minutes except for the 3-phenoxyphenoxthin where it was five hours. The melting points and analyses of these sulfones are given in Table III. A check on the completion of the oxidation was made in each case by treating a small portion of the product with concentrated sulfuric acid. The sulfones give no color while the phenoxthins and the sulfoxides give colored solutions.

Summary

1. It has been shown that the three methyl and the three chloro derivatives of diphenyl ether are converted into phenoxthins by heating with sulfur and aluminum chloride. The properties of these compounds and the corresponding sulfones are listed.

2. Preliminary examination of the chlorination products of phenoxthin indicates that substitution occurs to some extent ortho to sulfur.

EVANSTON, ILLINOIS RECEIVED OCTOBER 8, 1937

[CONTRIBUTION FROM THE FRICK CHEMICAL LABORATORY, PRINCETON UNIVERSITY]

The Chemiluminescence of Phthalhydrazide Derivatives[1]

BY CARL N. ZELLNER AND GREGG DOUGHERTY

The brilliant chemiluminescence of 3-aminophthalhydrazide was first investigated by Albrecht,[2] who found that various oxidizing agents, such as ferricyanide and hypochlorite, in alkaline solution, were effective in bringing about light emission. During the course of the present work, Huntress[3] has described a convenient method of preparing 3-aminophthalhydrazide, and methods of demonstration of the chemiluminescence. The reader may refer to these articles for references to previous work on other oxidation reactions accompanied by chemiluminescence.

In the present work, the relative chemiluminescence of a number of phthalhydrazide derivatives was measured by means of a photronic cell and galvanometer, and effects of structure on the intensity of the light emitted upon oxidation were noted. Measurements were made on the rate of oxidation of derivatives with different groups substituted in the benzene ring, and in the hydrazide ring. Also, the effect of hydroxyl ion and of inhibitors on the rate was noted.

Measurement of the Relative Chemiluminescence.—The apparatus consisted of a Weston photronic cell, a sensitive high-resistance galvanometer (Leeds and Northrup, internal resistance 896 ohms, and sensitivity of 128.35 mm. per microvolt) and a resistance connected in series. The reaction tube was directly in front of the photronic cell, and both were enclosed in a box, the inside walls of which were white. In the reaction tube was a stirrer, driven at constant rate. Table I shows the relative chemiluminescence of some phthalhydrazide derivatives in terms of cm. displacement of the beam, the scale being 1 meter from the galvanometer. Measurements were carried out at two different concentrations, namely, 0.001 and 0.004 molar solutions of phthalhydrazide, in 0.25% sodium hydroxide solution (20 cc.), to which 2 cc. of 0.2 *N* sodium hypochlorite was run in. The brilliant luminescence of 3-aminophthalhydrazide itself could only be measured by using 700,000 ohms resistance, connected in series. The displacement of the galvanometer beam was then 22 cm. for an 0.004 *M* solution in 0.25% sodium hydroxide solution. No resistance was used in the measurement of the compounds shown in the following table.

TABLE I

RELATIVE CHEMILUMINESCENCES OF SOME PHTHALHYDRAZIDE DERIVATIVES

Phthalhydrazide derivative	Cm. disp. 0.001 *M*	Cm. disp. 0.004 *M*
3-Series		
3-Hydroxy[a]	38.0	65.0
3-Acetamido	28.0	31.5
3-Acetamidoacetyl	11.5	26.5
3-Chloro[a]	4.0	3.5
3-Benzamidodiacetyl	0.8	1.1
α-3-Acetamido-N-methyl	.0	0.4
4-Series		
4-Acetamido	9.0	11.0
4-Acetamidoacetyl	8.5	10.0
4-Benzamidodiacetyl	0.2	0.2
α-4-Acetamido-N-methyl	.0	.2

[a] Not analytically pure.

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[1] From a thesis submitted by C. N. Zellner in partial fulfilment of the requirements for the degree of Doctor of Philosophy at Princeton University, September, 1934. Original manuscript received March 13, 1937.

[2] Albrecht, Dissertation, Kaiser Wilhelm-Institut, 1928; *Z. physik. Chem.*, **136**, 321 (1928).

[3] Huntress, THIS JOURNAL, **56**, 241 (1934); *J. Chem. Ed.*, **11**, 142 (1934).

Thus the intensity of the luminescence is dependent upon the nature of the group substituted in the benzene ring, and its position. In the case of ortho-, meta-, and para-aminobenzhydrazides, the ortho derivative gives an easily visible luminescence, the meta hardly visible, and the para no visible light at all. The light from *o*-methylaminobenzhydrazide seemed of the same intensity as that from *o*-aminobenzhydrazide. This light was not sufficient for measurement with the apparatus described. Benzhydrazide itself gave no visible light at all.

The effect of N-substitution, as in N-methyl and N-phenyl phthalhydrazide derivatives, was to diminish the light intensity greatly. The light emitted upon oxidation of α-4-acetamido-N-phenyl phthalhydrazide was not measurable with our apparatus, and was of the same order of magnitude as that of *o*-aminobenzhydrazide. The dull light emitted by these compounds must be attributed to their extremely slow rate of oxidation, as will be seen below.

Rate Measurements.—The rate of oxidation of the derivatives was measured to see if there were any correlations with the light intensity. The nitrogen evolved during oxidation was measured in a Hempel buret. The reaction vessel was immersed in a bath at 24° and the mixture was stirred mechanically through a mercury seal. In all rate measurements 2 millimoles of hydrazide in 0.33 *N* sodium hydroxide was oxidized with 5 millimoles of sodium hypochlorite.

The rate of oxidation was found to be independent of the substituting group in the benzene ring, although the chemiluminescence is very dependent upon it. For example, the nitrophthalhydrazides which give no light show the same rate curve as the aminophthalhydrazides. Half the nitrogen is evolved in approximately one and six-tenths minutes and three-quarters of it not until nine and four-tenths minutes.

In the case of the oxidation of phthalhydrazide itself an end-product can be obtained in good yield. It is precipitated out of the alkaline solution upon acidification, and melts at 273°. It was identified as 2,2′-dicarboxybenzil by W. Moyer, who also prepared this compound and found no depression of the melting point, on making a mixed melting point determination.[4] No end-products were isolated in the case of substituted phthalhydrazides.

The rate of oxidation of the benzhydrazides is similar, half the nitrogen coming off in eighteen minutes and three quarters of it not until two hours. With hydrazine itself, half the nitrogen is evolved in one and three-tenths minutes, and three-quarters of it in fifteen minutes. In each case a slowly oxidizable intermediate must be formed. In the case of benzhydrazide, benzalbenzhydrazide was isolated from the reaction mixture, as has also been described by Darapsky.[5]

The rate was found to be accelerated markedly with increasing hydroxyl ion concentration, which is interesting in connection with the fact that the light intensity decreases with increasing hydroxyl ion as will be shown below. Thus, in 0.17 *N* sodium hydroxide solution, half the nitrogen was evolved in approximately four and nine-tenths minutes; in 0.33 *N* sodium hydroxide, two and eight-tenths minutes; and in 0.5 *N*, nine-tenths minute. The time required for three quarters of the nitrogen to be evolved in the same three solutions was, respectively: twelve and one-tenth, eight and two-tenths, and three and one-tenth minutes.

The effect of increasing alkalinity on the light emitted upon oxidation of 3-aminophthalhydrazide is shown in the following measurements with the beam galvanometer: in 0.007 *N* sodium hydroxide solution, the displacement was 42 cm.; in 0.015 *N* sodium hydroxide, 66 cm. (maximum); in 0.03 *N*, 60 cm.; in 0.06 *N*, 50 cm.; in 0.125 *N*, 30 cm.; in 0.25 *N*, 18 cm.; and in 0.5 *N*, only 8 cm. (An aqueous solution of the sodium salt of 3-aminophthalhydrazide shows only a dull light and a slow rate of oxidation with sodium hypochlorite, probably because very little of the di-enol form is present.)

These results seem to indicate that the di-enol form of the phthalhydrazide is first oxidized, yielding energy-rich fragments, which then excite the keto form to fluorescence. Increasing alkali shifts the equilibrium toward the di-enol form, so that the rate of the reaction is increased, but the concentration of the light-emitting species is diminished, and less light is produced.

The light intensity is also affected by the concentration of the 3-aminophthalhydrazide, the optimum being about 0.02 molar, in 0.5% sodium hydroxide solution. A 0.5 molar solution in 0.5% sodium hydroxide solution, for instance, caused only half as much displacement of the galvanome-

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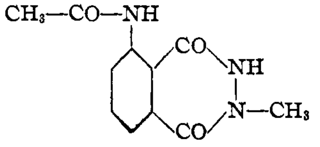
(4) Private communication.

(5) Darapsky, *J. prakt. Chem.*, **76**, 447 (1907).

ter beam as the 0.02 molar solution. (In these experiments, a 700,000 ohm resistance was used in series in the apparatus described earlier in this paper.)

It was also found that a small amount of inhibitor, such as hydroquinone or pyrogallol, would cause a great diminution in the light intensity, and rate measurements showed that the initial portion of the reaction, during which the brightest light emission occurs, was retarded.

The rate of oxidation of N-methyl- and N-phenylphthalhydrazides, in which the formation of a di-enol in alkaline solution is impossible, is very different from phthalhydrazides with no N-substitution. The rate curve is almost linear and half the nitrogen is evolved only after eighty minutes in the case of α-3-acetamido-N-methylphthalhydrazide (I), and ninety minutes for N-phenylphthalhydrazide, which gives the same type of curve. In these compounds only the mono-enol form (II) is possible, and consequently a carbonyl-carbon to nitrogen bond must be broken in the course of the oxidation process. It was shown further that when no enolization is possible, as with 4-hydroxy-N,N′-dimethylphthalhydrazide (III), no light is seen, and no gas evolution is apparent upon oxidation, during the course of several hours. (Regarding structural formulas I and II, it is to be noted that the relative positions of the N-methyl groups in the α- and β-derivatives has not yet been determined.)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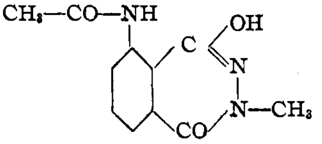
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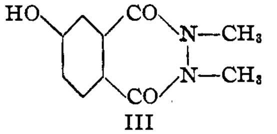
III

Experimental

3-Aminophthalhydrazide and its diacetyl derivative, m. p. 268° (corr.), were prepared according to Albrecht.[2]

4-Aminophthalhydrazide and its diacetyl derivative, m. p. 214°, were prepared according to Curtius and Hoesch.[6]

3-Acetamidophthalhydrazide.—To a boiling solution of 3.5 g. of 3-acetamidophthalic anhydride, a solution of 3.6 g. of hydrazine sulfate and 3.9 g. of sodium acetate in water was added. An immediate precipitate formed, probably a hydrazonium salt. The reaction mixture was heated to dryness and kept on a hot plate at 160° for several hours. The product was washed with hot water and alcohol, and melted unsharply at 310° (Kühlmann copper block). To obtain the compound analytically pure, it was given several treatments with hot acetic acid, finally heating to 160° each time and then washing with hot water.

Anal. Calcd. for $C_{10}H_9O_3N_3$: C, 54.78; H, 4.14. Found: C, 54.89; H, 4.23.

Upon acetylation of this compound the diacetyl derivative of 3-aminophthalhydrazide, m. p. 268° (corr.), was produced.

4-Acetamidophthalhydrazide.—In like manner, and also prepared according to Bogert and Renshaw,[7] who obtained it from dimethyl-4-acetamidophthalate and hydrazine hydrate.

By the reaction of 3- and 4-acetamidophthalic anhydrides[7,8] with methylhydrazine, the following were obtained.

α-3-Acetamido-N-methylphthalhydrazide.—M. p. 302° (corr.). *Anal.* Calcd. for $C_{11}H_{11}O_3N_3$: C, 56.65; H, 4.72. Found: C, 56.57; H, 4.65. Its acetyl derivative melted at 198–199°. *Anal.* Calcd. for $C_{13}H_{13}O_4N_3$: C, 56.73; H, 4.73. Found: C, 56.77; H, 4.96.

The same diacetyl-3-amino-N-methylphthalhydrazide (m. p. 198–199°) was obtained by reducing α-3-nitro-N-methylphthalhydrazide[9] (m. p. 305°) with zinc and dilute acetic acid, and acetylating the 3-amino-N-methylphthalhydrazide so obtained.

β-3-Acetamido-N-methylphthalhydrazide was separated by fractional crystallization from alcohol from the isomeric α-compound. It melted at 273–274° (corr.). The α- and β-isomers seemed to be produced in about equal proportions. *Anal.* Calcd. for $C_{11}H_{11}O_3N_3$: C, 56.65; H, 4.72. Found: C, 56.67; H, 4.67.

α-4-Acetamido-N-methylphthalhydrazide.—M. p. 328–329°. *Anal.* Calcd. for $C_{11}H_{11}O_3N_3$: C, 56.65; H, 4.72. Found: C, 56.31; H, 4.64. Its isomer (m. p. *ca.* 260°) was not obtained analytically pure.

Reacting 4-acetamidophthalic anhydride with phenylhydrazine, the following compounds were obtained.

4-Acetamido-N-phenylphthalhydrazide.—M. p. 353° (block), after two reprecipitations from alkaline solution with acid, and washing with hot alcohol. *Anal.* Calcd. for $C_{16}H_{13}O_3N_3$: C, 65.09; H, 4.41. Found: C, 64.90; H, 4.58. Its acetyl derivative melted at 309°. *Anal.* Calcd. for $C_{18}H_{15}O_4N_3$: C, 64.09; H, 4.45. Found: C, 63.96; H, 4.31.

4-Benzamidophthalhydrazide.—4 - Benzamidodimethylphthalate was prepared from the 4-amino ester, which had been obtained very simply by catalytic (Pt) reduction of

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(6) Curtius and Hoesch, *J. prakt. Chem.*, **76**, 801 (1907).

(7) Bogert and Renshaw, THIS JOURNAL, **28**, 617 (1906).

(8) Lawrence, *ibid.*, **42**, 1871 (1920).

(9) Zellner and Dougherty, *ibid.*, **58**, 1811 (1936).

the 4-nitro ester. Benzoyl chloride is added gradually to the pyridine solution of the 4-amino ester.[7] The benzamido ester was refluxed for two hours with an excess of hydrazine hydrate. The mixture was then heated and stirred at 150° for an hour, and washed with hot alcohol. The benzamido phthalhydrazide melted at about 310° on the block. It was not purified further, but was acetylated by boiling for fifteen minutes in acetic anhydride; a diacetyl derivative was obtained, melting at 273–274° (corr.), on recrystallization from acetic anhydride. *Anal.* Calcd. for $C_{19}H_{15}O_5N_3$: C, 62.47; H, 4.11. Found: C, 62.37; H, 4.14.

3-Benzamidophthalhydrazide.—Dimethyl 3-nitrophthalate was prepared according to the method of Miller[10] for making the diethyl ester. The dimethyl 3-nitrophthalate was reduced catalytically (Pt) in alcohol. It was treated with benzoyl chloride in pyridine, as described for the 4-compound above. 3-Benzamidophthalhydrazide was then made from the ester and hydrazine hydrate. It was not purified further, but was acetylated directly. Its diacetyl derivative melted at 269° (corr.), upon recrystallization from acetic anhydride. *Anal.* Calcd. for $C_{19}H_{15}O_5N_3$: C, 62.47; H, 4.11. Found: C, 61.95; H, 3.94.

4-Hydroxy-N,N'-dimethylphthalhydrazide.—From 4-hydroxyphthalic acid[11] and *sym*-dimethylhydrazine acetate in acetic acid; after washing with hot water, it melted at *ca.* 290°. *Anal.* Calcd. for $C_{10}H_{10}O_3N_2$: C, 58.25; H, 4.85. Found: C, 58.45; H, 4.94.

3-Hydroxy- and 3-chlorophthalhydrazides were prepared in like manner from 3-hydroxyphthalic anhydride,[12] and 3-chlorophthalic acid,[13] respectively. These two hydrazides were not analytically pure, but seemed sufficiently pure for the light measurements described here.

***o*-Methylaminobenzhydrazide** was obtained from the methyl-N-methylanthranilate[14] and hydrazine hydrate in alcohol, heated at 150° for eighteen hours. The product melts at 146–147° (corr.) after two recrystallizations from alcohol. *Anal.* Calcd. for $C_8H_{11}ON_3$: C, 58.18; H, 6.67. Found: C, 58.45; H, 6.69.

Summary

The preparation of a number of phthalhydrazide derivatives has been described. The relative chemiluminescence of these derivatives upon oxidation in alkaline solution with sodium hypochlorite has been measured.

The effect of different substituents in the benzene ring, and in the hydrazide ring, on the intensity of the light emitted was pointed out. Measurements on the rate of oxidation of these derivatives were made, and the effect of hydroxyl ion and inhibitors on the rate, and the light emitted was noted.

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[10] Miller, *Ann.*, **208**, 243 (1881).

[11] Baeyer, *Ber.*, **10**, 1079 (1877).

[12] Bernthsen and Semper, *ibid.*, **19**, 167 (1886).

[13] Bogert and Boroschek, THIS JOURNAL, **23**, 751 (1901).

[14] Schroeter and Eisleben, *Ann.*, **367**, 143 (1909).

PRINCETON, NEW JERSEY RECEIVED OCTOBER 21, 1937

[CONTRIBUTION FROM THE CHEMICAL LABORATORY OF WASHINGTON UNIVERSITY]

The Coupling of Organic Radicals by the Action of Grignard Reagents on Heavy Metal Salts. II. Coupling of Dissimilar Radicals

BY JOHN H. GARDNER, LIONEL JOSEPH AND FRANK GOLLUB[1]

A number of investigators have studied the reaction of Grignard reagents with various heavy metal salts resulting in the coupling of organic radicals.[2] In only one case has there been any report of the coupling of dissimilar radicals by this method. Bennett and Turner[3] treated a mixture of phenyl- and propylmagnesium bromides with anhydrous chromic chloride and obtained a very small yield of a product which appeared to be *n*-propylbenzene. On treating other mixtures of Grignard reagents similarly, they were unable to detect any of the products formed by the union of dissimilar radicals.

Gardner and Borgstrom found that treatment of Grignard reagents with dry silver bromide resulted in the formation of the products of union of the organic radicals in quite satisfactory yield in a number of cases. They did not extend their study to include mixed Grignard reagents. That has been done in the present investigation.

It appears to be well established that, when an organomagnesium halide is treated with silver bromide, the reaction proceeds according to the equations[4]

$$\mathrm{RMgX} + \mathrm{AgBr} \longrightarrow \mathrm{RAg} + \mathrm{MgBrX} \tag{1}$$

$$\mathrm{RAg} \longrightarrow \mathrm{R} + \mathrm{Ag} \tag{2}$$

$$2\mathrm{R} \longrightarrow \mathrm{R_2} \tag{3}$$

If a mixture of two Grignard reagents were to be treated with silver bromide, it would be ex-

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[1] Presented before the Division of Organic Chemistry, Kansas City, Missouri, April 14, 1936.

[2] Gardner and Borgstrom, THIS JOURNAL, **51**, 3375 (1929), give leading references. See Joseph, Dissertation, Washington University, 1937, for a bibliography and review.

[3] Bennett and Turner, *J. Chem. Soc.*, **105**, 1057 (1914).

[4] Krause and Wendt, *Ber.*, **56**, 2064 (1923); Reich, *Compt. rend.*, **177**, 322 (1923); Danehy and Nieuwland, THIS JOURNAL, **58**, 1609 (1936).