

259. *A Colour Reaction of Maleic Anhydride, p-Benzoquinone, their Partially Substituted Derivatives, and Citric Acid. Some Zwitterions.*

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Maleic anhydride and *p*-benzoquinone give sensitive colour reactions with triphenylphosphine (see *Nature*, 1939, **144**, 910). Similar colour reactions have been observed with many of their derivatives which contain one unsubstituted hydrogen atom in the group (I). Citric and *trans*-aconitic acids fail to give the colour reaction with triphenylphosphine, but after short heating (pyrolysis) the test is given owing to the formation of methylmaleic anhydride. When triphenylphosphine reacts with maleic anhydride, a pale-coloured crystalline zwitterion (III) is formed together with a strongly coloured material probably of amorphous nature.

Tetrachlorobenzoquinone reacts with pyridine in presence of formic or acetic acid to form the red zwitterion (VII) and in presence of water to form the yellow-orange di-zwitterion (VIII). The latter is also formed by the action of pyridine and water on (VII) or tetrabromobenzoquinone.

Maleic Anhydride and Triphenylphosphine.—When a very dilute solution of maleic anhydride is treated at room temperature with a few drops of a solution of triphenylphosphine in chloroform, a permanent orange-red colour is immediately produced. This is as far as we know the only sensitive colour test for maleic anhydride. Very minute traces can be detected under the microscope.

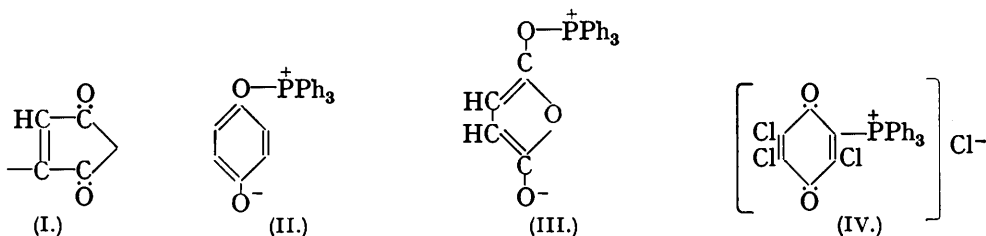
Similar colour reactions, in some cases less sensitive and occurring only in boiling chloroform, are observed with monosubstituted derivatives of maleic anhydride, *e.g.*, citraconic (methylmaleic), monochloromaleic, phenylmaleic and *cis*-aconitic anhydrides. The colour test is also shown with maleanil (Anschütz and Wirtz, *Annalen*, 1887, **239**, 141; Auwers and Schleicher, *ibid.*, 1899, **309**, 346). On the other hand, no colour is

developed with the disubstituted derivatives and the other substances, related in some way to maleic anhydride, named in group A (p. 1377).

Dry solid itaconic anhydride (unlike solid maleic anhydride) does not give a colour reaction with triphenylphosphine powder, but in solution the colour test is positive owing to isomerisation of the anhydride to citraconic anhydride, catalysed by the presence of a basic substance (Pfeiffer and Böttler, *Ber.*, 1918, 51, 1819).

Citric acid and *trans*-aconitic acid give no reaction with triphenylphosphine, but if they are heated above their melting points for a short time and are then treated with triphenylphosphine solution, intense violet-red colours are immediately produced owing to the formation of citraconic and itaconic anhydride respectively.

Formation of the Phosphorus Betaine (III).—When triphenylphosphine and maleic anhydride react in benzene solution at room temperature, a deposit separates which consists partly of almost colourless crystals and mostly of a brown, apparently amorphous solid. The latter substance forms a reddish-brown solution in chloroform and is responsible for the colour reaction described above; it yields triphenylphosphine on heating, but its constitution has not yet been elucidated. The crystalline substance is given the formula (III), its constitution being based on the fact that a substance (II) of similar behaviour and mode of preparation is obtained from *p*-benzoquinone and triphenylphosphine (Schönberg and Michaelis, *Ber.*, 1936, 69, 1080). The analogous behaviour of *p*-benzoquinone and maleic anhydride towards triphenylphosphine is another indication of the close relationship between the two (compare Pfeiffer and Böttler, *loc. cit.*).



p-Benzoquinone and Triphenylphosphine.—When a very dilute solution of *p*-benzoquinone is treated at room temperature with a few drops of a solution of triphenylphosphine in chloroform, a reddish-brown colour is immediately produced. Similar colour reactions, in some cases less sensitive and occurring only in boiling chloroform, are given by the quinone derivatives named on p. 1377. No colour is developed by the compounds in group B (p. 1377), which also includes some other substances, more or less related to *p*-benzoquinone, none of which contains the characteristic group (I). From these facts the conclusion may be drawn that the colour reaction is normally not shown by *p*-benzoquinone derivatives in which all the hydrogen atoms are substituted. However, a colour reaction is given by the tetrahalogeno-derivatives (*e.g.*, chloroanil and bromoanil), possibly owing to the formation of a substance such as (IV). A corresponding substance cannot be formed from, *e.g.*, triphenylphosphine and tetramethyl-*p*-benzoquinone on account of the stability of the methyl groups.

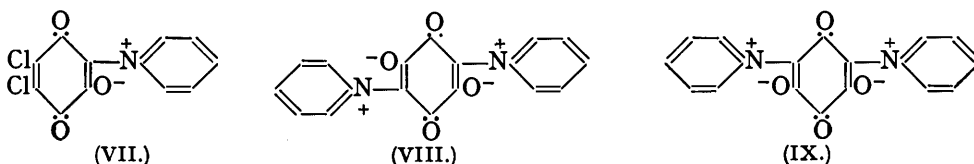
Theory of the Colour Test.—The fact that wholly substituted derivatives of maleic anhydride and *p*-benzoquinone, with the exception of chloroanil and bromoanil, do not show the colour reaction may be due either to steric hindrance or to the absence of the characteristic group (I).

Not all partially substituted derivatives of *p*-benzoquinone show the colour reaction. It is not given by 2 : 5-dimethoxy- and 2 : 5-diethoxy-*p*-benzoquinone, but these substances are known to behave differently from *p*-benzoquinone in other cases (Erdtman, *Proc. Roy. Soc.*, 1933, A, 143, 181; Schwechten, *Ber.*, 1931, 64, 971). If a substance of unknown structure (containing no halogen) gives the colour test with triphenylphosphine, the presence of the group (I), when forming a part of a quinonoid ring system, may be assumed. If the colour test is negative, no conclusion can be drawn with regard to the above-mentioned group.

Formation of Zwitterions by the Action of Pyridine on Halogenated p-Benzoquinones.—The hypothesis of the formation of a substance such as (IV) by the action of triphenylphosphine on chloroanil or bromoanil is based, *inter alia*, on the action of pyridine on 2 : 3-dichloro- α -naphthaquinone in the presence of water. In the latter reaction, according to Ullmann and Ettisch (*Ber.*, 1921, 54, 259), the compound (V) is first formed and then, under the influence of water or alcohol, is acted upon by the excess of pyridine in its capacity as a base with the formation of (VI; formulated with quinquevalent nitrogen in the original publication).



We have observed that, if chloroanil is acted upon with pyridine in the presence of formic or acetic acid, a red substance is produced which has already been obtained in a slightly different way by Imbert (*Compt. rend.*, 1901, 133, 162, 233, 633), to which he assigned the formula $C_5H_4N \cdot C_6Cl_2O_2 \cdot OH$ (*ibid.*, p. 939), indicating a hydroxyl group and only four hydrogen atoms attached to the pyridine ring. We assign to the red substance the formula (VII), analogous to (VI). This analogy is based on the fact that both substances are formed under similar conditions and show great similarity in properties. Ullmann has shown that (VI) yields pyridine when oxidised with potassium permanganate; the same is the case with the red betaine. Pyridine is also obtained easily when the red betaine is treated with alkali, *e.g.*, sodium carbonate solution (compare the formation of pyridine from benzylpyridinium chloride by sodium sulphide; Snyder and Speck, *J. Amer. Chem. Soc.*, 1939, 61, 2895). The ready formation of pyridine excludes the possibility that the pyridine residue is attached to the six-membered carbon ring by means of a C-C linkage.



When chloroanil, bromoanil or the red betaine (VII) is acted upon directly with pyridine and water, a yellow-orange crystalline substance is obtained which we regard as the di-zwitterion (VIII); formula (IX) is believed to be improbable [compare the formation of 3 : 6-dichloro-2 : 5-diaminobenzoquinone from chloroanil and alcoholic ammonia (Laurent, *Annalen*, 1844, 52, 347; v. Knapp and Schultz, *ibid.*, 1881, 210, 183)]. Substance (VIII) yields pyridine easily on oxidation with potassium permanganate and with difficulty on treatment with alkali hydroxide.

EXPERIMENTAL.

In the following experiments, except where otherwise stated, the solvent was chloroform and the colour tests were carried out at about 20° in tubes 0.7 cm. in diameter. The colours developed are given in parentheses. The sensitivities recorded could be largely increased by increasing the length of the coloured layer and by using optical measurements.

Spot Tests.—A crystal of maleic anhydride or *p*-benzoquinone, when treated with a drop of a 20% solution of triphenylphosphine (Dodonow and Medox, *Ber.*, 1928, 61, 907; now obtainable from British Drug Houses), immediately turned orange-red or reddish-brown respectively. Quantities too small to be weighed by an analytical balance were clearly detectable under the microscope. The same applies to methylmaleic anhydride (red), chloromaleic anhydride (wine-red), toluquinone (orange-red), 2 : 6-dichlorobenzoquinone (red-brown), trichlorobenzoquinone (wine-red), tetrachlorobenzoquinone (red), and tetrabromobenzoquinone (red).

When a crystal of triphenylphosphine was added to a solution of itaconic anhydride, an immediate violet-red colour was developed (reddish-violet with microscopic quantities).

Reaction in the Absence of a Solvent.—When triphenylphosphine was ground with maleic anhydride, the mixture became orange-red after a few minutes. In another experiment the two solids were placed apart over calcium chloride in a desiccator; the triphenylphosphine crystals became superficially orange-red in a few hours (more rapidly when warm) and the maleic anhydride crystals gradually diminished in size.

A powdered mixture of triphenylphosphine and thymoquinone quickly developed an intense red colour at 35° (less rapidly at the ordinary temperature).

Detection of Substances in Solution.—*Maleic anhydride.* When 2 drops (0.02 c.c.) of 0.19 M-maleic anhydride (*i.e.*, 0.00037 g.) were added to 0.25 c.c. of a 20% solution of triphenylphosphine, a permanent orange-red colour was immediately produced.

Maleic anhydride derivatives. A few crystals of triphenylphosphine (0.01–0.03 g.) were added to 0.5 c.c. of a concentrated solution of each of the following substances: freshly distilled methylmaleic anhydride (immediate orange, changing to deep violet-red), chloromaleic anhydride (immediate deep orange, changing quickly to wine-red), phenylmaleic anhydride (immediate deep yellow). With *cis*-aconitic anhydride (deep red) and maleanil (deep orange-red), the colours were produced when the triphenylphosphine crystals were added to their boiling solutions in benzene or chloroform.

Triphenylphosphine. When 4 drops (0.04 c.c.) of 0.038M-triphenylphosphine (*i.e.*, 0.0004 g.) were added to 1 c.c. of 0.038M-maleic anhydride, an intense orange-red colour was immediately produced.

p-Benzoquinone. Four drops (0.04 c.c.) of 0.19 M-*p*-benzoquinone (*i.e.*, 0.0008 g.), added to 0.25 c.c. of a 20% solution of triphenylphosphine, immediately produced a permanent reddish-brown colour.

p-Benzoquinone derivatives. An orange-red, red or reddish-brown colour, partly depending on the concentration (sometimes it was necessary to boil the solution), was immediately developed with toluquinone, 2 : 3-dimethyl-, 2 : 5-dimethyl-, 2-methyl-5-isopropyl-, 2 : 6-dichloro-, trimethyl-, and trichloro-benzoquinone, 6-hydroxy-4-methoxy-2 : 5-toluquinone (Anslow, Ashley, and Raistrick, *J.*, 1938, 439), chloroanil (crystallised six times from toluene to ensure its freedom from other chloro-quinones), and bromoanil. The colour reaction was less sensitive with α -naphthaquinone, where a reddish-brown colour was formed, which changed to green with the separation of green-yellow crystals. With 2-hydroxy- α -naphthaquinone, in boiling chloroform, a reddish-brown colour was obtained.

Substances showing no Colour Reaction with Triphenylphosphine.—*Group A.* Dimethyl-, dibromo-, diacetoxy- and diphenyl-maleic anhydrides, maleic acid and its dimethyl ester, fumaric acid, citraconic acid, *trans*-aconitic acid and its anhydride (Malachowski, Giedroyc, and Jermanowska, *Ber.*, 1928, 61, 2532), succinic anhydride, phthalic anhydride, anthracene-9 : 10-*endo*- $\alpha\beta$ -succinic anhydride (Clar, *Ber.*, 1931, 64, 2198), citric acid, dibenzylideneacetone, and *cis*- and *trans*-dibenzoyl ethylene. In all these cases the test was negative even in highly concentrated solutions, in the cold or on boiling, in the dark or in diffuse sunlight. For the substances slightly soluble in chloroform, the test was also tried in alcoholic or benzene solution.

Group B. Tetramethylbenzoquinone, 2-hydroxy-3-methyl-, 2-hydroxy-3-ethyl-, and 2 : 3-dichloro- α -naphthaquinone, anthraquinone (tested also in benzene), phenanthraquinone, quinol, tetrachloroquinol, and 2 : 6-dimethyl- γ -pyrone.

*Formation of the Phosphorus Betaine (III).**—A solution of 4.5 g. of maleic anhydride in 160 c.c. of thiophen-free benzene (dried over sodium) was treated with 12 g. of triphenylphosphine in 200 c.c. of the same solvent; the mixture soon became yellow, then orange, and finally brown. The vessel was tightly closed to prevent oxidation of triphenylphosphine and left in the dark. After 24 hours a partly crystalline solid had formed. After 80 hours the deposit (14 g.) was removed and washed with cold benzene. It consisted of a mixture of pale yellow crystals and a brown amorphous solid. It was boiled for 10 minutes with 250 c.c., then with 150 c.c., of dry benzene and the two extracts were mixed and kept at room temperature (20°) for 24 hours; 2.8 g. of a pale yellow, crystalline solid separated and a further 0.6 g. was obtained by concentrating the mother-liquor to 50 c.c. in a vacuum and keeping it for 3 hours. Recrystallisation from benzene or by addition of ether to a chloroform solution gave pale yellow (almost colourless) needles of the *betaine*, *m. p.* about 160° (decomp.), freely soluble in cold chloroform, soluble in hot methyl and ethyl alcohol, difficultly soluble in ether and benzene

* This substance was synthesised by Dr. Robert Michaelis and the senior author.

(Found: C, 73.3, 73.5; H, 4.9, 4.9; P, 8.5, 8.5. $C_{22}H_{17}O_3P$ requires C, 73.3; H, 4.8; P, 8.6%).

The residual brown amorphous product was purified by three extractions with dry benzene (100 c.c.). A purified sample (0.5 g.) was heated in a stream of dry carbon dioxide. At about 250° (bath temperature) a colourless liquid distilled which soon crystallised. Heating was continued at 320° for 20 minutes. The product (0.12 g.) was triphenylphosphine, as shown by a mixed m. p. determination and the colour test with maleic anhydride.

Action of Pyridine on Tetrahalogenated p-Benzoquinones.—Formation of the red betaine (VII). A solution of chloroanil (7 g.) in 200 c.c. of boiling chloroform was treated gradually with 4.3 g. of glacial acetic acid and then with 4.5 g. of pyridine, whereby an intense red colour was developed. After 20 minutes a red deposit separated. Boiling was continued for 3 hours. The product, after being extracted twice with boiling toluene (to free it from chloroanil), twice with a small amount of boiling water, and washed with cold alcohol and with ether, crystallised from 50% acetic acid in long, deep red needles (5.6 g.), m. p. above 330°, soluble in hot acetic acid and nitrobenzene, slightly soluble in hot water and alcohol, very slightly soluble in cold alcohol and ether (Found: C, 49.0; H, 2.0; N, 5.2. Calc. for $C_{11}H_5O_3NCl_4$: C, 48.9; H, 1.9; N, 5.2%).

When formic acid (3.3 g.) was used instead of acetic acid in the above experiment, the same compound was formed in almost the same yield (Found: C, 48.9; H, 2.1; N, 4.9%).

Formation of the orange betaine (VIII). (a) Chloroanil (5 g.) was mixed with 60 c.c. of an aqueous solution containing 15 g. of pyridine and refluxed for 10–15 minutes. The brown crystalline product was washed with cold water, alcohol, and ether and recrystallised from boiling water, forming long orange-yellow prisms (2.1 g.), m. p. above 300°, practically insoluble in hot benzene, ether, carbon disulphide, pyridine and nitrobenzene, soluble in boiling water (Found: C, 61.6; H, 3.95; N, 9.1. $C_{16}H_{10}O_4N_2 \cdot H_2O$ requires C, 61.5; H, 3.85; N, 9.0%).

(b) When a mixture of 5 g. of chloroanil and 15 g. of dry pyridine was carefully heated, a vigorous reaction took place and a black viscous product was formed. After 10 minutes' heating, the excess of pyridine was decanted, water (15 c.c.) added, and the mixture boiled for a few minutes. The brown crystalline solid that separated was treated as in (a); yield, 1.8 g.

(c) Experiments (a) and (b) were exactly followed with 5 g. of bromoanil and 9.3 g. of pyridine [the reaction with dry pyridine in (b) was so vigorous that it occurred in the cold with a violent evolution of heat] and also with 2 g. of the red betaine and 5 g. of pyridine. The yields of the orange betaine were 1 g. and 1.1 g., respectively, in the first pair of experiments and 1 g. and 1.2 g. in the second pair (Found: C, 61.6; H, 3.9; N, 9.1%).

Action of Acetic Anhydride on the Orange Betaine.—0.5 G. of the finely powdered betaine (containing water of crystallisation) was refluxed with 5 c.c. of acetic anhydride for 2 hours. The yellow-orange product, which separated even while hot, was filtered off and washed several times with dry ether (yield, almost quantitative). It melted above 300° and its solubility in organic solvents was similar to that of the hydrate (Found: C, 64.9; H, 3.5; N, 9.9; CH_3CO , 0. $C_{16}H_{10}O_4N_2$ requires C, 65.3; H, 3.4; N, 9.5%).

The above anhydrous compound, when boiled with water for some minutes, dissolved. The hydrate $C_{16}H_{10}O_4N_2 \cdot H_2O$ separated on cooling (Found: C, 61.4; H, 4.0; N, 8.8%).

Pyridine from the Red and the Orange Betaine.—(a) The red betaine (0.9 g.) was (1) refluxed with 100 c.c. of 15% sodium carbonate solution for 1 hour, (2) refluxed with 100 c.c. of water and treated gradually with 5% potassium permanganate solution until no further discharge of colour occurred (about 22 c.c.). The mixtures were then steam-distilled, and the expelled pyridine identified in the form of the picrate (mixed m. p.) and roughly estimated as the chloride; the yield in (1) was 0.11 g. and in (2) 0.2 g.

(b) The orange betaine (0.3 g.) was refluxed with 250 c.c. of water and 37.5 g. of sodium hydroxide for 1 hour. Steam-distillation then gave a small yield of pyridine. 0.5 G. of the orange betaine, oxidised as described above (100 c.c. of water and 15 c.c. of 15% permanganate solution), gave 0.1 g. of pyridine.

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