Action of Oxygen on Thiobenzophenone in the Dark

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Received November 14, 1975

Thiobenzophenone (1) reacts with oxygen in the dark forming benzophenone (2), thiobenzophenone *S*-oxide (3), sulfur, and sulfur dioxide. The reaction rate was observed to be highly solvent dependent although the product ratio of 3 to 2 was found to be nearly constant (ca. 0.8). Sulfur and sulfur dioxide were found in 47 and 2.9% yields, respectively. The reaction of 1 in the presence of oxygen with other thioketones to give the *S*-oxides corresponding to the latter provides support for an intermediate "$(C_6H_5)_2CSO_2$" (4). The possible mechanisms are discussed.

The stability of several thioketones toward oxygen with or without irradiation has been investigated by Schönberg and Mostafa.[1] Thiobenzophenone (1) differs from other thioketones in that it is autoxidizable in the dark as well in the solid state.[2] Products from 1 were found to be benzophenone (2), sulfur, and sulfur dioxide; yields and mechanistic information, however, were not reported.[1] The solid state reaction yielded in addition a cyclic trisulfide.[2]

In an attempt to study the mechanism of the oxidative conversion of thioketones to ketones, we report here a reinvestigation of the reaction between 1 and oxygen in the dark in different solvents.[3]

Passage of oxygen through a solution of 1 caused the intense blue color to fade in most of the cases studied (cf. Table I). The final reaction mixtures were observed to be slightly green.

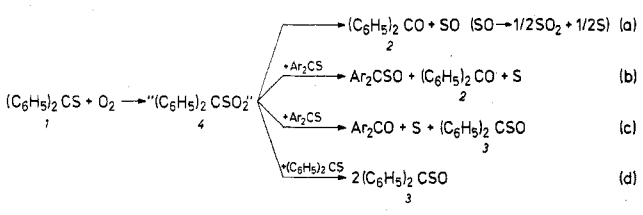
In none of the reactions investigated was there evidence for a cyclic trisulfide, which, if formed, is present to the extent of ≤4% (cf. Table I). However, besides 2 and elemental sulfur, sulfur dioxide was formed in low yields, while thiobenzophenone *S*-oxide (3)[4] was obtained in high yield. Although the

$$\underset{1}{(C_6H_5)_2CS} + O_2 \longrightarrow \underset{2}{(C_6H_5)_2CO} + \underset{3}{(C_6H_5)_2CSO} + S + SO_2$$

solubility of oxygen in the different solvents employed is nearly constant,[5] the reaction goes to completion rapidly in most solvents, but is surprisingly slow in acetonitrile and THF. The rather unusual solvent effect has not yet been rationalized. On the other hand, only a small variation in the ratio between the yields of 3 and 2 was observed (Table I). The yield of sulfur dioxide (average for several experiments) was determined to be ca. 3% in the reactions in methanol and benzene. Sulfur yields were determined to be 47%.

Passing oxygen through a solution of sulfine 3 under conditions where a similar solution of 1 had reacted completely caused no change in its concentration. This excludes a mechanism where primary formation of 3 is followed by reaction with oxygen leading to benzophenone. The reaction between thiobenzophenone (1) and oxygen consequently appears to involve an intermediate ["$(C_6H_5)_2CSO_2$" (4)], which in principle can decompose unimolecularly to give 2 and sulfur monoxide on one hand (Scheme I, path a) or 3 on the

Scheme I

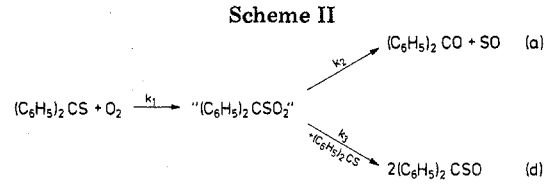


other. Alternatively 3 could be formed in a reaction between 1 and intermediate 4. The latter is supported by the oxidation of a mixture of 1 and a second aromatic thioketone. Thus oxygen purging of a solution of thioketone 1 containing ca. 10% 4,4′-dichlorothiobenzophenone (5) leads to total conversion of the latter to the corresponding 4,4′-dichlorothiobenzophenone *S*-oxide (6). Under these conditions a sample of pure 5 is unaffected by oxygen.[6]

For the reaction between intermediate 4 and thioketone, several pathways are possible. Intermediate 4 can oxidize the thioketone to the corresponding sulfine leading to 2 and sulfur (path b), or the thioketone may be directly oxidized to the corresponding ketone and sulfur to yield 3 (path c). The third possibility is the formation of 2 mol of 3 from the reaction between 1 and 4 (path d, Scheme I). In an attempt to distinguish between the above-mentioned sulfine-forming reaction pathways, the reaction was studied at different concentrations of 1 in benzene and methanol. The 3:2 ratios are given in Table II. The fact that this ratio was never found to be greater than about 0.9 may rule out path d, since 3:2 > 1.0 would be expected at higher concentrations, via selective conversion of the products to 3. Furthermore, the low yield of sulfur dioxide is in disagreement with path d.

A steady-state treatment of a reaction mechanism involving

Scheme II



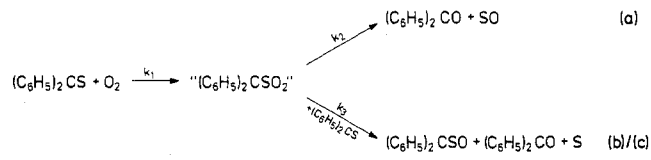
path a and path d (Scheme II) gives the following expression (eq 1).

$$\frac{[(C_6H_5)_2CSO]}{[(C_6H_5)_2CO]} = \frac{2k_3}{k_2}[(C_6H_5)_2CS] \qquad (1)$$

A plot of $[(C_6H_5)_2CSO]/[(C_6H_5)_2CO]$ vs. $[(C_6H_5)_2CS]$ does not give a straight line. Thus path d is effectively ruled out.

However, a mechanism based on simultaneous operation of path a and b or c cannot be distinguished in this way. A steady-state treatment of this mechanism (Scheme III) gives

Scheme III



rise to the following expression (eq 2), which can be transformed into eq 3.

$$\frac{[(C_6H_5)_2CSO]}{[(C_6H_5)_2CO]} = \frac{k_3[(C_6H_5)_2CS]}{k_2 + k_3[(C_6H_5)_2CS]} \qquad (2)$$

Table I. Yields of Thiobenzophenone *S*-Oxide and Benzophenone from the Reaction between Thiobenzophenone and Oxygen as a Function of Solvent

Solvent	% 1 recovered	% 3	% 2	3:2
MeOH	<1	46	52	0.88
2-PrOH	9	40	47	0.85
Benzene	9	38	51	0.75
Acetonitrile	95	~1	~2	
DMF	2	21	77	0.27
THF	>99		<1	

Table II. Ratio between the Yields of Thiobenzophenone *S*-Oxide and Benzophenone by Treatment of Different Concentrations of Thiobenzophenone with Oxygen

Solvent	Concn of 1	3:2
Benzene	0.025	0.61
	0.045	0.75
	0.140	0.80
MeOH	0.024	0.60
	0.034	0.70
	0.040	0.68
	0.123	0.86
	0.157	0.89
	0.179	0.90

$$\frac{k_3}{k_2}[(C_6H_5)_2CS] = \frac{[(C_6H_5)_2CSO]}{[(C_6H_5)_2CO]}\left(1 - \frac{[(C_6H_5)_2CSO]}{[(C_6H_5)_2CO]}\right)^{-1} \quad (3)$$

Figure 1 is a plot based on the data in Table II (methanol), which are well fitted by this expression with $k_3/k_2 = 48.3$. To distinguish between path b and c we attempted to oxidize other thioketones [**5**, 4,4′-dimethylthiobenzophenone (**7**), and 4,4′-dimethoxythiobenzophenone (**8**)], which are not affected by oxygen under the above mentioned conditions with intermediate **4**. Formation of the corresponding thioketone *S*-oxides would indicate path b, while ketone formation would favor path c. Oxygen was passed through solutions of **1** containing ca. 10% of **5**, **7**, or **8**, respectively.

As described above **5** was completely transformed to 4,4′-dichlorothiobenzophenone *S*-oxide (**6**). Compound **7** was partly converted to 4,4′-dimethylthiobenzophenone *S*-oxide (**9**), and in the last case only the products from the reaction between **1** and oxygen were found together with unreacted **8**. The formation of ketone from the substituted thiobenzophenones was not observed during the reactions.

Dondoni and co-workers in 1971 reported kinetics for the reaction between thiobenzophenones and peroxybenzoic acid which yield the corresponding *S*-oxides.[7] They found the Hammett constant for the reaction to be −0.88, indicating that electron-donating groups increase the reaction rate. It is interesting to note that the reverse trend is observed here. The latter could be a result of simple oxygen exchange[8] between initially formed **3** and the added thioketone to form the thermodynamically more stable sulfine (Cl > H ≳ CH_3 > CH_3O). Were this the case, it would not be necessary to postulate the existence of **4**. However, when a solution of **3** containing ca. 15% of the thioketone **5** was treated with oxygen gas as above, the blue color of the thioketones was observed to fade. An analysis of the final reaction mixture showed that 4,4′-dichlorobenzophenone (and not the sulfine **6**) was formed together with benzophenone **2**. This rules out the oxygen exchange mechanism. The data consequently support path b.

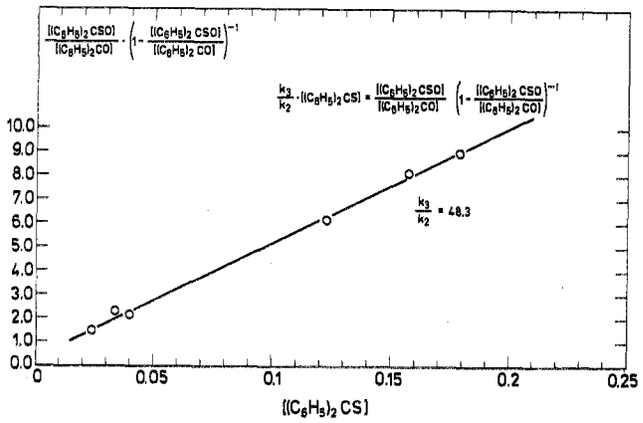
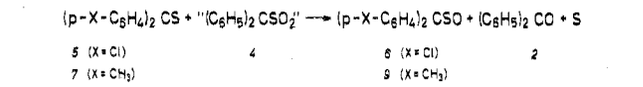
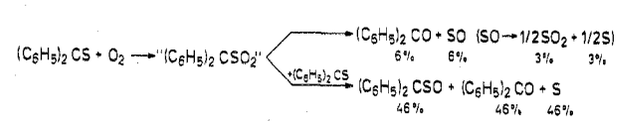


Figure 1. Reaction between thiobenzophenone and oxygen in the dark (0.05 M, methanol).



On this basis the total reaction scheme may now be rationalized (methanol, 0.05 M, cf. Table I) as follows.



Experimental Section

All reactions were carried out in the absence of light.

Reaction between Thiobenzophenone (1) and Oxygen in Different Solvents. Oxygen gas was passed through 0.05 M solutions of freshly prepared **1** for 1.5 h (rate 4.5–5 l./h). The reaction mixtures were submitted to GLC analysis [Pye Unicam 104 chromatograph, dual FID, connected to a Varian Aerograph 477 electronic integrator, on a 2 m × 0.25 in. column with 3% OV-1 (J.J.'s Chromatography Ltd.) on Gas Chrom Q 100/120 mesh (Applied Science Laboratories Inc.) with nitrogen as a carrier gas]. From the chromatograms the amounts of unreacted **1**, benzophenone (**2**), and thiobenzophenone *S*-oxide (**3**) were calculated by comparison with calibration curves. For yields, cf. Table I. By means of $I_2/S_2O_3^{2-}$ titration[9] the yields of sulfur dioxide (average for several experiments) were determined to be 2.9 and 2.5% for the reactions in methanol and benzene, respectively.

Sulfur was isolated by filtration of the final reaction mixtures, washed with ether, and dried in vacuo. Sulfur yields were determined to be 47%. The efficiency of the sulfur isolation was verified by control experiments to be ±3%.

Reaction between Intermediate 4 and Diaryl Thioketones. Oxygen was passed through 0.05 M solutions of **1** methanol containing ca. 10% of the substituted diaryl thioketone for 1.5 h (rate 4.5–5 l./h). The reaction mixtures were analyzed by means of TLC (petroleum ether–benzene, 1:4) and GLC (as described above).

Concentration Dependence in the Reaction between Thiobenzophenone and Oxygen. The solutions of **1** in methanol (or benzene) (concentrations, cf. Table II) were treated with oxygen gas (4.5–5 l./h) for 1 h. The reaction mixtures were analyzed by means of GLC as described above. For yields of **2** and **3**, cf. Table II.

Acknowledgments. The author is grateful to Drs. A. Holm, D. N. Harpp, and J. P. Snyder for valuable discussions and to the Danish Natural Science Research Council for financial support.

Registry No.—**1**, 1450-31-3; oxygen, 17778-80-2.

References and Notes

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(3) In a more recent investigation of thiobenzophenone [e.g., D. R. Kemp and P. de Mayo, *J. Chem. Soc., Chem. Commun.*, 233 (1972)] degassed samples have been used to prevent the dark reaction with oxygen. The photolysis

of thiobenzophenone in the presence of oxygen has been treated by G. Oster, L. Citarel, and M. Goodman, *J. Am. Chem. Soc.*, **84**, 703 (1962); no dark reaction was reported.
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Mass Spectra of Some Isomeric Monosubstituted Pyridines. Participation of the Ring Nitrogen in the Fragmentation of the 2 Isomers

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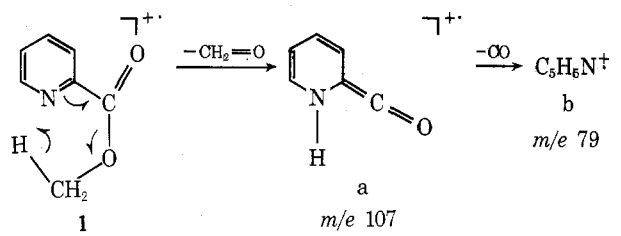
Received March 30, 1976

The mass spectra of several isomeric monosubstituted pyridines were investigated. The compounds studied include methyl and ethyl esters of isomeric pyridinecarboxylic acids, pyridinecarboxamides, pyridylacetic acids, and pyridylacrylic acids. The mass spectra of 2-substituted pyridine compounds reported in this study are different from those of their corresponding 3 or 4 isomers. The differences are attributable to the interaction of the side chain in the 2 isomers with the ring nitrogen. This interaction generally results in a hydrogen transfer to the ring nitrogen and elimination of a neutral molecule. The hydrogen transfer can be a six-membered as well as five- or seven-membered transition state.

It is often difficult to differentiate between isomers from their mass spectra. In a number of benzenoid aromatic isomers, however, the differentiation can be made as a result of ortho effects[1] or peri effects.[2] In the case of isomeric monosubstituted pyridine derivatives, distinction is sometimes possible due to the interaction of the 2-substituted side chain with the pyridine ring nitrogen.[3-5] In the present study the mass spectra of several sets of isomeric pyridine compounds were investigated to determine if the ring nitrogen is involved in the electron impact induced fragmentation. The participation of the ring nitrogen may be useful for identification purposes in differentiating the 2 isomer from the 3 and 4 isomers.

Methyl Esters of Pyridinecarboxylic Acids. The mass spectra of methyl picolinate (**1**), methyl nicotinate (**2**), and methyl isonicotinate (**3**) are shown in Figure 1. While mass spectra of **2** and **3** are very similar, large differences are observed between the mass spectrum of **1** and those of **2** and **3**. The 3- and 4-substituted pyridines exhibit strong molecular ion peaks and strong fragment ion peaks due to simple bond cleavage α to the carbonyl. In contrast, the mass spectrum of the 2 isomer shows that the molecular ion and an ion due to α-cleavage (*m/e* 106) are weak. Cooks and co-workers[3] also reported very low molecular ion abundances for the 2-substituted pyridines.

The formation of a relatively strong ion at *m/e* 107 in the spectrum of the 2 isomer is likely initiated by the interaction of the ring nitrogen with the substituent at the 2 position. The similar reaction product ion is absent or insignificant in the spectra of the 3 and 4 isomers. The relatively weak *m/e* 107 ion in the spectra of these two isomers is essentially attributed to the natural isotope abundance of the strong *m/e* 106 ion. The formation of the *m/e* 107 ion from the ionized 2 isomer **1** can be explained by a transfer of a methyl hydrogen to the ring nitrogen and elimination of formaldehyde to give an ion a in a McLafferty rearrangement. Similar elimination of formaldehyde has been shown in the spectrum of 2-methoxycarbonylimidazole.[6] Ion a further loses a CO to yield a very strong ion b (*m/e* 79) which is very weak in the spectra of the 3 and 4 isomers. The elemental compositions of ions a and b have been substantiated by high-resolution mass measurements. The fragmentations from *m/e* 137 to *m/e* 107 and *m/e* 107 to *m/e* 79 as well as other major fragmentation pathways shown in Figure 1 were confirmed by the presence of an appropriate metastable peak (denoted by an asterisk) determined by scanning in the metastable mode (see the Experimental Section).



Ethyl Esters of Pyridinecarboxylic Acids. The mass spectra of ethyl picolinate (**4**), ethyl nicotinate (**5**), and ethyl isonicotinate (**6**) are shown in Figure 2. As in their methyl ester homologues, the mass spectra of the 3- and 4-pyridine isomers are very similar, whereas striking differences are observed between the spectrum of the 2-pyridine compound and those of the 3 and 4 isomers. High-resolution mass measurements show that the strong *m/e* 123 peak in the spectra of the 3 and 4 isomers is due to the McLafferty rearrangement ion c by elimination of an ethylene molecule from the molecular ion **5**. Similar elimination of ethylene from the molecular ion is not in operation in the spectrum of the 2-pyridine compound. Instead, a McLafferty rearrangement involving a hydrogen