Molecular Rearrangements. XXIX.† Thermolysis of Aromatic Ketoximes

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Thermolysis of benzophenone *O*-benzoyloxime leads to the formation of NH_3, CO_2, benzene, biphenyl, benzophenone, benzanilide, benzonitrile, benzoic acid, 2-phenylbenzoxazole, salicylaldehyde and its *p*-isomer. Analogous results were also obtained on thermolysis of acetophenone *O*-benzoyloxime. Similarly, benzophenone and/or acetophenone *O*-benzyloximes give pyrolysis products of the same nature in addition to others corresponding to the benzyl moiety. Thermolysis of deoxybenzoin oxime gives NH_3, toluene, benzonitrile, bibenzyl, benzil, benzyl alcohol, and 2-phenylindole. Moreover, its *O*-benzoyl ether affords in addition to these products, benzoic acid and benzyl benzoate. The main feature of these pyrolyses is the homolysis of the N–O bond together with either *O*-benzyl or *O*-benzoyl bonds providing free radicals that undergo different reactions involving H-abstraction, dimerization, fragmentation, rearrangement and cyclization to form the identified products.

Benzophenone oxime was reported earlier not to undergo the well-known Beckmann rearrangement on heating between 100 and 150 °C although the oxime salt is characterized by this reaction irreversibly to give mainly benzanilide.[1] However, prolonged heating under these conditions leads to hydrolysis of benzanilide into aniline and benzoic acid. The photo-Beckmann rearrangement of benzaldehyde oximes to the corresponding amides was suggested at one time to proceed through the intermediate oxaziridines.[2] On the other hand, other workers found that *N,O*-diacylhydroxylamines on pyrolysis can act as free-radical initiators for polymerization.[3]

Recently, flash vacuum pyrolysis of acetophenone and/or benzophenone oximes[4] affords nitriles, benzoxazoles, arenes and biaryls which were presumably formed from both iminyl and iminoxyl radicals. Moreover, isomerization of benzophenone oxime into benzanilide was also observed to take place in the ion source of mass spectrophotometer and the process was attributed to a Beckmann-type rearrangement of the corresponding molecular ion via a thermal mechanism.[5] Such results prompted us to reinvestigate the thermal Beckmann rearrangement in order to add more clear mechanistic information. The present work deals with the thermolysis of *O*-benzoyl- and/or *O*-benzyl oximes of acetophenone and benzophenone.

Pyrolysis of benzophenone *O*-benzoyloxime by reflux in air for 30 min leads to the formation of ammonia, carbon dioxide, benzene, biphenyl, benzophenone, benzanilide, benzonitrile, and benzoic acid.

When thermolysis was affected by heating in a sealed tube under nitrogen atmosphere, at 200 °C for 8 h, the previous products were obtained in addition to 2-phenylbenzoxazole, salicylaldehyde and its *p*-isomer; whereas the yield of benzoic acid was greatly suppressed.

Thermolysis of acetophenone *O*-benzoyloxime gives ammonia, carbon dioxide, biphenyl, acetophenone, acetanilide, acetonitrile, 2-methylbenzoxazole, and benzoic acid.

The formation of these products can be assumed to follow the series of reactions shown in Scheme 1, which implies the preliminary homolysis of benzoyl–O bond (route a) forming iminoxyl and benzoyl radicals. The iminoxyl radicals may undergo the Beckmann rearrangement into the corresponding *N*-acylanilide which is rationalized to proceed through a mechanism involving an oxaziridine intermediate **1** and a biradical intermediate **2**.[6]

The formation of acetanilide, in case of acetophenone oximes under the present conditions, rather than its isomer *N*-methylbenzamide provides strong evidence for the selective migration of the phenyl as compared with the methyl group. This result is in agreement with the observed migratory aptitude values of such groups and can be explained in terms of the stability of the bridged intermediate radical **3** as compared with the corresponding intermediate of methyl migration.[7] In other cases alkyl migration has been recorded.[8] The iminoxyl radicals may abstract hydrogen forming the corresponding unsubstituted oxime, which subsequently undergoes homolysis of the N–O bond to form iminyl and hydroxyl free radicals. The iminoxyl radicals can undergo cyclization into benzoxazole derivative.[4]

The iminyl radicals may abstract hydrogen forming the corresponding imine which is considered to be the precursor of ammonia and the corresponding ketone during working-up processes.

The formation of salicylaldehyde and its *p*-isomer may be due to coupling of hydroxyl radicals in the *o*- and/or *p*-positions of the tautomeric benzoyl radicals.

Such a mechanism was further emphasized by the results obtained from the thermolysis of unsubstituted benzophenone oxime where ammonia, benzophen-

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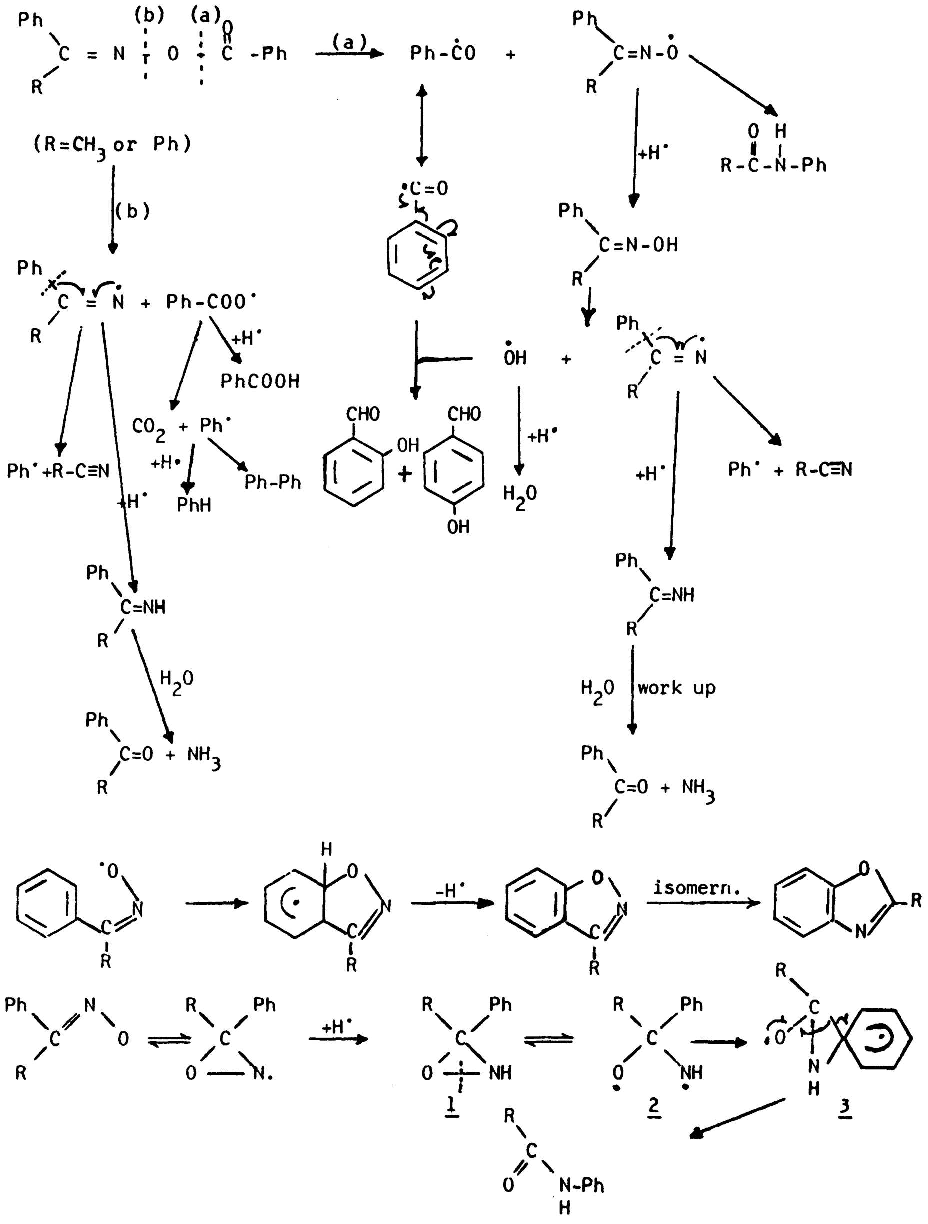
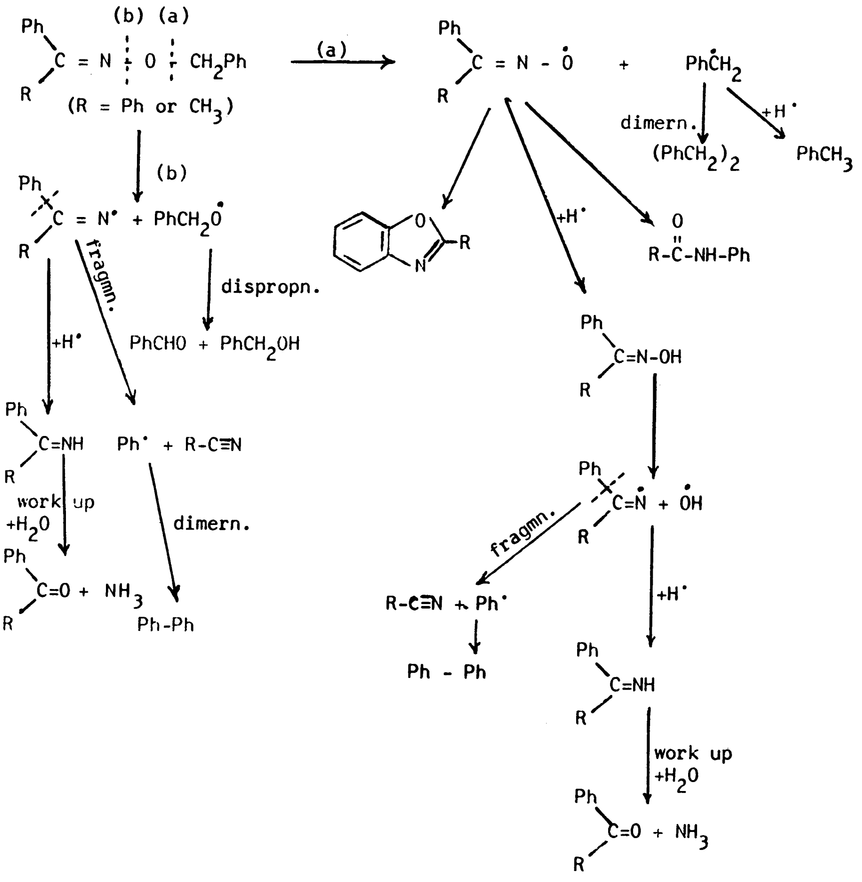


Scheme 1.

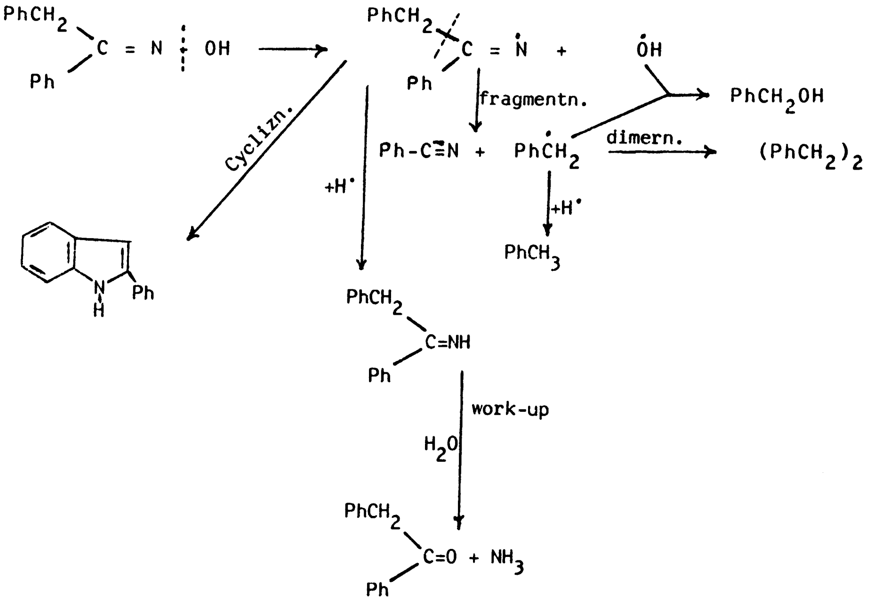
one, benzanilide and 2-phenylbenzoxazole were obtained, but no salicylaldehydes were detected among the products. However, such a mechanism cannot correlate for the formation of other products, namely; benzoic acid, biphenyl and carbon dioxide. Consequently, we have to take into consideration an alternative mode for homolysis of the benzophenone *O*-benzoyloxime molecules involving the N–O bond (route b) forming iminyl and benzoyloxyl radicals.

The normal fate of the iminyl radicals has been discussed previously, whereas the benzoyloxyl radicals may undergo decarboxylation into phenyl radicals which are the precursor of benzene and biphenyl through processes of H-abstraction or dimerization respectively. Furthermore, the benzoyloxyl radicals undergo predominantly H-abstraction forming benzoic acid. Although benzoic acid can be suggested to be formed from benzonitrile through hydrolysis, yet attempted hydrolysis of benzonitrile under comparable conditions does not afford benzoic acid.

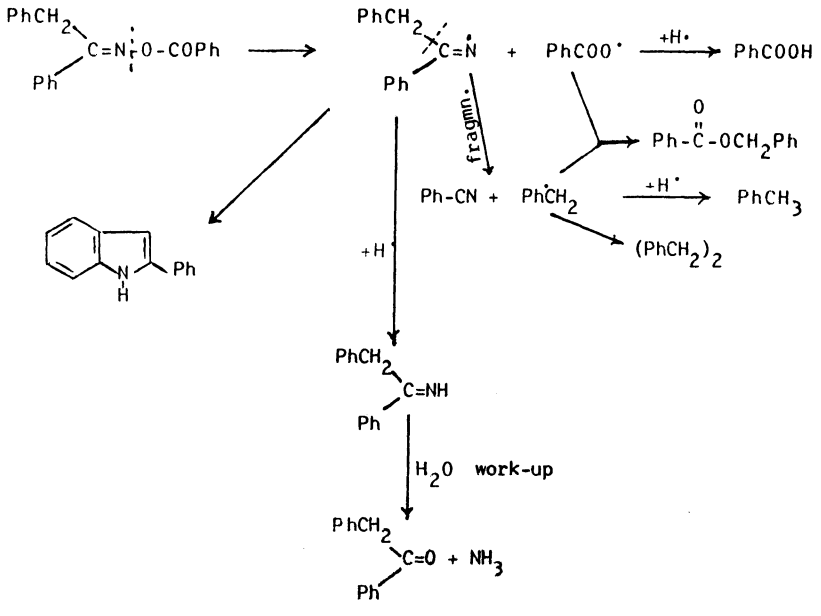
Thermolysis of benzophenone *O*-benzyloxime on heating in a sealed tube at 200 °C for 8 h. in absence of air gives, ammonia, toluene, benzaldehyde, benzyl alcohol, bibenzyl, biphenyl, benzophenone, and 2-phenylbenzoxazole. The formation of such products can be explained on basis of homolysis of benzyl–O bond (Scheme 2, route a) into iminoxyl and benzyl free radicals to a lesser extent than (route b) as shown by the relative amounts of products formed from both routes (cf. Table 1). Such bond homolysis although unfavorable as compared with the N–O bond as shown from bond energy values which are of the order of 68 and 48 kcal·mol^{-1}, yet the resonance stabilization of the benzyl radical so formed gives a driving



Scheme 2.



Scheme 3.



Scheme 4.

force for such process.

The normal fate of the iminoxyl radicals has been discussed previously, whereas the benzyl radicals are the precursor of toluene and bibenzyl through processes of H-abstraction and dimerization respectively. The formation of benzaldehyde and benzyl alcohol can be assumed to proceed through disproportionation of benzyloxyl radicals originating from the suspected homolysis of N-O bond (Scheme 2, route b).

Analoguous results were also obtained in case of acetophenone *O*-benzyloxime. Thermolysis of deoxybenzoin oxime under the same conditions leads to the formation of ammonia, toluene, benzonitrile, bibenzyl, benzil, benzyl alcohol, and 2-phenylindole. Similar results were also obtained in case of deoxybenzoin *O*-benzoyloxime where the previous products were also formed in addition to benzoic acid and benzyl benzoate. The formation of these products can be explained on similar grounds as shown in Schemes 3 and 4.

The main feature of deoxybenzoin oximes pyrolyses is the absence of the Beckmann rearrangement products, namely; α-phenylacetanilide ($PhCH_2\text{-}\overset{\overset{O}{\|}}{C}\text{-}NHPh$) or *N*-benzylbenzamide ($Ph\text{-}\overset{\overset{O}{\|}}{C}\text{-}\overset{\overset{H}{|}}{N}\text{-}CH_2Ph$), may be attributed to their thermal instabilities or more likely to the absence of the corresponding iminoxyl radical and consequently absence of its cyclization product, 2-benzylbenzoxazole, which implies that homolysis of deoxybenzoin oximes takes place in the N-O rather than the *O*-benzoyl bond.

Experimental

Melting points were measured with a Gallenkamp apparatus and are uncorrected. Thin-layer chromatography was carried out on glass plates covered with silica gel (25—40 mesh) and eluted with benzene-cyclohexane (2:1 v/v). Gas-liquid chromatography was carried out on a Perkin-Elmer Sigma 3B. Columns used are 4 ft.×4 mm. packed with 30% SE 30 on Chromosorb W (35—80 mesh), or 10% SE 30 on Celite (60—80 mesh), using nitrogen as a carrier gas. Molecular weight determination of some reaction products was carried out by Mass spectrophotometer, Model A. E. I. M. S. 902. Oximes were prepared by standard methods in the literature.[9] Acetophenone *O*-benzoyloxime, mp 98—100 °C. Benzophenone *O*-benzoyloxime, mp 101 °C. Acetophenone *O*-benzyloxime, bp 230 °C/20 mmHg (1 mmHg=133.322 Pa); mp 24 °C. Benzophenone *O*-benzyloxime, mp 55—56 °C. Deoxybenzoin oxime, mp 98 °C. Deoxybenzoin *O*-benzoyloxime, mp 75 °C.

Thermolysis of Oximes: The oxime (20 g) was heated either under reflux in air or in a sealed tube under nitrogen atmosphere at 250 °C for 24 h. The gases evolved were detected by standard chemical means (NH_3 detected by Nessler's reagent and CO_2 by baryta solution). The pyrolysate was first distilled under normal pressure up to 120 °C where the voltatile materials such as benzene, toluene are collected and identified. The remaining oil was separated into its constitutents by means of column chromatography over silica gel using gradient elution technique. The separated products were identified by physical constants; bps, mps, TLC, GLC, IR as compared with authentic samples.

The results are shown in Tables 1 and 2.

Preparation of Reference Compounds: α-Phenylacetanilide:[10] crystals from dilute ethanol, mp 117 °C. *N*-Benzylbenzamide:[11] needles from ethanol mp 105—106 °C. *N*-Methylbenzamide:[11] crystals from ethanol mp 82 °C. 2-Phenylindole:[12] crystals from ethanol mp 188—189 °C. 2-Methylbenzoxazole:[13] colorless oil, bp 200—201 °C. 2-Phenylbenzoxazole:[13] crystals from ethanol mp 101—102 °C.

Table 1. Pyrolysis Products of Substituted Ketoximes in g(%)

Product	Expt. No. 1	2	3	4	5
NH_3	Evolved	Evolved	Evolved	Evolved	Evolved
CO_2	Evolved	Evolved	Evolved	Evolved	Evolved
Benzene[a]	Trace	Trace	Trace	Trace	Trace
Toluene[b]	—	—	—	1.8(9)	2.5(12.5)
Biphenyl[c]	0.8(4%)	0.7(3.5)	0.7(3.5)	2.4(12)	2.6(13)
Bibenzyl[d]	—	—	—	2.3(11.5)	2.8(14)
Ketones[e]	2.3(11.5)	4.3(21.5)	3.8(19)	2.2(11)	1.8(9)
Aldehydes[f]	—	3.4(17)	3.5(17.5)	1.8(9)	2.1(10.5)
Anilides[g]	4.5(22.5)	3.2(16)	3.1(15.3)	3.1(15.5)	2.3(11.5)
Benzoic acid[h]	2.7(13.5)	1.6(8)	1.8(9)	—	—
Benzoxazoles[i]	—	3.1(15.5)	2.8(14)	1.8(9)	1.5(7.5)
Nitriles[j]	0.5(2.5)	0.7(3.5)	0.7(3.5)	0.8(4)	0.75(3.75)
Other products	k) 1.5(7.5)	—	—	l) 1.3(6.5)	l) 1.7(8.5)
Residue	2.5(15.5)	1.0(5)	1.2(6)	1.2(6)	1.3(6.5)

Expt. (1) Reflux of benzophenone *O*-benzoyloxime in air, (2) heating the same oxime in a sealed tube, (3) acetophenone *O*-benzoyloxime in a sealed tube, (4) benzophenone *O*-benzyloxime in a sealed tube, and (5) acetophenone *O*-benzyloxime in a sealed tube. a) n_n^{20} 1.500; *m*-dinitro deriv. 90 °C, trace amounts less than 1% yield. b) n_D^{20} 1.4970; 2,4-dinitro derivative mp and mixed mp 72—73 °C. c) Mp 70 °C, 4,4′-dinitro derivative mp and mixed mp 234 °C. d) Mp 52 °C, 4,4′-dinitro derivative mp and mixed mp 180 °C. e) Benzophenone in expts. 1, 2, and 4 mp 49 °C, D.N.P. derivative mp 238 °C, and acetophenone in expts. 2 and 5, D.N.P. derivative mp 250 °C. f) Salicyldehydes in expts. 2 and 3 identified by TLC; *o*/*p* ratio as estimated by GLC was 4:1 respectively; and benzaldehyde in expts. 4 and 5, D.N.P. derivative mp and mixed mp 237°C. g) Benzanilide in expts. 1, 2, and 4, mp and mixed mp 163°C and acetanilide in expts. 3 and 5, mp and mixed mp 114°C; IR coincident with that of authentic samples. h) Mp and mixed mp 121 °C. i) 2-Phenylbenzoxazole in expts. 2 and 4 identified by mixed mp 101 °C, *m*/*z* 194 and IR spectrum as compared with an authentic sample, and 2-methylbenzoxazole n_D^{20} 1.550; *m*/*z* 133 in expts. 3 and 5, identified by IR spectroscopy as compared with an authentic sample. j) Benzonitrile from expts. 1, 2, and 4, n_D^{20} 1.5270 and acetonitrile from expts. 3 and 5, n_D^{20} 1.3442, on acid hydrolysis give benzoic and acetic acid respectively. k) Recovered oxime. l) Benzyl alcohol n_D^{20} 1.540; IR spectrum coincident with that of an authentic sample; phenylurethane derivative mp and mixed mp 76°C.

Table 2. Pyrolysis Products of Deoxybenzoin Oximes in g(%)

Product	Deoxybenzoin oxime	Deoxybenzoin *O*-benzoyloxime
NH_3	Evolved	Evolved
Toluene	1.7(8.5)	1.5(7.5)
Bibenzyl	3.2(16)	2.5(12.5)
Benzil	2.1(10.5)	2.3(11.5)
Benzonitrile	2.0(10)	2.2(11)
Benzyl alcohol	2.2(11)	trace
2-Phenylindole[a]	3.6(18)	3.2(16)
Deoxybenzoin[b]	3.5(17.5)	2.8(14)
Benzoic acid	—	1.5(7.5)
Benzyl benzoate[c]	—	0.7(3.5)
Residue	1.5(7.5)	2.3(11.5)

a) Mp and mixed mp 188 °C and IR coincident with that of an authentic sample. b) Mp and mixed mp 60 °C. c) n_D^{20} 1.5681; IR coincident with that of an authentic sample.

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