hydrochloride, 29%. A sample for analysis was prepared by recrystallization from ethanol.

Anal. Calcd. for $C_{15}H_{16}ClNO$: C, 68.83; H, 6.16. Found: C, 68.95; H, 5.96.

In another experiment, the amino ketone was precipitated from the reaction mixture as a dark red oil by the addition of *p*-toluenesulfonic acid; it became pale yellow on standing in the mother liquor overnight, but did not crystallize. The oil was dissolved in water, washed with ether, and crystallized by evaporation to dryness repeatedly with absolute ethanol, followed by chilling to −17° of its solution in 3 ml. of absolute ethanol. There was obtained 0.44 g. (11%) of the toluenesulfonate, m.p. 182–190° dec. (reported 198°). Half of this was alkalized with ammonia, and the oil which separated was taken up in ether, with ample exposure to air. Crystallization could not be effected from ether or glacial acetic acid, but eventually the use of ethanol gave 0.08 g. of 2,5-dibenzyl-3,6-dimethylpyrazine, m.p. 135–151°; recrystallization from ethanol raised this to 149–151° (reported, 152°).

D. Pinacolone. Similar experiments with pinacolone trimethylhydrazonium iodide gave no detectable odor of trimethylamine, and no hydrochloride was obtained by the methods used with the foregoing compounds. In one such experiment the reaction mixture was concentrated by distillation and heated at 165–175° for 1 hr., but still no aminopinacolone could be found.

E. Benzophenone. A solution of 3.66 g. (0.01 mole) of benzophenone dimethylhydrazone methiodide and 0.734 g. (0.0105 mole) of sodium ethoxide in 40 ml. of magnesium-dried ethanol was refluxed for 3.5 hr. No trimethylamine could be detected at the top of the condenser. Most of the alcohol was then distilled and the residual mixture of yellow solid and red oil was held at 130° for 15 min. The resulting material was completely soluble in absolute ethanol, but water dissolved the solid and left a yellow oil. Treatment of the oil with hydroxylamine in alcoholic sodium hydroxide gave 1.22 g. (63%) of benzophenone oxime, m.p. 141.5–144° after recrystallization from methanol. No other organic product could be isolated, and it was concluded that rearrangement did not take place.

F. p,p'-Dimethoxybenzophenone. Under conditions similar to the foregoing, with refluxing for 14.5 hr., unchanged p,p'-dimethoxybenzophenone dimethylhydrazone methiodide was recovered in 85% yield.

Absorption spectra. Infrared absorption spectra were determined in carbon tetrachloride solution for the ketones and dimethylhydrazones, on a Baird Associates single-beam instrument with sodium chloride prism. The spectra of the quaternary hydrazones were determined in Nujol mulls, on a Perkin-Elmer single-beam instrument.

The ultraviolet spectra were determined over the range 220–370 mμ in approximately $10^{-4}M$ solution in ethanol with a Beckman model DU instrument.

ANN ARBOR, MICH.

[CONTRIBUTION FROM THE CHEMICAL LABORATORY, UNIVERSITY OF CALIFORNIA]

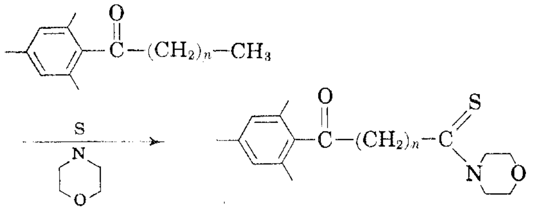
Mechanism of the Willgerodt Reaction. Studies with 1-Tetralones[1]

WILLIAM G. DAUBEN, RICHARD P. CIULA, AND JOHN B. ROGAN[2]

Received October 23, 1956

The reaction of 6-methoxy-1-tetralone with sulfur and morpholine yielded 6-methoxy-2-morpholinonaphthalene, showing attack occurred on the carbon atom adjacent to the carbonyl group. The role of a 2-morpholino-1-tetralone and a 1,2-dihydronaphthalene in this reaction was studied and it was shown that neither compound was an intermediate. The mechanism of the Willgerodt reaction is discussed.

The Willgerodt reaction with acylmesitylenes recently was investigated in this laboratory[1] and it was found that although the terminal methyl group was oxidized to a thioamide, the original carbonyl group of the acylmesitylene was retained. Such results clearly showed that contrary to previously postulated mechanisms,[3,4] neither addition to the carbonyl group nor reduction of the carbonyl group was an essential step in the Willgerodt reaction. Accordingly, the following modification of the mechanistic scheme of King and McMillan[3] was proposed: first, dehydrogenation to an α,β-unsaturated ketone; second, migration of the unsaturated linkage down the chain; third, an irreversible oxidation of the terminal carbon atom; and fourth, reduction of the carbonyl anytime after initial attack on the α-carbon atom. The first step possibly could involve attack on an α-carbon by sulfur followed by loss of hydrogen sulfide or displacement of the α-sulfur moiety by an amine to form an α-aminoketone which, in turn, could lose a molecule of amine to yield the α,β-unsaturated intermediate. The second step, *i.e.* migration of the unsaturated linkage, could proceed as suggested by King and McMillan[3] by reversible additions and eliminations of an amine or hydrogen sulfide to the olefinic linkage.



In order to gain evidence for some of these postulated intermediates it is necessary to study a system in which the final irreversible oxidation stage is prohibited. One such study has been reported by

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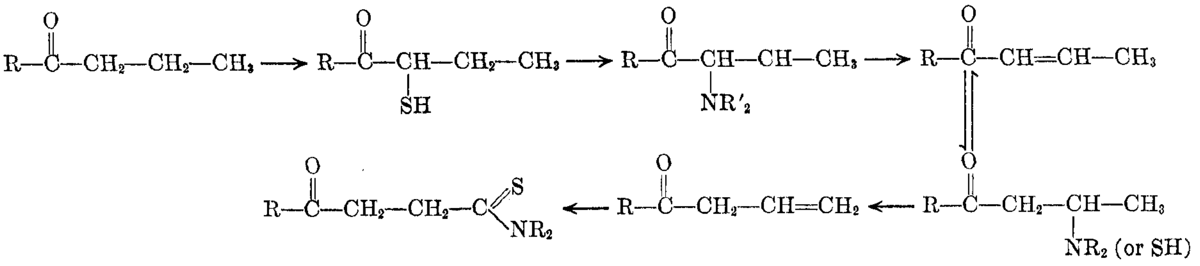
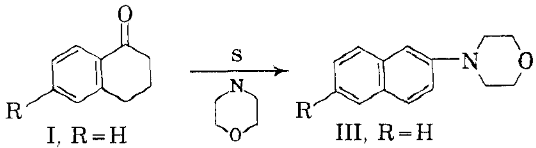
[1] For the previous paper in this series, see W. G. Dauben and J. B. Rogan, *J. Am. Chem. Soc.*, **78**, 4135 (1956).

[2] Recipient of the U. S. Rubber Co. Fellowship in Chemistry, 1954–55.

[3] J. A. King and F. H. McMillan, *J. Am. Chem. Soc.*, **68**, 632 (1946).

[4] M. Carmack and D. F. DeTar, *J. Am. Chem. Soc.*, **68**, 2029 (1946).

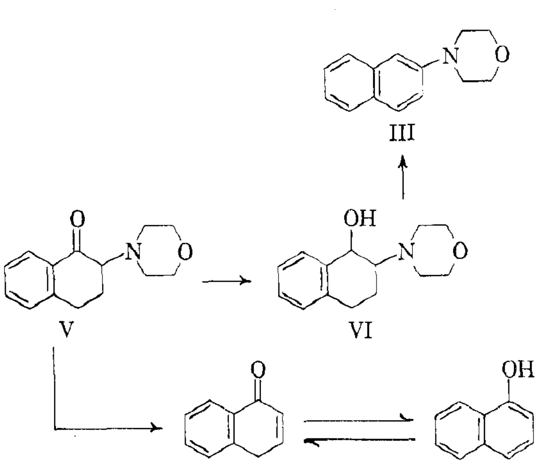




I, R=H
II, R=OCH3
III, R=H
IV, R=OCH3

Horton and Van Den Berghe[5] who investigated the reaction of 1-tetralone (I) with morpholine and sulfur under Willgerodt conditions and found that the only pure product isolatable was 2-morpholinonaphthalene (III). This latter material could have been formed by reduction and aromatization of the postulated α-aminoketone intermediate or, less likely in this aromatic series, attack of the amine at the β-position of the postulated α,β-unsaturated ketone or other similar intermediates. Due to the symmetry of 2-morpholinonaphthalene, it was not possible to ascertain whether attack by amine had occurred at a position α or β to the original carbonyl group. In order to establish this point, 6-methoxy-1-tetralone (II) was allowed to react with sulfur and morpholine under Willgerodt conditions. The crystalline product was shown to be 2-morpholino-6-methoxynaphthalene (IV) by comparison with an authentic sample which was prepared by allowing 2-hydroxy-6-methoxynaphthalene to react with morpholine under Bucherer conditions. For further comparison, the isomeric 2-morpholino-7-methoxynaphthalene also was prepared by the Bucherer reaction. The 2,6 and 2,7 isomers possess the same melting point but a mixture of the two compounds does show a depression in melting point.

The isolation of 2-morpholino-6-methoxynaphthalene (IV) from 6-methoxy-1-tetralone clearly establishes the fact that the amino group is substituted on the carbon atom which is adjacent to the original carbonyl linkage. This result is in line with the concept presented earlier in which the initial attack by reagents in the Willgerodt reaction occurs at a position α to the carbonyl grouping. In order to determine whether an α-aminoketone was an actual intermediate in the reaction, 2-morpholino-1-tetralone (V) was synthesized by allowing morpholine to react with 2-bromo-1-tetralone. When V was subjected to the Willgerodt reaction with morpholine and sulfur, none of the expected 2-morpholinonaphthalene (III) could be detected. The major product of the reaction was 1-naphthol (VIII) and it was obtained in 77% yield. This latter compound could arise by elimination of the amine to form the α,β-unsaturated ketone VII which then is stabilized by aromatization to VIII. The competition between such an elimination reaction and formation of the desired product (III) might be due to the fact that the requisite conditions for reduction of the carbonyl group were not present in the reaction. For example, in the reaction involving the aminoketone, the hypothetical step of attack by sulfur on the unsubstituted ketone had been bypassed. In order to guarantee that all species common to the Willgerodt reaction were present in the aminoketone reaction, the experiment was conducted in the presence of acetophenone. Under such conditions, 2-morpholinonaphthalene was isolated in 0.4% yield. The low yield in this case and the absence of desired product in the previous case indicate that the aminoketone is not one of the intermediates in the Willgerodt reaction with 1-tetralone.


III
V
VI
VII
VIII

In view of the incompatability of the α-aminoketone scheme in the tetralone reaction, attention next was directed toward a postulate which utilizes the original mechanistic pathway suggested by King and McMillan[3] for the Willgerodt reaction, itself. Such a postulate is outlined below and involves

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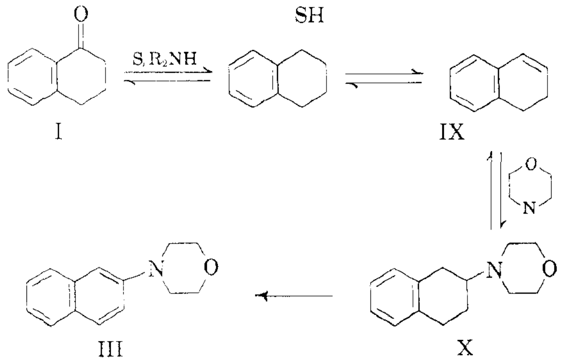
[5] W. J. Horton and J. Van Den Berghe, *J. Am. Chem. Soc.*, 70, 2425 (1948).

the formation of an olefin (IX) which, in turn, reacts with morpholine to form 2-morpholinotetralin



(X) and this latter compound undergoes dehydrogenation to 2-morpholinonaphthalene (III). The postulated intermediate, 1,2-dihydronaphthalene (IX), was prepared by sodium-liquid ammonia reduction of naphthalene to 1,4-dihydronaphthalene which was isomerized to the Δ^1-isomer by treatment with sodium amide in liquid ammonia.[6] It was found that this isomerization was temperature dependent and did not occur if the temperature was below $-70°$.

The 1,2-dihydronaphthalene (IX) was subjected to the conditions of the Willgerodt reaction and 2-morpholinonaphthalene was obtained in only 0.8% yield, the remainder of the product being naphthalene. In order to rule out any role of 1,4-dihydronaphthalene, this isomer also was allowed to react with morpholine and sulfur. The major product again was naphthalene but 2-morpholinonaphthalene was obtained in about 0.2% yield. Thus, it is apparent that the ease of dehydrogenation of these isomeric dihydronaphthalenes to naphthalene precluded the possibility of their playing a major role in the conversion of 1-tetralone to 2-morpholinonaphthalene. It is of interest to add that at room temperature or at reflux temperature, morpholine failed to react with 1,2-dihydronaphthalene.

The above results suggest that neither a simple aminoketone nor an olefin is an intermediate in the Willgerodt reaction of 1-tetralone. At the present time, it would appear that the mechanism of the Willgerodt reaction is more complex than previously assumed. It is clear, nevertheless, that attack by an amine at the position adjacent to the carbonyl group is possible under Willgerodt conditions and that when the ketone is not hindered, some transformation of the carbonyl grouping occurs prior to the placement of the amino group on the compound. It should be stressed, however, that the isolation of a morpholinonaphthalene does not in itself require attack by an amine on the position adjacent to the carbonyl group in the normal Willgerodt reaction which gives rise to amides. Since previous work[1] on hindered ketones has shown that reaction at the carbonyl group is not a requisite of the Willgerodt reaction, it is not clear whether reaction of hindered ketones follows a different mechanistic pathway than unhindered ketones or whether a similar pathway is followed by all ketones and that attack by some moiety occurs initially on the carbon atom adjacent to the carbonyl group and reaction of the carbonyl group itself plays no formal role in the formation of an amide.

EXPERIMENTAL[7]

Willgerodt reaction with 6-methoxy-1-tetralone. A mixture of 2.00 g. (11.3 mmoles) of 6-methoxy-1-tetralone, 1.00 g. (11.5 mmoles) of morpholine, and 0.37 g. (11.5 mmoles) of sulfur was heated at 130–140° for 8 hr. The dark reaction mixture was diluted with water and ether, the ethereal layer separated and washed with water and then extracted with 1*N* hydrochloric acid. Addition of sodium hydroxide to the acidic extract gave the product as a dark green solid, yield 0.83 g. (30%). Two recrystallizations from benzene-hexane (second time using Norit) gave 358 mg. of colorless plates, m.p. 158.0–158.5°. At 155°, the material appeared to melt and then resolidify, suggesting the presence of dimorphic forms.

Anal. Calcd. for $C_{15}H_{17}O_2N$: C, 74.04; H, 7.04; N, 5.76. Found: C, 73.93; H, 7.13; N, 5.89.

2-Morpholino-6-methoxynaphthalene. A mixture of 0.8 g. (4.6 mmoles) of 2-hydroxy-6-methoxynaphthalene, prepared according to Fischer and Hammerschmidt[8] from 2,6-dihydroxynaphthalene, 0.84 g. (9.8 mmoles) of morpholine, 0.53 g. (5 mmoles) of sodium bisulfite and 1 ml. of water was sealed in a glass tube and heated at 190–200° for 24 hr. After cooling, the tube was opened and the contents were extracted 3 times with a solution of 1 ml. of ethanol and 9 ml. of 6*N* hydrochloric acid. The extract was filtered and the filtrate on being made alkaline with 6*N* sodium hydroxide yielded a brown solid. The crude material was redissolved in acid, decolorized, and then regenerated to give 0.65 g. (52%) of light brown crystals. The product was recrystallized five times from benzene-hexane to yield white plates with a violet fluorescence, m.p. 155–156.5°.

Anal. Calcd. for $C_{15}H_{17}O_2N$: C, 74.04; H, 7.04; N, 5.76. Found: C, 74.15; H, 6.98; N, 5.89.

A mixed m.p. with the Willgerodt product above was 155.5–157.5°. The infrared spectra of the two materials when taken in CCl_4 were superimposable.

2-Morpholino-7-methoxynaphthalene. When 0.80 g. of 2-hydroxy-7-methoxynaphthalene, prepared according to Fischer and Hammerschmidt[8] from 2,7-dihydroxynaphthalene, was treated with morpholine and sodium bisulfite and processed as above, there was obtained 0.447 g. (40%) of a light brown solid. The product was recrystallized three times from benzene-hexane to give white plates, m.p. 157–159°, admixed with Willgerodt product, m.p. 127–140°. The infrared spectrum of the material differed markedly from that of the Willgerodt product.

Anal. Calcd. for $C_{15}H_{17}O_2N$: C, 74.04; H, 7.04; N, 5.76. Found: C, 73.99; H, 7.09; N, 5.56.

2-Morpholino-1-tetralone. A mixture of 9.00 g. (0.04 mole) of 2-bromo-1-tetralone[9] and 6.96 g. (0.08 mole) of morpho-

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(6) W. Hückel and H. Butschneider, *Ann.*, **540**, 157 (1939).

(7) All analyses were performed by the Microanalytical Laboratory of the Department of Chemistry and Chemical Engineering, University of California, Berkeley. All melting points are corrected.

(8) O. Fischer and F. Hammerschmidt, *J. prakt. Chem.*, **94**, 24 (1916).

(9) A. L. Wilds and J. A. Johnson, *J. Am. Chem. Soc.*, **68**, 86 (1946).

line was dissolved in 150 ml. of benzene. The solution was refluxed for 5 hr. during which time an insoluble precipitate of morpholine hydrobromide separated. The reaction mixture was cooled and the mixture filtered. There was obtained 4.8 g. (73%) of morpholine hydrobromide. The filtrate was extracted four times with 50 ml. portions of 6*N* hydrochloric acid and upon basification of the acidic extract with 6*N* sodium hydroxide a red-brown emulsion was obtained. The mixture was extracted with ether, the ethereal layer washed with water and then dried. The solvent was removed under reduced pressure and 4.60 g. (50%) of crude product was obtained in the form of a brown oil. A 2.30 g. portion of the oil was distilled through a short path molecular still, block temperature 127–129°, pressure 1.0 mm., yield 1.2 g.

Anal. Calcd. for $C_{14}H_{17}NO_2$: C, 72.71; H, 7.41; N, 6.06. Found: C, 71.74; H, 7.20; N, 6.18.

Willgerodt reaction with 2-morpholino-1-tetralone. A mixture of 0.60 g. (2.6 mmoles) of redistilled 2-morpholino-1-tetralone, 0.25 ml. (2.8 mmoles) of morpholine and 0.06 g. (2.8 mmoles) of sulfur was refluxed for 8 hr. After 30 min., the odor of hydrogen sulfide was detectable and at the end of the reaction, the mixture was dark brown. The cooled mixture was washed four times with dilute hydrochloric acid to leave a tan solid residue. The acidic solution was made alkaline with ammonium hydroxide and 0.06 g. of a yellow oil was obtained. The infrared spectrum of the material was different from that of morpholine or 2-morpholinonaphthalene. The product was not further identified.

The tan solid residue, remaining after the acid washing, was dissolved in 6*N* sodium hydroxide and the alkaline solution filtered and the filtrate acidified. The white solid formed was filtered and recrystallized from aqueous ethanol. The material so obtained was 1-naphthol, m.p. 93–95° (no depression on admixture with authentic sample), yield 0.30 g. (77%).

When this reaction was repeated using 1.65 g. (7.2 mmoles) of 2-morpholino-1-tetralone, 0.87 g. (7.2 mmoles) of acetophenone, 0.62 g. (7.2 mmoles) of morpholine and 0.23 g. (7.2 mmoles) of sulfur, the acidic wash, after basification, yielded 0.173 g. of material. Steam distillation of the oil, followed by recrystallization of the solid distillate yielded 6 mg. of 2-morpholinonaphthalene, m.p. 85–86°, mixed m.p. with authentic sample, m.p. 85.0–86.5°.

Willgerodt reaction with 1,2-dihydronaphthalene. A mixture of 4.97 g. (0.038 mole) of 1,2-dihydronaphthalene, 3.39 g. (0.039 mole) of morpholine, and 1.23 g. (0.038 mole) of sulfur was allowed to react under the usual conditions. The cooled reaction mixture which had partially solidified was washed, by decantation, with dilute hydrochloric acid. The acidic solution was made alkaline with concentrated ammonia and the dark suspension was extracted with ether. After removal of the solvent, the small amount of yellow oil was directly steam distilled. The white solid distillate, which had a strong blue fluorescence, was filtered and recrystallized from dilute ethanol to yield 0.05 g. (0.6%) of 2-morpholinonaphthalene, m.p. 84.5–85.0°. The material gave no depression upon admixture with an authentic sample and possessed an infrared spectrum identical with that of 2-morpholinonaphthalene.

The acid insoluble residue from the reaction was steam-distilled and the white solid distillate was recrystallized from dilute ethanol to yield 3.95 g. (83%) of naphthalene, m.p. 76.0–77.0°.

Willgerodt reaction with 1,4-dihydronaphthalene. A mixture of 0.71 g. (5.4 mmoles) of 1,4-dihydronaphthalene,[6] 0.50 g. (5.6 mmoles) of morpholine and 0.17 g. (5.4 mmoles) of sulfur was treated and processed as described above for the 1,2-dihydro isomer. From the acid extract, after steam distillation and recrystallization, there was obtained 2 mg. of 2-morpholinonaphthalene and from the insoluble residue there was obtained 0.6 g. (88%) of naphthalene.

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[CONTRIBUTION FROM THE CANCER RESEARCH LABORATORY, UNIVERSITY OF FLORIDA]

Physical Properties of the Aminoazobenzene Dyes. IV. The Position of Proton Addition[1]

EUGENE SAWICKI[2]

Received September 26, 1956

The basicity and absorption spectra of some azo dyes have been correlated with the position of proton addition to these dyes. Further spectral evidence has been given for the tautomer concept of proton addition to the 4-aminoazobenzene dyes.

Recently Klotz *et. al.*[3] in a study of the basicities of some 4-aminoazobenzene dyes concluded that the first proton added exclusively and unequivocally to the amino nitrogen. The spectral conclusions cited by these authors in support of their doctrine have been more carefully re-examined by Cilento, Miller, and Miller,[4] who have also given further spectral evidence for the presence of cationic tautomers in acid solutions of the 4-aminoazobenzene dyes.

But as Klotz's conclusions are based mainly on his basicity studies, the tautomer concept must fit in with the basicity data to be valid. For this reason the basicity and the spectral data of some azo dyes are compared in Fig. 1.

The following conclusions are drawn by an examination of these data. The addition of a proton to 4-dimethylaminoazobenzene, DAB, gives 2 tautomers. The ammonium, or A, tautomer λ_{max} 320, where the proton has added to the amino group, is apparently iso-*pi*-electronic with azobenzene, λ_{max} 320 mμ. The cationic resonating, or C, tautomer, where the proton has added to the β-nitrogen, is associated with the band at 516 mμ. The addition of

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[2] Present address: Robert A. Taft Sanitary Engineering Center, 4676 Columbia Parkway, Cincinnati 26, Ohio.

[3] Klotz, Fiess, Ho, and Mellody, *J. Am. Chem. Soc.*, 76, 5136 (1954).

[4] Cilento, Miller, and Miller, *J. Am. Chem. Soc.*, 78, 1718 (1956).