## [CONTRIBUTION FROM THE STERLING CHEMISTRY LABORATORY, YALE UNIVERSITY]

# PECHMANN'S DYE AND RELATED COMPOUNDS<sup>1</sup>

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In 1930, the Indian chemists, Sen and Roy, disclosed a new and simple synthesis of a benzocycloöctatetraene derivative (IV) by the cyclization of  $\delta$ benzallevulinic acid (Ib) in acetic anhydride (1). They described the new compound as a red, crystalline product of m.p. 196°. The reaction was reinvestigated twelve years later by Rapson and Shuttleworth (2) who also obtained a red compound which, however, melted one hundred degrees lower than that of the Indian investigators. They nevertheless believed the two red compounds to be identical, implying that the melting point had been incorrectly reported in the earlier publication. Rapson and Shuttleworth found that their red compound yielded benzoic acid upon oxidation and not phthalic acid as should have been expected had the compound been of structure IV. They concluded that the red compound was merely the lactone (Vb) of  $\delta$ -benzallevulinic acid.

It appeared a priori quite improbable to the present authors that the structure proposed by Rapson and Shuttleworth is that of a red compound. The number and arrangement of chromophoric groups in lactone Vb are insufficient to confer color upon the compound. In addition a colorless lactone of  $\delta$ -benzallevulinic acid of m.p. 91° has already been mentioned by Erdmann in 1891 (3) in one of his papers on the chemistry of the benzallevulinic acids. The probability was therefore strongly indicated that Rapson and Shuttleworth's red compound of m.p. 96° was Erdmann's lactone (Vb) containing as an impuirity the red compound of the Indian investigators. Accordingly the preparation of this compound was repeated in this laboratory. It was easily purified by steam-distillation to give a colorless material, m.p. 96°, identical with Erdmann's lactone.

Since they were obviously not dealing with the same compound the objections raised by Rapson and Shuttleworth against the structure (IV) proposed by the Indian investigators are invalid. Nevertheless this structure remains unacceptable for a variety of reasons. It does not, for example account for the deep-red color of the compound. It also seems most improbable that  $\delta$ -benzallevulinic acid (Ib) should cyclize with such comparative ease to form an eight-membered ring. When heated with acetic anhydrides aryl- $\gamma$ -ketoacids as a rule form lactones rather than cyclic ketones. Thus benzoylpropionic acid (II) affords  $\gamma$ phenyl- $\beta$ -butenolactone (Va) (4), and benzoylacrylic acid (IIIa) does not yield naphthoquinone but a red compound known as Pechmann's dye (VIa) (5). Since this dye is also obtained by the air-oxidation of lactone Va (4) it appeared most probable that the red compound obtained from  $\delta$ -benzallevulinic acid (Ib)

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was the distyryl analog of Pechmann's dye (VIc) formed by air-oxidation of the lactone intermediate (Vb). This probability was heightened when it was found that no red products are formed by heating this acid (Ib) with acetic anhydride in the absence of oxygen.

Pechmann's dye and a number of its derivatives have been prepared by a variety of methods. In addition to the two mentioned above it has been prepared by the action of phosphorus pentachloride on the ethyl ester of benzoylpyruvie acid and benzoylpropionic acid (Ia), (7). Bogert and Ritter (8) first proposed structure VIa for Pechmann's dye. It is based on the fact that it yields upon oxidation benzoic acid in excess of one mole, and that upon hydrolysis it is converted to a dicarboxylic acid, assumed to be diphenacylfumaric acid (VII). When this acid is lactonized, Pechmann's dye is not re-formed but instead a yellow product is obtained which Bogert and Ritter believed to be a di- $\delta$ -lactone VIII. For more than a decade and in numerous publications Chovin and coworkers (6) have presented arguments favoring a reversal of Bogert's formulations, in other words the assignment of the di- $\gamma$ -lactone structure (VIa) to the



yellow isomer, and the di- $\delta$ -lactone structure (VIII) to Pechmann's dye. It was only a few years ago that Chovin (9) finally reversed his opinion and has adopted Bogert's formulae.

An unambiguous synthesis of Pechmann's dye and its derivatives has now been developed in this laboratory which supports the di- $\gamma$ -lactone, or "indigoid" structure (VI) for this type of compound. It consists of condensing in acetic an-



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hydride a  $\gamma$ -lactone, such as Va, with an  $\alpha$ ,  $\gamma$ -diketoacid, such as IIa, to a monolactone (IX) which immediately forms the dilactone VIa.



The conditions of the reaction are such as to make extremely unlikely an opening of the  $\gamma$ -lactone ring. This method lends itself also to unambiguous syntheses of vinylogs of Pechmann's dye. Thus the condensation of benzalangelicalactone (Vb) with benzoylpyruvic acid (IIa) gave the mono-styryl analog of Pechmann's dye (VIb), m.p. 324°, in a yield of 80%. The symmetrical distyryl analogue (VIc), believed to be identical with the red compound described by the Indian investigators, was obtained in a yield of 75% by the condensation of lactone Vb with the ethyl ester of cinnamoylpyruvic acid (IIb). The shifts of the absorption maxima from 500 m $\mu$ , 535 m $\mu$  for Pechmann's dye (VIa) to 535 m $\mu$ , 555 m $\mu$  for the monovinylog (VIb) and to 555 m $\mu$ , 565 m $\mu$ , 575 m $\mu$  for the divinylog (VIc) follow the well known pattern of the polyene series (10).

For reasons stated above it was thought that the distyryl analog of Pechmann's dye (VIc) would prove to be identical with the red compound of the Indian investigators. Its melting point, however, was 150° higher than the reported one. While this discrepancy contraindicated the identity of the two compounds, the possibility remained that the red compound of lower melting point was a mixture of VIc and lower-melting products such as the lactone Vb. Accordingly attempts were made to repeat its preparation, first by following closely the directions given by the Indian authors, and later by slightly different procedures. In all instances deep red products of indistinct melting points were formed, and upon fractionation of such mixtures no compound of m.p. 196° was obtained. Only chromatographic separation afforded a small amount of crystalline material. It was of light yellow color, melted at 159–160°, and gave analytical data in agreement with the empirical formula  $C_{24}H_{20}O_4$ , which is that of a dimer of lactone Vb. Since it has been shown by Kugel (4), and Fittig (11) that lactone Va dimerizes to the unsymmetrical dilactone Xa, it may be assumed that the present dimer is of the analogous structure Xb. It would have been formed by the dimerization of Vb which, as has been shown above, is the first compound produced by the action of acetic anhydride on  $\delta$ -benzallevulinic acid (Ib). Fractionation of the least



soluble and most intensely colored fractions eventually gave some amorphous, dark-red material melting above 200°. The absorption spectrum of one fraction indicated the presence of some of the expected compound (VIc) but it has so far been impossible to isolate it in a state of reasonable purity.

From a practical point of view all the methods for the preparation of Pechmann's dye and its derivatives which have so far been reported, are unsatisfactory. While von Pechmann reported in his original paper yields as high as 45% based on benzoylacrylic acid (5) later investigators including the present authors rarely, if ever, obtained yields exceeding 19%. The other procedures, while giving better yields, require starting materials which are not readily accessible. It has now been found that the yields of the original process can be raised to 80% and above by the simple expedient of adding cuprous chloride and ammonium chloride to the reaction mixture of benzoylacrylic acid (IIa) and acetic anhydride. In addition to the preparation of Pechmann's dye this method has been used for the synthesis of the p, p-diphenyl derivative (VId) (12) and the new di-(m-nitro) derivative (VIe) in yields of 80% and 73% respectively.

It had originally been the intention of the present authors to substantiate Bogert's formula by a partial hydrogenation of Pechmann's dye followed by ozonolysis. The behaviour of the compound upon hydrogenation, however, is reminiscent of that of dienes of the type RCH=CHCH=CHR, which has been described by Allen (13). Regardless of whether one or two moles of hydrogen are used there is the formation of the completely reduced product (XI) which has not previously been described, while at the same time some of the starting material remains unattacked. When the hydrogenation is carried out under pressure, five moles of hydrogen are consumed and hydrogenolysis of the lactone rings



takes place to give the disubstituted succinic acid (XII).

### EXPERIMENTAL

Benzalangelicalactone (Vb). Steam was passed through a suspension in water of the red compound prepared according to the directions of Rapson and Shuttleworth (2). The color-less material which separated from the distillate upon cooling was collected, dried, and recrystallized several times from ligroin; plates, m.p. 96°. The compound was insoluble in an aqueous solution of sodium bicarbonate, but soluble in dilute sodium hydroxide. Acidification of the alkaline solution gave  $\delta$ -benzallevulinic acid, m.p. 122°.

In another experiment a mixture of 10 g. of benzallevulinic acid and 20 ml. of acetic anhydride was heated on the steam-bath for two hours under exclusion of oxygen. Under these conditions the solution did not turn red but only yellow. It was diluted with water and then steam-distilled. The colorless material obtained from the steam-distillate was recrystallized several times from ligroin; plates, m.p. 96°; yield 2 g. It did not give a depression of the m.p. when mixed with above product. The m.p. reported by Erdmann (3) is 91°.

Dimer of benzalangelicalactone (Xb). A solution of 2 g. of  $\delta$ -benzallevulinic acid in 10 ml. of acetic anhydride was refluxed for four hours. The deep-red solution was then poured into water and neutralized with sodium bicarbonate. The deep-red insoluble wax was then extracted with ether, and the extract was dried and evaporated to dryness. A solution of the residue in 200 ml. of acetone was passed through a column of 25 g. of alumina (Brockmann) and the yellow zone which had formed was eluted with acetone. The solution was concentrated to a small volume and cooled to  $-80^{\circ}$ . A small amount of crystalline precipitate was obtained which after twelve recrystallizations from a mixture of acetone and methanol gave 50 mg. of slightly yellow needles, m.p. 159–160°.

Anal. Cale'd for C24H20O4: C, 77.43; H, 5.43.

Found: C, 77.43; H, 6.08.

Pechmann's dye. (Method 1.) A mixture of 1.6 g. of  $\gamma$ -phenyl- $\beta$ -butenolactone (Va), prepared according to the method of von Kugel (4), 1.9 g. of benzoylpyruvic acid (IIa), prepared according to Brömme and Claisen (14), and 15 g. of acetic anhydride was heated for four hours on the steam-bath in an atmosphere of nitrogen. The solution first turned yellow, then orange and finally deep-red. At this point precipitation of a dark-red, microcrystalline powder took place. This was collected, washed with acetic acid, ethanol, and ether, and recrystallized from xylene; m.p. 317° (sublimation); yield 1.9 g., 61%.

Anal. Calc'd for C20H10O4: C, 75.94; H, 3.83.

Found: C, 75.71; H, 4.32.

(Method 2). In a reaction flask were placed 10 g. of cuprous chloride, 11 g. of ammonium chloride (equivalent to 0.1 mole of CuCl-2NH<sub>4</sub>Cl), 50 g. of benzoylacrylic acid (15), and 250 ml. of acetic anhydride. With stirring the mixture was gradually brought to a boil and then refluxed for two hours. The solution turned dark red after a few minutes and Pechmann's dye began to precipitate as a microcrystalline powder. After two hours the mixture was cooled thoroughly and the solid was collected and washed successively with acetic acid, ethanol, and ether. The crude product was then extracted with boiling toluene. During the extraction the compound crystallized from the boiling solvent. It was filtered, washed with toluene, and recrystallized from xylene. The yield of pure material was 33.5 g. or 74%, m.p.  $317^{\circ}$ .

p, p'-Diphenyldiphenacylfumaric,  $di-\gamma$ -lactone (VId). A mixture of 0.5 g. of cuprous chloride, 1 g. of ammonium chloride, 1 g. of  $\beta$ -(p-phenyl)benzoylacrylic acid (IIIb) (15), and 10 ml. of acetic anhydride was refluxed for one hour. The solution was then cooled and the red solid was collected, washed successively with acetic acid, ethanol, and ether, and extracted with boiling toluene. It was then recrystallized from xylene, m.p. 297° with sub-limation; yield 0.69 g. or 81%. This compound has previously been prepared by Bogert and Greenberg, but the m.p. has not been reported (12).

Anal. Calc'd for C<sub>32</sub>H<sub>20</sub>O<sub>4</sub>: C, 82.03; H, 4.30.

Found: C, 82.00; H, 4.63.

m,m'-Dinitrodiphenacylfumaric di- $\gamma$ -lactone (VIe). A mixture of 1.5 g. of  $\beta$ -(m-nitro)benzoylacrylic acid (IIIc) (16), 25 ml. of acetic anhydride, 0.5 g. of cuprous chloride, and 1 g. of ammonium chloride was treated as described above. The red material was extracted with xylene and recrystallized from the same solvent, m.p.  $361^{\circ}$ ; yield 0.6 g. or 73%. In a xylene solution the compound did not show the fluorescence typical of other Pechmann's dyes. Absorption maxima: 500 m $\mu$  and 525 m $\mu$  (xylene).

Anal. Calc'd for C20H10N2O8: C, 59.40; H, 2.47.

Found: C, 59.88; H, 3.02.

Phenacylstyracylfumaric di- $\gamma$ -lactone (VIb). A mixture of 1.86 g. of benzalangelicalactone (Vb), 1.92 g. of benzoylpyruvic acid (IIa), and 10 ml. of acetic anhydride was heated on a steam-bath under carbon dioxide for three hours. The solution rapidly turned dark red with the precipitation of a dark microcrystalline powder. This was collected and purified as described above; needles, m.p. 324°, yield 2.75 g. or 80%. In a xylene solution the absorption maxima are at 535 m $\mu$  and 555 m $\mu$ .

Anal. Calc'd for C<sub>22</sub>H<sub>14</sub>O<sub>4</sub>: C, 77.18; H, 4.12.

Found: C, 77.75; H, 4.20.

Distyracylfumaric-di- $\gamma$ -lactone (VIc). A mixture of 1.86 g. of benzalangelicalactone (Vb), 2.56 g. of ethyl cinnamoylpyruvate (IIb) (17), and 10 ml. of acetic anhydride was heated on the steam-bath for three hours. The dark red material which had formed was collected and purified as described above, m.p. 345°; yield 2.58 g. or 70%. In a xylene solution the absorption maxima are at 555 m $\mu$ , 565 m $\mu$ , and 575 m $\mu$ .

Anal. Cale'd for C24H16O4: C, 78.23; H, 4.38.

Found: C, 77.77; H, 4.48.

Hexahydrodiphenacylfumaric di- $\gamma$ -lactone (XI). A partial solution of 0.33 g. of Pechmann's dye (VIa) in 15 ml. of ethyl acetate was hydrogenated at room temperature and atmospheric pressure with a platinum black catalyst prepared by the reduction of 0.1 g. of platinum oxide. As the hydrogenation proceeded all material dissolved and the solution became colorless. After about 12 hours and a consumption of 3.1 moles of hydrogen no further reaction took place. The solution was then filtered and the solvent removed under reduced pressure. The residue was recrystallized three times from ethyl acetate, m.p. 220° yield almost quantitative. The compound was insoluble in an aqueous solution of sodium bicarbonate but dissolved slowly in dilute sodium hydroxide. It did not decolorize bromine in a carbon tetrachloride solution.

Anal. Cale'd for C20H18O4: C, 74.53; H, 5.59.

Found: C, 74.23; H, 5.65.

 $\alpha, \alpha'$ -Di-( $\beta$ -phenylethyl) succinic acid (XII). A mixture of 1 g. of Pechmann's dye, 0.1 g. of platinum oxide and 30 ml. of ethyl acetate was shaken at room temperature with hydrogen at 40 p.s.i. After 24 hours the hydrogen uptake corresponded to about 5.3 moles. The solution was then filtered, the solvent removed under reduced pressure, and the residue recrystallized several times from ethanol; m.p. 185°, yield 0.82 g.

Anal. Calc'd for C<sub>20</sub>H<sub>22</sub>O<sub>4</sub>: C, 73.65; H, 6.74; Neutr. equiv., 163.

Found: C, 73.29; H, 6.91; Neutr. equiv., 159.

#### SUMMARY

1. It has been shown that the red product obtained upon heating  $\delta$ -benzallevulinic acid does not possess the structure assigned to it by previous investigators, and it has been suggested that it is structurally related to Pechmann's dye.

2. A synthesis of Pechmann's dye has been described which supports the di- $\gamma$ -lactone structure first proposed by Bogert and Ritter.

3. A mono- and di-styrylanalog of Pechmann's dye have been prepared, and the suggestion has been made that the latter is identical with the red compound from  $\delta$ -benzallevulinic acid.

4. A simple synthesis of Pechmann's dye and two of its derivatives has been described which affords yields in excess of eighty per cent.

5. The hydrogenation of Pechmann's dye to two new derivatives has been described.

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