Mass Spectrometry in Structural and Stereochemical Problems. CCX.[1] Evidence for Transition States of Different Ring Sizes in the Loss of C_4H_8 from Phenyl *n*-Butyl Ether in the Mass Spectrometer[2]

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Abstract: In the loss of C_4H_8 from the molecular ion of phenyl *n*-butyl ether, the hydrogen transferred comes from all four positions of the butyl chain, for the formation of daughter ions in the source at 70 eV, but largely from the 3 position in ions undergoing metastable transitions; this increased specificity with a decrease in internal energy of the ions has not been observed before, and suggests that the transfer of hydrogen from the different positions is due to transition states of different ring sizes, rather than to the intervention of scrambling of the hydrogen prior to fragmentation.

In 1966, MacLeod and Djerassi[3] showed that in the loss of C_4H_8 from the molecular ions of phenyl *n*-butyl ether at 70 eV, the hydrogen transferred came from the 1, 2, 3, and 4 positions of the butyl chain (15, 25, 29, and 16%, respectively). This result is similar to the nonspecific transfer of hydrogen in the fragmentation of isopropyl *n*-butyl ether,[4] but sharply contrasts with the specific transfer of hydrogen from the γ position in the McLafferty rearrangement in ketones.[5] This nonspecific hydrogen transfer in the ethers led to the suggestion that the loss of C_4H_8 involves transitions of different ring sizes.[3]

Recent studies by Williams and coworkers[6] showed that in many aliphatic and aromatic compounds, hydrogen scrambling can occur prior to fragmentation and the extent of randomization is a function of the internal energies of the ions sampled. As a result, it is not possible to distinguish between (i) scrambling prior to specific hydrogen transfer and (ii) the intermediacy of transition states of different ring sizes, solely on the basis of the relative peak intensities of the daughter ions of the deuterated compounds at 70 eV. Examination of the change in specificity (or otherwise) as a function of the internal energy of the ions sampled would be required to provide more conclusive results.

Evidence is now presented to support the case that the nonspecific loss of C_4H_8 from phenyl *n*-butyl ether is the result of the intermediacy of transition states of different ring sizes and not the result of hydrogen scrambling prior to fragmentation.

At 70 eV, the loss of C_4H_8 involves the nonspecific transfer of hydrogen from the four positions. If this transfer were the result of scrambling prior to specific hydrogen transfer, then ions of lower internal energies and hence longer lifetimes (such as those decomposing in the second field-free region) would show a greater extent of scrambling since their longer lifetimes increase the probability for scrambling, assuming that the scrambling process has a lower activation energy and a lower frequency factor. This has been shown to be the case in the many aliphatic and aromatic compounds studied.[6] Conversely, if it is assumed that the scrambling process has a higher activation energy and a higher frequency factor than the specific hydrogen transfer process (no experimental evidence for this assumption has so far been uncovered), then it would be expected that the randomization of the hydrogens would be more complete with an increase in the internal energy of the ions. This is not the case as shown by the trends in the results in Figure 2 and Table I.

However, if the nonspecific hydrogen transfer were the result of transition states of different ring sizes, then it would be expected that the activation energies of the different processes would be different. On lowering the internal energies of the ions, the lower activation energy process would obviously be favored over the higher activation energy process. The overall transfer of hydrogen would therefore be expected to be more specific for ions of lower internal energy than those of higher internal energies.

The results in Table I show that the latter is indeed the case. Assuming that no isotope effect operates, at 70 eV, 34% of the hydrogen transferred comes from the 3 position (Table I, column 2). At 12 eV, this is increased to 43% (column 3). In the metastable transitions at 70 eV, 53% of the hydrogen transferred now comes from the 3 position (column 4) and in the 12-eV metastable transitions, the hydrogen transfer from the 3 position is even more pronounced (Figure 1). These results show that with a decrease in the internal energy of the ions the transfer of hydrogen from the 3 position becomes more and more dominant, while the transfer of hydrogen from the other three positions becomes less important. This suggests that the transfer from the 3 position has the lowest activation energy.

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[1] For paper CCIX, see M. Sheehan, R. J. Spangler, and C. Djerassi, *J. Org. Chem.*, **36**, 3526 (1971).

[2] Financial support by the National Institutes of Health (Grant No. AM 04257) and the National Aeronautics and Space Administration (Grant No. NGR-05-020-004) is gratefully acknowledged.

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[4] C. Djerassi and C. Fenselau, *ibid.*, **87**, 5747 (1965).

[5] H. Budzikiewicz, C. Djerassi, and D. H. Williams, "Mass Spectrometry of Organic Compounds," Holden-Day, San Francisco, Calif., 1967, p 155.

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Table I. Deuterium Transfer from the Various Positions in the *n*-Butyl Chain for the Loss of C_4H_7D from the Molecular Ions of Deuterated Phenyl *n*-Butyl Ethers

Phenyl *n*-butyl ethers[a]	$\frac{[m/e\ 95 - CO]^b}{[m/e\ 95 - CO] + [m/e\ 94 - CO]}$ (70-eV daughter peaks)	$\frac{[m/e\ 95]}{[m/e\ 95] + [m/e\ 94]}$ (70-eV daughter peaks)	$\frac{[m/e\ 95]}{[m/e\ 95] + [m/e\ 94]}$ (12-eV daughter peaks)	$\frac{[M^+ \rightarrow 95]}{[M^+ \rightarrow 95] + [M^+ \rightarrow 94]}$ (70 eV ²m*)	Calcd value for complete randomization
1,1-d_2	17 (20)[c]	15 (18)	12 (15)	11 (12)	(22.2)
2,2-d_2	28 (33)	25 (29)	22 (27)	20 (23)	(22.2)
3,3-d_2	22 (25)	29 (34)	35 (43)	46 (53)	(22.2)
4,4,4-d_3	19 (22)	16 (19)	12 (15)	11 (12)	(33.3)

[a] No correction is made for the minute isotopic impurity present in these deuterated compounds, since the salient feature of the results is the variation of the ratios with internal energies of the ions sampled, rather than the absolute value of the ratios for each individual compound. [b] *m/e* 95 and 94 are the masses of $C_6H_5DO^+$ and $C_6H_6O^+$, respectively. [c] The values given are in percentages. Since the sum of these percentages does not add up to 100, for the four deuterated compounds the sum is normalized to 100, and the normalized values are given in parentheses for easy comparison with the data at other internal energies, and with the calculated values for complete randomization.

Table II. Relative Intensities of *m/e* 65, 66, and 67, and the Calculated Intensities of $C_5H_6^+$ Peaks in the Deuterated Phenyl *n*-Butyl Ethers[a]

Phenyl *n*-butyl ethers	Obsd intensities *m/e* 65 *a*	*m/e* 66 *b*	*m/e* 67 *c*	Calcd intensities $[C_5H_6^+]$ *y*	$\frac{[C_5H_5D^+]}{[C_5H_5D^+] + [C_5H_6^+]}$
d_0	100	83.5			
1,1-d_2	100	79.5	14.6	74.0	17 (20)[b]
2,2-d_2	100	75.5	24.9	66.0	28 (33)
3,3-d_2	100	75.5	18.9	69.5	22 (25)
4,4,4-d_3	100	83.5	17.4	74.0	19 (22)

[a] The intensities of *m/e* 65, 66, and 67 have been corrected for ^{13}C isotope contributions. [b] See Table I, footnote *c*.

Howe and McLafferty[7] have shown that primary daughter ions undergoing further decomposition in the ion source have higher internal energies and shorter lifetimes than those that are collected without further decomposition in the 70-eV spectra. This approach was applied to the examination of the decomposition product of the $C_6H_6O^+$ ions (Scheme I). A comparison

Scheme I

$$C_6H_6O^+ \xrightarrow{-CO} C_5H_6^+$$

$$C_6H_5DO^+ \xrightarrow{-CO} C_5H_5D^+$$

of the ion intensities of the $C_5H_5D^+$ and the $C_5H_6^+$ ions would thus give the ratio of the intensities of the $C_6H_5DO^+$ and the $C_6H_6O^+$ ions that have sufficient energy to decompose *via* loss of CO in the ion source, *i.e.*, ions with higher internal energies than those giving rise to the $C_6H_5DO^+$ and the $C_6H_6O^+$ ions that do not decompose further prior to collection.

The results in Table II show clearly that in the $C_6H_6O^+$ ions with sufficient energy to decompose further in the ion source at 70 eV, there is more transfer of hydrogen from the 2 position than from the 1, 3, and 4 positions. This is in marked contrast to the results obtained from decompositions in the second field-free region (Table I).

It should be noted that the transfer from the 2 position is favored over that from the 3 position only in ions of high internal energies, whereas the situation is reversed in ions of low internal energies (Figure 2). These observations require that the transfer from the 2 position has a higher activation energy and a higher frequency factor than the corresponding transfer from the 3 position.[8] For hydrogen transfer from the 2 position, reaction 2 (Scheme II) is not favored, since the tighter four-membered transition state would be expected to have a lower frequency[8,9] factor than reactions 3 or 4 with the looser transitions states with seven- or five-membered rings respectively. Reaction 1 is therefore favored over reaction 2 for the transfer from the 2 position. Since the transfer from the 3 position has a lower activation energy than that from the 2 position, reaction 3 is not favored since this reaction with hydrogen transfer to the ring (as in reaction 1) would be expected to have an activation energy higher than reac-

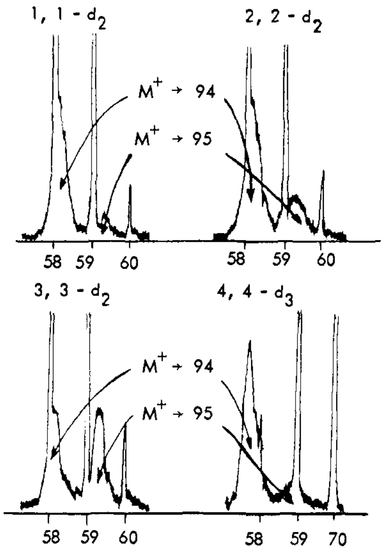

Figure 1. Metastable peaks in the spectra of the deuterated phenyl *n*-butyl ethers at 12 eV.

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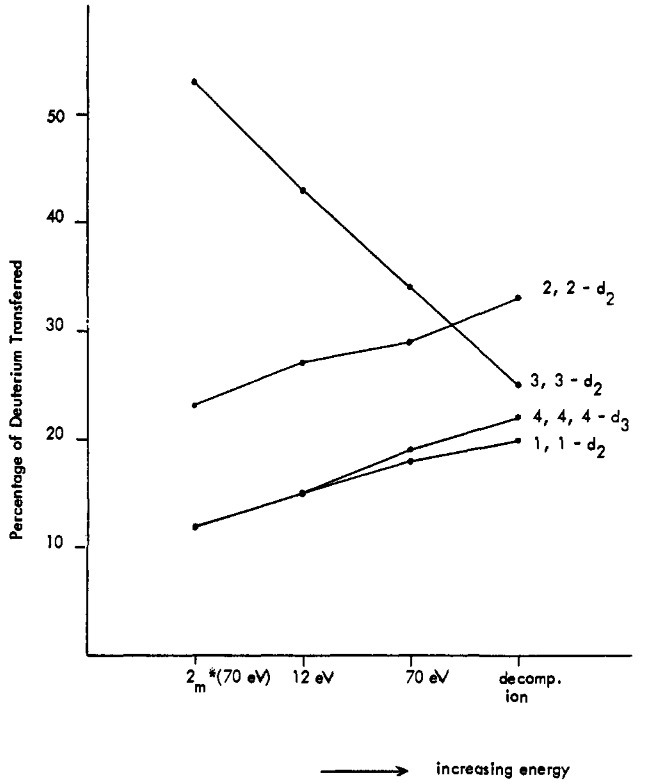
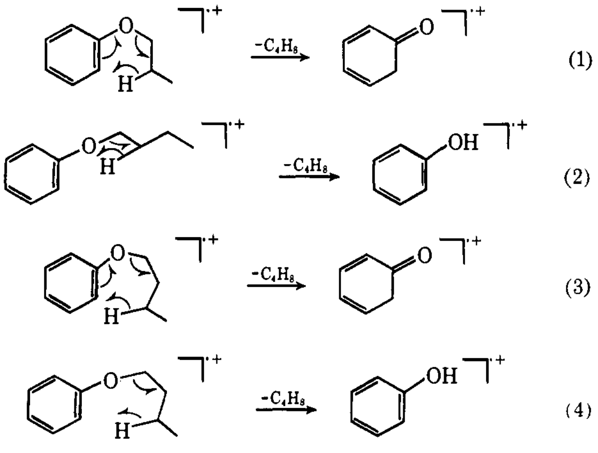


Figure 2. Variation of deuterium transfer from the various positions of the *n*-butyl chain in deuterated phenyl *n*-butyl ethers with internal energy. $^2m^*$ (70 eV), 12 eV, 70 eV, and decomp ion refer to the metastable transitions in the second field-free region at 70 eV, daughter ions at 12 and 70 eV, and decomposition ions of $C_5H_6^+$ and $C_5H_5D^+$ at 70 eV, respectively.

tion 1, because it would most likely involve the loss of methylcyclopropane in contrast to the loss of butene in reaction 1. It is probable, therefore, that reaction 4 operates since it is known that a transfer of hydrogen to an oxygen atom is energentically favored over a transfer to a double bond.[10]

Scheme II



For hydrogen transfers from the 1 and the 4 positions, transfers to the oxygen atom and to the benzene ring, respectively, would require transition states with three- and five-membered rings for the 1 position transfer, and six- and eight-membered rings for the 4 position transfer. It is likely that the five-membered ring would be energetically favored over the three-membered ring, and the six-membered ring over the eight-membered ring, so that hydrogen transfer from the 4 position would be to the oxygen atom, and hydrogen transfer from the 1 position would be to the benzene ring. The involvement of only five- and six-membered rings for the hydrogen transfer from the four different positions of the *n*-butyl chain would be consistent with the relatively close similarity in the activation energies as indicated by the detection of metastable peaks for hydrogen transfer from all the four positions.[6c]

These results suggest that the initial structures of the $C_6H_6O^+$ ions would be the ionized 2,4-cyclohexadienone structure for hydrogen transfer from the 1 and the 2 positions, and the ionized phenol structure for hydrogen transfer from the 3 and 4 positions. These postulates should be amenable to being tested by ion cyclotron resonance spectroscopy,[11] and experiments in this direction are currently in progress.

Experimental Section

The preparation of the deuterated phenyl *n*-butyl ethers has been previously reported.[3] Isotopic purities are *1,1-d*$_2$, 98% d_2, 2% d_1; *2,2-d*$_2$, 91% d_2, 9% d_1; *3,3-d*$_2$, 95% d_2, 5% d_1; *4,4,4-d*$_3$, 94% d_3, 4% d_2, 2% d_1. The mass spectra were taken on the AEI-MS9 double-focussing mass spectrometer. Samples were introduced *via* the heated inlet system, with an operating source temperature of about 200°, and an accelerating voltage of 8 kV. The low-voltage spectra were taken at a nominal 12 eV.

Appendix

Assuming that (i) the structures of the $C_5H_6^+$ ions are identical, (ii) $C_5H_5^+$ ions come exclusively from $C_5H_6^+$ (metastable present), and (iii) the isotope effect for this process occurring in ions with relatively high internal energy is negligible, the ratio of the intensities of $C_5H_6^+$ and $C_5H_5D^+$ can be estimated (see also Table II).

From the d_0 compound, it is noted that a relative intensity of 83.5 for $C_5H_6^+$ is associated with a relative intensity of 100 for $C_5H_5^+$; *i.e.*, the intensity of $C_5H_5^+$ is 1.2 times that of its precursor $C_5H_6^+$.

For the unlabeled compound

$$\underset{(b)}{C_5H_6^+\ (m/e\ 66)} \xrightarrow{-H} \underset{(1.2b)}{C_5H_5\ (m/e\ 65)}$$

For the deuterated compounds

$$\begin{tikzcd}[column sep=small] & \underset{(x)}{C_5H_4D^+\ (m/e\ 66)} \\ \underset{(c)}{C_5H_5D^+\ (m/e\ 67)} \arrow[ur, "-H"] \arrow[dr, "-D"'] & \\ & \underset{(1.2c\ -\ x)}{C_5H_5^+\ (m/e\ 65)} \end{tikzcd}$$

$$\underset{(y)}{C_5H_6^+\ (m/e\ 66)} \xrightarrow{-H} \underset{(1.2y)}{C_5H_5^+\ (m/e\ 65)}$$

where the intensity of m/e 66 is $x + y = b$, the intensity of m/e 65 is $1.2y + (1.2c - x) = a$, and, therefore, the intensity of $C_5H_6^+$ is $y = [(a + b) - 1.2c]/2.2$.

It should be emphasized that significance is attached not to the absolute calculated value of the ratio of $C_5H_5D^+/C_5H_6^+$, but to the relative values for the ratio for the four deuterated compounds.

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