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STUDIES ON TAUTOMERISM IV ¹⁾.

The complexes of 3-halogenobenzene-6-diazo-oxides with quinone monoximes (nitrosophenols) ²⁾ and some other complexes

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The nature of the product of m.p. 142°, formed during the nitrosation of *meta*-chlorophenol in neutral or weakly acidic medium, has been investigated. The view that it should be considered as a complex compound of equimolecular amounts of 3-chlorobenzoquinone-4-oxime (3-chloro-4-nitrosophenol) and 3-chlorobenzene-6-diazo-oxide is supported by the analytical data, by its formation from the components, by its behaviour during crystallization and by X-ray data. Moreover, many discrepancies in the literature find an obvious explanation and there are no longer difficulties such as arise in explaining the chemical behaviour of the substance when regarded as a tautomer of the 3-chloroquinone-monoxime (m.p. 184°). One of the possible reactions leading to the formation of the diazo-oxide is the diazotization of the corresponding nitroso-compound. The presence of 3-chlorobenzene-4-diazo-oxide amongst the nitrosation products of *meta*-chlorophenol is demonstrated. The nitrosation of *m*-bromophenol is shown to give products completely analogous to the chloro-compounds. Finally, the formation of some characteristic complexes, in which diazo-oxides take part, are discussed. The conclusion is reached that the 3-halogeno-4-nitrosophenols (3-halogeno-benzoquinone-4-oximes) now fit in smoothly with the other nitrosophenols.

In the preceding paper it has been proved that the product (m.p. 142°), obtained by nitrosation of *meta*-chlorophenol in neutral or weakly acid media, consists of 3-chlorobenzoquinone-4-oxime (m.p. 184°) and 3-chlorobenzene-6-diazo-oxide (m.p. 124°). Generally, small amounts of decomposition products of the diazo-oxide are also found to be present.

When discussing the nature of the product under investigation, the possibility that it might simply be a mixture of the two components, had soon to be discarded. The product can be recrystallized unchanged

¹⁾ Preceding paper of this series: A. Kraaijeveld, E. Havinga, this vol., p. 537.

²⁾ For the nomenclature used, compare l.c. ¹⁾ note ⁸⁾.

from aqueous methanol in spite of the fact that the solubility of the diazo-oxide in this solvent is much greater than that of the quinone monoxime.

We should not overlook the possible formation of mixed crystals which might well also take place in this system, if only to a small extent. One feels inclined, however, to consider the product to be a molecular complex, having a well-defined and constant composition.

The results of the micro-elementary analysis ³⁾ were consistent with a 1 : 1 ratio of the component molecules.

Calc. for $C_6H_4O_2NCl \cdot C_6H_5ON_2Cl$: C 46.15, H 2.24, N 13.46, Cl 22.76 %.

Found: " 46.36, " 2.29, " 13.25, " 22.68 %.

Moreover, chromatographic separations were performed with amounts of 0.5 g, as described in the preceding paper, the components being recovered as completely as possible; the data obtained also indicated a 1 : 1 ratio.

Composition calculated: diazo-oxide 49.5 %; quinone oxime 50.5 %.

Found by recovery (3 exp.) " 48.0 %; " " 47.0 %.

" 47.6 %; " " 48.7 %.

" 48.1 %; " " 48.4 %.

Finally, the fact should be stressed, that the nitrosation product of m.p. 142° could easily be reconstituted by crystallizing an equimolecular mixture of chlorobenzoinone oxime and chlorobenzene diazo-oxide from aqueous methanol.

Before concluding, however, that the assumption of an equimolecular complex is valid, we should consider the fact that our preliminary studies suggested the chloroquinone monoxime to be the main component ⁴⁾. In one case a content of approx. 80 % even was tentatively estimated from counter-current analysis ⁵⁾.

At present, the explanation is obvious since we know the lability of the other constituent, the chlorobenzene diazo-oxide, when exposed to daylight. Unless special precautions are taken, part of the diazo-oxide decomposes during recrystallization. In this procedure the strongly coloured decomposition products are adsorbed on the activated carbon to obtain a clean yellow product. The excess of quinone oxime crystallizes with the complex, their solubilities being comparable. It could be observed under the melting microscope, that part of such a product decomposed around 140°, the rest (excess of chlorobenzoinone) keeping the form of clearly distinct needles up to 170—180°).

³⁾ Microanalyses are by Mr. P. J. Hubers, Laboratory of Organic Chemistry Municipal University of Amsterdam.

⁴⁾ E. Havinga, A. Schors, Rec. trav. chim. 70, 59 (1951).

⁵⁾ A. Schors, Thesis, Leiden (1950).

⁶⁾ E. Havinga, A. Schors, Rec. trav. chim. 69, 457 (1950).

Chloro-nitro-sophenol	Complex
1.51 s	1.25 s 1.50 m 1.90 m
2.03 m 2.13 m	2.19 m
2.29 w 2.40 m	2.44 m*) 2.80 ss
2.80 ss 2.90 ww	2.98 m
3.09 m	3.19 m 3.34 m
3.48 m	3.53 m
3.70 s	3.81 m
3.91 w 4.18 s	4.22 m 4.71 w
4.83 m	4.94 m 5.13 w
5.13 m 5.30 m	5.34 m 5.46 m 5.57 m
5.64 m	5.75 ww
5.84 m	5.94 ww
6.00 w 6.10 m	6.12 ww

*) This line is very broad and may be not single.

Table I. s = strong, m = medium, w = weak

The results of the analyses (cf. l.c. ⁶), p. 467) carried out before the true nature of the low melting product was recognized, also support the view given here.

In order to demonstrate the effect under consideration carried to an extreme, a concentrated solution of the complex in methanol was exposed to diffuse daylight at room temperature for one day. The dark red solution was then slightly warmed after addition of some water and activated carbon and filtered. From the now purely yellow solution only 3-chlorobenzoquinone oxime crystallized (m.p. 184°), the diazo-oxide evidently having suffered almost complete decomposition⁷). As a further check, two parts of diazo-oxide and one part of oxime were crystallized after admixture, yielding the complex melting at 142° in a pure state. The excess of diazo-oxide had remained in solution. When, on the other hand, one part of diazo-oxide was combined with two parts of the oxime, only part of the product obtained after crystallization melted at ~ 142°, about one third of it seemingly consisting of uncombined chloroquinone oxime.

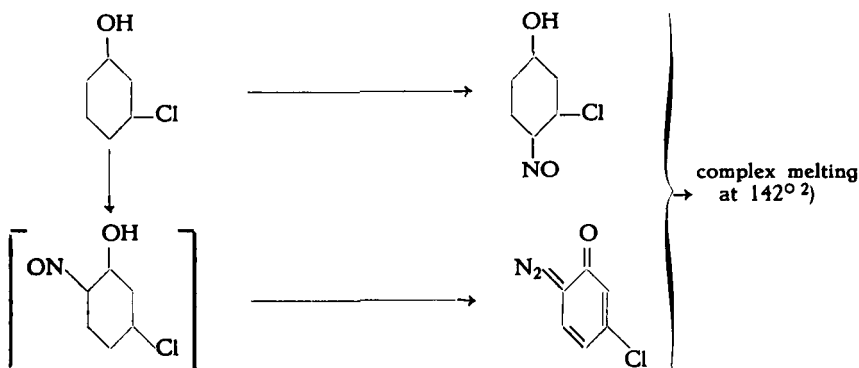
In order to corroborate the view that intermolecular binding exists between the two components in the complex, X-ray powder diagrams of 3-chlorobenzoquinone-4-oxime (m.p. 184°) and its complex with 3-chlorobenzene-6-diazo-oxide (m.p. 142°) were taken. As can be seen in table I the two preparations show clearly different spacings

⁷) These experiments and considerations may also afford an explanation for the fact that Mme *Ramart-Lucas* and *Martynoff* — contrary to other investigators — report a rise in melting point upon recrystallization of the low-melting product from benzene, finally resulting in the high-melting chlorobenzoquinone oxime. (Bull. soc. chim. France (5) 15, 579 (1948)). The French authors, however, report a melting point of 210°, which is considerably higher than the value given by *Hodgson* et al. and by ourselves; compare, however, *H. H. Hodgson*, *F. H. Moore*, J. Chem. Soc. 123, 2499 (1923).

and intensities, several lines of the quinone oxime not being found in the complex. (Compare also l.c.⁵), page 63).

Summarizing, all the evidence available at present supports the conclusion that the much discussed product of m.p. 142° is an equimolecular complex compound of 3-chlorobenzene-6-diazo-oxide and 3-chlorobenzoquinone-4-oxime (or 3-chloro-4-nitrosophenol). This substance should probably be placed in the class of molecular addition compounds like the well known picrates.

Formally, we may describe the formation of this complex during the reaction of *meta*-chlorophenol with nitrous acid by the following scheme:



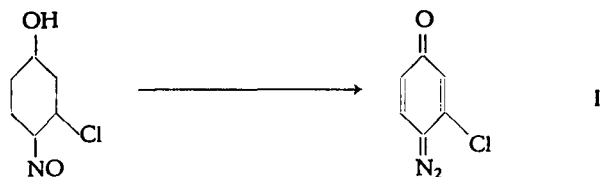
This scheme implies the "diazotization" of a nitroso-group. The possibility of such a reaction came to our attention by a few older publications⁸⁾. In order to check this possibility we diazotized nitrosobenzene with nitrite in aqueous acid solution and coupled the product with alkaline β -naphthol solution; benzene-azo- β -naphthol was obtained in a 95% yield. Moreover subsequent closer inspection of the literature revealed that this reaction had been fully described by Bamberger^{9a)}, whilst a kinetic study was made by Westheimer c.s.^{9b)}.

From the data mentioned, it follows that one should expect also the formation of 3-chlorobenzene-4-diazo-oxide (I) during the nitrosation of *meta*-chlorophenol:

⁸⁾ C. Jaeger, Ber. 8, 894 (1875); M. Ikuta, Ann. 243, 282 (1888); H. H. Hodgson, J. Chem. Soc. 133, 1494 (1931).

^{9a)} E. Bamberger, Ber. 30, 508 (1897); 32, 217 (1899); 51, 634 (1918).

^{9b)} F. H. Westheimer, E. Segel, R. Schramm, J. Am. Chem. Soc. 69, 773 (1947).



We therefore neutralized the mother liquor, obtained after removal of the crystallized nitrosation product (complex of m.p. 142°), with solid potassium carbonate and extracted with chloroform. The chloroform solution was dried and chromatographed over an aluminium oxide column, using chloroform as eluent. The solvent was removed from the yellow-red eluate by distillation under reduced pressure. The melting point of the residue (98° , decomposition) differed considerably from the melting point (118° , decomposition) of the 3-chlorobenzene-4-diazo-oxide, synthesized by diazotization of 3-chloro-4-aminophenol or of 3-chloro-4-nitrosophenol. The ultraviolet spectra revealed, however, that 3-chlorobenzene-4-diazo-oxide was undoubtedly present, probably contaminated with some 6-diazo-oxide (fig. 1).

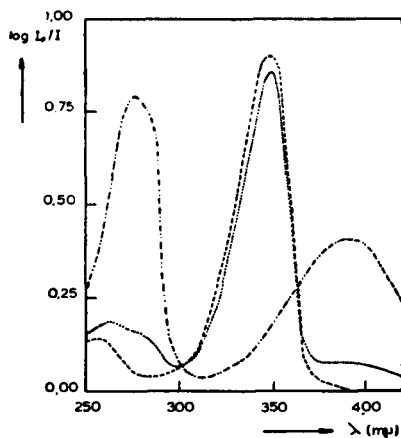


Fig. 1. Spectra of aqueous solutions of 3-chloro-benzene-6-diazo-oxide (---), 3-chloro-benzene-4-diazo-oxide (-.-.-) and the product of m.p. 98° isolated from the mother liquor (....).

We therefore chromatographed the residue once more, this time using Whatman paper no. 1 as an adsorbent and water containing 15 % of methanol as eluent. The product was indeed found to consist of two components, of which the R_f -values, 0.8_8 and 0.7_8 respectively, were identical with the R_f -values determined for pure 3-chlorobenzene-4-diazo-oxide and 3-chlorobenzene-6-diazo-oxide.

Therefore, it is fairly certain that small amounts of 3-chlorobenzene-4-diazo-oxide are also formed in the nitrosation process of *meta*-chlorophenol. One of the reasons why this compound has not been detected earlier, seems to be that it does not form very stable complexes with chloronitrosophenol in the way its 6-isomer does. We checked this by crystallizing a mixture of equal amounts of the 4-diazo-oxide and the nitrosophenol from aqueous methanol. Indications were found for the formation of a complex melting at about 130°, which, however, was unstable to such an extent that recrystallization yielded the pure nitrosophenol only (m.p. 183°).

3-Chlorobenzene-6-diazo-oxide is not alone in showing a tendency towards forming addition complexes; the 3-bromo-isomer displayed a comparable behaviour. Thus, upon nitrosation of *meta*-bromophenol according to the procedure of Hodgson and Moore¹⁰), a product is obtained melting at 142—145° after crystallization from aqueous methanol. This product, which is evidently fairly stable, behaved like the low-melting nitrosation product of *m*-chlorophenol. It could be separated by chromatography into 3-bromoquinone monoxime (m.p. 194°) and the hitherto unknown 3-bromobenzene-6-diazo-oxide (m.p. 123—125°). The latter has an absorption spectrum very similar to that of the chloro-compound; there is a shift of only a few $m\mu$ towards the red in the wavelengths of the maxima and the minimum. The structure could be proved by synthesis from 3-bromo-6-aminophenol and comparison of the synthetic compound (m.p. 123—126°) with the isolated substance (identity of the ultra-violet spectrum, no depression of the mixed melting point). Moreover a complex could be synthesized by crystallizing equal amounts of 3-bromoquinone-4-oxime and 3-bromo-6-diazo-oxide from aqueous methanol. The melting points obtained after three successive crystallizations: 148—150°, 146—148° and 146—148°, respectively, indicated that the complex was fairly stable.

We should like to make a few remarks on the nitrosation of 3-halogenophenols in general. Our own experience with 3-chlorophenol led us to the assumption that in a weakly acid or neutral medium quantities of the same order of 4- and 6-derivatives are formed. In a strong sulphuric acid medium the 4-position seems to be favoured, however. The difference might be explained by assuming that in a weakly acid solution it is the phenolate ion predominantly that is being nitrosated while in sulphuric acid the reaction occurs via the undissociated phenol. Assuming that in the nitrosation reaction the attacking agent is positively charged (NO^+), the electrostatic attraction between this agent and the negative oxygen of the phenolate might be the cause of the fact that the transition state for *ortho*-

¹⁰) H. H. Hodgson, F. H. Moore, J. Chem. Soc. 127, 2260 (1925).

substitution is relatively less unfavourable in weakly acid solutions. Semi-quantitative evaluations give a reasonable value for the magnitude of this effect.

Considering the other halogeno-compounds, the behaviour of *m*-bromophenol suggests a tendency to react somewhat more easily at the 4-position. This tendency seems to prevail more strongly in the case of *m*-iodophenol, where *Hodgson* and *Moore*¹¹⁾ obtained only the "high melting" nitrosation product (3-iodobenzoquinone-4-oxime). On the other hand, 3-fluorophenol was found to yield exclusively a 6-derivative upon nitrosation¹¹⁾. This change from a preference for the 6-nitrosation to that of predominant 4-substitution in the sequence *meta*-fluoro-, -chloro-, -bromo-, -iodophenol has analogies in other electrophilic substitution reactions. As a classical example, we may cite the nitration of the halogenobenzenes where the following percentages of *para*-substitution have been reported¹²⁾: F: 87.6, Cl: 69.9; Br: 62.4, I: 58.7.

The 3-chloro-(and 3-bromo-)6-diazo-oxides were found to have a remarkable capacity for complex formation in general. Besides the complexes discussed above we may further mention as examples:

3-chlorobenzene-6-diazo-oxide + 3-bromoquinone-4-oxime; m.p. 146°;
3-chlorobenzene-6-diazo-oxide + 2-chloroquinone-4-oxime; m.p. 122°;
3-chlorobenzene-6-diazo-oxide + picric acid; decomp. 150°.

The latter complex brings us back to some of the peculiarities of the nitrosation products of *meta*-chlorophenol that originally aroused our interest. The fact that the low-melting product yields an addition complex with picric acid, whereas the high-melting one fails to do so¹³⁾, can now be understood as being due to the presence of the diazo component. Actually the diazo-oxide-picric acid complex was prepared by us from the nitrosation product (m.p. 142°) in a 40 % yield, which is almost exactly half the yield (84 %) we obtained starting from pure chlorobenzene-diazo-oxide. Evidently, under these circumstances a picrate of the quinone monoxime is either formed hardly at all or its tendency to crystallize is too small.

On the other hand, the 3-chlorobenzoquinone-monoxime yields an addition complex with urea, which is not given by the low-melting product¹³⁾. This also finds a logical explanation on the basis of our view that the latter is a very stable complex of the oxime with chlorobenzene diazo-oxide. The complex of chloroquinone oxime with urea was found to yield the quinone oxime (m.p. 184°) only upon recrystallization from aqueous methanol, demonstrating that the urea complex is less stable than the diazo-oxide complex. The first complex will not be formed therefore to any appreciable extent from the latter, i.e. from the low-melting nitrosation product.

¹¹⁾ H. H. Hodgson, D. E. Nicholson, J. Chem. Soc. 1939, 1405.

¹²⁾ A. F. Holleman, Chem. Revs. 1, 192 (1924).

¹³⁾ H. H. Hodgson, J. Chem. Soc. 133, 1494, 2227 (1931).

It may be concluded, that the at first sight rather puzzling phenomena in this field, no longer offer essential difficulties in understanding. We recall in this connection — besides the addition complex formation discussed above — also the different behaviour of the two nitrosation products with respect to "diazo" reactions, the discrepancies between various authors on the subject of the transformation of the low-melting into the high-melting product by repeated crystallization from organic solvents, the difficulties in the nitrogen analysis of the low-melting product ⁶⁾, its sensitivity to light and its spectral anomalies. With regard to the latter phenomena, it is now possible to explain why the long wavelength absorption (around 400 m μ) of the nitrosophenols which in general could be suppressed by acidification, is, at least partly, persistent in acidic solutions of the low-melting nitrosation product (see l.c. ⁶⁾, Fig. 5). The long wave-length absorption of the latter compound is not only due to the presence of phenolate ions but also to the diazo compound. This reasoning also explains the difficulty pointed out by *Anderson* and *Yanke* ¹⁴⁾ that the absorption spectrum of this "nitrosophenol" does not resemble the spectrum of its methyl ether. The same applies to the fact that *Mme Ramart-Lucas* and *Martynoff* ¹⁵⁾ found a " β -form" absorption with solutions in ether, where any appreciable ionisation can hardly be expected.

It seems therefore that the tautomerism of the 3-halogenoquinone-4-oximes (3-halogeno-4-nitrosophenols) is no longer afflicted with some strange peculiarities and discrepancies. Its problems have become similar to those concerning the tautomerism of other nitrosophenols. In our next publication we propose to make some remarks on these problems in general.

Acknowledgements.

The authors wish to express their gratitude to Dr. C. *Romers* for advice and help with the X-ray examination and to Mr. J. N. *Leget* for valuable assistance, especially in the quantitative chromatographic analysis of the complex chloro-compound.

Experimental ¹⁷⁾.

1. Synthesis of diazo-oxides.

a. 3-Chlorobenzene-6-diazo-oxide: for the synthesis see preceding paper ¹⁾, experimental part no. 3.

¹⁴⁾ L. C. *Anderson*, R. L. *Yanke*, J. Am. Chem. Soc. 56, 732 (1934).

¹⁵⁾ P. *Ramart-Lucas*, M. *Martynoff*, Bull. soc. chim. France (5) 15, 571 (1948).
P. *Ramart-Lucas*, M. *Martynoff*, Bull. soc. chim. France (5), 16, 53 (1949).

¹⁷⁾ Melting points are uncorrected.

b. **3-Chlorobenzene-4-diazo-oxide** was prepared from 3-chloro-4-aminophenol in a way analogous to the synthesis of the 6-diazo-oxide mentioned above; yield 70%. Yellow brown needles from benzene, melting at 117—119° (decomposition).

Analysis:

Calc. for $C_6H_3ON_2Cl$: C 46.60, H 1.94, N 18.12, Cl 22.98.

Found: ,, 46.96, ,, 2.11, ,, 18.09, ,, 22.98.

c. The latter compound was also obtained from 3-chloro-4-nitrosophenol²⁾. 0.3 g of this compound was suspended in a mixture of 15 ml of acetic acid, 15 ml of dioxan and 15 ml of water, and a solution of sodium nitrite in water was added to the well stirred suspension cooled in ice. After the diazotization, the reaction mixture was neutralized with solid potassium carbonate and the diazo-oxide was extracted with chloroform. The extract was passed through an aluminium oxide column from which the diazo-oxide was eluted with chloroform. The resulting solution was evaporated to dryness. The residue was identical (melting point, absorption spectrum) with the product synthesized according to b). The low yield (30 %) may be due to the low solubility of the nitrosophenol; the diazotization proceeded very slowly.

d. **3-Bromobenzene-6-diazo-oxide** was synthesized from 3-bromo-6-aminophenol in the way described for the chloro-compound (sub a). M.p. 123—126° (decomposition).

Analysis:

Calc. for $C_6H_3ON_2Br$: C 36.18, H 1.51, N 14.07, Br 40.20.

Found: ,, 36.85, ,, 1.83, ,, 14.48, ,, 40.20.

The absorption spectrum in water is almost identical with that of the chloro-analogue (fig. 4 of the preceding paper): maxima at 282 and 391 m μ , a minimum at 318 m μ .

2. Complexes:

a. The complex **3-chloro-4-nitrosophenol²⁾ : 3-chlorobenzene-6-diazo-oxide** (i.e. the "low-melting" product of nitrosation of *m*-chlorophenol) was obtained by direct nitrosation as described in the preceding paper. It was also prepared by crystallizing a mixture of equal parts (equimolecular amounts) of the components from methanol-water in a way identical with that described for the purification of the nitrosation products (l.c.¹⁾, experimental part no. 1).

b. The complex **3-bromo-4-nitrosophenol²⁾ : 3-bromobenzene-6-diazo-oxide** was prepared in the same way as the chloro-analogue. The yield, obtained by direct nitrosation (Hodgson and Moore¹⁰⁾) was lower than in the case of the chloro-derivatives, while an attempt to work according to the indications of Hodgson and Nicholson¹⁸⁾ proved unsuccessful. On the other hand, the formation by crystallization of a mixture of the components proceeded smoothly. M.p. of the complex 148°.

c. The complexes of **3-chlorobenzene-6-diazo-oxide** with 3-bromo- and with **2-chloro-4-nitroso-phenol** were also obtained by crystallizing equimolecular mixtures of the components from aqueous methanol. M.p.'s 145—146° and 121—122° respectively.

d. The **picrate** of **3-chlorobenzene-6-diazo-oxide** was obtained strictly according

¹⁸⁾ H. H. Hodgson, D. E. Nicholson, J. Chem. Soc. 1939, 1808.

to *Hodgson's* directions¹³). In agreement with the expectation that the yield could not be higher than 49.5 %, calculated on the nitrosation product used, our yield was only 41 %. Starting from isolated pure 3-chlorobenzene-6-diazo-oxide, a 84 % yield was obtained in the form of yellow plates melting under decomposition between 145–150° (*Hodgson* 151°).

e. The complex of **3-chloro-4-nitrosophenol and urea** was obtained in the way described by *Hodgson*¹³), from the components in alcoholic solution. M.p. 157–158°.

Analysis:

Calc. for $C_7H_5O_3N_3Cl$ C 38.62, H 3.68, N 19.31, Cl 16.32.

Found: ,, 38.78, ,, 3.59, ,, 19.36, ,, 15.97.

It dissociated during an attempt to recrystallize the complex from aqueous alcohol. M.p. of the recovered product 183–184°.

f. No urea complex was obtained by mixing **urea** and the complex **3-chloro-4-nitrosophenol : 3-chlorobenzene-6-diazo-oxide** and crystallizing from methanol. The recovered product was identical with the diazo-oxide complex (m.p. 138–140°; 141–142° after crystallization from aqueous methanol).

3. Diazotization of nitrosobenzene:

0.43 g of nitrosobenzene (0.004 moles) were dissolved in a mixture of 9 ml (0.15 moles) of acetic acid and 2 ml of water. The addition of water was necessary to prevent freezing on cooling down to 0°. In the course of 15 minutes 1.12 g of sodium nitrite (0.016 moles), dissolved in 5 ml water, were added and the mixture was left by itself for another 15 minutes. Then it was slowly added to a solution of 0.60 g (0.004 moles) of β -naphthol and 6.0 g (0.15 moles) of sodium hydroxide in 50 ml water. The reaction was carried out under cooling in ice. The precipitate was filtered and recrystallized from ethanol. Yield: 95 %. M.p. 134°.

The products were chromatographed on an aluminium oxide column, using carbon tetrachloride as solvent and eluent. When less than 3 moles of nitrite per mole nitrosobenzene were used, the chromatogram showed a blue band of nitrosobenzene, moving faster than the orange-red one of the azo-dye. In this case the precipitated products were tarry and not pure after one crystallization from ethanol. When, however, 3 or more moles were used, the blue band was not observed and the products were not tarry.

Instead of using acetic acid as solvent and medium for the diazotization, this reaction can also be carried out in aqueous hydrochloric acid, the nitroso-compound being dissolved by the addition of dioxan.

4. X-ray diagrams:

The diagrams of 3-chloro-4-nitrosophenol²) and of the complex of the latter compound with 3-chlorobenzene-6-diazo-oxide were made with a Debye-Scherrer camera, the finely powdered samples being kept in small capillaries. Pure 3-chlorobenzene-6-diazo-oxide, however, could not be powdered sufficiently. In this case an Astbury quadrant camera was used. The sample prepared from 3-chloro-6-aminophenol and the one obtained from the product of nitrosation showed the same spacings, proving the identity of the products.

5. **Ultra-violet absorption spectra** were measured with a Beckman quartz spectrophotometer, model D.U.; 1 cm cells were used.

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