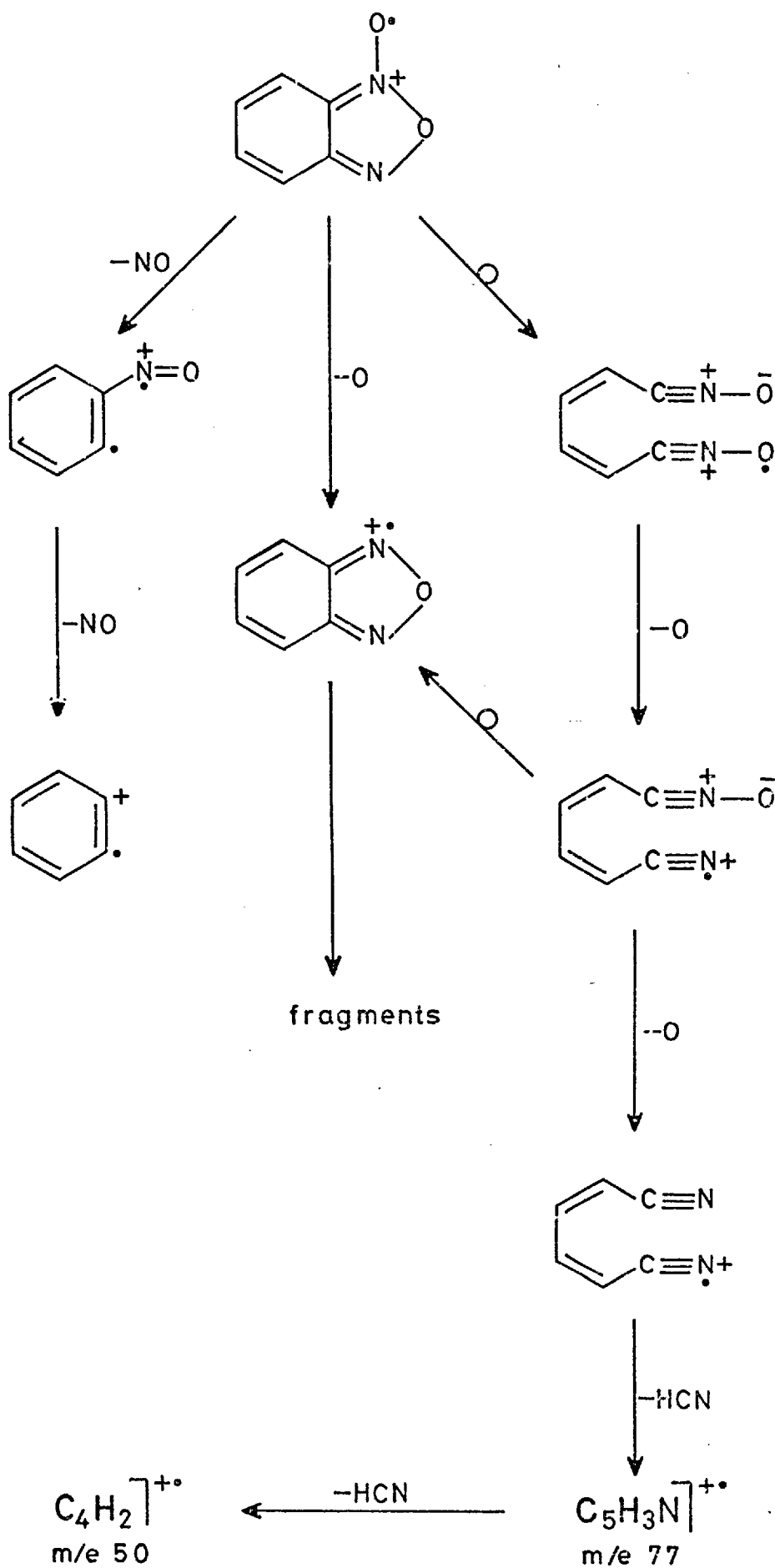
Compound				(ev)		
R ₁	R ₂	R ₃	R ₄	IP(M) ⁺⁺	AP(M-NO) ⁺	E _a
-	-	-	-	9.73	12.23	2.50
-	Cl	-	-	9.78	13.08	3.30
-	OCH ₃	-	-	8.94	13.14	4.20
CH ₃	-	-	-	9.18	12.63	3.45
-	CH ₃	-	-	9.18	12.63	3.45
-	CH ₃	Cl	-	10.43	13.73	3.30
-	CH ₃	OCH ₃	Cl	8.68	12.33	3.65
-	CH ₃	-	OCH ₃	8.83	12.83	4.00

BENZOFUROXANS

Benzofuroxans are the N-oxides of the corresponding benzofurazans. As a result one would expect these compounds to lose an oxygen atom and fragment in an analogous way to the benzofurazans. However besides this fragmentation process the mass spectra of benzofuroxans show fragmentation patterns characteristic to themselves.

The most interesting fragmentation process in the spectra of these compounds under electron impact is the consecutive loss of two atoms of oxygen. By analogy to the photolytic cleavages the molecular ion of benzofuroxan can undergo a ring opening to form the corresponding di-N-oxide which can easily lose the oxygen atoms. The first loss of oxygen is generally a more favourable process since the product ion can be stabilized by rearrangement to the molecular ion of corresponding benzofurazan. The presence of typical fragmentations of the benzofurazan in the mass spectra of the corresponding benzofuroxan confirms this process. The loss of the first oxygen atom and the formation of benzofurazan can also be explained via a direct cleavage of the molecular ion. These fragmentations are explained in scheme XVI.

The main fragmentation of the molecular ion of benzofuroxan (MS-27) is the consecutive loss of two molecules of nitric oxide most probably via a dinitroso intermediate. This consecutive losses of two NO molecules



SCHEME XVI

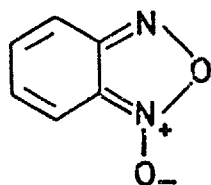
generally occurs very rapidly in the source of mass spectrometer. The reason for this rapid fragmentation may be the production of the relatively stable benzyne intermediate. The molecular formulae of the $(M-2NO)^{+}$ ions in the spectra of the benzofuroxans were confirmed by accurate mass measurements.

The mass spectra of the methyl-benzofuroxans show the same type of fragmentation described for the parent compound. The $(M-O)^{+}$ at m/e 134 undergoes exactly the same decomposition processes described for the corresponding methylbenzofurazans.

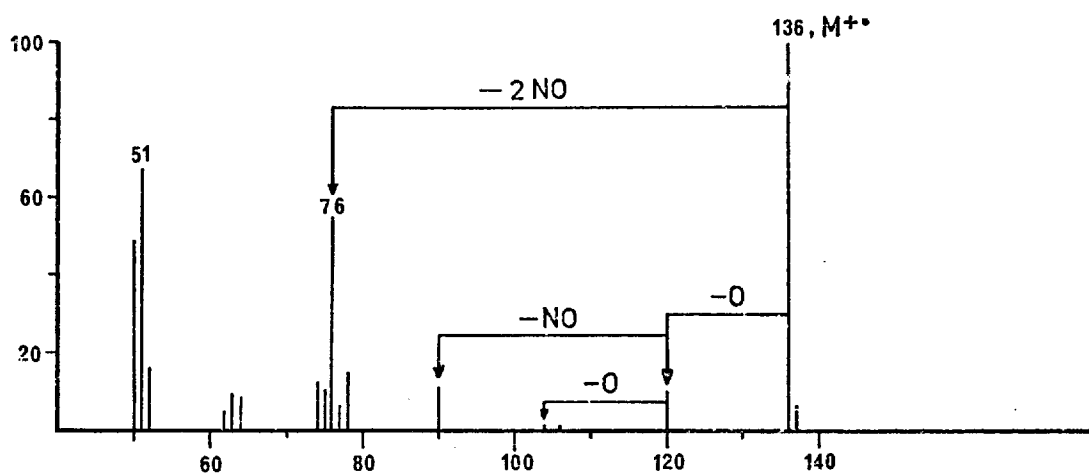
The main difference between the mass spectra of 4- and 5-methyl-benzofuroxan (MS-29 and MS-30 respectively) is that the molecular ion of the former compound shows a loss of 29 a.m.u. (CHO) resulting in the ion at m/e 121. A metastable ion at m/e 97.6 and accurate mass measurement of the ion at m/e 121 ($C_6H_5N_2O$) confirm the loss of CHO. This loss, unlike the similar loss from the molecular ion of methylbenzofurazans, can be explained through an ortho effect analogous to the one observed in ortho-nitrotoluenes. The production of this ion at m/e 121 also explains the higher intensity of the ion m/e 91 which corresponds to a loss of NO from the ion m/e 121 in the spectrum of 4-methylbenzofuroxan.

The most intense peak in the spectra of the methylbenzofuroxans is the ion at m/e 65. Mass measurements have shown this ion to be (C_5H_5). A metastable ion at m/e 45.9 indicates that this ion arises from the ion m/e 92. The relatively low intensity of this ion

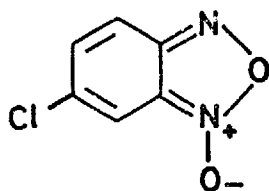
MS-27



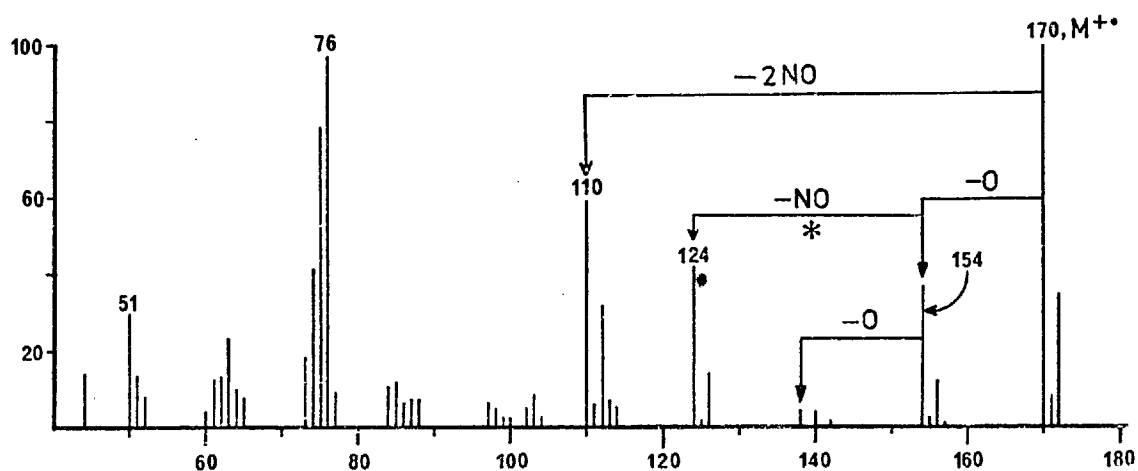
m^+	transition	loss
82.6 : 136	$\longrightarrow$ 106	(NO)
33.3 : 78	$\longrightarrow$ 51	(HCN)
32.9 : 76	$\longrightarrow$ 50	(C ₂ H ₂)



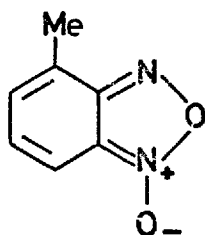
MS-28



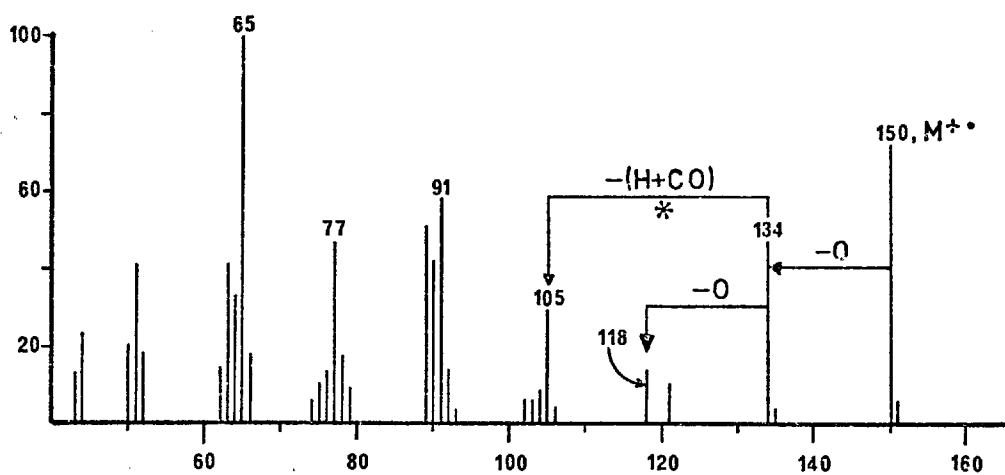
115.2 : 170	$\longrightarrow$ 140	(NO)
99.8 : 154	$\longrightarrow$ 124	(NO)
51.6 : 112	$\longrightarrow$ 76	(HCl)
51.1 : 110	$\longrightarrow$ 75	(Cl)



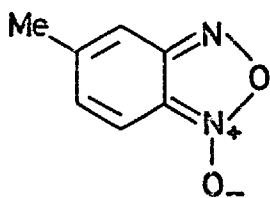
MS - 29



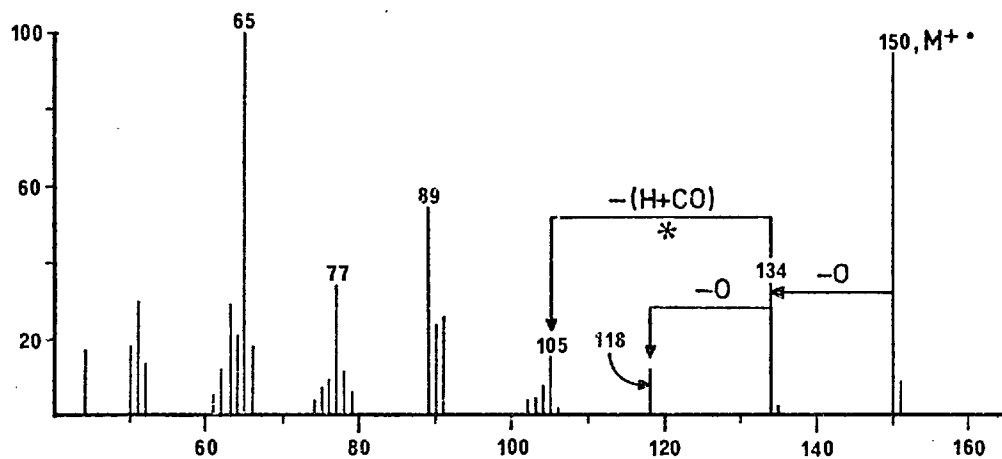
<u>m*</u>	<u>transition</u>	<u>loss</u>
97.6 : 150	→ 121	(CHO)
82.3 : 134	→ 105	(H+CO)
57.9 : 105	→ 78	(HCN)
57.0 : 104	→ 77	(HCN)
45.9 : 92	→ 65	(HCN)



MS - 30



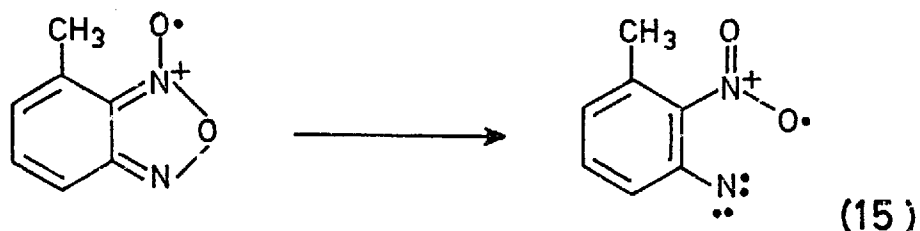
96.0 : 150	→ 120	(NO)
88.0 : 90	→ 89	(H)
82.5 : 134	→ 105	(H+CO)
70.2 : 118	→ 91	(HCN)
57.9 : 105	→ 78	(HCN)
57.0 : 104	→ 77	(HCN)
45.9 : 92	→ 65	(HCN)



(m/e 92) made its mass measurement a difficult task.

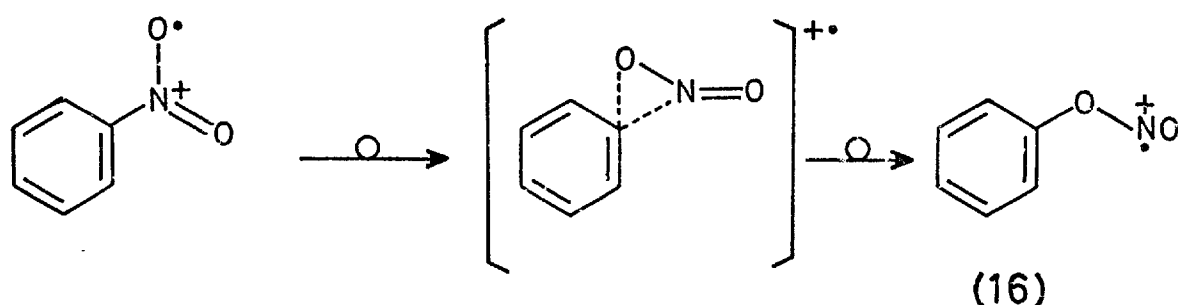
However, since 27 a.m.u. are lost in the above metastable transition it is reasonable to assume the neutral fragment lost corresponds to HCN. As a result the molecular formula of the ion at m/e 92 could be $(C_6H_6N)^+$. The fragment that should be lost from the molecular ion therefore corresponds to CNO_2 . The most reasonable path would be elimination of a combination of CO and NO, probably first the loss of NO followed by CO.

With the help of the metastable defocusing technique it has been possible to establish that the origin of the weak $(M-58)^+$ ion in the spectra of substituted benzofuroxans and the parent compound is the ion $(M-30)^+$. This confirms the original assumption that the loss of 58 a.m.u. correspond to sequential loss of NO followed by CO from the molecular ion. The fact that the ions $(M-NO)^+$ and $(M-NO-CO)^+$ are not observed in the spectra suggests that this sequential loss occurs very rapidly in the source of the mass spectrometer. The loss of NO+CO does not seem to involve the nitro-nitrene intermediate (15).



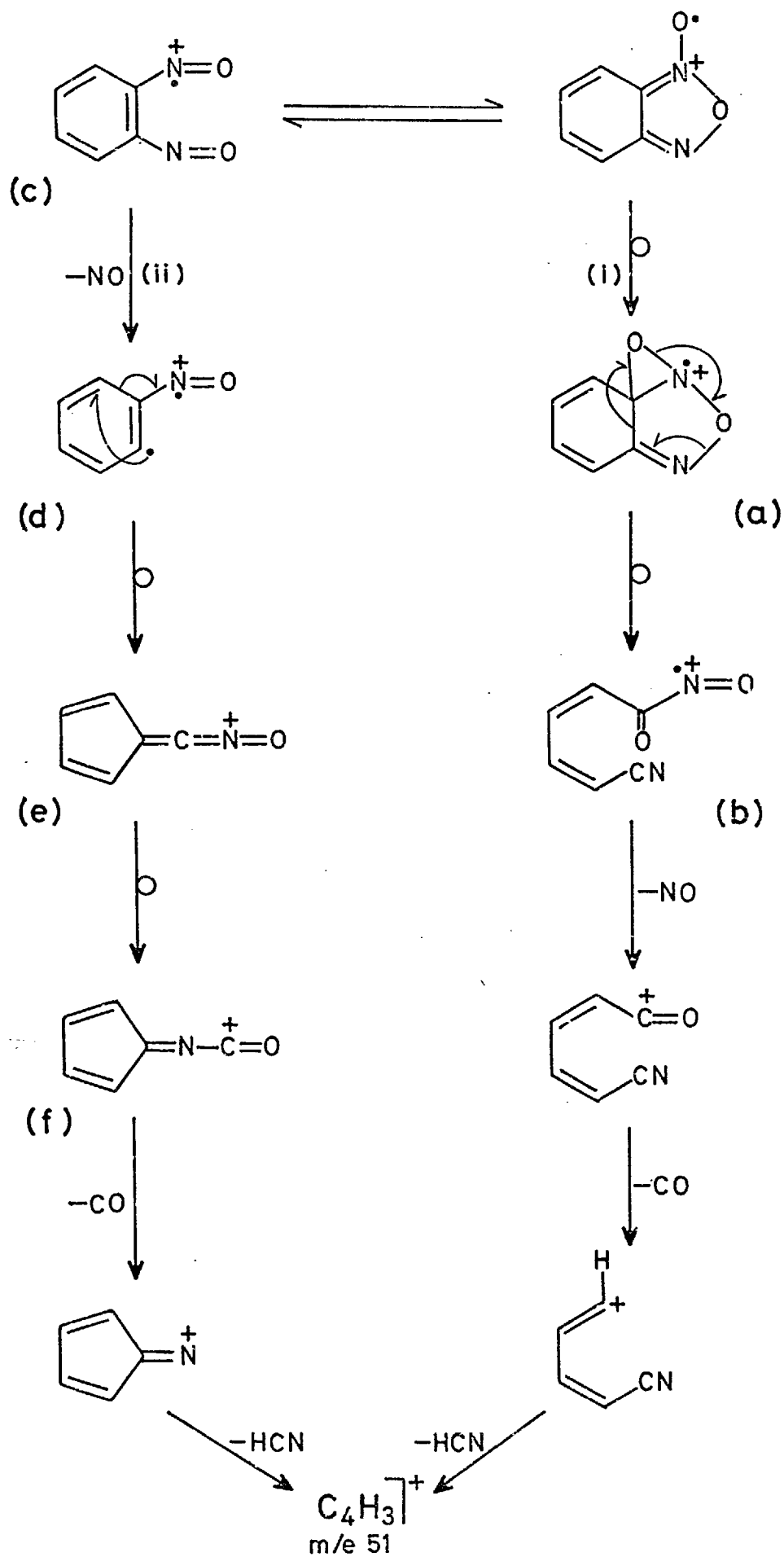
If such an intermediate were involved then one would expect to observe the known loss of a hydroxyl radical ¹²⁵ through an ortho effect in the case of 4(7)-methylbenzofuroxan. Since no ion corresponding to $(M-OH)^+$ is

observed in the mass spectrum of this compound, an intermediate different from the nitro-nitrene must be involved in the loss of NO + CO. Two probable mechanistic pathways for this consecutive fragmentation are shown in scheme XVII. In path (i) the first step involves the formation of the three-membered intermediate (a). This step is analogous to the intermediate in the rearrangement of aromatic nitro compounds to the corresponding nitrite¹³¹ (16).



The formation of (a, Scheme XVII) is probably more favoured than the formation of the intermediate in the rearrangement of aromatic nitro compounds since it corresponds to an oxazirane ring. The ion (a) can then rearrange to form the intermediate (b) which can easily lose NO + CO.

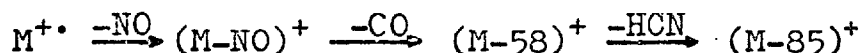
Alternatively the molecular ion can lose a molecule of nitric oxide via the dinitroso intermediate (c) (path ii, Scheme XVII). The resulting ion (d) may then undergo a ring contraction to form the nitrile oxide (e). The rearrangement of the nitrile oxide to the corresponding isocyanate (f) could explain the facile loss of CO from the (M-NO)⁺ ion.



SCHEME XVII

Comparison of the mass spectra of the benzofuroxans and the corresponding benzofurazans indicates that loss of one oxygen atom and formation of the molecular ion of benzofurazans makes little contribution to the fragmentation pattern of the benzofuroxans. It is apparent that the molecular ion of the benzofuroxans undergo facile characteristic fragmentation resulting in the most intense peaks in the spectra. These characteristic fragmentations can be divided into the following three categories:

1. All benzofuroxans exhibit a sequential loss of two atoms of oxygen (probably via nitrile N-oxide intermediate).
2. All benzofuroxans show the loss of two molecules of nitric oxide (the intermediate for this fragmentation involves a dinitroso compound).
3. All benzofuroxans undergo the facile sequential losses shown below:



The exception to the above losses are observed in the benzofuroxans containing substituents which can easily be eliminated or partially eliminated. In such cases the last step, i.e. loss of HCN, is replaced by the most facile fragmentation.

The point (3) above can be explained by considering the appropriate fragmentation in some substituted benzofuroxans.

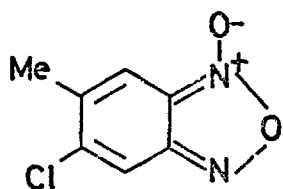
In the case of the parent compound and the 4- and 5-methyl-derivatives the main fragmentation of the $(M-58)^+$ involves the metastable loss of HCN resulting in the ions at m/e 51, m/e 65 and m/e 65 respectively.

In the spectra of 5-chloro- and 5-methyl-6-chloro-benzofuroxanes (MS-28 and MS-31 respectively) the $(M-58)^+$ ions show the loss of HCN giving rise to the ions m/e 85 and m/e 99 respectively. However, the more favourable fragmentation of the $(M-58)^+$ ion involves the elimination of HCl resulting in the ions m/e 76 and m/e 90 respectively.

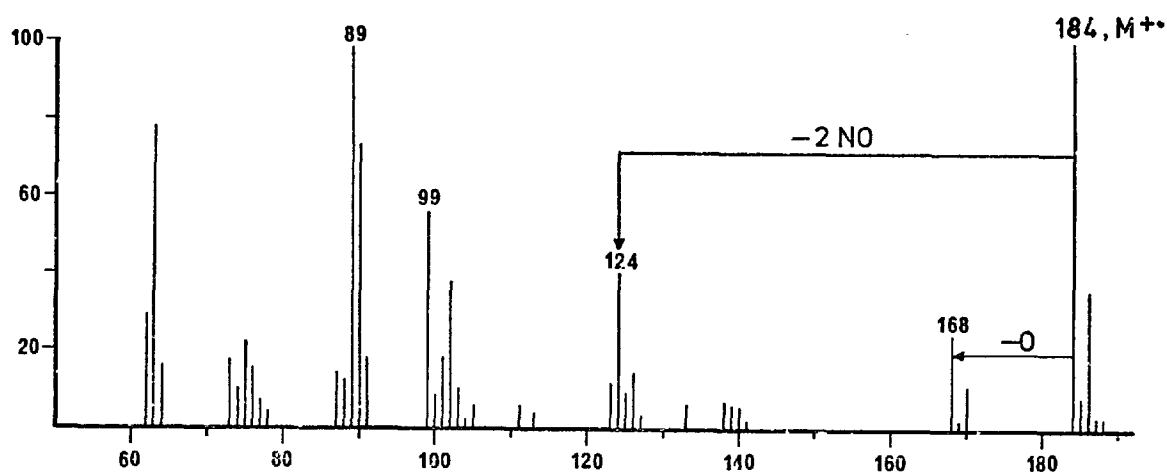
In contrast to their benzofurazan analogues which show an intense molecular ion, the 5-methoxy-(MS-33) and 4-methoxy-6-methyl-benzofuroxans (MS-34) undergo facile losses of two molecules of nitric oxide resulting in the intense ions at m/e 106 and m/e 120 respectively. These ions undergo typical fragmentation of aromatic methoxides¹²⁹ namely loss of CH_3 followed by expulsion of CO resulting in the ions at m/e 91 and m/e 63 in the case of 5-methoxy-benzofuroxan, and m/e 105 and m/e 77 in the case of 4-methoxy-6-methyl derivative.

The $[M-(NO+CO)]^+$ ion in the spectra of these compounds is of extremely low intensity. However ions corresponding to the loss of CH_3 from the ion $(M-58)^+$ are observed at m/e 93 (C_5H_3NO) and m/e 107 (C_6H_5NO) in the spectra of 5-methoxy-(MS-33) and 4-methoxy-6-methyl-benzofuroxans (MS-34) respectively. Metastable defocusing and mass measurements confirm the above losses.

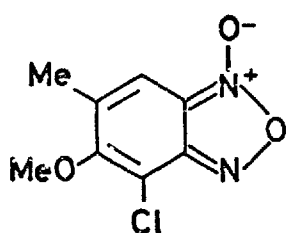
MS-31



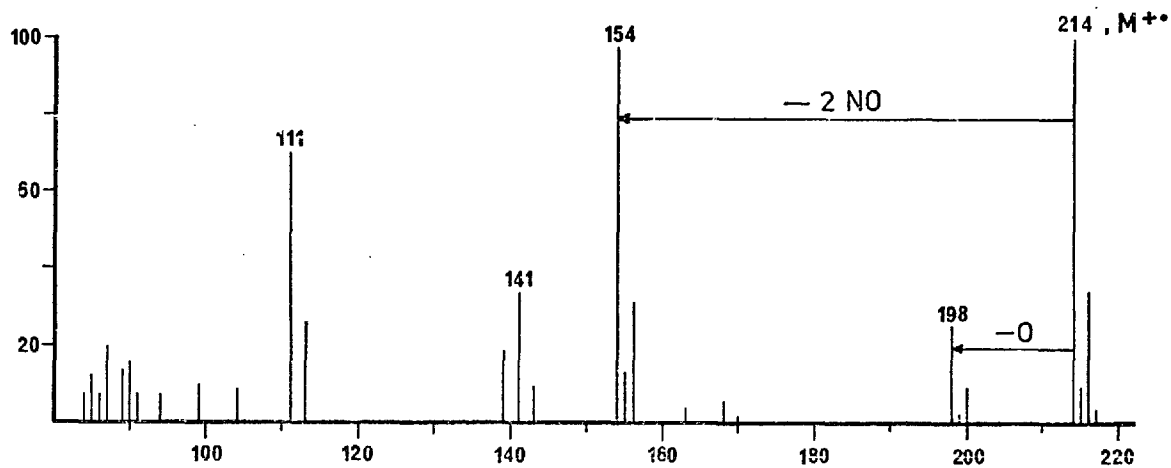
m^+	transition	loss
128.9	: 184 $\longrightarrow$ 154	(NO)
115.0	: 168 $\longrightarrow$ 139	(H+CO)
77.8	: 126 $\longrightarrow$ 99	(HCN)
75.4	: 138 $\longrightarrow$ 102	(HCl)
63.9	: 124 $\longrightarrow$ 89	(Cl)
55.1	: 102 $\longrightarrow$ 75	(HCN)
53.8	: 99 $\longrightarrow$ 73	(C ₂ H ₂)
44.6	: 89 $\longrightarrow$ 63	(C ₂ H ₂)



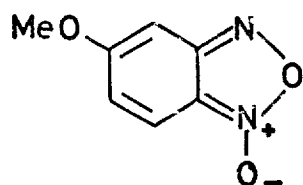
MS-32



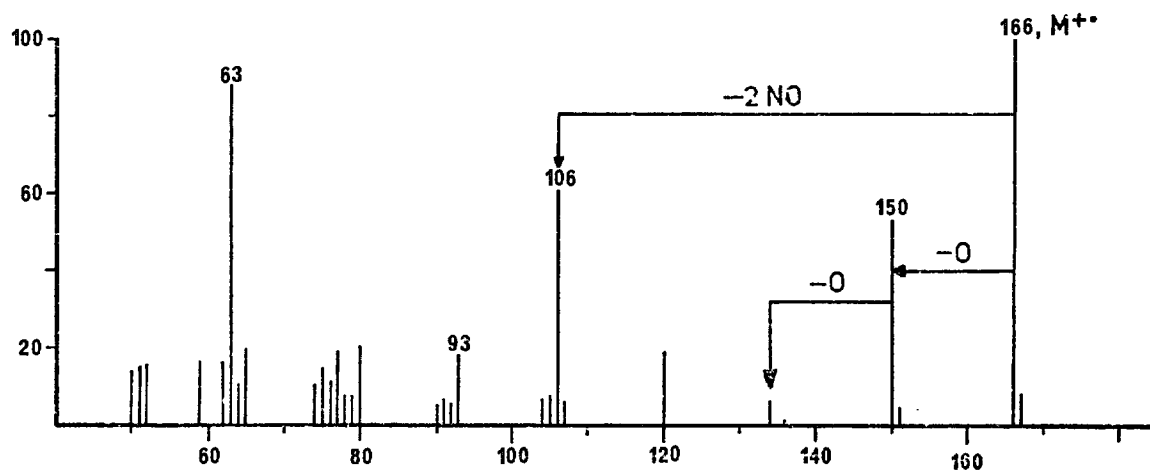
128.3	: 156 $\longrightarrow$ 141	(Me)
125.5	: 154 $\longrightarrow$ 139	(Me)
90.6	: 141 $\longrightarrow$ 113	(CO)
88.6	: 139 $\longrightarrow$ 111	(CO)
80.0	: 154 $\longrightarrow$ 111	(Me+CO)
50.7	: 111 $\longrightarrow$ 75	(HCl)



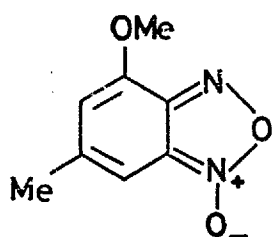
MS-33



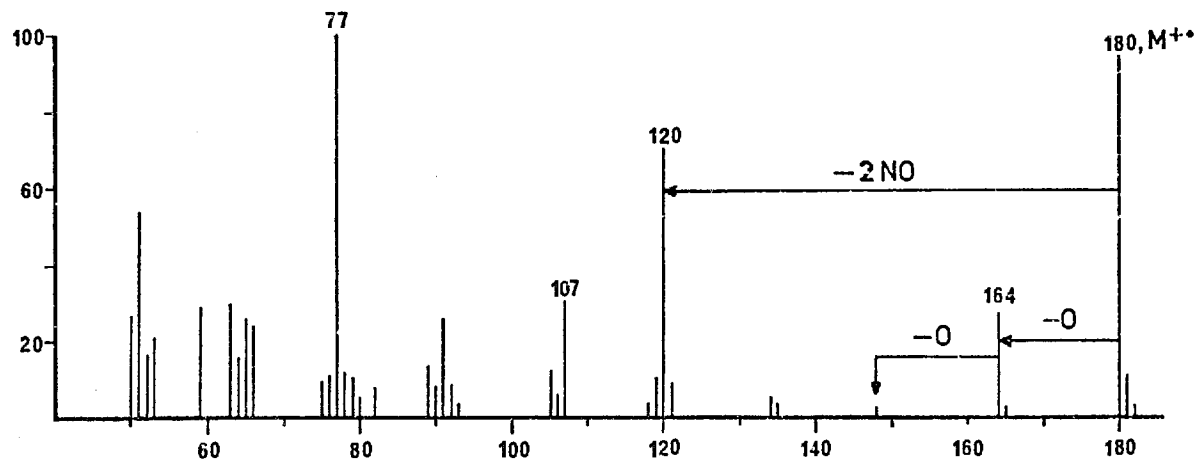
E^*	transition	loss
111.4	166 $\longrightarrow$ 136	(NO)
96.0	150 $\longrightarrow$ 120	(NO)
78.1	106 $\longrightarrow$ 91	(CH ₃)



MS-34



125.0	180 $\longrightarrow$ 150	(NO)
91.9	120 $\longrightarrow$ 105	(CH ₃)
88.0	90 $\longrightarrow$ 89	(H)
69.6	119 $\longrightarrow$ 91	(CO)
67.5	120 $\longrightarrow$ 90	(CH ₂ O)
56.5	105 $\longrightarrow$ 77	(CO)
46.4	91 $\longrightarrow$ 65	(C ₂ H ₂)
44.6	89 $\longrightarrow$ 63	(C ₂ H ₂)



The mass spectra of the methyl-nitro-benzofuroxans are generally very complicated because of the number of competitive fragmentations that can occur from the molecular ion. However, some generalization concerning the positions of the methyl group and nitro group in relation to each other and the furoxan ring can be made.

The molecular ion of 5-methyl-6-nitro-benzofuroxan (MS-35) shows the characteristic loss of oxygen followed by the expected loss of OH through an ortho effect resulting in the base peak at m/e 162. The loss of a hydroxyl radical is the characteristic fragmentation of ortho-nitrotoluenes through an ortho effect.

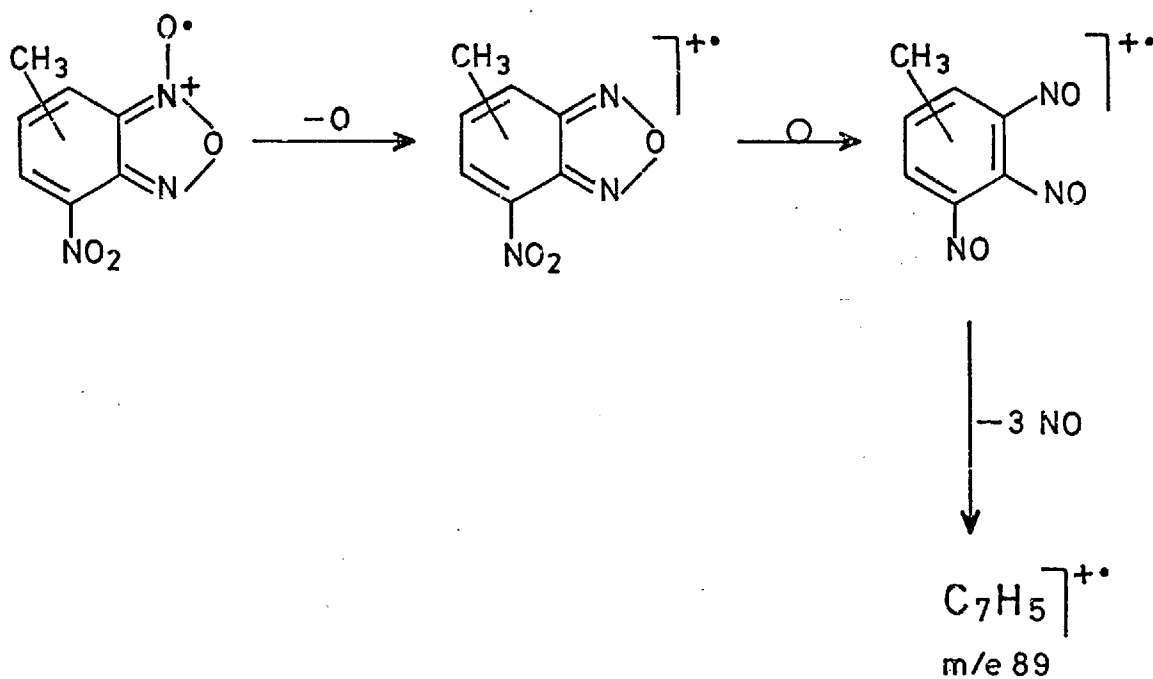
The molecular ion of the 4-methyl-6-nitro (MS-36) isomer shows the consecutive losses of two oxygen atoms. Analogous to the 4(7)-methyl-benzofuroxan the molecular ion also shows the loss of CHO through an ortho-effect.

Both the above methyl-nitro-derivatives exhibit the characteristic loss of two molecules of nitric oxide.

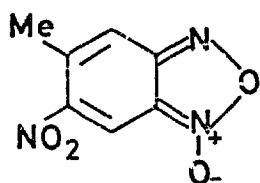
The mass spectra of the 4-nitro-7-methyl- and 4-nitro-6-methyl-benzofuroxans (MS-37 and MS-38 respectively) are even more complicated than the previous two isomers. The 4-nitro-7-methyl-derivative, through the ortho effect, exhibits the loss of CHO from its molecular ion. However this process does not seem to be compatible with the main fragmentation process of these two methyl-nitro-derivative where the nitro group is ortho to the furoxan ring.

The molecular ions in the 6- and 7-methyl-4-nitrobenzofuroxans (MS-38 and MS-37 respectively) undergo

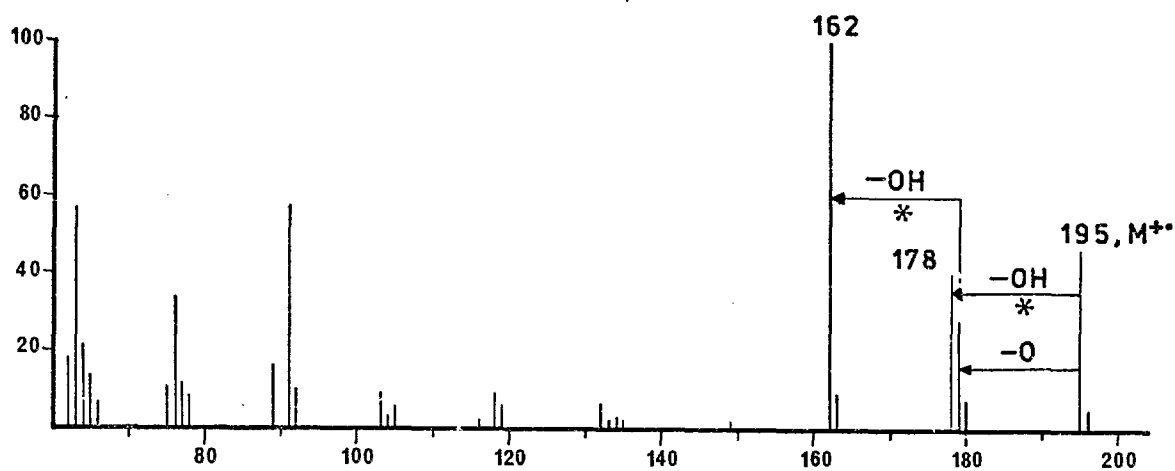
a facile loss of oxygen atom. The resulting ions at m/e 179, as mentioned previously, correspond to the molecular ion of the appropriate nitro-methyl-benzofurazans. As a result the $(M-O)^{+\bullet}$ undergoes three consecutive losses of nitric oxide resulting in the intense ion at m/e 89 (C_7H_5).



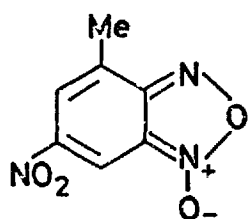
MS-35



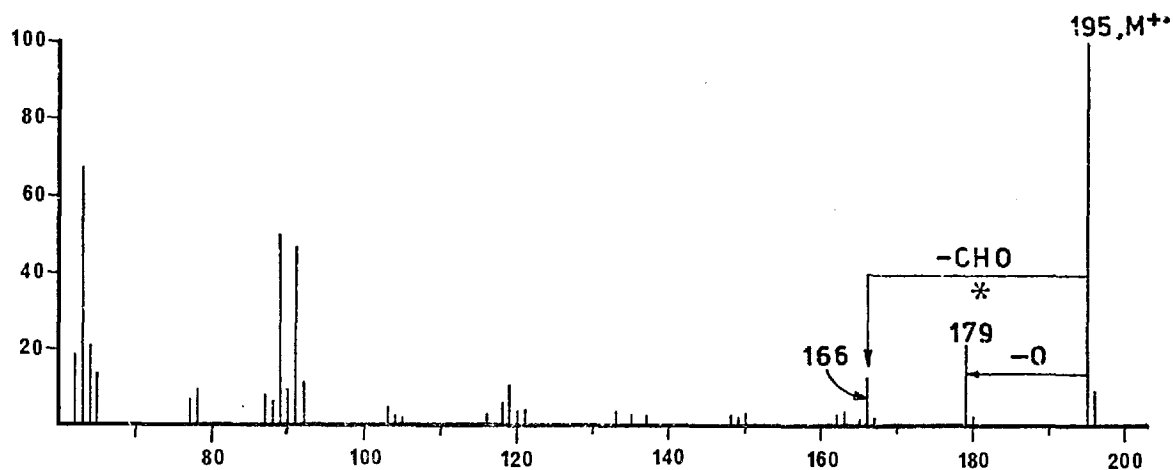
m^+	transition	loss
162.5 : 195	$\longrightarrow$ 178	(OH)
146.6 : 179	$\longrightarrow$ 162	(OH)
107.6 : 162	$\longrightarrow$ 132	(NO)
56.1 : 103	$\longrightarrow$ 76	(HCN)
45.0 : 91	$\longrightarrow$ 64	(HCN)
44.60 : 89	$\longrightarrow$ 63	(C ₂ H ₂)



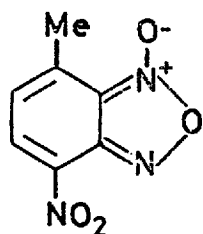
MS-36



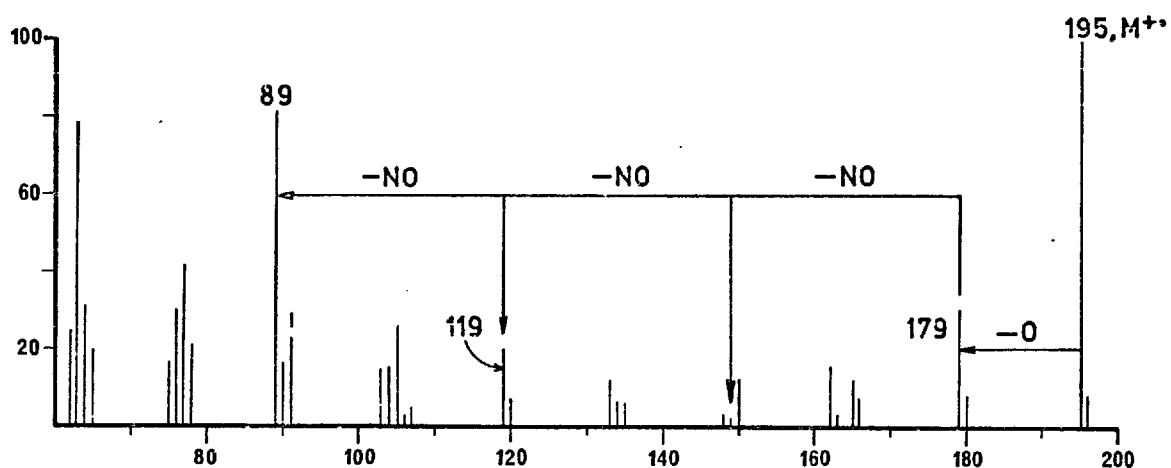
141.3 : 195	$\longrightarrow$ 166	(CHO)
92.2 : 195	$\longrightarrow$ 137	(CO+NO)
69.6 : 119	$\longrightarrow$ 91	(CO)



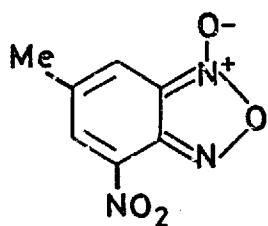
MS-37



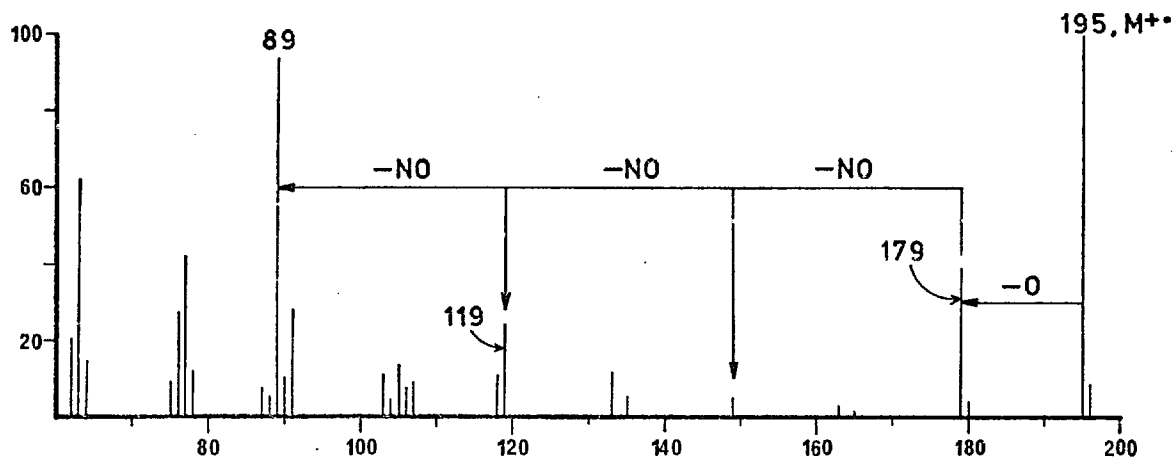
m^*	transition	loss
141.3	$195 \longrightarrow 166$	(CHO)
139.6	$195 \longrightarrow 165$	(NO)
44.6	$89 \longrightarrow 63$	(C ₂ H ₂)



MS-38



139.6	$195 \longrightarrow 165$	(NO)
44.6	$89 \longrightarrow 63$	(C ₂ H ₂)



BENZOTHIADIAZOLES

In this section the mass spectra of 1,2,3-benzothiadiazoles and 2,1,3-benzothiadiazoles are discussed and the fragmentation patterns compared to those of the analogous benzotriazoles and benzofurazans.

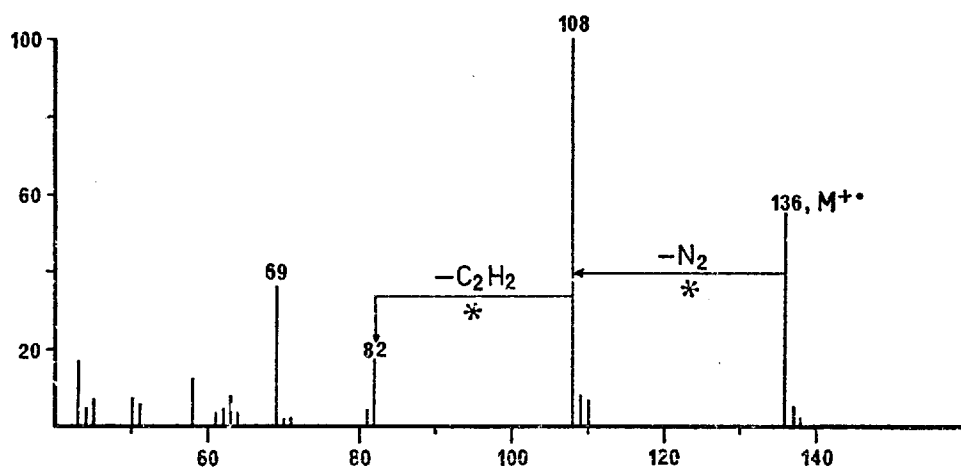
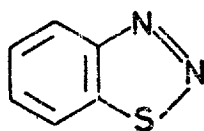
The molecular ion of 1,2,3-benzothiadiazole like the benzotriazole undergoes metastable loss of a nitrogen molecule. The resulting $(M-N_2)^{+\bullet}$ appears to be quite stable and gives rise to the base peak in the spectrum (MS-39). The only major metastable fragmentation of the ion $(M-N_2)^{+\bullet}$ involves the loss of acetylene giving the ion m/e 82. A metastable ion at m/e 62.3 confirms this loss. The metastable defocusing technique also shows the loss of a C_3H_3 radical from the ion $(M-N_2)^{+\bullet}$ resulting in the ion at m/e 69.

As in the analogous benzotriazole introduction of a methyl group into the benzene ring alters the fragmentation pattern to a large extent. The molecular ion undergoes only one fragmentation process, namely the loss of N_2 resulting in the ion $(M-N_2)^{+\bullet}$ at m/e 122. Metastable ions at m/e 99.2 in the mass spectra of 5- and 6-methylbenzothiadiazoles (MS-42 and MS-41 respectively) confirm the loss of N_2 from the molecular ion.

The ion $(M-N_2)^{+\bullet}$ in the spectra of these compounds as expected undergoes metastable loss of a hydrogen atom giving rise to the base peak at m/e 121. This loss of hydrogen can be explained in two ways. The first involves a ring expanded mechanism (path i, scheme XVIII).

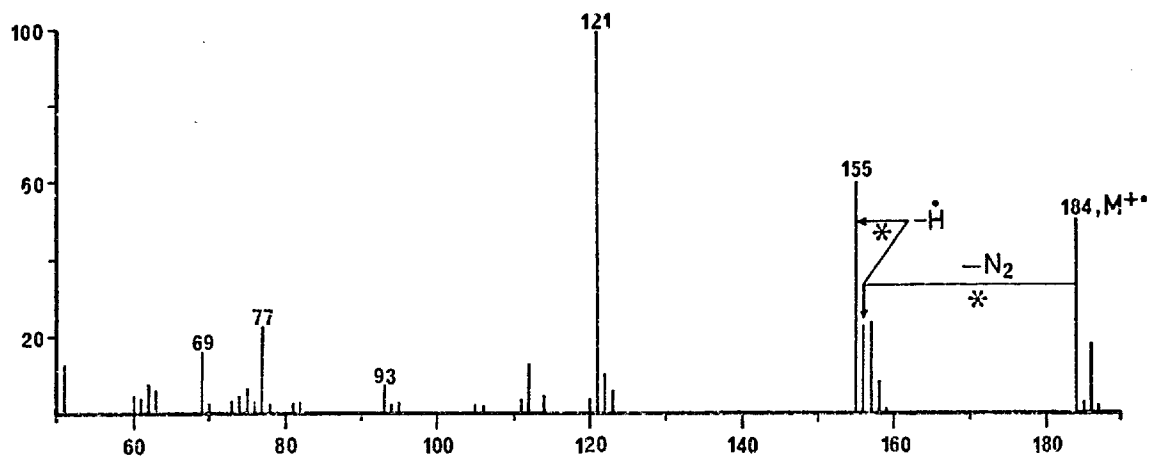
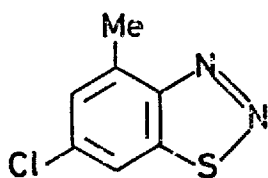
MS-39

<u>transition</u>	<u>loss</u>
85.8 : 136 $\longrightarrow$ 108	(N ₂)
62.3 : 108 $\longrightarrow$ 82	(C ₂ H ₂)

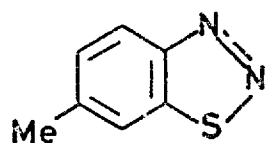


MS-40

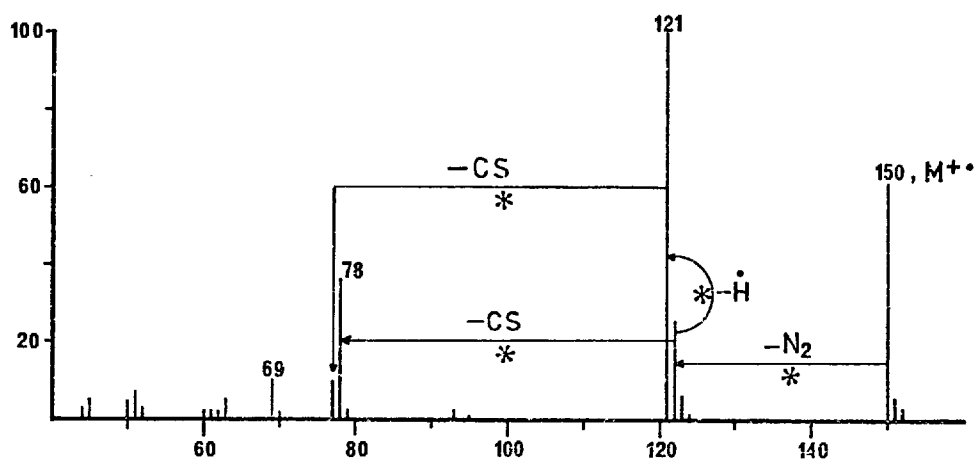
154.0 : 156 $\longrightarrow$ 155	(H)
132.3 : 184 $\longrightarrow$ 156	(N ₂)
93.8 : 156 $\longrightarrow$ 121	(Cl)
92.9 : 155 $\longrightarrow$ 120	(Cl)
49.0 : 121 $\longrightarrow$ 77	(CS)



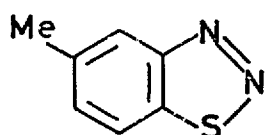
MS-41



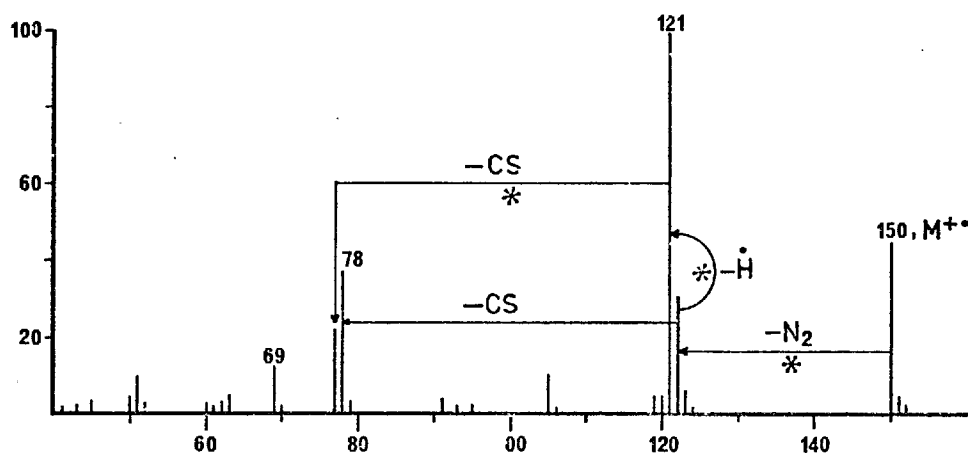
E^*	transition	loss
120.0 : 122	$\longrightarrow$ 121	(H)
99.2 : 150	$\longrightarrow$ 122	(N ₂)
49.9 : 122	$\longrightarrow$ 78	(CS)
49.0 : 121	$\longrightarrow$ 77	(CS)

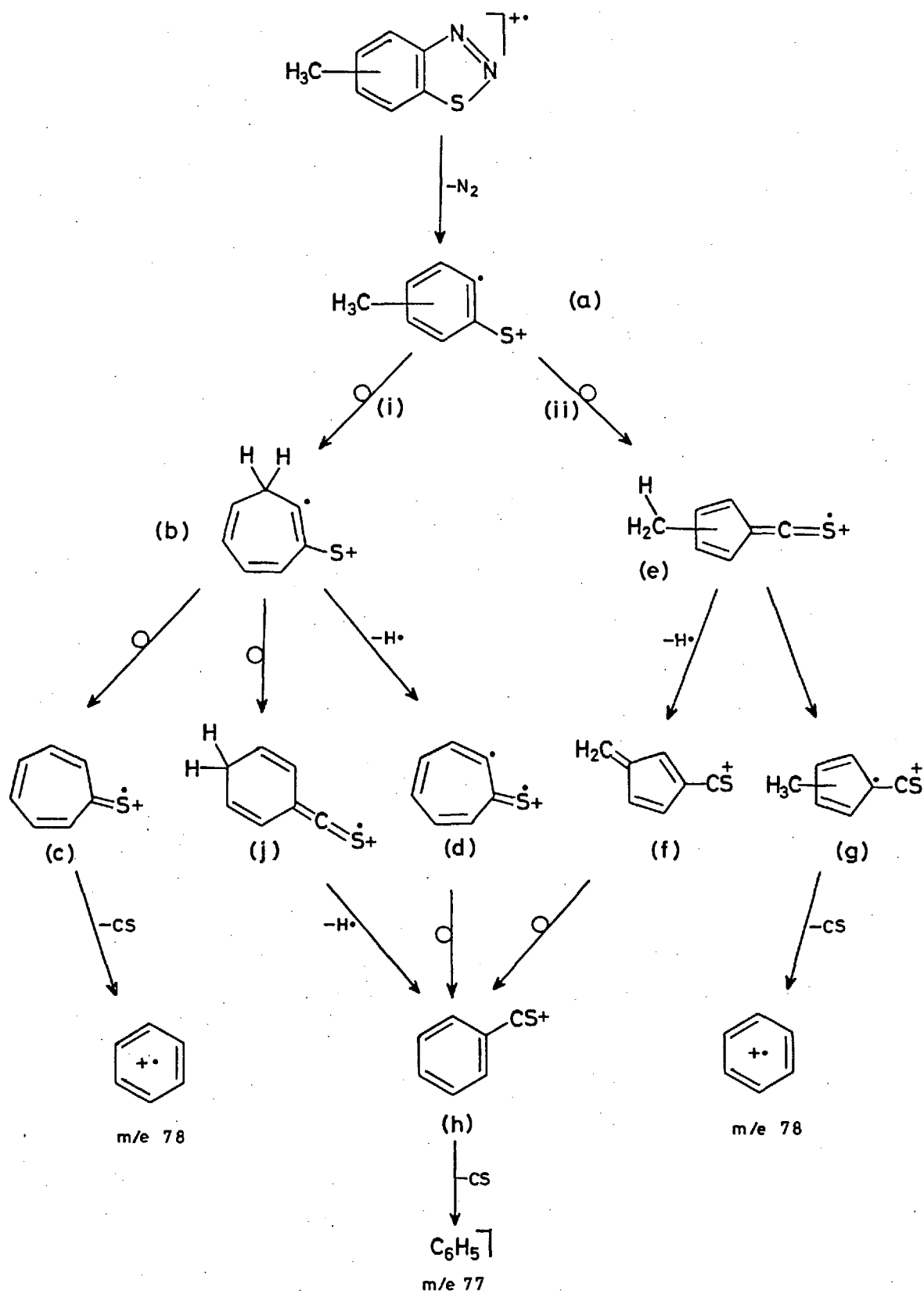


MS-42



120.0 : 122	$\longrightarrow$ 121	(H)
99.2 : 150	$\longrightarrow$ 122	(N ₂)
49.0 : 121	$\longrightarrow$ 77	(CS)
33.8 : 77	$\longrightarrow$ 51	(C ₂ H ₂)



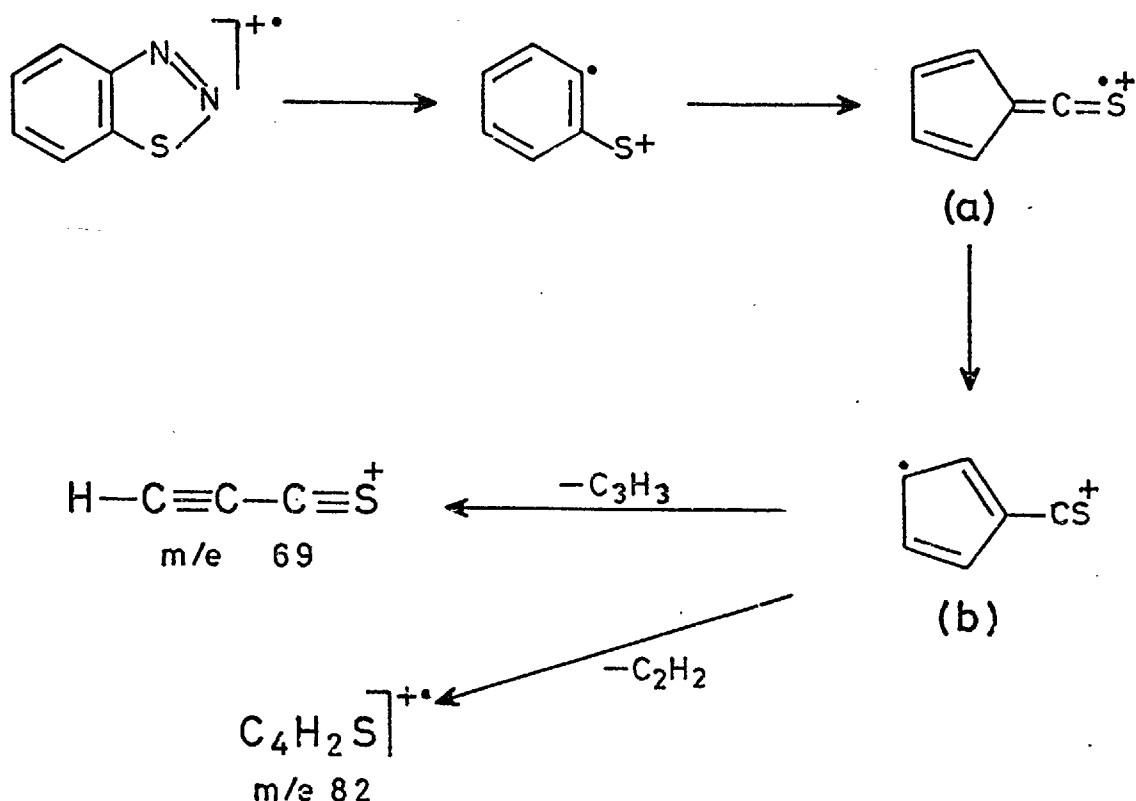


SCHEME XVIII

The second (path ii) on the other hand involves a ring contracted mechanism.

Both the ions $(M-N_2)^{+\bullet}$ and $(M-N_2-H)^+$ show the loss of CS. The loss of CS seems to be more favourable from the $(M-N_2)^{+\bullet}$ ion. This may be justified if one considers that the product ion in this fragmentation corresponds to the molecular ion of benzene.

The $(M-N_2)^{+\bullet}$ in the spectrum of the parent compound unlike that in the methyl derivatives does not show any loss of CS. This may be explained through the ring contracted mechanism (scheme XIX). The loss of CS from the intermediate (a and b scheme XIX) may be much slower than the same loss from the corresponding methyl substituted intermediate (g, scheme XVIII).



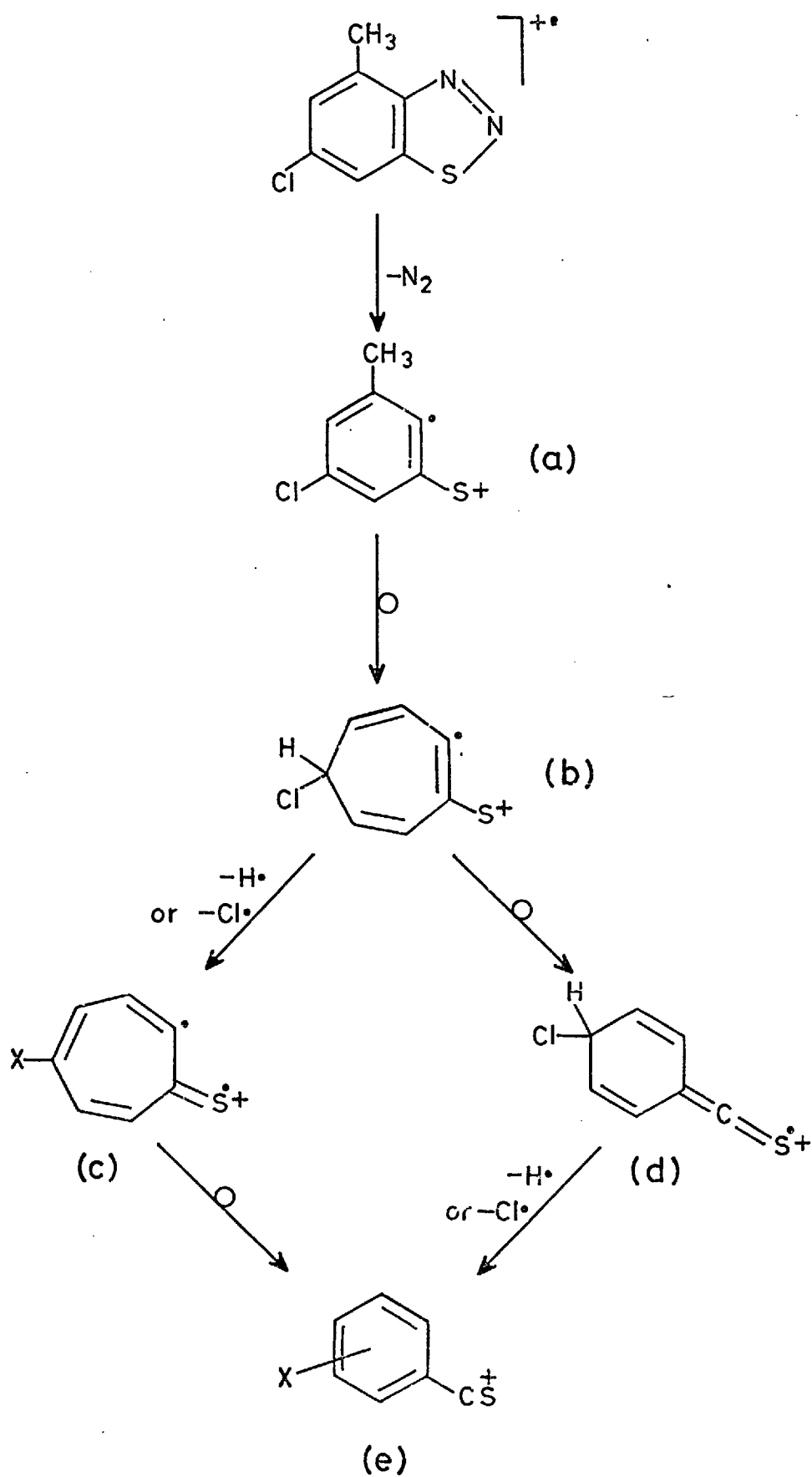
SCHEME XIX

The reason for the faster rate in the latter is probably because of the benzene molecular ion. The intermediate (b, scheme XIX) also explains the losses of C_2H_2 and C_3H_3 from the ion $(M-N_2)^{+•}$ in the spectrum of benzothiadiazole.

In the mass spectrum of 4-methyl-6-chloro-benzothiadiazole (MS-40) the molecular ion like that of the methyl-derivatives shows the loss of a nitrogen molecule resulting in the ion m/e 156. This ion, however, unlike the ion $(M-N_2)^{+•}$ in the spectra of the methyl-derivatives loses CS only to a small extent giving rise to the ion m/e 112. The reason for this behaviour is probably because of the highly competitive loss of a chlorine atom. The ion $(M-N_2)^{+•}$ also shows the loss of a hydrogen atom. Metastable ions at m/e 154.0 and m/e 93.8 confirm the losses of $H•$ and $Cl•$ from the ion m/e 156. Comparison of the ion intensities indicates that the loss of a chlorine atom from the ion $(M-N_2)^{+•}$ is a more favourable process resulting in the base peak of the spectrum at m/e 121.

The mechanism for the competing metastable losses of hydrogen and chlorine atoms may conceivably involve the ring expansion ring contraction process (scheme XX).

The greater loss of a chlorine atom relative to hydrogen from the ion $(M-N_2)^{+•}$ is not surprising, since a similar observation has been made in the spectrum of chloro-toluenes ²⁵ (see review, page 24). The relatively small loss of CS from the ion $(M-N_2)^{+•}$ may also be justified through the intermediate (d, scheme XX). The most



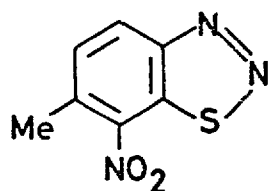
SCHEME XX

probable decomposition that (d) undergoes is the loss H. or Cl. resulting in product ions which are relatively stable, i.e. the benzenoid structure (e) in scheme XX.

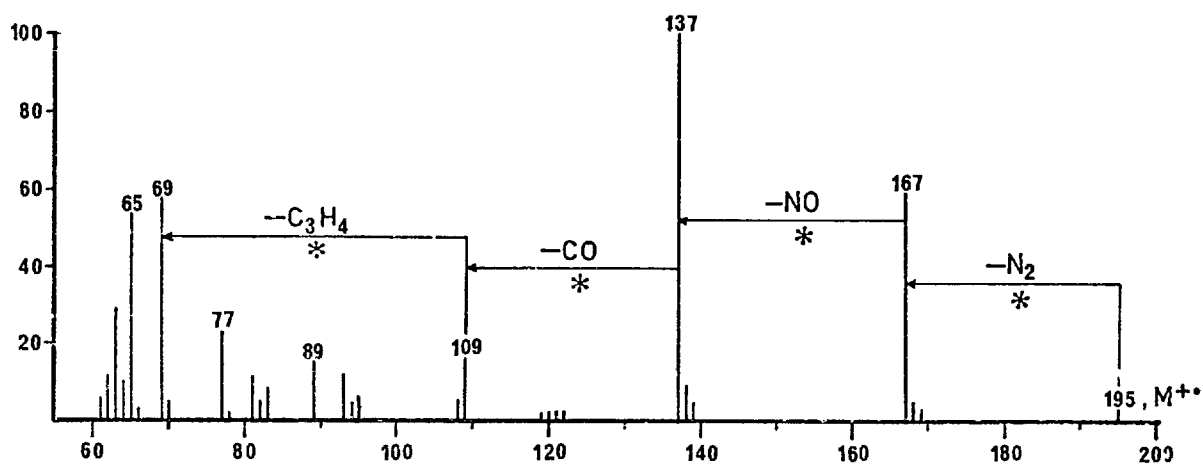
Some interesting results concerning the mass spectral fragmentation of nitro-methyl-benzothiadiazoles have been obtained. In the mass spectrum of the 6-methyl-7-nitrobenzothiadiazole (MS-43) the molecular ion is hardly observable, whereas the molecular ion of the 5-methyl-4-nitro-benzothiadiazole (MS-44) constitutes the base peak in the spectrum.

The molecular ion of the 4-nitro-5-methyl-derivative (MS-44) shows the loss of N_2 resulting in the ion at m/e 167. Typical fragmentations of aromatic nitro compounds ¹²⁵ are observed from the ion $(M-N_2)^+$, namely loss of NO_2 and losses of NO followed by CO giving rise to the ions m/e 121 (rel. 4%), m/e 137 (rel.int.19%) and m/e 109 (rel. 32%) respectively. The main fragmentation of the ion m/e 121 involves the loss of CS giving rise to the ion m/e 77. A metastable ion at m/e 49.0 confirms this loss. The ion m/e 109 $(C_6H_5S)^+$ however, undergoes two major fragmentations. These involve the losses of CS and C_3H_4 (methylacetylene) resulting in the ions m/e 65 and m/e 69 respectively. A metastable ion at m/e 38.8 confirms the loss of CS from the ion $(C_6H_5S)^+$, while metastable defocusing technique and accurate mass measurement of the ion m/e 69 established the loss of C_3H_4 . A probable mechanism for the above fragmentation from the 4-nitro-5-methylbenzothiadiazole is shown in scheme XXI.

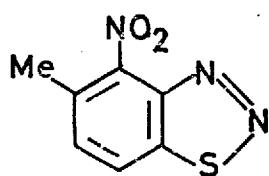
MS-43



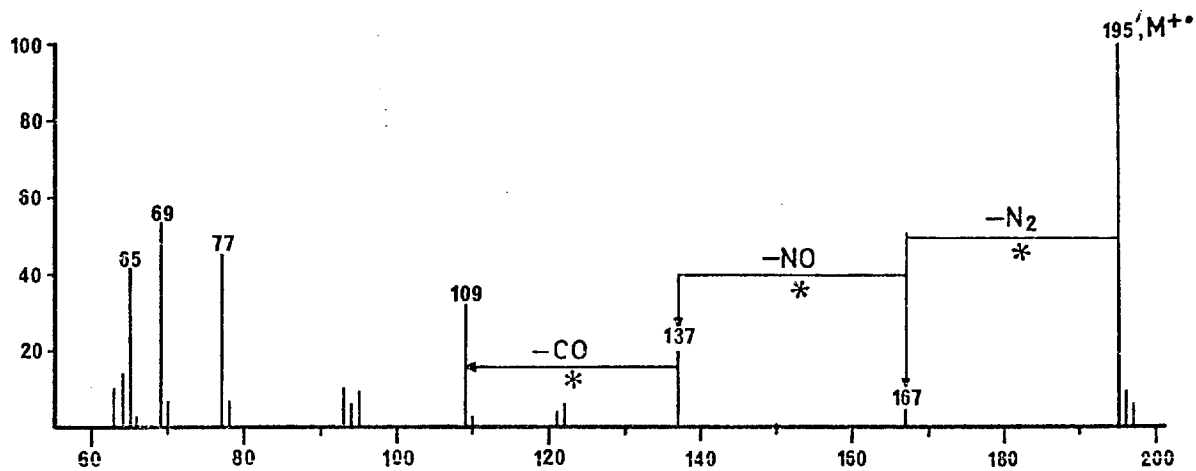
<u>m*</u>	<u>transition</u>	<u>loss</u>
143.0	: 195 $\longrightarrow$ 167	(N ₂)
112.4	: 167 $\longrightarrow$ 137	(NO)
86.7	: 137 $\longrightarrow$ 109	(CO)
49.0	: 121 $\longrightarrow$ 77	(CS)
44.6	: 89 $\longrightarrow$ 63	(C ₂ H ₂)
43.7	: 109 $\longrightarrow$ 69	(C ₃ H ₄)
38.8	: 109 $\longrightarrow$ 65	(CS)
33.8	: 77 $\longrightarrow$ 51	(C ₂ H ₂)

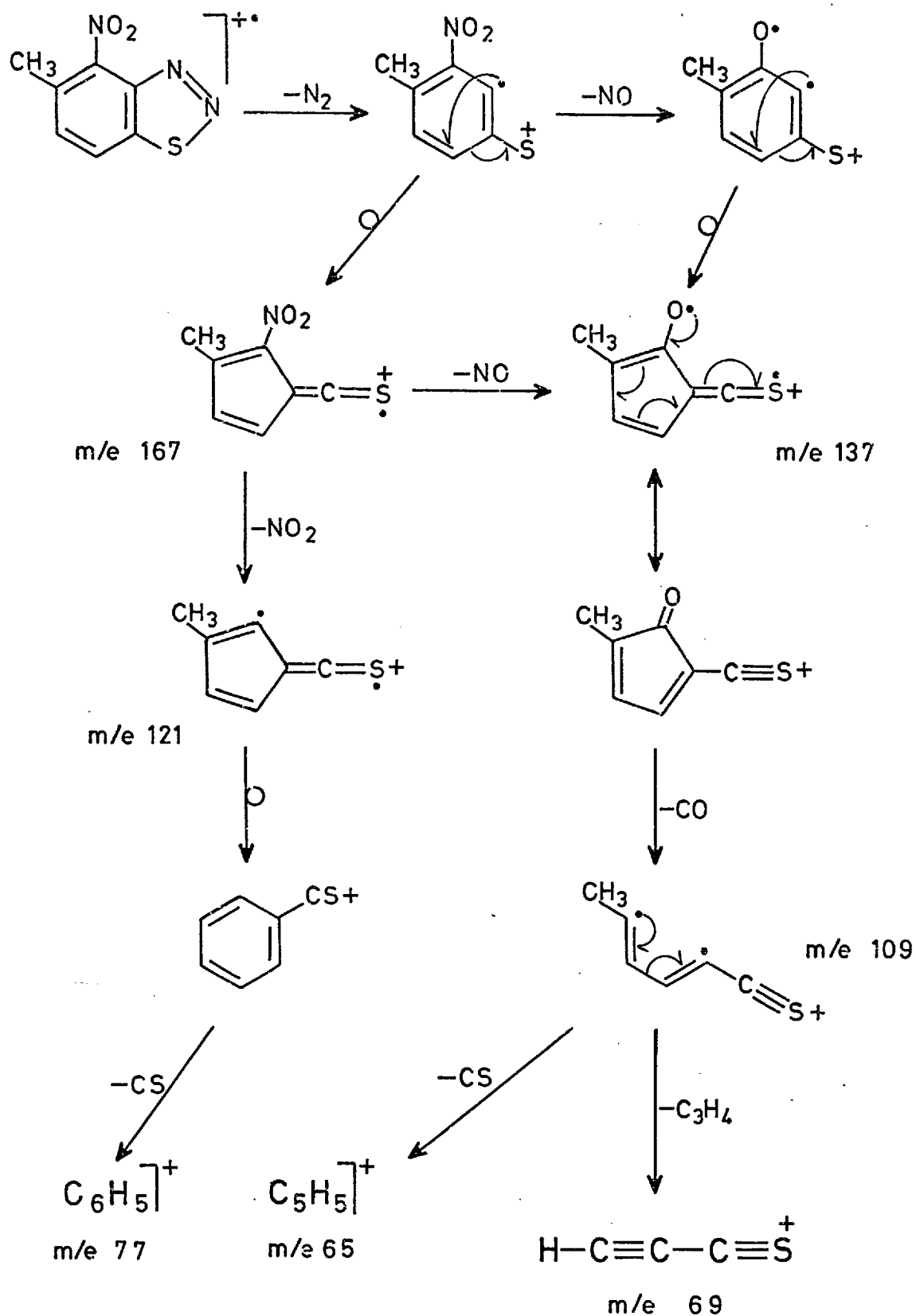


MS-44



143.0	: 195 $\longrightarrow$ 167	(N ₂)
112.4	: 167 $\longrightarrow$ 137	(NO)
86.7	: 137 $\longrightarrow$ 109	(CO)
49.0	: 121 $\longrightarrow$ 77	(CS)
38.8	: 109 $\longrightarrow$ 65	(CS)
33.8	: 77 $\longrightarrow$ 51	(C ₂ H ₂)

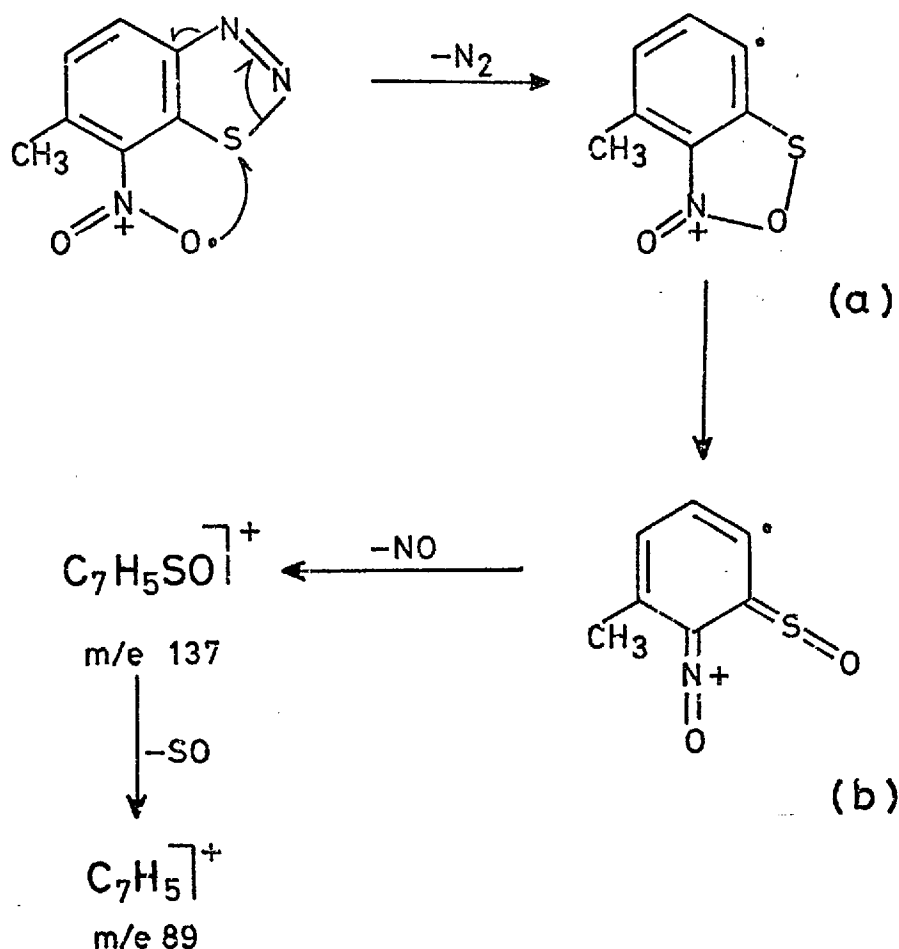




SCHEME XXI

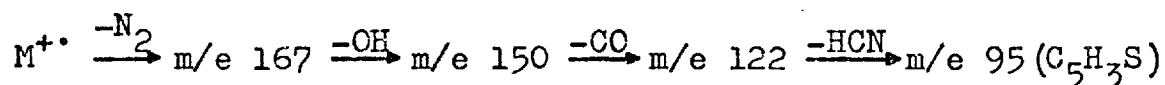
In the mass spectrum of 7-nitro-6-methylbenzothiadiazole (MS-43) the same type of fragmentations described for the 4-nitro-5-methyl-derivative are observed. However, the base peak in the spectrum corresponds to the $(M-N_2-NO)^+$ ion at m/e 137. The molecular ion in contrast to the 4-nitro-5-methylbenzothiadiazole has a low relative intensity of only 3% suggesting instability. The loss of N_2 from the molecular ion of 7-nitro-6-methyl-derivative is accompanied by stabilization of the product ion by the intermediate (a) (Scheme XXII). The nitro group in the position 7 is also responsible for the extremely facile loss of N_2 from the molecular ion by the concerted mechanism shown in scheme XXII. The production of the intermediate (a) is very probable. This intermediate could rearrange to the ion (b) which would lose NO and SO resulting in the ions m/e 137 and m/e 89. Mass measurements of the ion m/e 89 showed that it corresponds to the losses of $(N_2 + NO + SO)$ from the molecular ion giving rise to $(C_7H_5)^+$. The absence of the ion m/e 89 in the spectrum of 4-nitro-5-methyl benzothiadiazole and the higher relative intensities of the ions m/e 167 and m/e 137 in the case of 7-nitro-5-methyl-isomer are in support of the mechanism in scheme XXII.

In the spectra of the 4-nitro-5-methyl- and 7-nitro-6-methyl-benzothiadiazoles (MS-44 and MS-43 respectively), although the methyl and nitro groups are ortho to each other, the expected ortho effect does not seem to be operating to any significant extent. However the small contribution of this fragmentation pathway accounts for the low intensity ions at m/e 122 and m/e 95.



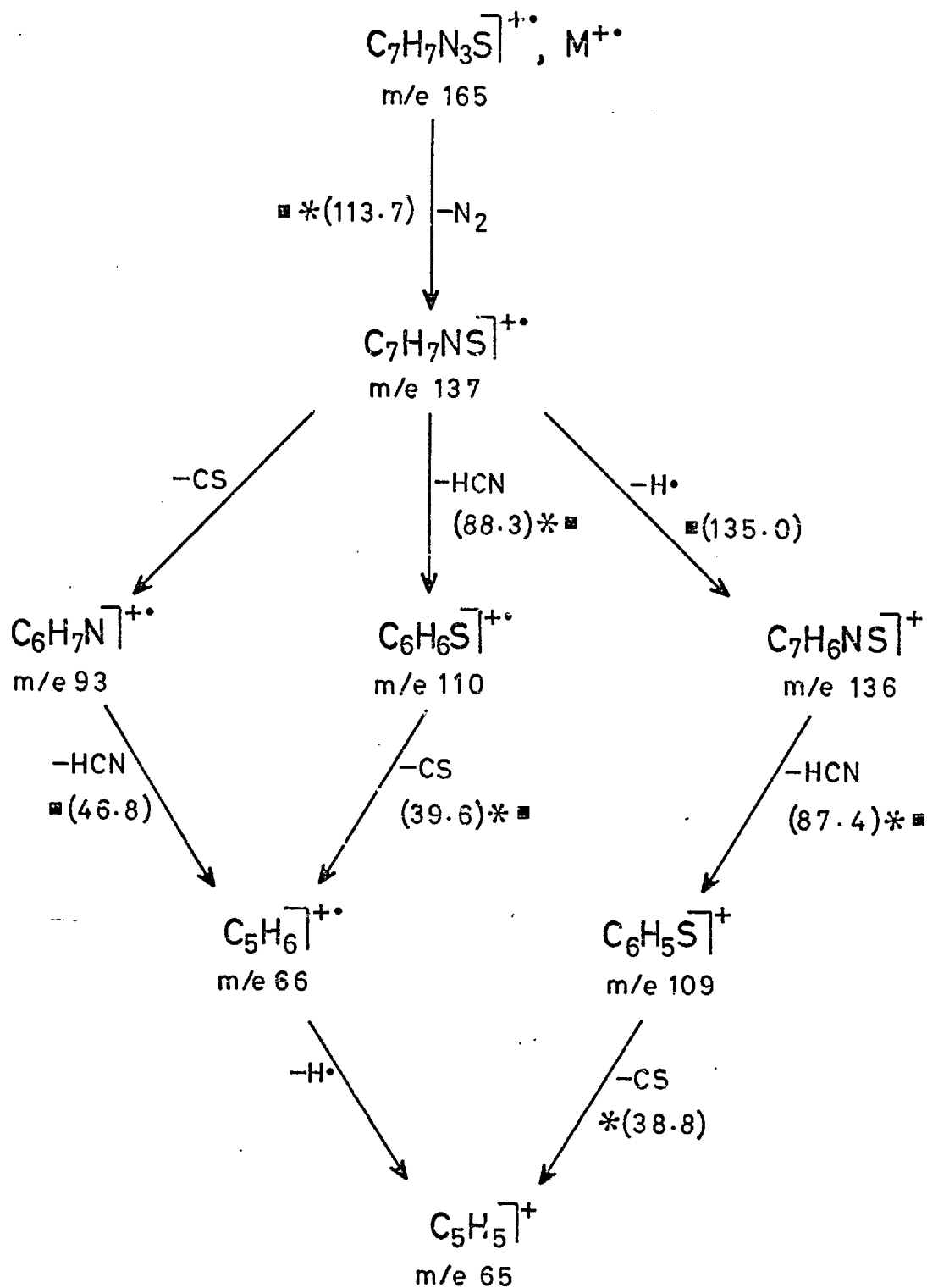
SCHEME XXII

Accurate mass measurement of the ion $m/e \ 95$ ($\text{C}_5\text{H}_3\text{S}$) confirms the occurrence of this process.



The molecular ion of the 4-amino-5-methyl- and 7-amino-6-methyl-benzothiadiazoles like other 1,2,3-benzothiadiazoles undergo facile loss of N_2 resulting in the ions $m/e \ 137$ in the two spectra (MS-46 and MS-45 respectively). This ion undergoes three major processes resulting in the ions in the lower mass region. These three

fragmentation processes are best explained in the scheme XXIII.

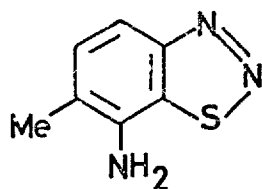


* Metastable ions for 4-amino-5-methyl-derivative.

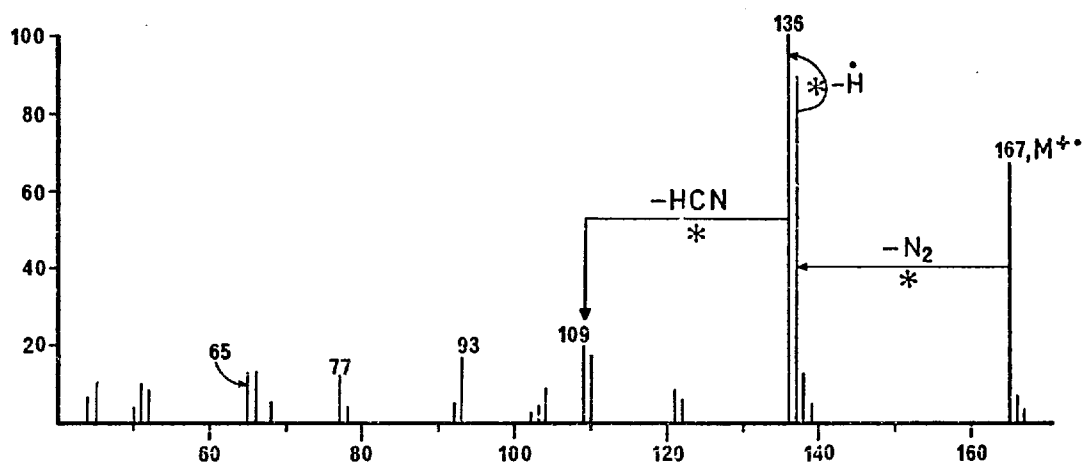
$\blacksquare$ Metastable ions for 7-amino-6-methyl-derivative.

SCHEME XXIII

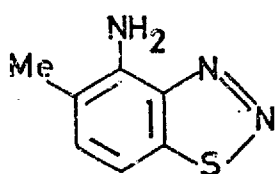
MS-45



<u>m*</u>	<u>transition</u>	<u>loss</u>
135.0	: 137 $\longrightarrow$ 136	(H)
113.7	: 165 $\longrightarrow$ 137	(N ₂)
88.3	: 137 $\longrightarrow$ 110	(HCN)
87.4	: 136 $\longrightarrow$ 109	(HCN)
46.8	: 93 $\longrightarrow$ 66	(HCN)
39.6	: 110 $\longrightarrow$ 66	(CS)



MS-46



113.7	: 165 $\longrightarrow$ 137	(N ₂)
88.3	: 137 $\longrightarrow$ 110	(HCN)
87.4	: 136 $\longrightarrow$ 109	(HCN)
62.2	: 136 $\longrightarrow$ 92	(CS)
39.6	: 110 $\longrightarrow$ 66	(CS)
38.8	: 109 $\longrightarrow$ 65	(CS)

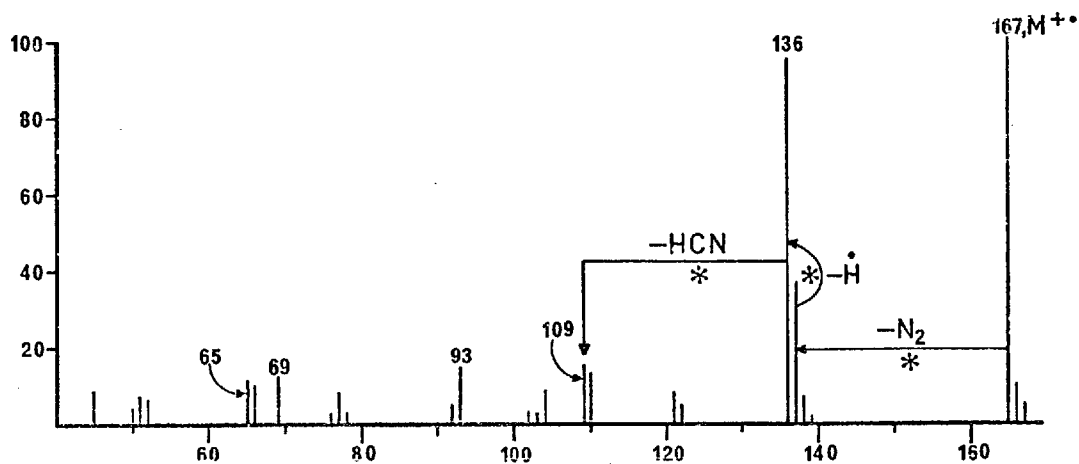
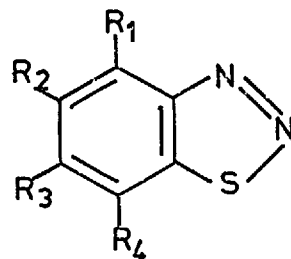


TABLE VIII



Compound				(ev)			
R ₁	R ₂	R ₃	R ₄	IP(M) ⁺⁺	AP(M-N ₂) ⁺⁺	E _a	AP(M-[N ₂ +H]) ⁺
-	-	-	-	8.98	10.03	1.05	-
-	CH ₃	-	-	8.73	9.78	1.05	11.28
-	-	CH ₃	-	8.98	9.98	1.00	-
CH ₃	-	Cl	-	8.93	10.23	1.30	12.08
NH ₂	CH ₃	-	-	7.53	9.88	2.35	11.43
-	-	CH ₃	NH ₂	7.48	9.13	1.65	11.53
NO ₂	CH ₃	-	-	9.73	-	-	-
-	-	CH ₃	NO ₂	-	-	-	-

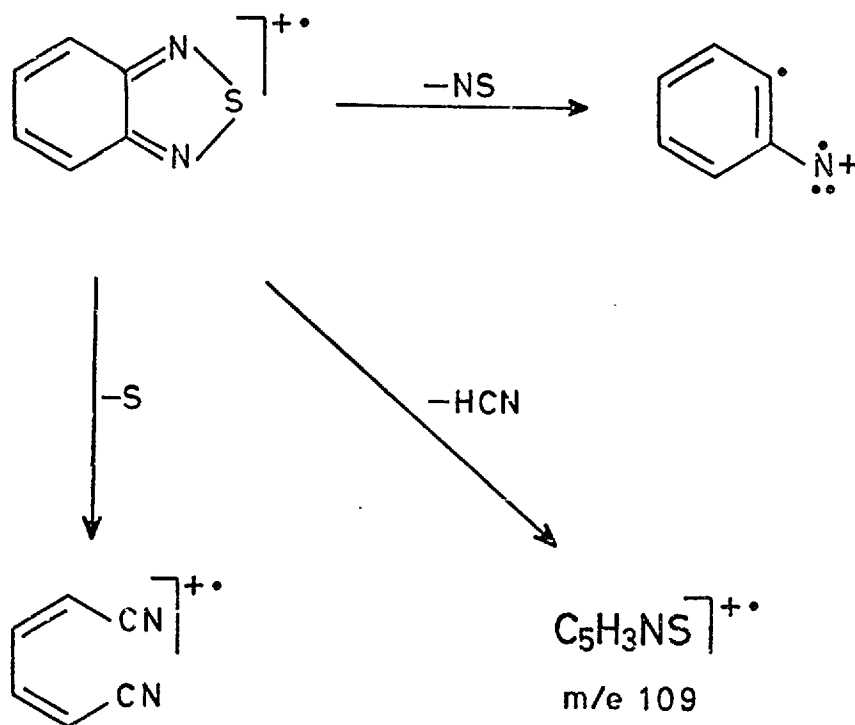
The ionization potential values for the production of the molecular ions of the 1,2,3-benzothiadiazoles are dependent on the substituents. The compounds with an amino group have the lowest IP values whereas the highest value corresponds to the nitro-substituted derivatives, (Table VIII).

The value of the energy of activation was calculated in the same way as the E_a values for the benzotriazoles and benzofurazans. Again these values are largest for the amino derivatives which can be explained as in the previous cases.

2,1,3-Benzothiadiazoles

Unlike the 1,2,3-benzothiadiazoles the mass spectra of the 2,1,3-benzothiadiazoles do not show fragmentation of the molecular ion to any appreciable extent. The molecular ion constitutes the base peak in the spectra, and the main fragmentation of this ion involves the loss of hydrogen cyanide.

By analogy to the fragmentation of benzofurazan the molecular ion of the 2,1,3-benzothiadiazole shows the loss of NS to a very small extent (MS-47). The low abundance of the ion $(M-NS)^+$ may be because of the relative instability of NS as compared to NO. The molecular ion also shows a small loss of S which may be explained via a similar mechanism suggested for the pyrolytic and photo-lytic cleavages. (Scheme XXIV).

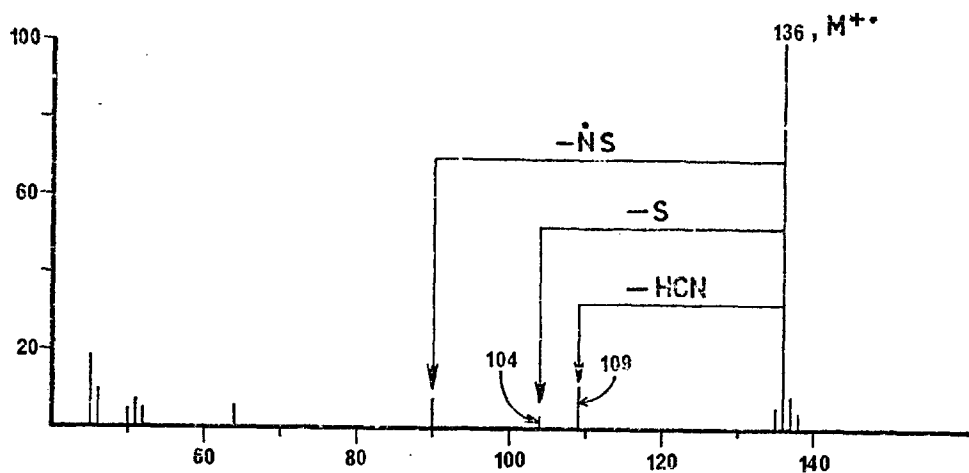
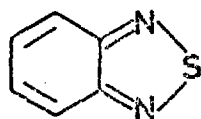


SCHEME XXIV

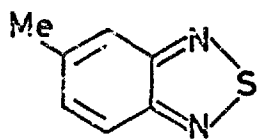
Like the parent compound the molecular ion of 5-methyl-2,1,3-benzothiadiazole is the base peak in the spectrum (MS-48). Losses of HCN, NS and S are observed from the molecular ion resulting in the ions m/e 123, m/e 104 and m/e 118 respectively. The most significant fragmentation of the molecular ion is the loss of a hydrogen atom giving rise to the ion m/e 149. Besides the metastable loss of HCN, the ion $(M-H)^+$ also exhibits a loss of CS to a very small extent resulting in the ion m/e 105 ($\text{C}_6\text{H}_5\text{N}_2^+$) (rel. int. 2%). The identity of the ion m/e 105 has been confirmed by accurate mass measurement.

The combined loss of H + CS from the molecular ion of 5-methyl-benzothiadiazole is analogous to the loss

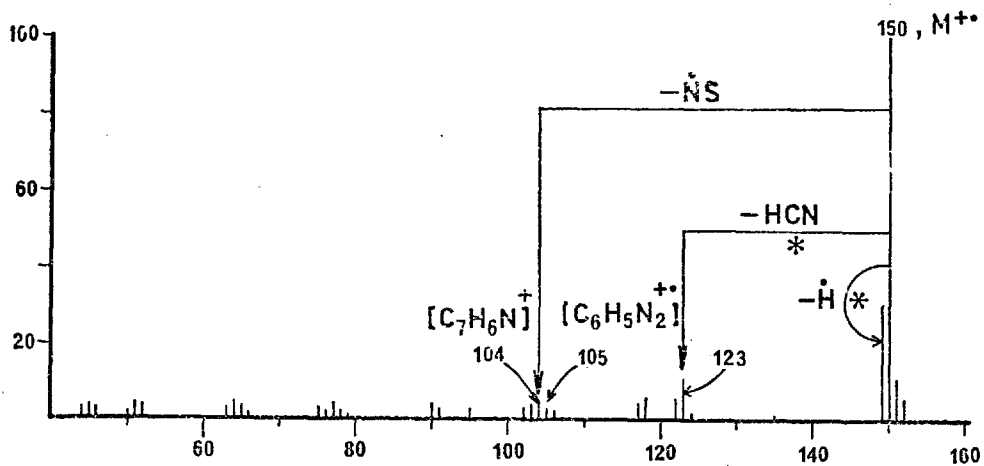
MS-47



MS-48



m^*	transition	loss
148.0 : 150	$\longrightarrow$ 149	(H)
121.5 : 150	$\longrightarrow$ 135	(Me)
100.9 : 150	$\longrightarrow$ 123	(HCN)
99.9 : 149	$\longrightarrow$ 122	(HCN)
74.9 : 123	$\longrightarrow$ 96	(HCN)
69.2 : 117	$\longrightarrow$ 90	(HCN)

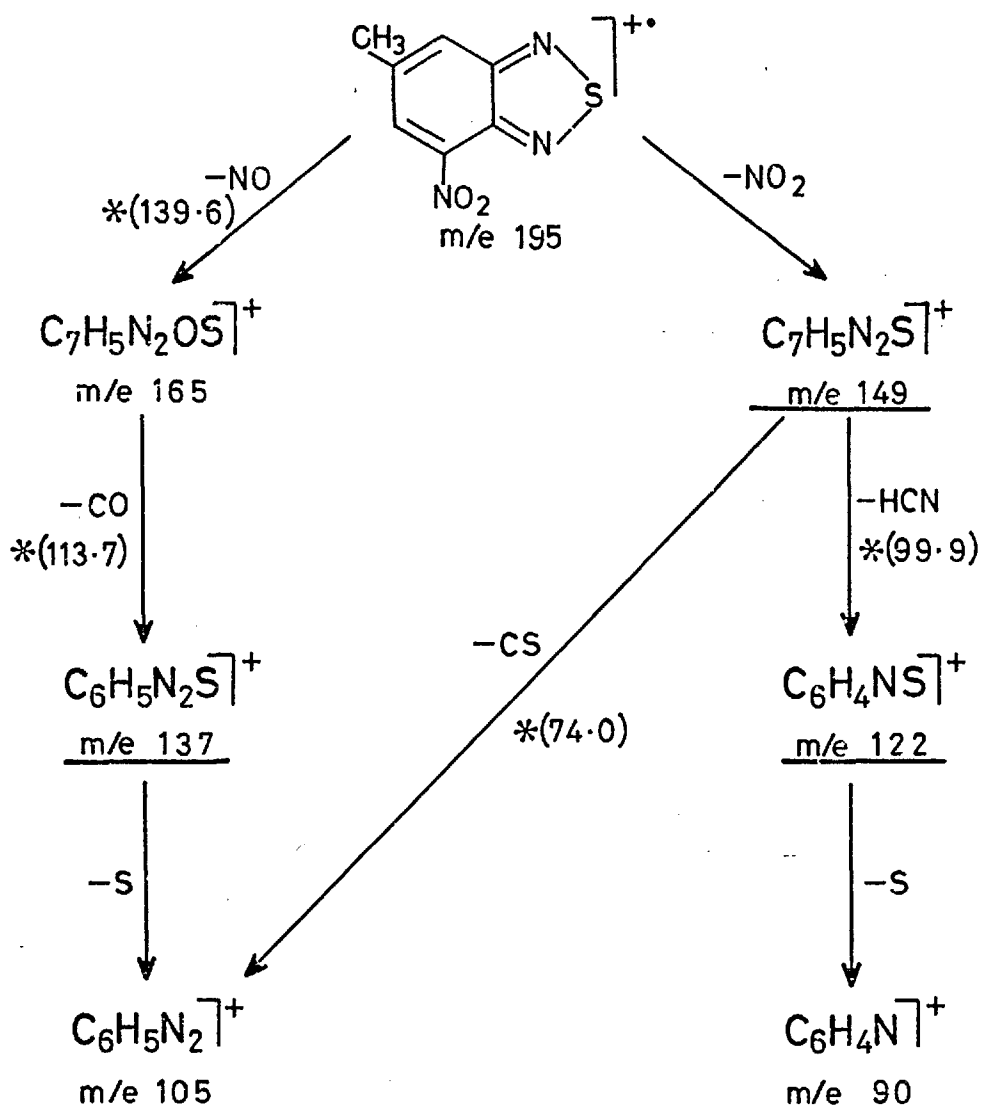


of (H + CO) from the molecular ion of methyl-benzofurazans. It may be that because of the greater stability of CO the (M-H)⁺ in the latter compounds undergoes extremely facile decomposition resulting in the ion (M-CHO)⁺, whereas in the case of the 5-methylbenzothiadiazole the loss of CS is not favourable and as a result most of the (M-H)⁺ ions are detected at the collector without decomposition. The loss of CS most probably follows the same type of mechanism proposed for the loss CO in the methylbenzofurazans. (Scheme XIV page 170).

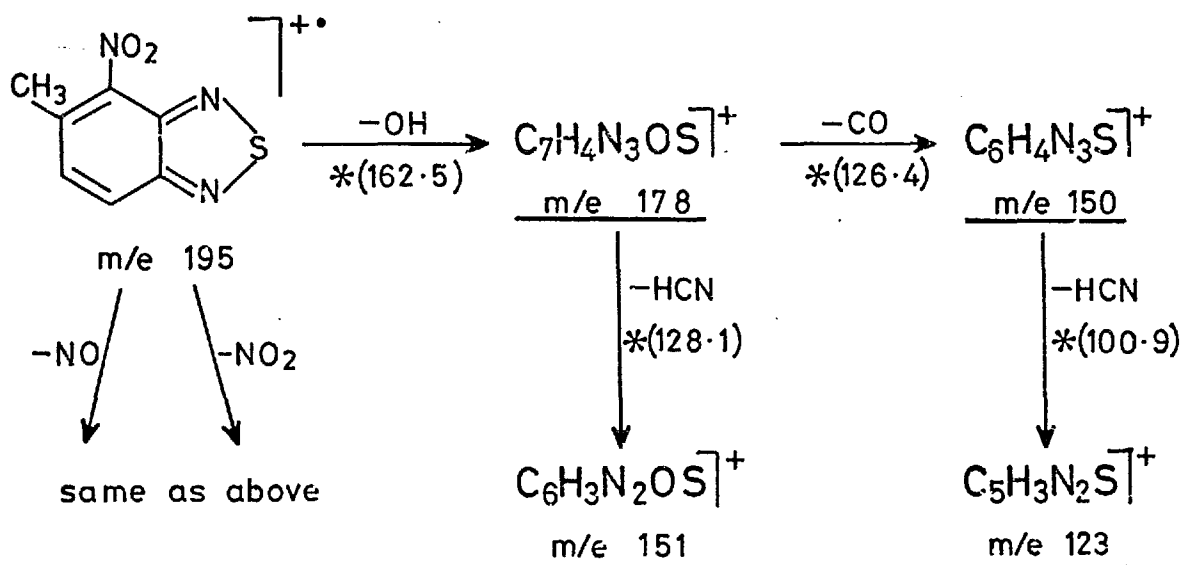
The main fragmentations of the molecular ion of the 5- and 6-methyl-4-nitrobenzothiadiazoles are those corresponding to aromatic nitro-compounds¹²⁵ (MS-50 and MS-49 respectively).

The fragmentation processes in the spectrum of the 6-methyl-4-nitro-derivative are shown in scheme XXV. Mass measurement of the ion m/e 149 shows that this ion corresponds to the loss of NO₂ and not NS from the molecular ion.

In the spectrum of the 5-methyl-4-nitro-benzothiadiazole the same fragmentations described for the 6-methyl-4-nitro-isomer are observed. However, because of the positions of the methyl and nitro groups with respect to each other, the main fragmentations are caused by the known ortho effect, i.e. the loss of OH followed by expulsion of CO giving rise to the ions m/e 178 and m/e 150 respectively. (Scheme XXVI).



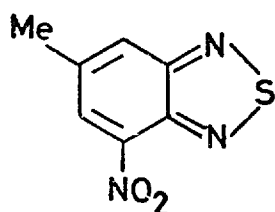
SCHEME XXV



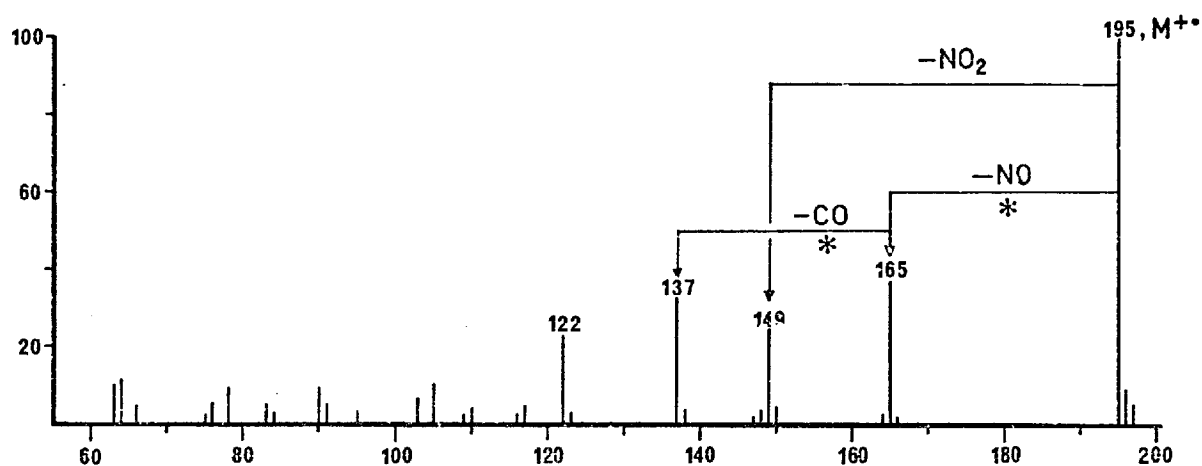
The underlined ions have been identified by accurate mass measurements.

SCHEME XXVI

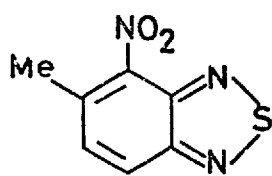
MS - 49



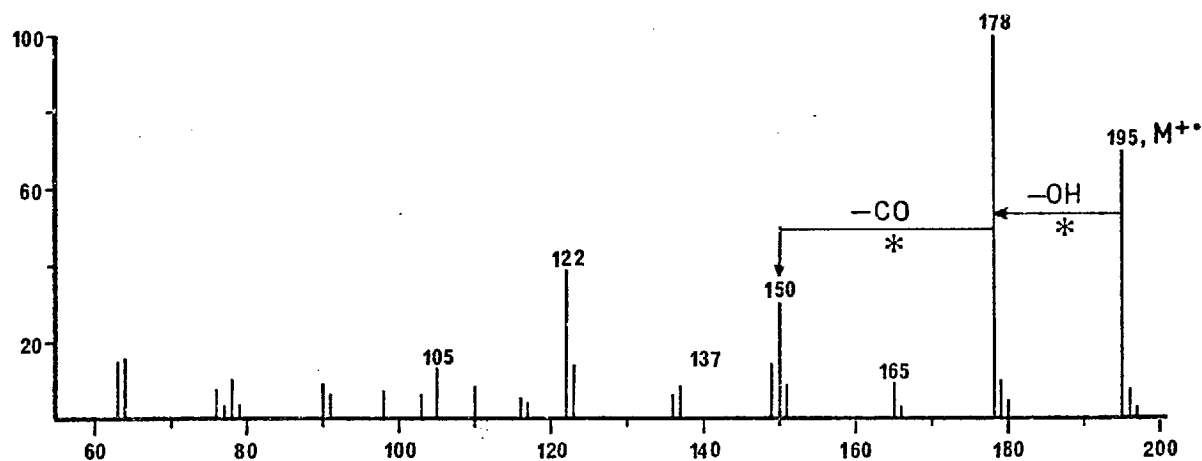
<u>m*</u>	<u>transition</u>	<u>loss</u>
139.6	: 195 → 165	(NO)
113.7	: 165 → 137	(CO)
99.9	: 149 → 122	(HCN)
74.00	: 149 → 105	(CS)



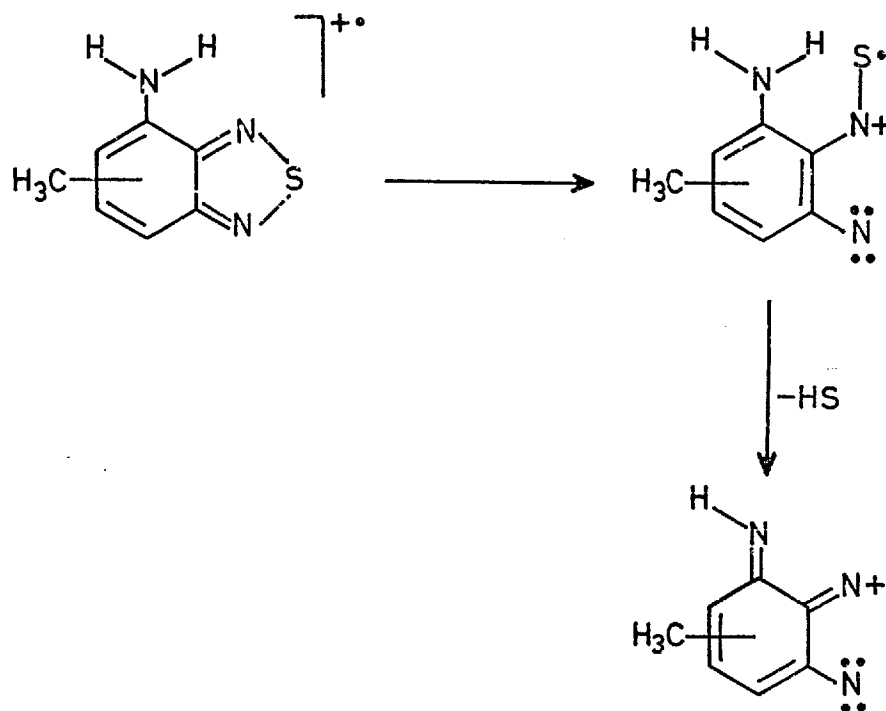
MS - 50



162.5	: 195 → 178	(OH)
128.1	: 178 → 151	(HCN)
126.4	: 178 → 150	(CO)
100.9	: 150 → 123	(HCN)
99.9	: 149 → 122	(HCN)
88.3	: 137 → 110	(HCN)
74.0	: 149 → 105	(CS)



In the spectra of the 5- and 6-methyl-4-amino-2,1,3-benzothiadiazoles like other 2,1,3-benzothiadiazoles the base peaks are the molecular ions, (MS-51 and MS-52 respectively). The molecular ion in both spectra shows a loss of HS radical. This loss most likely occurs via an ortho effect.

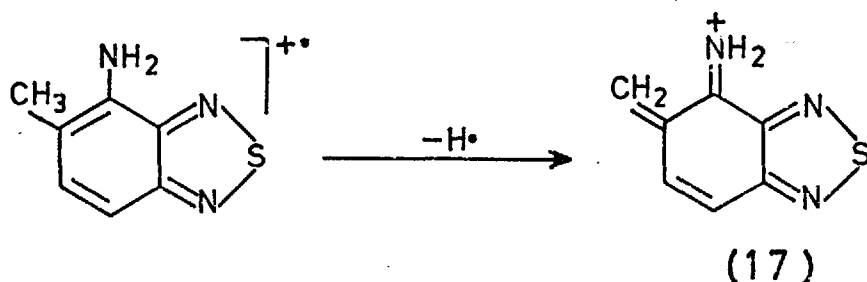


The $(M-HS)^+$ ions in both spectra undergo further decomposition by three consecutive losses of HCN resulting in the ions m/e 105, m/e 78 and m/e 51. These losses are confirmed by the presence of metastable ions at m/e 83.5, m/e 57.9 and m/e 33.4.

The most important fragmentation of the molecular ion, however, is the loss of a hydrogen atom resulting in the ion m/e 164. Comparison of the relative intensities of this ion in the two spectra clearly indicates that the loss of $H\cdot$ is more favoured in the case of 4-amino-5-methyl-benzothiadiazole. Aromatic amines are known¹²⁷ to exhibit

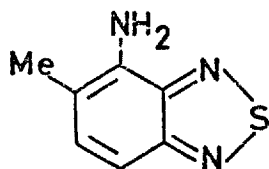
a strong molecular ion and an $(M-1)^+$ ion with a relative intensity of approximately 11%. It is therefore the loss of methyl hydrogen which is responsible for the strong $(M-1)$ ion in these compounds. The differences in the intensities clearly rule out the possibility of tropylium ion formation since in such a case one would expect to observe the same intensity for the $(M-1)$ ions in the two spectra.

The greater loss of $H\cdot$ from the 4-amino-5-methyl-isomer is due to the stabilization of the product ion by the resonance contributing structure (17).

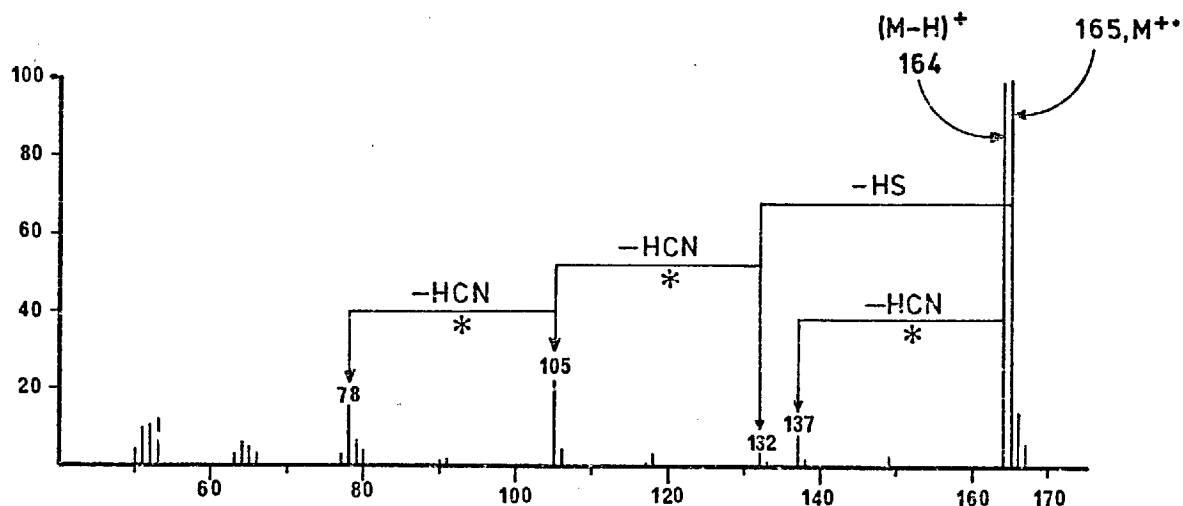


The formation of this structure could be the driving force for the loss of the hydrogen atom. Since no such driving force can operate in the case of 4-amino-6-methyl-derivative the loss of a hydrogen atom does not seem to be as favoured.

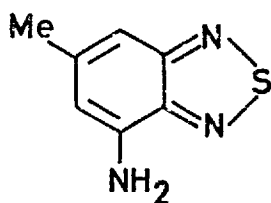
MS-51



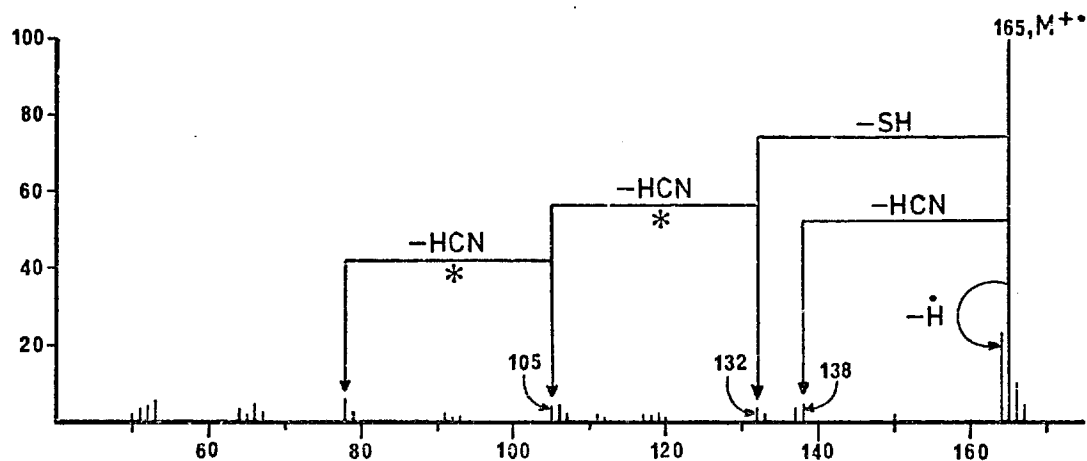
m^*	transition	loss
163.0	: 165 $\longrightarrow$ 164	(H)
114.4	: 164 $\longrightarrow$ 137	(HCN)
83.5	: 132 $\longrightarrow$ 105	(HCN)
57.9	: 105 $\longrightarrow$ 78	(HCN)
33.4	: 78 $\longrightarrow$ 51	(HCN)



MS-52

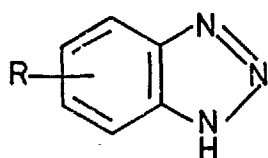


115.4	: 165 $\longrightarrow$ 138	(HCN)
114.4	: 164 $\longrightarrow$ 137	(HCN)
85.8	: 165 $\longrightarrow$ 119	(NS)
83.5	: 132 $\longrightarrow$ 105	(HCN)
57.9	: 105 $\longrightarrow$ 78	(HCN)
33.3	: 78 $\longrightarrow$ 51	(HCN)

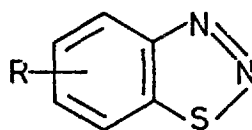


Comparison of the IP values for the benzotriazoles, benzofurazans and benzothiadiazoles clearly show that the highest values correspond to the benzofurazans. The values of IP for the other two groups of compounds appear to be very close to each other.

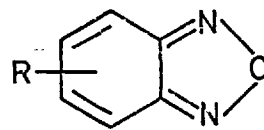
The values of the activation energy for the loss of N_2 are much lower than the values for the loss of NO. One way of justifying this behaviour is the consideration of the structure of the following three groups of compounds (structures 18, 19 and 20).



(18)



(19)



(20)

The most stable forms of the above groups of compounds in the ground state are represented by the structures (18), (19) and (20). It can be seen that the loss of N_2 requires the cleavage of two single bonds, whereas for the loss of NO one single and one double bond have to be ruptured. Therefore it is not surprising to see that a greater amount of energy is needed for the loss of NO.

An interesting result has been obtained while measuring the appearance potential of the $(M-N_2)^{+}$ ion in the spectra of the 5-methyl-4-amino-benzothiadiazoole. The slope of the ionization efficiency curve is abruptly changed in the low ev region (fig. 1). This type of

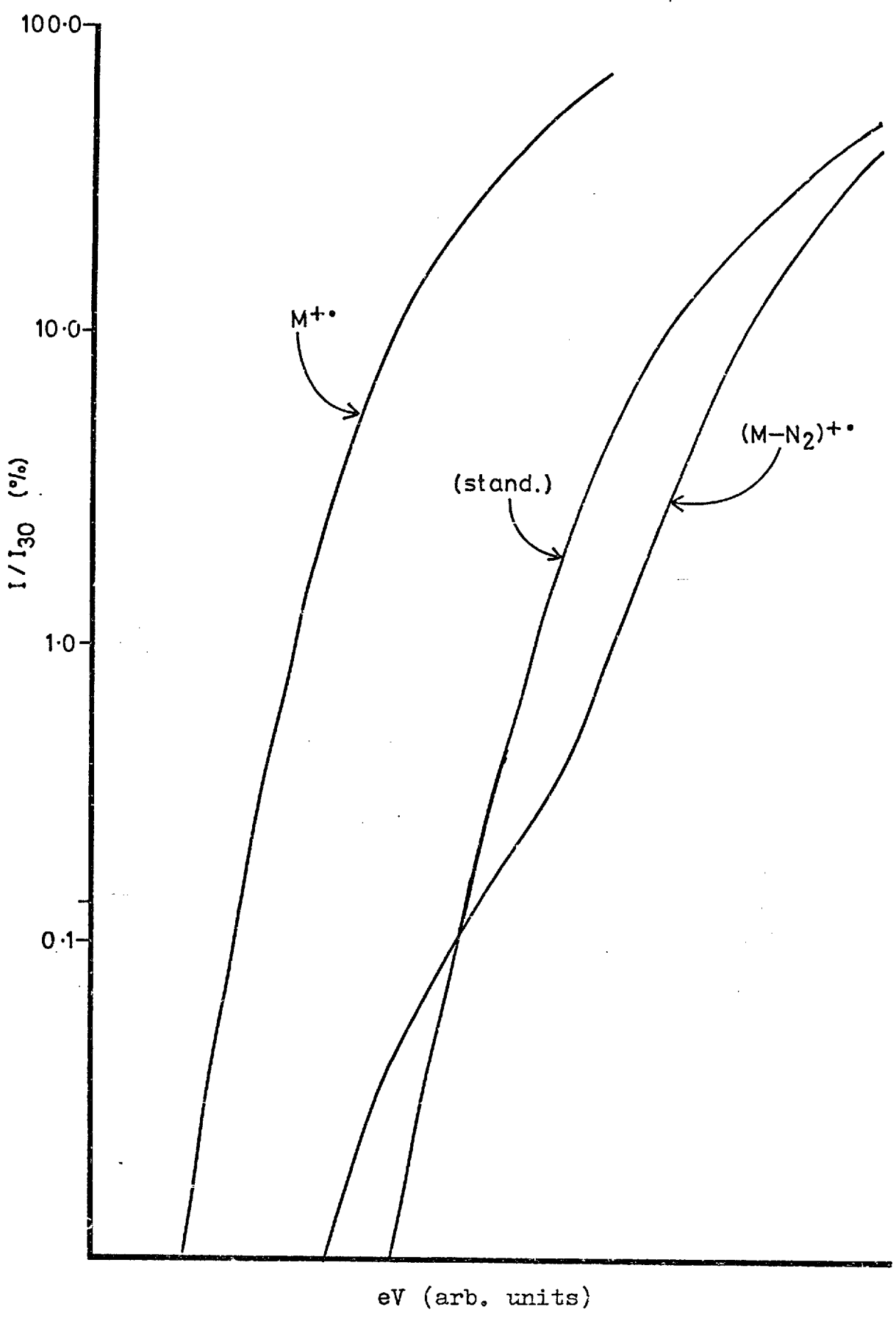
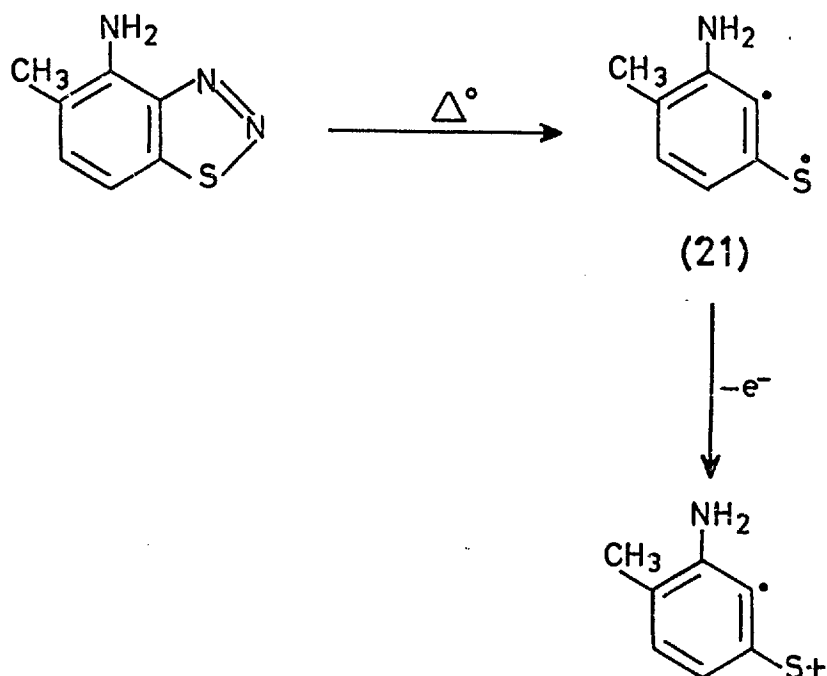


Figure 1.

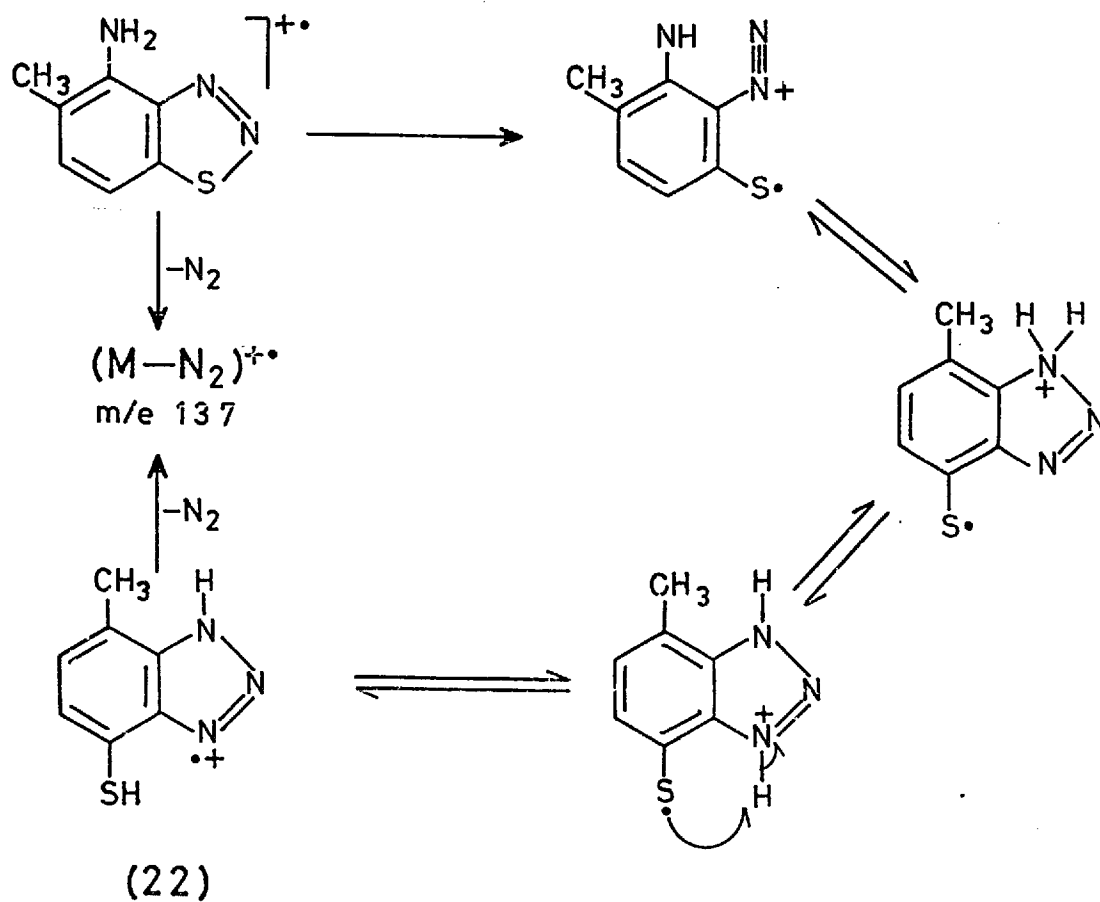
unusual abrupt change in the I.E. curve has been reported in the case of some nitro-aromatic compounds for the (M-30) ions¹¹. Beynon et al.¹¹ have studied the mass spectra of some five nitro aromatic compounds under high resolving power. In the vicinity of the (M-30)⁺ ion weak peaks fractionally higher in mass were observed. These weak peaks corresponded to the amino compounds obtained by the reduction of the nitro compound under investigation. Introduction of D₂O into the mass spectrometer shifted these small peaks by 2 a.m.u. Since the samples were purified by GLC the presence of such impurity peaks suggested the occurrence of catalytic reduction in the source of the mass spectrometer.

Another process which can cause this type of change in the slope of the IE curve is if a certain fragment ion is being produced via two different processes from the molecular ion or the same process from molecular ions which are at different states of energy²⁴. In other words if the minor process has a lower appearance potential than the major one, then the IE curve for the fragment ion would show a drastic change in its slope at low electron energies.

Finally the most probable process which could cause such a behaviour is the occurrence of pyrolysis in the heated inlet or in the vicinity of the filament²⁴. In such a case then the AP value obtained would correspond to the IP value for the ionization of the pyrolysate which in the case of the benzothiadiazole would be the bi-radical (21).



Another likely process which could account for this behaviour in the methylaminobenzothiadiazole is the rearrangement of the molecular ion to the benzotriazolothiol(22) followed by expulsion of N_2 .



CHAPTER FOUR

EXPERIMENTAL

The mass spectra were measured with an AEI MS9 instrument with an ionizing energy of 70 ev. High resolution data were obtained with the same instrument operating at 70 ev electron beam energy and 100 μ A trap current with a resolution of about 10,000 (10% valley). Mass measurements were carried out using heptacosafuorotri-n-butylamine as an internal standard. The samples were introduced through the heated inlet system into the source. The ion chamber temperature was normally at 200°C. The ionization and appearance potential measurements were carried out with the same instrument with the trap current at 10 μ A. The ion currents in the low ev region of the ionization efficiency curves were measured in increments of 0.1 ev using Fluke 8000A digital multimeter. The ionization efficiency curves were plotted as a percentage of 30 ev ion current against the electron energy.

The melting points are uncorrected and were measured on Kofler microscope hot-stage.

The infra-red spectra were obtained as nujol mulls using a Pye-Unicam SP200 or Perkin-Elmer 157 instrument.

The 60 MHz and 100 MHz n.m.r. spectra were recorded on Varian A60 and HA 100 instruments respectively using tetra-methylsilane as an internal standard.

BENZOTRIAZOLES3,4-Diaminotoluene¹³²

2-Nitrotoluidine (5.0g) and granulated tin (12.0g) were mixed and concentrated hydrochloric acid (25.0 ml.) was added in portions. After the initial reaction subsided the mixture was refluxed for a total of 2.5 hours. The solution was cooled, neutralized with 1-N sodium hydroxide solution and the product extracted with ether. The ether layer was dried (Na_2SO_4) and evaporated. The title compound was recrystallized from pet. ether to give colourless masses of plates. Yield: 3.7 g. (90%). This experiment was repeated on 10.0 g. of starting material resulting in 7.2 g. of the title compound. m.p.: 87 - 88°C (Lit. 88.5 ¹³² and 89.0 ¹³³).

5-Methyl-1,2,3-Benzotriazole⁷²

3,4-Diaminotoluene (5.0 g.) was dissolved in dil. HCl (20 ml.). The solution was cooled to about 5°C in ice and a solution of sodium nitrite (3.0 g.) in 10 ml. cold water was added. The mixture was stirred for 10 minutes. Sodium bicarbonate was added until no more CO_2 was evolved. The product was extracted with ether. The ether layer was dried (Na_2SO_4) and evaporated. The title compound was crystallized from benzene. Yield 3.4 g. (64%), m.p. 82-83°C (Lit. ⁷² m.p. 83-84°C).

5-Methyl-1,2,3-benzotriazole-nitrate.

- (a) In an experiment analogous to the one described above 3,4-diaminotoluene was diazotized with a two fold excess of sodium nitrite. The product was collected

prior to neutralization of the excess nitrous acid with sodium bicarbonate. The product decomposed with evolution of a gas at about 138°C .

IR: cm^{-1} 3200 - 2300, 2000 - 1840, 1620, 1310, 1240, 1150, 1040, 970, 940, 820, 760, 730.

- (b) 5-Methyl-1,2,3-benzotriazole (0.2g) was dissolved in acetic acid (5 cc) and this solution was added dropwise to a cold ($5-10^{\circ}$) mixture of conc. nitric acid (2 cc) acetic acid (5 cc). A few drops of water was added and the precipitate collected and dried in air. m.p. 138°C Dec.

IR: same as above.

NMR: same as that of 5-methylbenzotriazole (see table VII, Chapter two, page 114) except for two exchangeable protons at about -0.53τ .

Analysis		A = $\text{C}_7\text{H}_7\text{N}_3$		B = $\text{C}_7\text{H}_7\text{N}_3 \cdot \text{HNO}_3$		
	1st. anal.	2nd. anal.	3rd. anal.	Calculated for		
				B	5.2% A 94.8% B	6.4% A 93.6% B
C	43.84	44.21	44.03	42.86	43.91	44.16
H	4.20	4.26	4.20	4.11	4.17	4.19
N	28.83	28.67	28.94	28.56	28.72	28.75
O	23.13	22.86	22.83	24.47	23.20	22.90

2,3-Diaminotoluene ¹³⁴

The title compound was synthesized by reduction of 2-amino-3-nitrotoluene (3.0g.) with aluminum amalgam according to the procedure of H. McCombie et al. ¹³⁴. The t.l.c. of

the product showed only one spot, therefore, no attempt was made to purify the product and it was used in the next step. Yield 2.0g. (83%).

4-Methylbenzotriazole⁷³

2,3-Diaminotoluene (2.0 g.) from previous experiment was dissolved in glacial acetic acid (5.0 ml.). The mixture was cooled in ice to about 0-5°C and a solution of sodium nitrite (1.2 g.) in the minimum amount of cold water was added with shaking. The mixture was left stirring at room temp. for 2 hrs. Water was added and the solution neutralized with bicarbonate. The precipitate formed was crystallized from hot water to give almost colourless needles. Yield, 0.9 g. (41%), m.p. 149-50 (lit.⁷³, m.p.150).

4-Amino-3,5-Dinitro-toluene⁷⁶

The title compound was synthesised by nitration of N-acetyl-p-toluidine (5.0 g.) with fuming nitric acid followed by hydrolysis with 50% sulfuric acid according to a standard procedure. The product was crystallized from ethanol to give the title compound as bright orange crystals. Yield 3.3 g. (50%), m.p. 170°C (Lit.⁷⁶ 172°C).

3,4-Diamino-5-Nitrotoluene⁷⁶

4-Amino-3,5-dinitrotoluene (2.0 g.) was suspended in hot ethanol (5 ml) and to it was added a solution of sodium sulfide (5.0g.) in 5 ml. of water in two portions. The mixture turned dark red and started to boil. It was heated for a further 5-10 minutes on the steam bath. Water was then added (20 ml) and the mixture was left standing for 2 hours. The precipitate formed was collected and crystallized from water to give the title

compound as dark red needles. Yield, 0.8 g. (47%).

m.p. 158°C (Lit.⁷⁶ m.p. 158°C).

5-Methyl-7-Nitro-1,2,3-benzotriazole⁷⁶

3,4-Diamino-5-nitrotoluene (0.4 g.) was suspended in dil. HCl (5 ml). The solution was cooled in ice bath and a solution of sodium nitrite (0.2 g.) in the minimum amount of water was added slowly. The mixture was left standing at room temperature for 10 minutes and then heated on the steam bath for 20 minutes. A precipitate was formed which was collected and crystallized from ethanol to give the title compound. Yield, 0.3 g. (70%). m.p.: sublimes below 270°C (Lit.⁷⁶ 277°C).

N-3-Tolylsuccinimide¹³⁵

m-Toluidine (10.0 g.) and succinic anhydride (10.0 g.) were treated according to the literature procedure to give the title compound. m.p. 114-115°C (Lit.¹³⁵ 113°C). Yield, 9.0g. (54%).

2,4-Dinitro-5-aminotoluene¹³⁵

N-3-tolylsuccinimide (2.4 g.) was nitrated followed by hydrolysis according to the procedure of Evans, et al.¹³⁵ to give the title compound. Overall yield, 1.2 g. (48%). m.p. 241-242°C (Lit.¹³⁵ 240°C).

2-Nitro-4,5-diaminotoluene

2,4-Dinitro-5-aminotoluene (1.0 g) was reduced with sodium sulfide the same way as for the synthesis of 3,4-diamino-5-nitrotoluene. The product was crystallized from water to give the title compound as bright orange needles. Yield, 0.4 g. (47%). m.p. 140-141°C.

5-Methyl-6-Nitro-1,2,3-Benzotriazole

2-Nitro-4,5-diaminotoluene (0.4 g.) was diazotized by the same method as for the synthesis of 5-methyl-7-nitro-1,2,3-benzotriazole. The product was crystallized from ethanol to give the title compound. Yield, 0.25 g. (59%), m.p. sublimes at 218-219°C.

NMR: See table VII, Chapter two, page 114.

Mass Measured M^+	$C_7H_6N_4O_2$	error(ppm)
178.0496	178.0491	2.8

3,5-Dinitro-2-Aminotoluene ¹³⁶

Acetyl-o-toluidide (7.0 g.) was added to ice-cold fuming nitric acid (25 ml) during 20 minutes. The mixture was stirred for one hour and then poured on ice with stirring. The precipitate was collected and heated with 50% sulfuric acid at 80° for 10 minutes. This solution was poured on to ice and the precipitate collected and crystallized from ethanol to give the title compound as orange yellow needles. Yield, 3.0 g. (32%), m.p.: 212-213 (Lit.¹³⁶ m.p. 214°C).

2,3-Diamino-5-nitrotoluene ⁷⁷

3,5-Dinitro-2-aminotoluene (1.0 g.) was reduced with sodium sulfide (4.0 g.) in the same way as for the synthesis of 3,4-diamino-5-nitro-toluene. The product was crystallized from water to give the title compound as red needles. Yield, 0.4 g. (50%), m.p. 184-5°C (Lit.⁷⁷ m.p. 185°C).

4-Methyl-6-Nitro-1,2,3-Benzotriazole ⁷⁷

2,3-Diamino-5-nitrotoluene (0.4 g.) was diazotized in the same way as for the synthesis of 5-methyl-7-nitro-1,2,3-benzotriazole. The product was crystallized from

aqueous ethanol to give the title compound. Yield, 0.30 g. (71%) m.p. 252-3°C (Lit.⁷⁷ 252-3°C).

6-Methyl-7-Nitro-1,2,3-Benzotriazole ⁷⁵

5-Methyl-1,2,3-benzotriazole (0.1 g.) was dissolved in concentrated H_2SO_4 (2.0 ml) and nitric acid (D:1.42) (0.1 ml) was added. The mixture was heated on a steam bath for 10 minutes, cooled, and finally poured on to ice. The precipitate was crystallized from ethanol to give the title compound. Yield, 0.1 g. (82%), m.p. 249-50°C (Lit.⁷⁵ not reported).

4-Methyl-5-Nitro-1,2,3-Benzotriazole and

4-Methyl-7-Nitro-1,2,3-Benzotriazole.

To a solution of 4-methyl-1,2,3-benzotriazole (0.2 g.) in concentrated sulfuric acid (2.0 ml) concentrated nitric acid (0.5 ml) was added at room temp. The mixture was first heated on a steam bath for 5 minutes and then left at room temperature for 45 minutes. The mixture was then poured on to ice and the precipitate collected.

T.l.c. (50% EtOH/ $CHCl_3$) of the mixture showed the presence of two products which were separated and purified by the same method. The two derivatives were identified by their mass spectra. Fast running compound 4-methyl-5-nitro-1,2,3-benzotriazole. Yield 30%, m.p. 208-209°C.

NMR: see table VII, chapter two, page 114.

Mass Measured M^{+}	$C_7H_6N_4O_2$	error (ppm)
178.0494	178.0491	1.7

Slow running compound 4-methyl-7-nitro-1,2,3-benzotriazole. Yield, 40%, m.p. 236-237°C.

NMR: see table VII, chapter two, page 114.

Mass Measured M^{+}	$C_7H_6N_4O_2$	error (ppm)
178.0494	178.0491	1.7

5,6-Dimethyl-1,2,3-Benzotriazole ⁷⁸

A mixture of 4,5-diamino-o-xylene (1.0g.), glacial acetic acid (2.0 ml) and water (3.0 ml) was cooled to 5°C. A solution of sodium nitrite (1.0 g.) in water (1 ml) was added slowly. The mixture was then left standing at room temperature for 24 hours. The precipitate was collected, dried and crystallized from benzene to give the title compound. Yield, 0.9 g. (83%), m.p. : 156-7°C (Lit.⁷⁸ m.p. 156-7°C).

4,5-Dinitro-6-Chlorotoluene ⁷⁴

The title compound was synthesized by nitration of 2-chloro-4-nitrotoluene (5.0 g.) according to the literature procedure. Yield, 4.8 g. (80%), m.p. 88.5°C (Lit.⁷⁴, m.p. 88.5°C).

4,5-Diamino-2-Chlorotoluene ⁷⁴

The title compound was synthesized by reducing 4,5-dinitro-2-chlorotoluene (2.0 g.) with granulated tin (5.0 g) in concentrated HCl. The product was not purified and was used for the next step. Yield, 1.2 g.(83%).

5-Methyl-6-Chloro-1,2,3-Benzotriazole ⁷⁴

4-5-Diamino-2-chlorotoluene (1.2 g.) was diazotized with sodium nitrite (1.0 g.) according to the literature method to give the title compound. Yield, 1.0 g. (78%), m.p. 192°C (Lit.⁷⁴ m.p. 192°C).

2,3-Dinitro-6-Chlorotoluene ⁷⁴

2-Chloro-6-nitrotoluene (6.0 g.) was nitrated according to the literature procedure to give the title compound. Yield, 6.5 g.(86%), m.p. 106.5°C (Lit.⁷⁴, m.p. 106.5°C).

4-Methyl-5-Chloro-1,2,3-Benzotriazole ⁷⁴

2,3-Dinitro-6-chlorotoluene (2.0 g.) was first reduced and the product diazotized in the same way as for the synthesis of 5-Methyl-6-chloro-benzotriazole to give the title compound. Yield, 0.9 g. (58%, overall), m.p. : Dec. 230-1°C, (Lit.⁷⁴ m.p. 232°C).

4-Amino-5-methyl-1,2,3-Benzotriazole

4-Nitro-5-methyl-1,2,3-benzotriazole (0.2 g.) was added slowly to a stirred solution of anhydrous stannous chloride (1.2 g.) (Synthesized by treatment of the hydrated form with acetic anhydride) in concentrated hydrochloric acid (1.0 ml). The mixture was left stirring at room temperature for 45 minutes, and then neutralized with 20% sodium hydroxide solution. The amine was extracted twice with ether. The ether extracts were dried (Na_2SO_4) and evaporated under reduced pressure. T.l.c. (5% EtOH/ CHCl_3) showed one spot. The title compound was further purified by sublimation at 160°C under reduced pressure. Yield, 0.14 g. (84%), m.p. 157-8°C.

NMR: see table VII, Chapter two, page 114.

Mass Measured M^{+}	$\text{C}_7\text{H}_8\text{N}_4$	error (ppm)
148.0751	148.0749	1.3

7-Amino-5-methyl-1,2,3-Benzotriazole ⁷⁶

7-Nitro-5-methyl-1,2,3-benzotriazole (0.2 g.) was reduced with anhydrous stannous chloride (1.2 g.) in the same way as for the synthesis of the 4-amino-derivative. The title compound was purified by sublimation under vacuum at 160°. Yield, 0.12 g. (72%), m.p. 154-155°C, (Lit.⁷⁶, m.p. 155°C).

Attempted reaction of 4-nitro-6-methyl-1,2,3-benzotriazole with sodium hypochlorite.

4-Nitro-6-methyl-1,2,3-benzotriazole (0.1 g.) was treated with sodium hypochlorite in a solution of potassium hydroxide (0.2 and 0.4 g.) in methanol (20 cc) at room temperature, at 50°C and at reflux temperature. The starting material was recovered quantitatively in every case when the mixture was neutralized with dilute hydrochloric acid.

BENZOFUROXANS AND BENZOFURAZANS

Benzofuroxan ^{86,137}

o-Nitroaniline (10.0g.) in ethanolic potassium hydroxide was treated with sodium hypochlorite solution according to a standard procedure. Yield, 9.0 g.(91%), m.p. 72°C (Lit.¹³⁷, m.p. 72-73°C).

Benzofurazan ⁸⁸

Benzofuroxan (5.0 g.) was treated with hydroxylamine hydrochloride (7.5 g.) according to the literature procedure. After steam distillation the product was extracted with chloroform. The chloroform extract was dried (sodium sulfate, anhydrous) and evaporated under reduced pressure to leave the title compound as a pure (t.l.c.) low melting colourless solid. Yield, 3.0 g. (68%), m.p. 54°C (Lit.⁸⁸, m.p. 55°C)

5-Methylbenzofuroxan ⁸⁵

4-Amino-3-nitrotoluene (10.0 g.) in ethanolic potassium hydroxide was treated with sodium hypochlorite solution (commercially available bleach) according to a standard procedure. The title compound was recrystallized from aqueous ethanol. Yield 8.5 g. (86%), m.p. 96-7°C (Lit.⁸⁵, m.p. 97°C).

5-Methylbenzofurazan ⁸⁵

(a) Hydroxylamine method.

The procedure of Zincke and Schwarz⁸⁵ was used to deoxygenate 5-methylbenzofuroxan (5.0 g.). The title compound was purified by preparative t.l.c. (CHCl₃). Yield, 3.5 g.(78%), m.p. 36.5°C (Lit.⁸⁵, m.p. 37°C).

(b) Triphenylphosphine method.

5-Methylbenzofuroxan (1.5 g.) and triphenylphosphine (2.5 g.) were refluxed in benzene for one hour.

The benzene was evaporated under reduced pressure and the residue steam distilled. The distillate was cooled and the solidified product was separated.

The solid was purified by preparative t.l.c. (CHCl_3) to give the title compound. Yield, 1.0 g. (75%), m.p. $36.5\text{--}37^\circ\text{C}$ (Lit.⁸⁵ m.p. 37°C).

2-Azido-3-Nitrotoluene⁸⁵

2-Amino-3-nitrotoluene (4.56 g.) was dissolved in a mixture of acetic acid (50 ml) and concentrated sulfuric acid (30 ml). The solution was cooled in ice and sodium nitrite (2.1 g.) was added. The mixture was stirred keeping the temperature at $0\text{--}5^\circ$ by addition of ice.

Excess nitrous acid was destroyed by addition of urea.

Finally, sodium azide (2.0 g.) was added and the mixture warmed to room temperature and left standing for 3 hours.

The precipitate was collected and washed with water and finally crystallized from ethanol to give the title compound. Yield, 4.8 g. (90%), m.p. 50°C (Lit.⁸⁵ m.p. 50°C).

4-Methylbenzofuroxan⁸⁵

The above azide (2.0 g.) was refluxed in a mixture of water and ethanol in the ratio of 90/10 for 24 hours.

The mixture was cooled and the solid recrystallized from 95% ethanol to give the title compound. Yield, 1.2 g. (71%), m.p. 60°C (Lit.⁸⁵, m.p. 60°C).

4-Methylbenzofurazan⁸⁵

4-Methylbenzofuroxan (2.0 g.) was deoxygenated in the same manner as the 5-methyl derivative, using the

Zincke and Schwarz⁸⁵ procedure. Yield, 1.2 g. (67%),
m.p. : 44°C (Lit.⁸⁵, m.p. 44°C).

3,5-Dinitro-4-Azidotoluene ⁹²

4-Amino-3,5-dinitrotoluene (4.0 g.) was diazotized followed by treatment with sodium azide (1.5 g.) in the same manner as for the synthesis of 2-azido-3-nitrotoluene. Yield, 3.5 g. (76%), m.p. 96-97°C (Lit.⁹² m.p. 97°C).

4-Nitro-6-Methylbenzofuroxan ⁹²

4-Azido-3,5-dinitrotoluene (2.0 g.) was refluxed in acetic acid for 30 minutes. The mixture was cooled and water was added. A precipitate formed which was crystallized from ethanol to give the title compound. Yield, 1.5 g. (86%), m.p. 144°C (Lit.⁹² m.p. 145°C).

4-Amino-2,5-Dinitrotoluene ⁸⁰

4-N-Acetyl-2-nitrotoluene (5.0 g.) was nitrated with potassium nitrate in concentrated sulfuric acid followed by hydrolysis according to the procedure described by Scott and Robinson⁸⁰. The title compound crystallized from ethanol as orange-red needles. Yield, 3.0 g. (60%), m.p. 188-9°C (Lit.⁸⁰ m.p. 189°C).

4-Amino-2,3-Dinitrotoluene ^{79,80}

4-N-Acetyl-2-nitrotoluene (5.0 g.) was nitrated with fuming nitric acid (D:1.5) at 0°C followed by hydrolysis according to the procedure of Scott and Robinson⁸⁰. The title compound crystallized from aqueous ethanol as yellow needles. Yield, 1.5 g. (30%), m.p. 123-4°C (Lit.⁸⁰ m.p. 124°C).

4-Azido-2,5-Dinitrotoluene ⁹²

4-Amino-2,5-dinitrotoluene (2.0 g.) was diazotized followed by treatment with sodium azide (1.5 g.) in the usual manner.

Yield, 1.8 g.(75%). The azide was not purified and was used directly for the following decomposition.

5-Methyl-6-Nitrobenzofuroxan ⁹³

4-Azido-2,5-dinitrotoluene (1.5 g.) was suspended in a little water and heated on a steam bath for one hour. On cooling a precipitate formed which crystallized from ethanol to give the title compound. Yield, 1.0 g.(78%), m.p. 208-209°C (Lit.⁹³, m.p. 209-210°C).

2-Azido-3,5-Dinitrotoluene ⁹²

2-Amino-3,5-dinitrotoluene (2.0 g.) was diazotized followed by treatment with sodium azide in the usual way to give the title compound. Yield, 1.7 g.(75%), m.p.60-61°C (Lit.⁹² m.p. 61°C).

4-Methyl-6-Nitrobenzofuroxan ⁹²

The title compound was synthesized by decomposition of 2-azido-3,5-dinitrotoluene in the usual way. M.p. 69°C (Lit.⁹² m.p. 70°C).

2-Chloro-4-N-acetylaminotoluene ¹³⁹

2-Chloro-4-nitrotoluene (5.0 g.) was reduced with tin (5.0 g.) and HCl in the usual way. The acidic reaction mixture was neutralized with dil. NaOH and the amine extracted with ether. The ether layer was dried (Na_2SO_4) and evaporated. The crude amine (3.5 g.) was acetylated with acetic anhydride in the usual way. The reaction mixture was poured on ice to destroy the excess acetic anhydride. The product was crystallized from aqueous ethanol to give the title compound. Yield, 3.5 g. (65%), m.p. 83°C (Lit.¹³⁹, m.p. 83°C).

2-Chloro-4-amino-5-nitrotoluene ¹⁴⁰

2-Chloro-4-N-acetylaminotoluene (2.0 g.) was added very slowly to a stirred solution of ice cold conc. nitric acid (10 cc). The mixture was left standing at room temperature for 10 minutes and then poured onto ice. The yellow precipitate was collected and crystallized from ethanol to give 1.8 g. of the N-acetyl derivative of the title compound. This was dissolved in 50% sulfuric acid (10 cc) and heated on a steam bath for ten minutes. The mixture was poured onto ice and the yellow precipitate collected and dried in air. Crystallization from ethanol gave yellow crystals. Yield, 1.4 g. (64%), m.p. 164-165°C (Lit.¹⁴⁰ m.p. 165°C).

5-Methyl-6-Chlorobenzofuroxan

(a) The azide method:

The above aniline (1.2 g.) was diazotized followed by treatment with sodium azide (0.42 g.). The procedure was analogous to those described for the synthesis of other azides. The azide was not purified and was decomposed directly by refluxing in acetic acid for 30 minutes. The mixture was cooled and water was added to complete crystallization. The title compound was recrystallized from ethanol. Yield, 0.8 g. (67%), m.p. 122°C.

(b) The sodium hypochlorite method:

2-Chloro-5-nitro-p-toluidine (0.2 g.) was dissolved in a hot solution of methanol (15 cc) and potassium hydroxide (0.6 g.). The mixture was cooled to about 15°C and a solution of sodium hypochlorite (commercial

bleach) was added until the solution was completely decolourized. A pale yellow precipitate formed which was separated and dried in air. Recrystallization from ethanol resulted in the title compound. Yield, 0.04 g. (20%), m.p. 122°C.

NMR: see table VIII, Chapter two, page 116.

Mass Measured M^{+}	$C_7H_5N_2O_2Cl$	error (ppm)
184.0037	184.0039	1.1

5-Methyl-6-chloro-benzofurazan.

(a) The hydroxylamine hydrochloride method:

The corresponding N-oxide (0.8 g.) was dissolved in ethanol (10 cc) and hydroxylamine hydrochloride (1.0g.) in the minimum amount of water was added. A solution of 25% NaOH was added dropwise until no more N_2 evolved. The mixture was made alkaline with NaOH solution and steam distilled. The product was extracted with $CHCl_3$, the chloroform was dried over sodium sulfate and finally evaporated under reduced pressure leaving the pure title compound as colourless crystals. Yield, 0.58 g.(79%), m.p. 51°C.

(b) The sodium azide method:

2-Chloro-4,5-dinitrotoluene (1.08 g.) and sodium azide (0.65 g.) were mixed in ethylene glycol (20 cc). The mixture was heated to 140°C for 90 minutes and at 185°C for 2-3 minutes. The mixture was cooled and water was added. The product was extracted with chloroform. The chloroform layer was dried over sodium sulfate and finally evaporated leaving the pure title compound as colourless crystals.

Yield, 0.2 g. (24%), m.p. 51°C.

NMR: see table IX, Chapter two, page 117.

Mass Measured M^{+}	$C_7H_5N_2OCl$	error (ppm)
168.0092	168.0090	1.2

4-Nitro-7-Methylbenzofuroxan ⁹²

(a) By nitration of 5-methylbenzofuroxan:

5-Methylbenzofuroxan (0.5 g.) was added to cold concentrated nitric acid (5 ml) and to the mixture two or three drops of concentrated sulfuric acid was added. The mixture was left standing in ice for 30 minutes followed by 30 minutes at room temperature. The mixture was then poured onto ice and the precipitate collected and dried. The solid was then refluxed in acetic acid for $\frac{1}{2}$ hr. The mixture was cooled, water was added and the precipitate collected and crystallized from ethanol to give the title compound. Yield, 0.37 g. (57%), m.p.: 161-162°C (Lit.⁹², m.p. 162°C).

(b) By decomposition of p-azido-2,3-dinitrotoluene:

p-Azido-2,3-dinitrotoluene was synthesized from 2,3-dinitro-p-toluidine by diazotization followed by treatment with sodium azide in the usual manner. The azido compound was refluxed in acetic acid for 1 hr. to give the title compound. m.p. 162°C (Lit.⁹², m.p. 162°C).

4-Nitrobenzofurazan ⁹⁴

Benzofurazan (1.0 g.) was added slowly to a cold solution of concentrated nitric acid. The mixture was left standing at room temperature for 30 minutes. The solution was

then poured on to ice and the precipitate collected.

The product was crystallized from ethanol to give the title compound as yellow crystals. Yield, 0.9 g. (46%), m.p. 99°C (Lit.⁹⁴, m.p. 98°C).

5-Nitrobenzofuroxan ⁹⁴

2,4-Dinitroaniline (5.0 g.) was diazotized followed by treatment with sodium azide (2.0 g.) in the usual way. The product (2,4-dinitroazidobenzene) was not separated from the reaction mixture but was decomposed by warming up the mixture on a steam bath until no more nitrogen evolved. The mixture was then cooled and the solid separated. It was crystallized from ethanol to give the title compound. Yield, 3.0 g. (61%), m.p. 71-72°C (Lit.⁹⁴ m.p. 72°C).

5-Nitrobenzofurazan ¹⁰³

The corresponding N-oxide (0.9 g.) and triphenylphosphine (1.35 g.) were refluxed in benzene for one hour. The mixture was cooled and filtered through silica. A clear solution was obtained which was dried over sodium sulfate and the benzene evaporated under reduced pressure leaving 0.45 g. (55%) of the pure title compound. m.p. 65°C, (Lit.¹⁰³, m.p. 64-65°C).

4-Chloro-5-methoxy-6-methylbenzofuroxan.

4-Amino-3,5-dinitrotoluene (0.5 g.) was dissolved in a hot mixture of methanol (25 ml) and potassium hydroxide (1.0 g.). The mixture was then cooled to about 30-40°C and sodium hypochlorite solution (commercial bleach) was added until the solution was decolourized. Water was added and the precipitate formed was collected and

crystallized from ethanol to give the title compound in the form of yellowish white small prisms. Yield, 0.35 g. (65%), m.p. 121°C.

NMR: see table VIII, Chapter two, page 116.

Mass Measured M^+	$C_8H_7N_2O_3Cl$	error (ppm)
214.0143	214.0145	0.9

4-Chloro-5-methoxy-6-methylbenzofurazan

The corresponding furoxan (0.5 g.) was dissolved in ethanol (10 cc) and hydroxylamine hydrochloride (0.5 g.) dissolved in minimum amount of water was added. 1-N sodium hydroxide was added dropwise until no more nitrogen evolved.

The mixture was made alkaline and steam distilled until all the furazan was collected. Water was added to the distillate and the product extracted with chloroform. The chloroform solution was dried over sodium sulfate and evaporated under reduced pressure. The solid product was recrystallized from ethanol to give the title compound as white needles. Yield, 250 mg. (54%), m.p. 95°C.

NMR: see table IX, Chapter two, page 117.

Mass Measured M^+	$C_8H_7N_2O_2Cl$	error (ppm)
198.0200	198.0196	2.0

4-Methoxy-6-methylbenzofuroxan

2,5-Dinitro-4-aminotoluene (0.5 g.) was dissolved in a hot solution of potassium hydroxide (1.0 gs.) in methanol (50 ml). The mixture was cooled to about 40°C and sodium hypochlorite solution (commercially available bleach) was added dropwise while the mixture was stirred vigorously. The addition was continued until no more decolourization occurred at which time the mixture was diluted with water.

The precipitate was collected, dried in air, and was crystallized from 90% ethanol/water to give light amber fine needles. Yield, 0.2 g. (44%), m.p. 121-122°C.

NMR: see table VIII, Chapter two, page 116.

Mass Measured M^{+}	$C_8H_8N_2O_3$	error (ppm)
180.0536	180.0535	0.6

4-Methoxy-6-methylbenzofurazan

The corresponding benzofuroxan (0.5 g.) was deoxygenated with hydroxylamine hydrochloride (0.45 g.) followed by steam distillation in the usual way. Crystallization from aqueous ethanol gave the title compound as white crystals. Yield, 0.3 g. (66%), m.p. 118-119°C.

NMR: see table IX, Chapter two, page 117.

Mass Measured M^{+}	$C_8H_8N_2O_2$	error (ppm)
164.0581	164.0586	3.0

4-Azido-3-nitro-anisole

2-Nitro-4-methoxyaniline (4.0 g.) was diazotized with sodium nitrite (1.75 g.) followed by treatment with sodium azide (1.7 g.) according to a standard procedure. Yield, 3.9 g. The product was not purified and was used in the following experiment.

5-Methoxybenzofuroxan ⁹⁵

The above azide (3.0 g.) was refluxed in acetic acid for 30 minutes. The solution was cooled and water was added to complete crystallization. The solid was recrystallized from ethanol. Yield, 2.0 g. (78%), m.p. 118°C (Lit.⁹⁵, m.p. 118°C).

5-Methoxybenzofurazan ⁹⁵

The corresponding N-oxide (1.0 g.) was deoxygenated in

the usual way using hydroxylamine hydrochloride. Yield, 0.4 g. (44%), m.p. 98°C (Lit.⁹⁵ m.p. 99°C).

4-Nitro-5-methylbenzofurazan ⁹²

5-Methylbenzofurazan (0.2 g.) was added in portions to ice cold concentrated nitric acid (5 ml). The mixture was left standing at room temperature for one hour and then poured onto ice. A yellow precipitate formed which was collected and dried in air. The solid was crystallized from ethanol to give the title compound as pale yellow crystals. Yield, 0.2 g. (75%), m.p. 82°C (Lit.⁹² m.p. 83°C).

5-Chlorobenzofuroxan ⁸⁶

2-Nitro-4-chloroaniline (5.0 g.) was converted to the title compound with sodium hypochlorite in the usual way. Yield, 3.5 g. (71%), m.p. 46-47°C (Lit.⁸⁶, m.p. 48°C).

5-Chlorobenzofurazan ⁸⁶

The corresponding N-oxide (2.0 g.) and triphenylphosphine (3.2 g.) were refluxed in benzene for 30 minutes. The benzene was evaporated under reduced pressure and the residue steam distilled until no more oily substance came over. The distillate was cooled and the product extracted with chloroform. The chloroform layer was dried (sodium sulfate) and the chloroform evaporated under reduced pressure leaving the pure title compound. Yield, 1.7 g. (94%), m.p. 43-44°C (Lit.⁸⁶ m.p. 44°C).

BENZOTHIADIAZOLES5-Methyl-2,1,3-benzothiadiazole ¹⁰⁶

The title compound was synthesized from 4-methyl-o-phenylenediamine (1.0 g.) according to the procedure of Dea Dal Monte Casoni, *et al.*¹⁰⁶. Yield, 0.9 g. (73%), m.p. 34°C, b.p. 234°C, (Lit.¹⁰⁶ m.p. 34°; b.p. 233°C).

4-Nitro-6-methyl-2,1,3-benzothiadiazole ¹⁰⁷

A solution of thionylchloride (3.0 g.) in toluene (10 ml) was slowly added to a solution of 3,4-diamino-5-nitrotoluene (0.55 g.) and triethylamine (1.5 g.) in toluene (30 ml). The mixture was refluxed for 36 hours. The triethylamine hydrochloride was filtered off and the solvent evaporated on the rotary pump. The title compound was crystallized from ethanol to give light amber needles. Yield, 0.4 g. (63%), m.p. 146-147°C (Lit.¹⁰⁷, m.p. 145.7°C).

4-Nitro-5-methyl-2,1,3-benzothiadiazole ¹⁰⁸

To a cold solution of 5-methyl-2,1,3-benzothiadiazole (0.2 g.) in concentrated H₂SO₄ (1 ml) fuming nitric acid (0.2 ml) was added. The mixture was left standing at room temperature for 5 minutes after which time it was poured on to ice. The precipitate was collected and dried in air. T.l.c. of the precipitate showed only one spot. The solid was crystallized from methanol to give the title compound as yellowish white crystals. Yield, 190 mg. (73%), m.p. 156-157°C (Lit.¹⁰⁸ m.p. 157°C).

1,2,3-Benzothiadiazole ¹⁰⁴

2-Aminobenzenthionol (2.5 g.) was suspended in dil. hydrochloric acid (25 cc) and the mixture cooled in ice.

A solution of sodium nitrite (2.0 g.) in water (10 cc) was added and the mixture stirred for 5 minutes at room temperature. The solution was stirred for a further 5 minutes at about 50-60°C, and the product isolated by steam distillation. The distillate was extracted with ether. The ether layer was dried (Na_2SO_4) and the ether evaporated under vacuum. The product was purified by t.l.c. (CHCl_3). Yield, 1.5 g., m.p. 35°C (Lit.^{104,109}, m.p. 35°C).

bis-(4-Methyl-2-nitrophenyl)trisulfide ¹¹²

The title compound was synthesized from 3-nitro-4-chlorotoluene (17.1 g.) according to the procedure of Dannley *et al.*¹¹². The product was not purified and was used for the following reduction. Yield, 14.1 g. (77%).

4-Methyl-2-aminobenzenethiol Hydrochloride ¹¹²

The above trisulfide (4.0 g.) was reduced according to the procedure of Dannley, *et al.*¹¹². The product obtained (2.0 g.) consisted of the title compound and tin salts. The title compound was not purified and was used directly for the synthesis of 5-methylbenzothiadiazole.

5-Methyl-1,2,3-benzothiadiazole ¹³⁸

The above mixture of salts (2.0 g.) was dissolved in dilute hydrochloric acid (10.0 ml) and the solution cooled to 0-5°C. A solution of sodium nitrite (1.0 g.) in the minimum amount of water was added in one portion. The mixture was left standing at room temperature for one hour after which time it was neutralized with 1-N NaOH. The product was extracted with ether, the ether evaporated under reduced pressure and finally the product purified by preparative t.l.c. (CHCl_3). Yield, 140 mg., m.p. 26°C (Lit.¹³⁸ m.p. 26°C).

6-Methyl-2-aminobenzothiazole ¹¹³

The title compound was synthesized from p-toluidine according to the procedure of Fridman¹¹³. Yield, 6.3 g. (40%), m.p. 137°C (Lit.¹¹³ m.p. 137°C).

5-Methyl-2-aminothiophenol ¹¹³

The procedure of Fridman was used for the preparation of the title compound by hydrolysis of the 6-methyl-2-amino-benzothiazole. The product (1.5 g.) was not purified and was used in the next step.

6-Methyl-1,2,3-benzothiadiazole ^{110,111}

The crude product from the previous experiment (1.0 g.) was diazotized with sodium nitrite (0.5 g.) in the usual way¹¹¹. Prior to separation of the product the excess nitrous acid was destroyed with sodium bicarbonate. The product was extracted with ether; the ether layer dried over sodium sulfate (anhydrous) and finally evaporated under reduced pressure. The crystalline solid product showed one spot on t.l.c. Yield, 0.8 g., m.p. 41-42°C (Lit.^{110,111}, m.p. 42-43°C).

4-Nitro-5-methyl-1,2,3-benzothiadiazole

5-Methyl-1,2,3-benzothiadiazole (200 mg.) was dissolved in conc. H₂SO₄ (5 ml) and the solution cooled to 0-5°C. Fuming nitric acid (0.5 ml) was added and the mixture was left standing for 10-15 minutes at room temperature. Finally it was heated on a steam bath until the colour of the solution became light yellow (2 minutes). The mixture was then cooled and poured onto ice. The precipitate was collected and dried in air. T.l.c. (CHCl₃) of the solid showed only one spot. The solid was crystallized from

ethanol to give the title compound as very light amber crystals. Yield, 180 mg. (70%), m.p. 148°C.

NMR: see table X, Chapter two, page 118.

Mass Measured M^{+}	$C_7H_5N_3O_2S$	error (ppm)
195.0104	195.0102	1.1

7-Nitro-6-methyl-1,2,3-benzothiadiazole

The same procedure as described above was used for the nitration of 6-methyl-1,2,3-benzothiadiazole (200 mg.).

The product was crystallized from ethanol to give the title compounds. Yield, 190 mg. (73%), m.p. 114.5-115°C.

NMR: see table X, Chapter two, page 118.

Calculated for $C_7H_5N_3O_2S$: C : 43.07%; H : 2.58; N : 21.53;
S : 16.43,

found C : 42.93 ; H : 2.77; N : 21.51; S : 16.36.

4-Amino-5-methyl-1,2,3-benzothiadiazole

To a stirred solution of anhydrous stannous chloride (1.5 g.) in conc. HCl (2 ml) 4-nitro-5-methyl-1,2,3-benzothiadiazole (200 mg.) was added. The mixture was warmed, while stirring was continued, until a clear solution was obtained. The acidic solution was neutralized with dil. sodium hydroxide and the product extracted with ether. The ether layer was dried (Na_2SO_4 , anhydrous) and evaporated under reduced pressure. The bright yellow solid was crystallized from water to give the title compound. Yield, 135 mg. (80%), m.p. 94-95°C.

NMR: see table X, Chapter two, page 118.

Mass Measured M^{+}	$C_7H_7N_3S$	error (ppm)
165.0359	165.0361	1.2

7-Amino-6-methyl-1,2,3-benzothiadiazole

7-Nitro-6-methyl-1,2,3-benzothiadiazole (150 mg.) was reduced with anhydrous stannous chloride (1.2 g.) in an experiment analogous to that described in the previous experiment. Yield, 105 mg. (83%), m.p. 133-4°C.

NMR: see table X, Chapter two, page 118.

Mass Measured M^{+}	$C_7H_7N_3S$	error (ppm)
165.0364	165.0361	1.8

4-Amino-5-methyl-2,1,3-benzothiadiazole

An analogous procedure to that described above was carried out for the reduction of 4-nitro-5-methyl-2,1,3-benzothiadiazole (300 mg) with stannous chloride (1.7 g.). Crystallization from water gave the title compound as bright orange needles. Yield, 200 mg. (79%), m.p. 78-79°C.

NMR: see table X, Chapter two, page 118.

Mass measured M^{+}	$C_7H_7N_3S$	error (ppm)
165.0357	165.0361	2.4

4-Amino-6-methyl-2,1,3-benzothiadiazole

The title compound was synthesized by reduction of 4-nitro-6-methyl-2,1,3-benzothiadiazole (120 mg.) with anhydrous stannous chloride (1.0g.) analogous to the previous experiments. Crystallization from water afforded 90.0 mgs. (89%) of bright yellow needles. M.p. 89.5-90°C.

NMR: see table X, Chapter two, page 118.

Mass measured M^{+}	$C_7H_7N_3S$	error (ppm)
165.0356	165.0361	3.0

4-Methyl-6-chloro-1,2,3-benzcthiadiazole ¹¹⁴

o-Toluidine hydrochloride (2.0 g.) was added to sulfur monochloride (15.0 g.) at room temperature stirring the

mixture at all times. The mixture was warmed to 65°C and kept at this temperature for 4 hours. The mixture was cooled and benzene was added. The product was filtered off and the solid washed with benzene until the washings were colourless. The solid was added to 50% sulfuric acid (20 cc.) at 60°C. The mixture was filtered through glass wool to get rid of tars. The filtrate was cooled in ice to 0°C and a solution of sodium nitrite (1.4 g.) in the minimum amount of water was added with stirring. Stirring was continued for one hour at 0°C after which time the mixture was poured into ice-water and left standing for four hours. The product was extracted with ether. The ether layer was dried over sodium sulfate and finally evaporated under reduced pressure leaving the pure title compound. Yield, 1.9 g. (74%), m.p. 63-64°C (Lit.¹¹⁴ m.p. 63.4-64.5°C).

REFERENCES

1. J.H. Beynon, R.A. Saunders and A.E. Williams, "The Mass Spectra of Organic Molecules", Elsevier, Amsterdam, 1968.
2. F.H. Field and J.L. Franklin, "Electron Impact Phenomena and the Properties of Gaseous Ions", Academic Press, New York, 1957, p.58.
3. D.H. Williams and Ian Howe, "Principles of Organic Mass Spectrometry", McGraw Hill, 1972, p.75.
4. W.A. Chupka, J. Chem. Phys., 30, 191 (1959).
5. H.M. Rosenstock, M.B. Wallenstein, A.L. Wahrhaftig and H. Eyring, Proc. Natl. Acad. Sci. U.S., 38, 667 (1952).
6. Ref. 3, pp. 46-52.
7. F.W. McLafferty, "Interpretation of Mass Spectra", Second Ed., W.A. Benjamin, Inc., 1973, pp. 208-209.
8. R.E. Fox and A. Langer, J.Chem.Phys., 18, 460 (1950).
9. B. Steiner, C.F. Giese and M.G. Inghram, ibid., 34, 189 (1961).
10. W.A. Chupka and J. Berkowitz, ibid., 47, 2921 (1967).
11. J.H. Beynon, J.A. Hopkinson and R.G. Lester, J.Mass Spec. and Ion Phys., 2, 291 (1969).
12. R.D. Hickling and K.R. Jennings, Org.Mass Spec., 3, 1499 (1970).

13. T.W. Bentley, R.A.W. Johnstone and B.N. McMaster, J.Chem.Soc. (Chem.Comm.), 510 (1973).
14. R.A.W. Johnstone, F.A. Mellon and S.D. Ward, Int.J. Mass Spec.Ion Phys., 5, 241 (1970).
15. R.H. Vought, Phys. Rev., 71, 93 (1947).
16. J.W. Warren, Nature, 165, 810 (1950).
17. F.P. Lossing, A.W. Tickner and W.A. Bryce, J.Chem. Phys., 19, 1254 (1951).
18. R.W. Kiser, "Introduction to Mass Spectrometry and its Applications", Prentic-Hall, 1965, pp. 169-170.
19. R.E. Honig, J.Chem.Phys., 16, 105 (1948).
20. A.F. Barfield and A.L. Wahrhaftig, J.Chem.Phys., 41, 2947 (1964).
21. R.W. Kiser and E.J. Gallegos, J.Phys.Chem., 66, 947(1962).
22. G.D. Flesch and H.J. Svec, Int.J.Mass Spec.Ion Phys., 9, 106 (1972).
23. R.A.W. Johnstone and F.A. Mellon, J.Chem.Soc.Faraday II, 68, 1209 (1972).
24. J.L. Occolowitz, B.J. Cerimele and P. Brown, Org. Mass Spec., 8, 61 (1974).
25. H.M. Grubb and S. Meyerson, "Mass Spectrometry of Organic Ions", F.W. McLafferty, Ed., Academic Press Inc., New York, N.Y. 1963, Chapter 10.
26. F.P. Lossing, K.U. Ingold and I.H.S. Henderson, J.Chem.Phys., 22, 621 (1954).
27. D.O. Schissler and D.P.Stevenson, J.Chem.Phys., 22, 151 (1954).

28. J.B. Farmer, I.H.S. Henderson, C.A. McDowell and F.P. Lossing, J.Chem.Phys., 22, 1948 (1954).
29. P.N. Rylander, S. Meyerson and H.M. Grubb, J.Am.Chem.Soc., 79, 842 (1957).
30. S. Meyerson and P.N. Rylander, J.Chem.Phys., 27, 901 (1957).
31. S. Meyerson and P.N. Rylander, J.Phys.Chem., 62, 2(1958).
32. S. Meyerson and E.K. Fields, Org.Mass Spec., 2, 1309 (1969).
33. S. Meyerson and P.N. Rylander, E.L. Eliel and J.D. McCollum, J.Am.Chem.Soc., 81, 2606 (1959).
34. R.F. Pottie and F.P. Lossing, J.Am.Chem.Soc., 82, 2634 (1961).
35. F. Meyer and A.G. Harrison, J.Am.Chem.Soc., 86, 4757 (1964).
36. F.H. Field and J.L. Franklin, J.Chem.Phys., 22, 1895 (1954).
37. J.M.S. Tait, T.W. Shannon and A.G. Harrison, J.Am.Chem.Soc., 84, 4 (1962).
38. K.L. Rinehart, Jr., A.C. Buchholz, G.E. Van Lear and H.L. Cantrill, J.Am.Chem.Soc., 90, 2983 (1968).
39. A.S. Siegel, J.Am.Chem.Soc., 92, 5277 (1970).
40. A.S. Siegel, J.Am.Chem.Soc., 96, 1251 (1974).
41. G. Hvistendahl, K. Undheim and P. Györösi, Org.Mass Spec., 7, 903 (1973).

42. A.G. Harrison, P. Kebarle and F.P. Lossing, J.Am. Chem.Soc., 83, 777 (1961).
43. P. Brown, J.Am.Chem.Soc., 90, 2674 (1968).
44. W.T. Pike and F.W. McLafferty, J.Am.Chem.Soc., 89, 5954 (1967) and previous papers in this series.
45. P. Brown, Org.Mass Spec., 2, 1085 (1969)
46. R.H. Shapiro and J.W. Serum, Org.Mass Spec., 2, 533 (1969).
47. P. Brown, Org.Mass Spec., 2, 1317 (1969).
48. R. Westwood, D.H. Williams and A.N.H. Yeo, Org.Mass Spec., 3, 1485 (1970).
49. A.V. Robertson and C. Djerassi, J.Am.Chem.Soc., 90, 6992 (1968).
50. K.L. Rinehart, Jr., A.C. Buchholz and G.E. Van Lear, J.Am.Chem.Soc., 90, 1073 (1968).
51. S.D. Sample, D.A. Lightner, O. Buchardt and C.Djerassi, J.Org.Chem., 32, 997 (1967).
52. M. Marx and C. Djerassi, J.Am.Chem.Soc., 90, 678(1968).
53. D.G.I. Kingston and J.D. Henion, Org.Mass Spec., 3, 413 (1970).
54. P.O. Woodgate and C. Djerassi, Tetrahedron Letters, 1875 (1970).
55. C. Wentrup, K. Wilczek and C. Mayor, Chimia, 25, 250 (1971).
56. C. Wentrup, C. Mayor and G. Gleiter, Helv., 55, 2628 (1972).

57. C. Wentrup, C. Mayor and R. Gleiter, Helv., 55, 2633 (1972).
58. C. Wentrup, Chem. Com., 1386 (1969).
59. W.D. Crow and C. Wentrup, Tetrahedron Letters, 6149 (1968).
60. R. Lawrence, Ph.D. Thesis, Imperial College, London, (1968).
61. R. Lawrence and E.S. Waight, Org.Mass Spec., 3, 367 (1970).
62. M. Ohashi, K. Tsujimoto, A. Yoshino and T. Yonezawa, Org. Mass Spec., 4, 203 (1970).
63. A. Maquestiau, Y. Van Haverbeke and R. Flammang, ibid, 7, 1267 (1973).
64. A.N. Nesmeyanov, V.N. Babin, L.A. Fedorov, M.I. Rybinskaya and E.I. Fedin, Tetrahedron, 25, 4667(1969).
65. J.D. Crow and C. Wentrup, Tetrahedron Letters, 4379 (1967).
66. J.D. Crow and C. Wentrup, Chem.Com., 1026 (1968).
67. C. Wentrup and J.D. Crow, Tetrahedron, 26, 3965(1970).
68. C. Wentrup, Chimia, 26, 54 (1972).
69. T.S. Cantrell and W.S. Haller, Chem.Com., 977 (1968).
70. T. Mukai, T. Oine and A. Matsubara, Bull.Chem.Soc.Jap., 42, 581 (1969).
71. T. Mukai and M. Nitta, Chem.Com., 1192 (1970).
- 71a. F.R. Benson and W.L. Savell, Chem.Rev., 46, 1 (1950).

72. G.T. Morgan and F.M.G. Micklethwait, J.Chem.Soc., 103, 1391 (1913).
73. D. Dal Monte and P. Veggetti, Boll.Sci.Fac.Chim.Ind. Univ. Bologna, 16, 1 (1958).
74. G.T. Morgan and H.D.K. Drew, J.Chem.Soc., 117, 784 (1920).
75. J.C. Brown, R.A. Cheer and P.J. Keogh, Chem.Abs., 74, P 118358d.
76. H. Lindemann and H. Krause, J.Prakt.Chemie, 115, 256 (1927).
77. O. Kym and M. Ringer, Ber., 48, 1671 (1915).
78. G.E.W.Plaut, J.Am.Chem.Soc., 76, 5801 (1954).
79. H.J. Page and B.R. Heasman, J.Chem.Soc., 123, 3235 (1923).
80. J. Scott and R. Robinson, J.Chem.Soc., 121, 844 (1922).
81. J. Meisenheimer and E. Patzig, Ber., 39, 2533 (1906).
82. N.L. Miller and E.C. Wagner, J.Am.Chem.Soc., 76, 1847, (1954)
83. F. Krollpfeiffer, H. Potz and A. Rosenberg, Ber., 71, 596 (1938).
84. F.B. Mallory, C.S. Wood and B.M. Hurwitz, J.Org.Chem., 29, 2605 (1964).
85. T. Zincke and P. Schwarz, Ann., 307, 28 (1899).
86. A.G. Green and F.M. Rowe, J.Chem.Soc., 103, 897(1913).
87. J.H.Boyer and S.E. Ellzey,Jr., J.Org.Chem., 26, 4684 (1961).

88. A.G. Green and F.M. Rowe, J.Chem.Soc., 101, 2452 (1912).
89. J.H. Boyer in "Heterocyclic Compounds" Ed. R.C. Elderfield, Vol. 7 (1961), Chapter 6.
90. J.H. Boyer, R.F. Reinisch, M.J. Danzig, G.A. Stoner and F. Sahhar, J.Am.Chem.Soc., 77, 5688 (1955).
91. P.B. Ghosh, J.Chem.Soc.(B), 334-8 (1968).
92. P. Drost, Ann., 313, 299 (1900).
93. M. Giua, Gazzetta Chimia Italiana, 53, 660 (1923).
94. P. Drost, Ann., 307, 49 (1899).
95. R.J. Gaughran, J.P. Picard and J.U.R. Kaufman, J.Am.Chem.Soc., 76, 2233 (1954).
96. A.G. Green and F.M. Rowe, J.Chem.Soc., 103, 2023 (1913).
97. L.R. Dyll and K.H. Pausacker, Aust.J.Chem., 11, 491 (1958).
98. F.B. Mallory and S.P. Varimbi, J.Org.Chem., 28, 1656 (1963).
99. A.J. Boulton and A.R. Katritzky, Proc.Chem.Soc. London, 257 (1962).
100. J.I.G. Cadogan, R.R. Mackie and M.J. Todd, Chem.Com., 491 (1966).
101. L. DiNunno and S. Florio, J.Chem.Soc.[Perkin I], 1954 (1973).
102. J.M. Prokipcak, P.A. Forte and D.D. Lennox, Can.J.Chem., 47, 2482 (1969).

103. J.M. Prokipcak and P.A. Forte, ibid., 48, 3059(1970).
104. P. Jacobson, Ber., 21, 3104 (1888).
105. A. Michaelis, Ann., 274, 262 (1893).
106. Dea Dal Monte Casoni, E. Sandri and C. Brizzi, Ann.Chim.(Rome), 53, 918 (1963).
107. V.G. Pesin, A.M. Kaletskii and V.A. Sergeev, Zh.Obshch Khim., 33, 1759 (1963).
108. Dea Dal Monte Casoni, E. Sandri and C. Brizzi, Ann.Chim.(Rome), 54, 462 (1964).
109. P. Jacobson and H. Janssen, Ann., 277, 218 (1893)
110. P. Jacobson and E. Ney, Ber., 22, 904 (1889).
111. P. Jacobson and E. Ney, Ann., 277, 232 (1893)
112. R.L. Dannley and D.A. Zazaris, Can.J.Chem., 43, 2610 (1965).
113. S.G. Fridman, J.Gen.Chem.(Rus.), 20, 1191 (1950).
114. P. Kirby, S.B. Soloway, J.H. Davies and S.B. Webb, J.Chem.Soc.(C), 2250 (1970).
115. P. Hope and L.A. Wiles, J.Chem.Soc.(C), 1642(1967).
116. L. Phillips et. al., unpublished results.
117. L. Phillips et. al., unpublished results.
118. A.J. Boulton, A.R. Katritzky, M.J. Sewell and B. Wallis, J.Chem.Soc.(B), 914 (1967).
119. A.J. Boulton, P.J. Halls and A.R. Katritzky, ibid., 637 (1970).
120. D.L. Hammick, W.A.M. Edwardes and E.R. Steiner, J.Chem.Soc., 3308 (1931).

121. R. Hollenstein and W. von Philipsborn, Helv.Chem. Acta., 56, 320 (1973).
122. F.W. McLafferty, Anal.Chem., 34, 16 (1962).
123. J.H. Beynon, R.A. Saunders, A. Topham and A.E. Williams, J.Chem.Soc., 6403 (1965).
124. S. Meyerson, I. Puskas and E.K. Fields, J.Am.Chem. Soc., 88, 4974 (1966).
125. H. Budzikiewicz, C. Djerassi and D.H. Williams, "Mass Spectrometry of Organic Compounds" Holden-Day, Inc., 1967, pp. 515-517.
126. Ref. 3 pp. 16-17.
127. P.N. Raylander, S. Meyerson, E.L. Eliel and J.D. McCollum, J.Am.Chem.Soc., 85, 2723 (1963).
128. Ref. 125, pp.328-329.
129. Ref. 125, pp.237-240.
130. Ref. 125, p. 524.
131. J.H. Beynon, R.A. Saunders and A.E. Williams, Ind.Chim.Belge, 29, 311 (1964).
132. F. Beilstein and A. Kuhlberg, Ann., 158, 351(1871).
133. A. Landenburg, Ber., 8, 1210 (1875).
134. H. McCombie, H.A. Scarborough and W.A. Waters, J.Chem.Soc., 355 (1928).
135. W.H. Evans and A. McGookin, J.Applied Chem., 1, 26 (1951).
136. G.M. Robinson, J.Chem.Soc., 109, 1086 (1916).

137. F.B. Mallory, Org.Synth., Coll.Vol. IV, p. 74 (1963).
138. H.H. Hodgson and P.D. Dodgson, J.Chem.Soc., 1006 (1948).
139. M. Schofield, J.Chem.Soc., 2903 (1927).
140. J.J. Blanksma, Rec.Trav.Chim., 29, 410 (1910).