

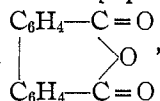
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STUDIES IN THE DIPHENIC ACID AND IN THE FLUORENONE SERIES. I

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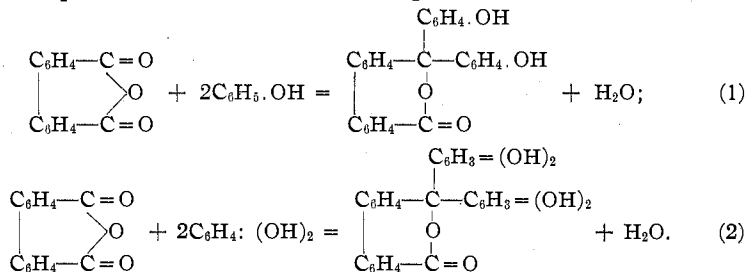
Phenolphthalein, fluorescein and gallein are prepared by well-known methods which involve the condensation of phthalic anhydride with phenol, resorcinol and pyrogallol, respectively. A part of this paper is an account of results obtained by using diphenic anhydride,



and allied compounds in place of phthalic anhydride in these processes. Sulfuric acid is frequently employed as a condensing agent in the synthesis of fluorescein. On account of the fact that sulfuric acid transforms diphenic anhydride into the isomeric diphenyleneketone-4-carboxylic acid,

$\begin{array}{c} \text{C}_6\text{H}_4 \\ | \quad \diagup \quad \diagdown \\ \text{C}=\text{O} \\ | \\ \text{C}_6\text{H}_3-\text{CO}_2\text{H} \end{array}$ we have used anhydrous zinc chloride and fuming stannic

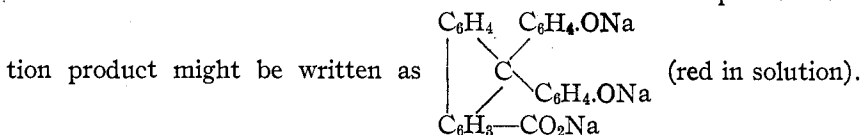
chloride as dehydrating agents in our work. Equations for the condensations with phenol and with resorcinol might be written as follows:



The crystalline substance obtained from the phenol reaction did not give a red solution when it was dissolved in caustic alkali, nor did the sodium salt of the crystalline compound isolated from the resorcinol-anhydride condensation show fluorescence in solution. However, the amorphous residue from Reaction 1 behaved like phenolphthalein and that from Reaction 2 showed properties similar to those of fluorescein. Consideration of these results caused us to believe that the dehydrating agents employed might have changed a part of the diphenic anhydride into diphenyleneketone-4-carboxylic acid and that the ketone oxygen of the latter had reacted with two atoms of ring hydrogen from two molecules of phenol

¹ The experimental results described in this paper are taken from a thesis submitted to the Faculty of the Massachusetts Institute of Technology by E. L. Kochmann in partial fulfillment of the requirements for the degree of Bachelor of Science.

or of resorcinol to yield substances respectively colored or fluorescent in alkaline solution. The formula for the sodium salt of the phenol reac-



Experiments were carried out to test the validity of these ideas. It is customary to explain the red color of phenolphthalein in alkaline solution by saying that a quinoid ring is formed; this phenomenon is also said to be involved in salt formation by fluorescein. If salts having formulas analogous to that given above are responsible for the color and fluorescence obtained in our experiments, then we have instances of indicator effects and of fluorescence which do not involve quinoid ring formation. To secure further evidence on this point, we have condensed fluorenone with phenol and with resorcinol² on the supposition that the oxygen atom in this ketone would unite with two atoms of ring hydrogen from two molecules of phenol or of resorcinol. The remainder of our research consists of an investigation of the value of the bromine derivative of the resorcinol-diphenylene-ketone-4-carboxylic acid compound and of the pyrogallol-diphenic anhydride condensation product as dyes.

After a considerable part of this work had been completed two articles which mentioned reactions of diphenic anhydride were published. Dutt³ described phenoldiphenic and resorcinoldiphenic and Bischoff and Adkins⁴ dealt with the latter as well as the reaction between diphenylene-ketone-4-carboxylic acid and resorcinol. Apparently all of these investigators ascribe the production of color and fluorescence in alkaline solutions to the diphenic anhydride condensation products, and they do not touch upon the transformation of diphenic anhydride into the isomeric ketone acid by the condensing agents they employed. The differences between our results and those obtained by Dutt and by Bischoff and Adkins with regard to this matter, and in other respects, are brought out in the description of our experiments and in the summary of this paper.

Discussion of Experiments

All of the temperatures given below are uncorrected.

Diphenic Anhydride.—In order to ascertain whether diphenic acid could be transformed into the anhydride by heat, samples of the material were maintained at temperatures 10° above its melting point for half

² Experiments involving some of these reactions of fluorenone and of diphenylene-ketone-4-carboxylic acid were performed long ago by Graebe and Aubin [*Ann.*, **247**, 257 (1888)].

³ Dutt, *J. Chem. Soc.*, **123**, 225 (1923).

⁴ Bischoff and Adkins, *THIS JOURNAL*, **45**, 1030 (1923).

an hour. Examination of the product showed that no diphenic anhydride had been formed.

Subsequently, the following procedure was adopted.

Mixtures of diphenic acid, acetic anhydride and glacial acetic acid (solvent) were heated at 145°, then allowed to cool, the crystalline solid was collected on a filter and the filtrate poured into water in order to obtain any material held in solution. All of the solid reaction products were treated with a cold 20% solution of sodium carbonate to remove diphenic acid. Results are given below.

Diphenic acid G.	Acetic anhydride G.	Calc. amt. ×	Acetic acid G.	Time of heating hours	Diphenic anhydride G.	Yield %
10	20	4.8	20	0.50	8.7	94.0
25	50	4.8	50	1.25	21.5	92.9
25	11.5	1.1	45	1.25	18.5	79.9
15	9.4	1.5	27	1.00	12.1	87.1
15	12.6	2.0	27	1.00	12.2	87.9
15	15.7	2.5	25	1.00	12.65	91.1
30	31.4	2.5	50	2.00	24.7	89.0

These experiments produced diphenic anhydride which melted at 222–224°.

Phenol and Diphenic Anhydride.—Twenty-one g. of phenol (calc. amt. × 2.7), 10 g. of diphenic anhydride and 16 g. of fuming stannic chloride were placed in a round-bottom flask provided with an air condenser and heated at 130–135° for 15 hours. Steam distillation was employed to remove excess of phenol. The solid reaction product was collected on a filter, dried and finely powdered. Treatment with (1) a 50% solution of sodium bicarbonate showed that none of the condensation product was soluble in this medium. Repeated extractions with (2) ammonium hydroxide, with (3) sodium carbonate solution and with (4) 3 *N* sodium hydroxide solution followed by acidification of the extract liquors and washing and drying of the precipitates thereby produced, gave amorphous brown or cream-colored powders having the following weights: (2) 11.56 g., (3) 0. g., (4) 2.9 g. The ammonium hydroxide used in these extractions was prepared by mixing equal volumes of material having a density of 0.90 and water; the sodium carbonate solution was 50%. Solutions of these concentrations and others given above were employed in all of the experiments described in this paper. When the several alkaline liquids were made acid, the solids formed as gelatinous precipitates which held inorganic salts very tenaciously. It was necessary to grind the dried powders repeatedly with water in order to remove the sodium chloride which was mixed with them. By the use of glacial acetic acid as a solvent, colorless rhombic crystals (m. p., 250–251°) were obtained from the portion of the condensation product soluble in ammonium hydroxide; 2.7 g. of crystals was obtained from 5 g. of crude material. These crystals gave a yellow solution in sodium hydroxide, but the amorphous powder produced by dilution of the acetic acid filtrate dissolved in aqueous sodium hydroxide with a deep red color. Dutt⁸ described phenoldiphenoin as pinkish white needles (from dil. alcohol, m. p., 134°, containing 2 molecules of water of crystallization) which dissolved in sodium hydroxide solution with a reddish-pink color.

Analyses (crystals, m. p., 250–251°). Calc. for C₂₆H₁₈O₄: C, 79.16; H, 4.60. Found: C, 78.74, 78.80; H, 5.02, 5.09.

We intend to investigate the acetyl derivative of phenoldiphenoin; preliminary experiments indicate that it is insoluble in cold caustic alkali solutions.

Resorcinol and Diphenic Anhydride.—Twenty g. of fused and finely divided zinc chloride was gradually added to a mixture of 25 g. of resorcinol (calc. amt. $\times 1.27$) and 20 g. of diphenic anhydride stirred and maintained at 175° . The total time of heating was 4 hours. After the dark red melt had cooled, it was powdered, boiled with dil. hydrochloric acid, drained on a filter and dried. It was then washed thoroughly with water, treated with a 50% solution of sodium hydroxide and the undissolved material collected on a filter. Acidification of the alkaline liquid yielded a brown precipitate which weighed 25.5 g. when washed and dried. To an almost neutral solution of this material in aqueous sodium hydroxide an excess of lead acetate solution was added and the lead lake thereby produced was removed by filtration. After drying the latter, it weighed 50.4 g. The finely powdered lead compound was suspended in alcohol and treated with an excess of hydrogen sulfide. After removal of the lead sulfide, the alcoholic solution of the condensation product was evaporated to dryness or diluted with water to obtain the crude resorcinoldiphenic which came down as a reddish-brown powder (weight when dry, 22 g.). A filtered solution of the latter in hot alcohol was carefully diluted with water until a slight precipitate appeared, and then warmed and allowed to stand. Almost colorless crystals were thereby obtained, which melted at $178\text{--}179^\circ$ when dry; 1.9 g. of crystals was secured from 5 g. of crude material. These crystals dissolved in sodium hydroxide solution to yield a yellow liquid with practically no fluorescence. The brown, amorphous powder obtained by concentration of the alcoholic solution gave a strongly fluorescent solution when dissolved in aqueous sodium hydroxide.

According to statements made by Dutt,³ resorcinoldiphenic forms brown prisms (from dil. alcohol), m. p., 172° , which show a brilliant green fluorescence when dissolved in caustic alkalis. He gave the formula as $C_{26}H_{10}O_5$. Although Bischoff and Adkins⁴ did not report a quantitative analysis of resorcinoldiphenic for carbon and hydrogen, they concluded from a determination of the metal content of the sodium salt, which they write as $C_{26}H_{14}O_5Na_4$, that the oxygen bridge present in the original compound is opened by dissolving the material in sodium hydroxide solution.

Analyses (crystals, m. p., $178\text{--}179^\circ$). Calc. for $C_{26}H_{18}O_6$: C, 73.22; H, 4.25. Found: C, 72.94, 73.00; H, 4.55, 4.45.

Pyrogallol and Diphenic Anhydride.—A mixture of 7 g. of pyrogallol (calc. amt. $\times 1.25$), 5 g. of diphenic anhydride and 8 g. of fuming stannic chloride was heated at $125\text{--}130^\circ$ for 7 hours. The mass was cooled and diluted with water. Subsequent treatment of the product was the same as that employed in the case of the phenol condensation, except that the steam distillation was omitted. Yields were as follows: none of the material was soluble in (1) sodium bicarbonate or in (2) ammonium hydroxide; (3) sodium carbonate extract, 4.2 g. of a black powder; (4) sodium hydroxide extract, 4.4 g. of a black powder. None of these materials melted at 325° , and they were practically insoluble in all of the usual organic solvents as well as nitrobenzene, aniline and quinoline. We did not succeed in getting these substances pure enough for accurate analyses.

Diphenylene-ketone-4-carboxylic Acid from Diphenic Anhydride.—Five g. of diphenic anhydride and 7 g. of anhydrous stannic chloride were heated at $120\text{--}130^\circ$ for 7 hours. The cold reaction product was poured into water, filtered and washed. It was found to be completely soluble in a 50% solution of sodium carbonate. When the latter was acidified, it yielded a yellow precipitate. This was identified as diphenylene-ketone-4-carboxylic acid by a mixed-melting-point with some of the ketone acid prepared by treating diphenic acid with sulfuric acid.⁵ Evidently the stannic chloride transformed all the diphenic anhydride into the isomeric diphenyleneketone-4-carboxylic acid.

⁵ Graebe and Mensching, *Ber.*, 13, 1302 (1880).

Similar results were obtained by maintaining a mixture of 5 g. of diphenic anhydride and 4 g. of anhydrous zinc chloride at 225° for 8 hours.

Diphenic Anhydride from Diphenyleneketone-4-carboxylic Acid.—A mixture of 5 g. of diphenyleneketone-4-carboxylic acid, 10 g. of acetic anhydride and 5 cc. of glacial acetic acid was heated at 140–150° for 6 hours. The solid reaction product obtained when this mixture was cooled, diluted with water and filtered, was treated twice with a 50% solution of sodium carbonate. The undissolved residue upon recrystallization from benzene formed needles (0.9 g.) which melted at 222°. This was identified as diphenic anhydride by a mixed-melting-point with some anhydride of known purity. Apparently diphenyleneketone-4-carboxylic acid can be changed into diphenic anhydride, but the process is very slow.

Phenol and Diphenyleneketone-4-carboxylic Acid.—A mixture of 10 g. of phenol, 5 g. of diphenyleneketone-4-carboxylic acid and 8 g. of fuming stannic chloride was maintained at 120–125° for 5 hours. Subsequent treatment of the product was the same as that employed in the case of phenoldiphenic. Yields were as follows: none of the product dissolved in (1) sodium bicarbonate solution or in (3) sodium carbonate solution; (2) ammonium hydroxide extract, 4.5 g. of a salmon-red powder (m. p., 180–185°); (4) sodium hydroxide extract, 1.05 g. of reddish-brown material (m. p., 213–220°).

Analyses. Calc. for $C_{26}H_{18}O_4$: C, 79.16; H, 4.60. Found: C, 78.63, 78.70; H, 5.1, 5.13.

Resorcinol and Diphenyleneketone-4-carboxylic Acid.—A mixture of 7 g. of resorcinol (calc. amt. \times 1.4), 5 g. of diphenyleneketone-4-carboxylic acid and 18 g. of fuming stannic chloride was heated for 10 hours at 120–130°. The method used for working up the reaction mass was similar to that already described for the phenoldiphenic anhydride condensation product. The yields were: (1) sodium bicarbonate extract, 1.3 g. of an amorphous substance (m. p., 215–240°); (2) material soluble in ammonium hydroxide, 6.7 g. (did not melt at 325°); (3) sodium carbonate extract, 0 g.; (4) a substance removed by sodium hydroxide solution, 0.5 g. (this remained solid at 325°). All of these materials were brown or red amorphous powders which gave a deep green fluorescence when dissolved in caustic alkali solution. Analyses were made of samples obtained directly from the reaction product by treatment with sodium hydroxide solution. The material was subsequently dissolved in alcohol, filtered and the alcohol-soluble portion obtained by dilution with water; this treatment was repeated several times.

*Analyses.*⁶ Calc. for $C_{26}H_{18}O_6$: C, 73.22; H, 4.25. Found: C, 72.87, 72.79; H, 4.61, 4.7.

It is planned to investigate the acetyl derivatives of this condensation product as well as the one obtained from phenol; preliminary experiments indicate that the acetyl compounds are soluble in cold sodium hydroxide solution.

Phenol and Fluorenone.—In an Erlenmeyer flask 3.5 g. of fluorenone and 5.5 g. of phenol (50% excess) were mixed with 9 g. of fuming stannic chloride, and the whole was then heated at 130–140° for 6 hours. After cooling the mass, it was steam distilled to

⁶ It was found impossible to burn this compound, as well as several others produced in our work, in ordinary combustion tubing. Consequently, for all the carbon-hydrogen determinations mentioned in this paper we used tubes made of fused silica, mixed the compounds intimately with fine copper oxide and burned them in a current of oxygen during the course of 8 to 10 hours. Special precautions were taken with regard to the hygroscopicity of fine copper oxide, and in some cases hydrogen was determined separately. Every compound analyzed was previously dried at 110° to constant weight.

remove excess of phenol, then filtered and treated with 3 *N* sodium hydroxide solution. When the latter was acidified a salmon-red precipitate was obtained which weighed 4.1 g. after it had been washed and dried, and melted incompletely at 241–243°. This substance dissolves in sodium hydroxide and forms a deep red solution. A portion was several times dissolved in hot alcohol, separated from impurities by filtration and recovered by dilution of the alcoholic solution with water. This material was analyzed.

Analyses. Calc. for $C_{26}H_{18}O_2$: C, 85.68; H, 5.17. Found: C, 85.27, 85.35; H, 5.50, 5.56.

Resorcinol and Fluorenone.—Three and one-half g. of fluorenone, 5.4 g. of resorcinol (25% excess) and 9 g. of anhydrous stannic chloride were heated together at 130–140° for 6 hours. The reaction product was treated by a procedure similar to that used in the case of the phenol-fluorenone condensation, except that the steam distillation was omitted. One g. of a brown powder was thereby obtained, and 5.0 g. of the crude material was found to be insoluble in sodium hydroxide solution. This brown powder showed a strong fluorescence in alkaline solution. It was prepared for analysis by treatment with alcohol as already described in the account of the previous experiment.

Analyses. Calc. for $C_{26}H_{18}O_4$: C, 78.51; H, 4.74. Found: C, 78.12, 78.20; H, 5.10, 5.3.

Bromination of Resorcinol Condensation Products.—One g. of the crystalline resorcinoldiphenein was dissolved in 15 cc. of hot alcohol, the solution placed in an Erlenmeyer flask provided with a reflux water condenser and then 4 g. of bromine (calc. amt. \times 2.7) was added to the boiling solution during the course of an hour. Yellow rhombic crystals soon appeared in the liquid. At the completion of the reaction these were collected and dried. They melted at 273° and weighed 1.2 g. When dissolved in sodium hydroxide solution, the bromine compound gave a yellow solution which showed no fluorescence. If the bromine is added quickly to the hot alcoholic solution or to a cold one, the product is an amorphous powder.

Analyses (crystals dried at 110°). Calc. for $C_{26}H_{14}O_6Br_4$: Br, 43.08. Found: 42.90, 42.95.

One g. of the part of the resorcinol-diphenylene ketone-4-carboxylic acid condensation product which was soluble in ammonium hydroxide was brominated in a similar way. Filtration of the cold reaction mixture yielded a brownish-red, amorphous powder which weighed 0.8 g. when washed and dried. It did not melt at 325°, and dissolved in sodium hydroxide solution with the development of a deep red color. This powder was dissolved in a mixture of acetone and alcohol, separated from impurities by filtration and recovered by evaporation of the solvents. Determinations of the bromine content of a sample prepared in this way gave results which were several per cent. below that calculated for the tetrabromo derivative, and which indicated the presence of some dibromo compound or other impurities.

Dyeing Experiments.—A sample of skein silk and one of woollen yarn were worked for half an hour in slightly acid baths containing 3% (based on weight of silk or wool) of the sodium salt of the bromine derivative of the resorcinol-diphenylene ketone-4-carboxylic acid condensation product. The wool was dyed a very light pink, and the silk acquired a flesh color. Parallel experiments in which eosin was used in place of the keto acid derivative gave the usual results.

One gram of woollen yarn previously mordanted with potassium dichromate solution was stirred for an hour in a slightly acid, hot aqueous

suspension of 0.4 g. of freshly precipitated and washed pyrogalloldiphenicin. After the wool was washed it showed a very slight brown coloration.

Summary

From the reaction product obtained by condensing phenol with diphenic anhydride in the presence of fuming stannic chloride a crystalline compound, phenoldiphenicin, can be obtained. This dissolves in sodium hydroxide solution with development of a yellow color. Crystalline resorcinoldiphenicin has been isolated from the crude material secured by heating resorcinol and diphenic anhydride together with the use of fused zinc chloride as a dehydrating agent. Resorcinol-diphenicin gives a yellow solution with sodium hydroxide, but does not show fluorescence. The appearance of the solutions of the sodium salts of these compounds is strange in view of the fact that they are similar to phenolphthalein and to fluorescein in structure. The statements made by Dutt and by Bischoff and Adkins as to the constitution and properties of phenoldiphenicin and resorcinoldiphenicin appear to be in error.

The amorphous condensation product of phenol and diphenyleneketone-4-carboxylic acid has been secured by heating these two compounds together and also from the residues left after the removal of the crystalline compound obtained by the reaction between phenol and diphenic anhydride. The presence of the ketone acid derivative here is apparently due to the transformation of a part of the diphenic anhydride into the isomeric diphenyleneketone-4-carboxylic acid by the action of fuming stannic chloride. This amorphous condensation product dissolves in sodium hydroxide solution with development of a deep red color. Similarly crude resorcinoldiphenicin was found to contain the ketone acid-resorcinol product. The latter has also been prepared directly from diphenyleneketone-4-carboxylic acid.

One molecule of fluorenone reacts with two of phenol or of resorcinol to give condensation products which show, respectively, a red color and a green fluorescence in alkaline solutions. Apparently, these compounds, as well as those obtained from diphenyleneketone-4-carboxylic acid, are examples of substances which show indicator effects and fluorescence without the formation of a quinoid ring.

As dyes, the bromine derivatives of resorcinoldiphenicin and of the ketone acid-resorcinol condensation product as well as pyrogalloldiphenicin have little or no value.