Mass Spectrometry of Organic Compounds. VII.[1a] Energetics of Substituent Isomerization in Diphenyl Sulfide and Diphenyl Ether

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Abstract: Studies of diphenyl ether and diphenyl sulfide specifically labeled with ^{13}C show that the molecular ions of both compounds undergo substituent isomerization prior to the loss of CO and CS, respectively. The difference between this result and the lack of isomerization observed in the corresponding fragmentation of phenol is shown not to be due to any significant difference in the activation energy of the fragmentation processes, and it is proposed that differences in the frequency factors for the elimination of CO from the two compounds are responsible for the observed differences in scrambling. The elimination of CH_3 from diphenyl sulfide is shown to involve preferential loss of the C-1 carbon atom.

One of the most intriguing problems in mass spectrometry concerns the skeletal rearrangement reactions undergone by benzene, its derivatives, and its heterocyclic analogs on electron impact. In benzene itself it has been shown that the carbon atoms are randomized with respect to each other prior to the elimination of acetylene,[2] while skeletal rearrangement also precedes the loss of fragments such as CHS from ^{13}C-labeled thiophenes.[3,4] Further studies on the thiophene system have been carried out, and it has been shown that isomerization of phenyl substituents occurs in phenylated thiophenes,[5] and that this substituent isomerization occurs essentially independently of any ring carbon scrambling in 3-phenylthiophene.[6] Ring carbon scrambling also occurs in benzothiophene[7] and in the thienothiophenes.[8]

In addition to isomerization of the ring atoms and to any substituent isomerization that takes place, aromatic compounds in general may undergo more or less extensive hydrogen rearrangements. These rearrangements have been studied by many investigators during the last few years,[9] and it has been shown in the case of benzene that hydrogen scrambling proceeds independently of any skeletal reorganization that may be occurring.[10,11] There are thus three related and yet distinct isomerization reactions that are undergone by aromatic molecules on electron impact: ring atom isomerization; substituent isomerization; and hydrogen scrambling. Frequently these rearrangements proceed independently and concurrently in the molecular ion of an aromatic compound, but it is possible to study them separately by suitable experimental techniques, and this paper is concerned with the occurrence and energetics of substituent isomerization in some aromatic compounds.

In the case of disubstituted benzenes, various indirect methods (metastable ion abundances, substituent effect considerations, and energetic studies) have led to the conclusion that substituent isomerization occurs in some cases.[12,13] Metastable ion abundance data similarly provide evidence of substituent isomerization in chlorinated diphenyls.[14] For simple monosubstituted benzene derivatives, however, substituent isomerization cannot be detected without recourse to isotopic labeling of an aromatic carbon atom. Nevertheless, a number of compounds have been investigated by this technique, and it has been shown that substituent isomerization occurs in the molecular ions of toluene,[15] thiophenol,[16] and diphenyl sulfide,[17] in the ion of composition $C_6H_5N^+$ generated from phenyl azide,[18] and in the ion $C_6H_6N\cdot^+$ from aniline,[19,20] sulfanilamide,[20] and *p*-nitroaniline.[20] On the other hand, substituent isomerization is not observed in the molecular ions of phenol[11,16] or aniline,[19,20] or in the ions $C_6H_6O\cdot^+$ generated from phenyl *n*-butyl ether,[21] or $C_7H_7N\cdot^+$ from acetanilide.[19,20]

It should be noted that in all the monosubstituted

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(1) (a) Part VI: D. G. I. Kingston, *Tetrahedron*, 27, 2691 (1971); (b) abstracted from the Ph.D. thesis of J. D. Henion, State University of New York at Albany, 1972; (c) Virginia Polytechnic Institute and State University.

(2) I. Horman, A. N. H. Yeo, and D. H. Williams, *J. Amer. Chem. Soc.*, **92**, 2131 (1970).

(3) F. deJong, H. J. M. Sinnige, and M. J. Janssen, *Org. Mass Spectrom.*, 33, 1539 (1970).

(4) A. S. Siegel, *Tetrahedron Lett.*, 4113 (1970).

(5) T. A. Elwood, P. F. Rogerson, and M. M. Bursey, *J. Org. Chem.*, 34, 1138 (1969).

(6) M. E. Rennekamp, W. O. Perry, and R. G. Cooks, *J. Amer. Chem. Soc.*, 94, 4985 (1972).

(7) R. G. Cooks and S. L. Bernasek, *J. Amer. Chem. Soc.*, **92**, 2129 (1970).

(8) A. Bugge, *Acta Chem. Scand.*, **25**, 1504 (1971).

(9) For a recent review of hydrogen rearrangements in aromatic systems see J. T. Bursey, M. M. Bursey, and D. G. I. Kingston, *Chem. Rev.*, 73, 191 (1973).

(10) W. O. Perry, J. H. Beynon, W. E. Baitinger, J. W. Amy, R. M. Caprioli, R. N. Renaud, L. C. Leitch, and S. Meyerson, *J. Amer. Chem. Soc.*, **92**, 7236 (1970).

(11) R. J. Dickinson and D. H. Williams, *J. Chem. Soc. B*, 249 (1971).

(12) F. W. McLafferty, M. M. Bursey, and S. M. Kimball, *J. Amer. Chem. Soc.*, **88**, 5022 (1966).

(13) P. Brown, *Org. Mass Spectrom.*, 4, 519 (1971).

(14) S. Safe and O. Hutzinger, *Chem. Commun.*, 466 (1971).

(15) K. L. Rinehart, Jr., A. C. Buchholz, G. E. VanLear, and H. L. Cantrill, *J. Amer. Chem. Soc.*, **90**, 2983 (1968).

(16) A. Siegel and K. L. Rinehart, Jr., 158th National Meeting of the American Chemical Society, New York, N. Y., Sept 1969, Abstract ORGN-66.

(17) J. D. Henion and D. G. I. Kingston, *Chem. Commun.*, 258 (1970).

(18) P. D. Woodgate and C. Djerassi, *Tetrahedron Lett.*, 1875 (1970).

(19) K. L. Rinehart, Jr., A. C. Buchholz, and G. E. VanLear, *J. Amer. Chem. Soc.*, **90**, 1073 (1968).

(20) A. V. Robertson and C. Djerassi, *J. Amer. Chem. Soc.*, **90**, 6992 (1968).

(21) P. D. Woodgate and C. Djerassi, *Org. Mass Spectrom.*, 3, 1093 (1970).

Table I. Some Fragment Ions from the Diphenyl Ethers **1** and **2**[a]

		Relative abundance, 70 eV			Relative abundance, 20 eV		
m/e	Ion(s)	**1**	**2**	Calcd[b]	**1**	**2**	Calcd[c]
143	$^{13}CC_{10}H_{10}$	0	0.198	0.198	0	0.197	0.197
142	$^{13}CC_{10}H_9 + C_{11}H_{10}$	0.270	0.556	0.556	0.339	0.534	0.534
141	$C_{11}H_9$	0.730	0.246	0.246	0.661	0.269	0.269

[a] Corrected for natural abundance ^{13}C contributions and normalized in each region of interest. Values for **2** are adjusted to 100% ^{13}C incorporation (see text). [b] Calculated values for 56 and 39% isomerization (see text). [c] Calculated values for 19 and 22% substituent isomerization (see text).

benzenes studied, the extent of skeletal reorganization and/or substituent isomerization has been monitored by observation of the loss of a small neutral fragment from the ion of interest. This technique clearly can give little or no information about the detailed mechanism by which isomerization occurs, and such mechanisms can in theory run the entire range from the ring expansion postulated for toluene[15] to the migration of a substituent on an intact carbon skeleton. Since the available technique precludes a detailed understanding of the mechanism, we propose to use an operational definition of substituent isomerization as being any process by which a substituent can become bonded to a ring carbon atom other than the one to which it was originally bonded, whether or not such isomerization occurs on the intact aromatic ring.

The existence of two different processes for loss of a small neutral fragment from substituted aromatic ions (loss with substituent isomerization and loss without substituent isomerization) raises at once the question of why some ions undergo isomerization while others do not. Particularly intriguing is the observation that thiophenol undergoes substituent isomerization while the closely related compound phenol does not, and the present study was undertaken with the object of elucidating the factors that differentiate these two cases. In particular, a comparison of the occurrence of substituent isomerization in diphenyl ether and diphenyl sulfide with that in phenol and thiophenol, respectively, would be expected to lead to new insight into the energetics of the isomerization reaction since for each pair of compounds the same neutral fragment (CO or CS, respectively) is eliminated and the same bond must be broken for isomerization to occur. In the case of phenol and thiophenol, however, loss of CO or CS can involve a mere hydrogen rearrangement followed by expulsion of the neutral fragment, while in the case of the diphenyl ethers such a simple mechanism is precluded[22] and expulsion of CO or CS must take a more complex pathway.

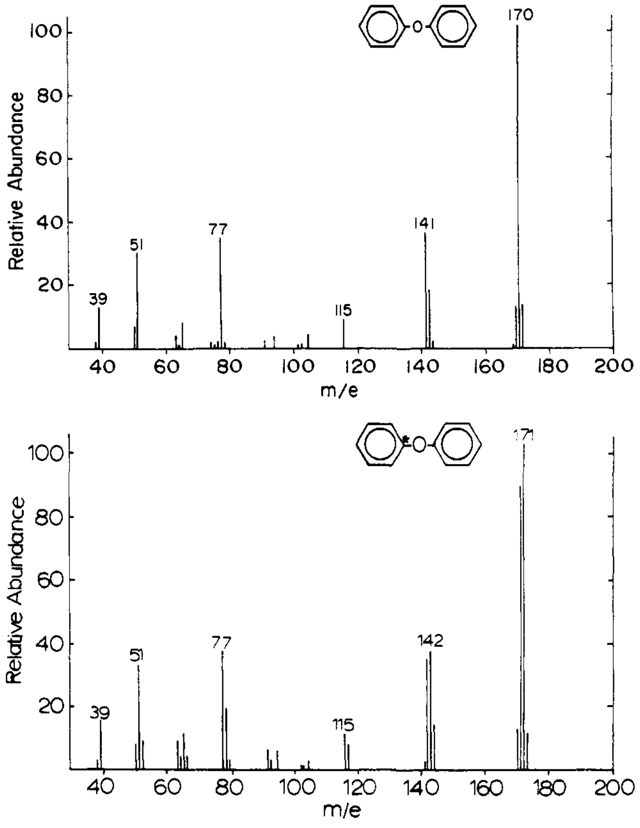
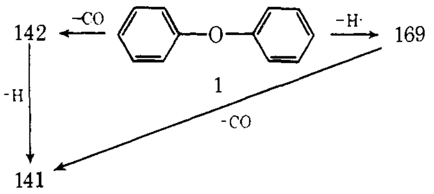


Figure 1. (Top) Mass spectrum (70 eV) of diphenyl ether and (bottom) mass spectrum (70 eV) of diphenyl-*1*-^{13}C ether.

Scheme I



Results

Diphenyl Ether. The normal 70 eV mass spectra of diphenyl ether (**1**) and diphenyl-*1*-^{13}C ether (**2**) are presented in Figure 1. The incorporation of ^{13}C in **2** was determined to be 59.2% by low electron energy scans. Major aspects of the fragmentation pattern of **1** are given in Scheme I, all reactions having been substantiated by the observation of the appropriate metastable ion decompositions and by exact mass measurements. The reactions of primary interest are those which can be used to monitor the extent of scrambling in the molecular ion, namely the loss of CO to give an ion $C_{11}H_{10}\cdot^+$ at *m/e* 142 and the loss of CHO to give an ion $C_{11}H_9^+$ at *m/e* 141. Daughter ion abundances for the labeled and unlabeled compounds for the *m/e* 141–143 region are given in Table I. The values for the labeled compound **2** have been adjusted to the values which would have been observed for a compound with 100% ^{13}C at the 1 position and no ^{13}C at any other position. This adjustment was made by subtracting from each peak in the normalized spectrum of the labeled compound (corrected by natural abundance ^{13}C) the relative abundance of the same peak in the normalized spectrum of the corrected unlabeled compound, multiplied by the percentage of unlabeled compound in the labeled

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(22) It has been shown in the case of diphenyl ether that phenyl migration from oxygen to the ortho carbon does not occur.[23]

(23) D. H. Williams, S. W. Tam, and R. G. Cooks, *J. Amer. Chem. Soc.*, **90**, 2150 (1968).

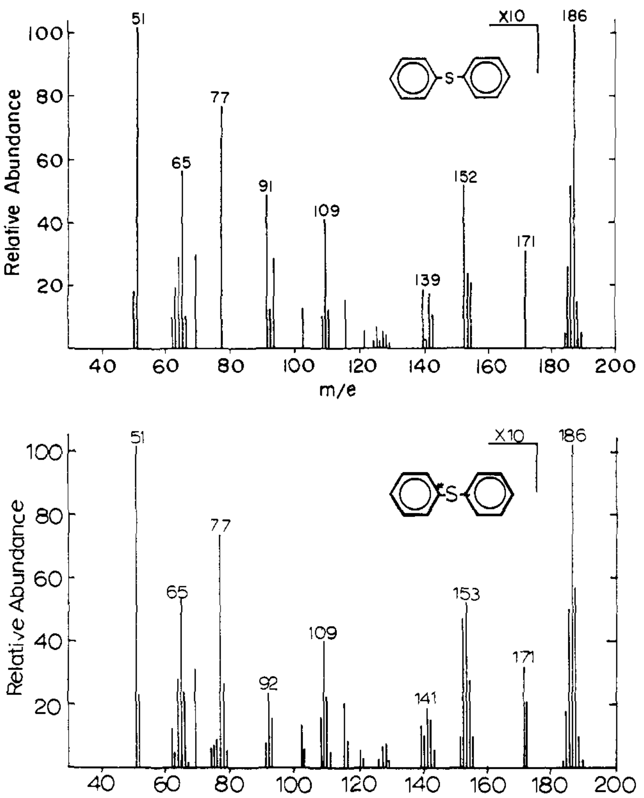


Figure 2. (Top) Mass spectrum (70 eV) of diphenyl sulfide and (bottom) mass spectrum (70 eV) of diphenyl-*1*-^{13}C sulfide.

compound (40.8% in this case). The resulting ion abundances were then renormalized to $\Sigma_{141-143} = 1.00$.

A calculated spectrum of 100% labeled diphenyl-*1*-^{13}C ether can be obtained from the spectrum of the unlabeled compound in the following way.[24] If the fraction of substituent isomerization in the molecular ion of diphenyl-*1*-^{13}C ether is designated f, then loss of ^{12}CO from the labeled molecular ion will be given by the expression

$$[\mathrm{M} - {}^{12}\mathrm{CO}] = {}^1\!/_2(0.270) + {}^1\!/_2(0.270)^5\!/_6 f = 0.135 + 0.112f$$

since one-half of the CO lost will come from the unlabeled phenyl ring and $^5/_6$ of the CO lost from the labeled ring that has undergone substituent scrambling will be unlabeled also. Similarly, the loss of ^{13}CO will be given by the expression

$$[\mathrm{M} - {}^{13}\mathrm{CO}] = {}^1\!/_2(0.270)^1\!/_6 f + {}^1\!/_2(0.270)(1 - f) = 0.135 - 0.112f$$

If it is assumed that a fraction of ions f' is isomerized before or during the loss of CHO from the molecular ion (or loss of CO from the $(\mathrm{M} - \mathrm{H})^+$ ion), then the intensities of the ions M − CHO and M − ^{13}CHO may be calculated in the same way.

$$[\mathrm{M} - {}^{12}\mathrm{CHO}] = {}^1\!/_2(0.730) + {}^1\!/_2(0.730)^5\!/_6 f' = 0.365 + 0.304f'$$

$$[\mathrm{M} - {}^{13}\mathrm{CHO}] = {}^1\!/_2(0.730)^1\!/_6 f' + {}^1\!/_2(0.730)(1 - f') = 0.365 - 0.304f'$$

The values of f and f' can then in principle be found by solving the following equations.

$$[143] = 0.198 = [\mathrm{M} - {}^{12}\mathrm{CO}] = 0.135 + 0.112f$$

$$[142] = 0.556 = [\mathrm{M} - {}^{13}\mathrm{CO}] + [\mathrm{M} - {}^{12}\mathrm{CHO}] = 0.500 - 0.112f + 0.304f'$$

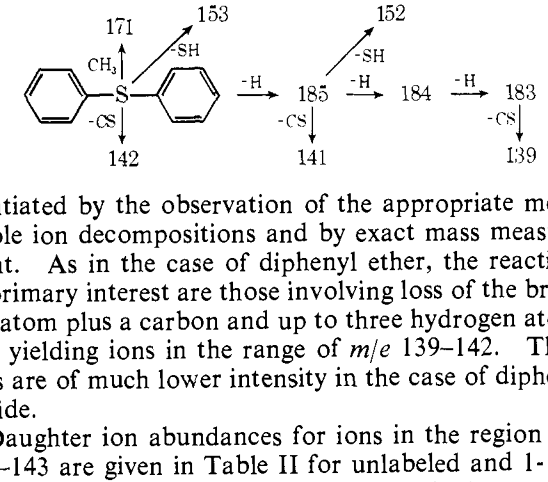
$$[142] = 0.246 = [\mathrm{M} - {}^{13}\mathrm{CHO}] = 0.365 - 0.304f'$$

Since there are three equations and only two unknowns, the exact solution of the equations provides a check on the reliability of the results. In the event, values of 0.56 for f and 0.39 for f' satisfy all three equations exactly. While it is not claimed that these values are accurate to better than ±10%, it is clear that substantial substituent isomerization occurs prior to or during the loss of CO and CHO from diphenyl ether.

The occurrence of substituent isomerization was also investigated at 20 eV. Methods exactly analogous to those used for the calculation of scrambling at 70 eV yield values of f and f' of 0.19 and 0.22, respectively; here again, the calculated and observed values of the ion intensities agree exactly.

Diphenyl Sulfide. The normal 70 eV mass spectra of diphenyl sulfide (**3**) and diphenyl-*1*-^{13}C sulfide (**4**) are presented in Figure 2. The incorporation of ^{13}C in **4** was determined to be 49.7% by low electron energy scans. Major aspects of the fragmentation pattern of **3** are given in Scheme II, all reactions having been substantiated by the observation of the appropriate metastable ion decompositions and by exact mass measurement. As in the case of diphenyl ether, the reactions of primary interest are those involving loss of the bridging atom plus a carbon and up to three hydrogen atoms and yielding ions in the range of *m/e* 139–142. These ions are of much lower intensity in the case of diphenyl sulfide.

Scheme II



Daughter ion abundances for ions in the region *m/e* 139–143 are given in Table II for unlabeled and 1-^{13}C-labeled diphenyl sulfide; the values for the latter compound have been corrected to 100% ^{13}C enrichment, as described above for diphenyl ether. The fraction of isomerized ions involved in formation of the various daughter ions may be calculated by a method analogous to that described above for diphenyl ether. In this case, however, it did not prove possible to adjust the values of f so that perfect agreement was obtained between experimental and calculated figures. A best fit calculation gave the values recorded in Table II for values of f of 0.80 for molecular ions decomposing by loss of CS and 0.65 for ions formed by other pathways. While the actual extent of substituent isomerization in the formation of each ion is thus somewhat uncertain, it is clear that at least 65% scrambling precedes

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[24] This calculation makes the reasonable assumption that randomization of the substituent oxygen atom may occur over all six ring carbon atoms. A few specific mechanisms may require a different assumption, but since the object of the work described is to determine the approximate significance of the scrambling process rather than to make a quantitative assessment of the precise extent of scrambling, this assumption is justifiable.

Table II. Some Fragment Ions from the Diphenyl Sulfides **3** and **4**[a]

m/e	Ion(s)	Relative abundance, 70 eV			Relative abundance, 20 eV		
		3	**4**	Calcd[b]	**3**	**4**	Calcd[c]
143	$^{13}CC_{10}H_{10}$	0	0.173	0.173	0	0.386	0.387
142	$^{13}CC_{10}H_9 + C_{11}H_{10}$	0.208	0.335	0.368	0.447	0.481	0.475
141	$^{13}CC_{10}H_8 + C_{11}H_9$	0.432	0.102	0.117	0.527	0.096	0.093
140	$^{13}CC_{10}H_7 + C_{11}H_8$	0.024	0.301	0.265	0.026	0.037	0.023
139	$C_{11}H_7$	0.336	0.088	0.077	0	0	0

[a] Corrected for natural abundance ^{13}C contributions and normalized in each region of interest. Values for **4** are adjusted to 100% ^{13}C incorporation (see text). [b] Calculated for a 80% substituent isomerization prior to loss of CS and 65% substituent isomerization prior to formation of all other ions. [c] Calculated for 88% substituent isomerization prior to formation of all ions.

the formation of all the major ions in the *m/e* 139–142 region.

At 20 eV the spectrum of diphenyl sulfide is simplified by the absence of any ion *m/e* 139. Calculations performed as previously described give a good fit between observed and calculated spectra for a fraction f of scrambled ions of 0.88 preceding all fragmentations (Table II).

The spectrum of diphenyl sulfide shows an additional peak of interest at *m/e* 171 due to the loss of a methyl group.[25] A corresponding peak is not shown by diphenyl ether,[25] although benzene does have an ion at *m/e* 63. In the spectrum of diphenyl-*1*-^{13}C sulfide (**4**), adjusted to 100% ^{13}C enrichment, this ion is split between $^{13}CC_{10}H_7S$ (*m/e* 172) and $C_{11}H_7S$ (*m/e* 171) in the ratio 56:44. Thus, 44% of the methyl groups lost from fully labeled diphenyl-*1*-^{13}C sulfide are lost as $^{13}CH_3$, a percentage which significantly exceeds the value of 8.5% expected for loss of CH_3 from a completely scrambled molecule, and which approaches the value of 50% expected for specific loss of carbon from the 1 or 1′ position.

Discussion

The results presented above provide strong evidence that *both* diphenyl sulfide and diphenyl ether undergo substantial substituent randomization on electron impact prior to the elimination of CS or CH_nS and CO or CHO fragments, respectively. The observation that in both cases scrambling is somewhat greater before loss of CS or CO than before loss of CH_nS or CHO is somewhat surprising in view of the reported[30,31] increase in scrambling in the loss of H_2CN from aniline as compared with the loss of HCN. It should be noted that the available data would be almost as well satisfied by the assumption of equal scrambling before the loss of all fragments considered, and hence as noted above it is the fact of substantial but not complete substituent isomerization rather than the exact extent of such scrambling for any particular ion that is of paramount importance.

The fact that substituent isomerization occurs prior to the loss of CS from diphenyl sulfide and from thiophenol and prior to the loss of CO from diphenyl ether but *not* prior to the loss of CO from phenol raises the question of what factors govern whether or not substituent isomerization will occur in any particular molecule. The occurrence of substituent isomerization in benzene and phenol has reasonably been linked with the energetic requirements of the fragmentation process used to monitor the scrambling.[11] If the activation energy for fragmentation is greater than the activation energy for the substituent isomerization process, then all ions with enough energy to fragment will also have sufficient energy to undergo isomerization and the occurrence of isomerization becomes a strong possibility. On the other hand, if the isomerization reaction has a higher activation energy than the fragmentation reaction, then ions with insufficient energy to isomerize may undergo fragmentation and the occurrence of isomerization will be reduced or eliminated. In the cited study, however, the two fragmentation processes compared involved the loss of different neutral fragments and thus necessarily also the breaking of different bonds in the transition state both of the isomerization reaction and the fragmentation reaction. A more direct test of the importance of energetic considerations on the degree of substituent isomerization observed can be made by comparing phenol with diphenyl ether and thiophenol with diphenyl sulfide. In both pairs of compounds the same neutral fragment(s) are eliminated, and the same bond must be broken in order that substituent scrambling may occur. It is thus reasonable to assume that the activation energy for substituent isomerization in phenol should be closely similar to that for diphenyl ether, while the values for thiophenol and diphenyl sulfide should also be similar (but different from those for phenol and diphenyl ether). If the energetic considerations outlined above were the determining factor in the occurrence of substituent isomerization, we should then expect to find that the activation energy for loss of CO from diphenyl ether would be considerably greater than that for loss of CO from phenol, while the values for loss of CS from thiophenol and diphenyl sulfide ought to be closely comparable.

The values of the activation energy for each fragmentation process may be estimated by the difference between the appearance potential (AP) of the fragment ion in question and the ionization potential (IP) of the parent compound. Relevant values for the compounds of interest are presented in Table III; some values for other aromatic compounds taken from the literature are included for comparison purposes. Inspection of the values in Table III indicates that there is *no* clear-cut correlation between the (AP − IP) values and the occurrence of substituent isomerization in the molecular ion. Thus, diphenyl ether has a value only slightly higher than that of phenol, although substituent isomerization occurs in the former but not in the latter. On the other hand, thiophenol undergoes substituent isomerization at least as extensively as does diphenyl sulfide, although its (AP − IP) value is about 0.9 eV lower than that for diphenyl sulfide. Similarly, aniline, with the highest (AP − IP) value of all the substituted benzenes in Table III, does not undergo sub-

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[25] J. H. D. Eland and C. J. Danby, *J. Chem. Soc.*, 5935 (1965).

Table III. Ionization and Appearance Potential Data for Various Compounds

Compound	IP, eV	AP, eV	Fragment elided	AP − IP, eV	Ref
		A. Substituent isomerization observed			
Benzene	9.24	14.95	C_2H_2	5.71	*a*
Diphenyl ether	8.82	12.56	CO	3.74	*a*
Diphenyl sulfide	8.45	12.57	CS	4.12	*b*
Thiophene	9.20	12.80	CHS	3.60	*a*
Thiophenol	8.95	12.18	CS	3.23	*b*
		B. Substituent isomerization not observed			
Aniline	7.69	12.30	HCN	4.61	*a*
Phenol	9.09 (9.16)	12.45 (12.50)	CO	3.36 (3.34)	*b*, *c*

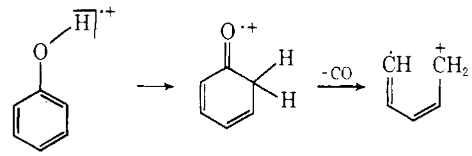
[a] J. L. Franklin, J. G. Dillard, H. M. Rosenstock, J. T. Herron, K. Draxl, and F. H. Field, "Ionization Potentials, Appearance Potentials, and Heats of Formation of Gaseous Positive Ions," NSRDS-NBS 26, Washington, D. C., 1969. [b] This work. Values obtained by the semilogarithmic plot method, with precision ±0.1 eV. [c] J. L. Occolowitz and G. L. White, *Aust. J. Chem.*, **21**, 997 (1967); G. F. Crable and G. L Kearns, *J. Phys. Chem.*, **66**, 436 (1962).

stituent isomerization prior to the loss of HCN. These observations are of course the exact reverse of those predicted on the basis of the simple energetic theory, and although part of the discrepancies observed could be rationalized on the basis of kinetic shifts of uncertain magnitude, the overall picture is such that we must look for additional factors governing substituent isomerization.

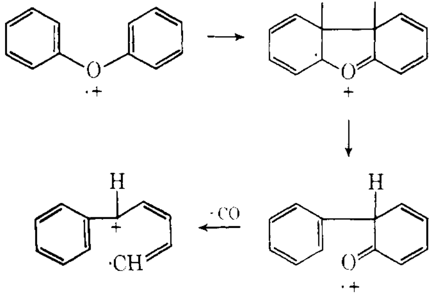
The observation that substituent isomerization in diphenyl ether decreases as the ionizing voltage is lowered from 70 to 20 eV provides further insight into the energetics of the process. Since both isomerization and fragmentation processes for this molecule must involve substantial rearrangement, it is reasonable to suppose that they have comparable frequency factors, say within an order of magnitude of each other.[26] As the energy of the ionizing beam is lowered, the average energy of the molecular ions will be lowered and, according to simplified quasi-equilibrium theory (QET), reactions of lower activation energy will be significantly favored over reactions of higher activation energy, assuming comparable frequency factors.[26] The results for diphenyl ether thus suggest that the activation energy for substituent isomerization is somewhat *above* that for fragmentation, *i.e.*, above 3.74 eV. In the case of diphenyl sulfide, however, the extent of substituent isomerization *increases* as the ionizing beam energy is lowered from 70 to 20 eV, and the converse of the above argument leads to the conclusion that the activation energy for substituent isomerization is less than that for fragmentation, *i.e.*, less than 4.12 eV. If we assume a common mechanism for substituent isomerization in these two closely related systems, it is thus possible to infer that the activation energy for this reaction is in the range of 3.74–4.12 eV.

Since the lack of substituent isomerization in phenol cannot be explained by an activation energy effect alone, the difference between this compound and diphenyl ether must logically be due to significantly different frequency factors for substituent isomerization or for CO elimination or both of these. While it is difficult to make a choice between these alternatives in view of our present lack of detailed knowledge of the mechanisms of these reactions, it may be noted that the proposed mechanism for loss of CO from phenol[27] (Scheme III) involves only a presumably rapid hydrogen migration to reach a suitable precursor for elimination of CO. On the other hand, any mechanism proposed for the loss of CO from diphenyl ether, as for example that represented in Scheme IV,[27] must involve a ring closure reaction to reach a comparable structure suitable for elimination of CO. Such a ring closure reaction would be expected to occur with a lower frequency factor than a hydrogen migration. On the reasonable assumption that the actual expulsion of CO is rapid compared to the steps preceding it, the failure of phenol to undergo substituent isomerization may be attributed largely to its rapid fragmentation by this pathway, favoring fragmentation over a slower substituent isomerization process.

Scheme III



Scheme IV



The fact that *both* diphenyl sulfide and thiophenol undergo substituent isomerization is less easy to explain. It may be noted, however, that substituent isomerization in these molecules would involve the breaking of the weaker C–S bond rather than the stronger C–O bond. In addition, the lower electronegativity of sulfur as compared with oxygen would make structures of the ring-expanded type such as **5** more favorable than in the case of phenol, thus offering a possible rapid pathway for partial substituent randomization.

The occurrence of hydrogen randomization prior to the expulsion of CHO and CHS from diphenyl ether[23] and diphenyl sulfide[28] has already been noted. Since

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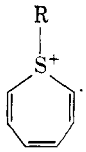
(26) R. G. Cooks, I. Howe, and D. H. Williams, *Org. Mass Spectrom.*, 2, 137 (1969).

(27) J. H. Beynon, G. R. Lester, and A. E. Williams, *J. Phys. Chem.*, 63, 1861 (1959).

(28) P. C. Wszolek, F. W. McLafferty, and J. H. Brewster, *Org. Mass Spectrom.*, 1, 127 (1968).



5, R = H or C_6H_5

this randomization is essentially complete, while substituent isomerization in these molecules is incomplete, it is clear that hydrogen scrambling occurs, at least to some extent, independently of substituent scrambling. This result agrees well with conclusions drawn from recent studies of skeletal and hydrogen rearrangements in benzene[10,11] and in thiophene.[6]

The loss of CH_3 from diphenyl sulfide is intriguing because the labeling evidence clearly shows that the C-1 carbon atoms are lost more frequently than the other ring carbons, a result which would probably not have been predicted *a priori*. While mechanistic schemes which rationalize this finding may be proposed, it is not thought that such would be profitable in the absence of more detailed information.

Experimental Section

Aniline-*1*-^{13}*C*. Aniline-*1*-^{13}*C* was initially prepared from barium carbonate-^{13}*C* by essentially the same method used for the preparation of aniline-*1*-^{14}*C*.[29,30] This route proceeds *via* the pathway sodium acetate, ethyl acetate, 1-methylcyclohexanol, 1-methylcyclohexene, toluene, benzoic acid, and aniline. The dehydrogenation of 1-methylcyclohexene to toluene was effected by passing 1-methylcyclohexene vapor over a commercial dehydrogenation catalyst[31] at 350°. This step was attended with considerable difficulties, and although yields of better than 90% were obtained using pure unlabeled 1-methylcyclohexene, the use of ^{13}C-labeled material gave yields for this step in the region of 40%. Similar difficulties with this step have been noted by others,[32] and alternate procedures have been used in other cases.[20]

Material obtained by this route was used in the preparation of diphenyl-*1*-^{13}*C* sulfide. Subsequently, benzoic acid-*1*-^{13}*C* became available commercially[33] and was used to prepare the aniline-*1*-^{13}*C* used in the preparation of diphenyl-*1*-^{13}*C* ether.

Phenol-*1*-^{13}*C*.[34] A 50-ml flask was charged with 260 μl of water followed by 35 μl of concentrated sulfuric acid. Aniline-*1*-^{13}*C* (30 mg) was added and solution was effected by warming gently. An additional 260 μl of water was added, the solution cooled in an ice bath, and an ice cold solution of sodium nitrite (27.1 mg) in water (300 μl) added in 50-μl portions. After stirring at 0° for 30 min, the solution of phenyldiazonium-*1*-^{13}*C* sulfate was added in 50-μl portions to a flask containing sulfuric acid at 285° over the surface of which steam was being passed. Vigorous reaction followed each addition, and the phenol formed passed into the distillate. After continued distillation for 30 min following the last addition of the diazonium solution, the distillate was collected and extracted with ether. The ether solution was dried and most of the ether removed by careful distillation to yield a residue containing approximately 10 mg (30%) of phenol-*1*-^{13}*C* (estimated by gas chromatography).

Diphenyl-*1*-^{13}*C* Ether (2). A solution of sodium phenoxide-*1*-^{13}*C* in dimethyl sulfoxide was prepared by the addition of sodium hydride (10 mg) followed by phenol-*1*-^{13}*C* (10 mg) in dry dimethyl sulfoxide (2 ml) to dry dimethyl sulfoxide (2 ml) in a 10-ml flask under a nitrogen atmosphere. The mixture was stirred at 72° for 30 min and then treated with diphenyliodonium bromide (136 mg)[35] and the mixture stirred for 30 min at 72°. The cooled reaction mixture was diluted with 50 ml of water and extracted with 4 × 40 ml portions of ether. The combined ether extracts were washed (5% NaOH, H_2O) and dried, and most of the ether was removed by careful distillation. Diphenyl-*1*-^{13}*C* ether was obtained from the distillation residue by preparative gas–liquid chromatography (glc) (6 ft × $^1/_4$ in. 10% Carbowax 20M on Chromosorb W, 80–100 mesh, 195°), and sealed in capillary tubes until required for analysis. The material collected had identical retention times on analytical columns (Carbowax 20M, UC-W98) to authentic diphenyl ether.

Diphenyl-*1*-^{13}*C* Sulfide (4). A solution of phenyldiazonium-*1*-^{13}*C* chloride was prepared by treating aniline-*1*-^{13}*C* (77 mg) in concentrated hydrochloric acid (170 μl) and water (420 μl) at −10° with a solution of sodium nitrite (113 mg) in water (210 μl). The cold aqueous diazonium salt solution was added in one portion to a cold aqueous solution of sodium thiophenolate prepared from thiophenol (113 mg) and sodium hydroxide (166 mg) in water (840 μl). The reaction mixture was stirred at −10° for 20 min, at room temperature for an hour, and at 55° for 20 min, and was then cooled and extracted with 4 × 20 ml portions of ether. The combined ether extracts were washed, dried, and distilled to leave a small residue consisting of ether and diphenyl sulfide. Samples of chromatographically pure diphenyl-*1*-^{13}*C* sulfide were obtained by preparative glc (12 ft × $^1/_2$ in. 10% UC-W98 on Chromosorb W, 60–80 mesh, 256°). The material collected showed identical retention times on analytical columns to authentic diphenyl sulfide.

Mass Spectra. Mass spectra were measured on an AEI MS-902 instrument at 70 and 20 eV, using an all-glass heated inlet system. Exact mass measurements were made at a resolution of 10,000 (10% valley definition) by the peak-matching technique, using heptacosafluorotri-*n*-butylamine as a reference compound. Measurement of the labeling enrichment was carried out by scans of the parent ion region for each compound at a low voltage (12–14 eV) which was shown not to yield any (M − 1) fragment ions. The average of six scans was taken in each case. The intensities of ions in the regions of interest were measured under low-resolution conditions at 70 and 20 eV; again the average of at least six slow scans was used to obtain the data presented in Tables I and II. Because of the limitations of sample size, the small percentage of the total ion current carried by the ions of interest, and the extremely severe decrease in sensitivity with increasing resolution, it was not possible to obtain meaningful data for these ions at a resolution of 40,000, sufficient to separate isobaric labeled and unlabeled ions. Metastable measurements of ions decomposing in the first field-free region were obtained by the HV–scan method.[36]

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(29) M. Fields, M. A. Leaffer, S. Rothchild, and J. Rohan, *J. Amer. Chem. Soc.*, 74, 5498 (1952).

(30) M. Fields, S. Rothchild, and M. A. Leaffer, *J. Amer. Chem. Soc.*, 74, 2435 (1952).

(31) Universal Oil Products palladium dehydrogenation catalyst.

(32) A. Rieker, K. Scheffer, and E. Mueller, *Justus Liebigs Ann. Chem.*, **670**, 23 (1963).

(33) Merck, Sharp and Dohme of Canada, Ltd., Montreal Canada; the material used contained 66.5 atom % ^{13}C.

(34) J. E. Johnston, Ed., *Radioisotope Conf. Proc. Int. Conf. 2nd.*, 2, 29 (1954).

(35) F. M. Beringer, M. Drexler, E. M. Grindler, and C. C. Lumpkin, *J. Amer. Chem. Soc.*, 75, 2508 (1953).

(36) K. R. Jennings, *J. Chem Phys.*, 43, 4176 (1965).