320. *The Iodous Cation as an Agent for Aromatic Substitution.*

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In concentrated sulphuric acid, yellow crystalline iodyl sulphate I_2O_3,SO_3 (which is easily made; see following paper) rapidly attacks nitrobenzene, giving a 50—60% yield of *m*-iodosonitrobenzene. This is the first time that the iodoso-group has been directly substituted for aromatic hydrogen. Benzenesulphonic acid similarly gives iodosobenzenesulphonic acid, and benzoic acid is likewise attacked, though with complications. These results are compared with those produced by the same reagent's action upon benzene derivatives with *op*-directing substituents, which gave quantitative yields of the diaryliodonium radical, with para-orientation (Masson and Race, J., 1937, 1718). The reactions are explained as ionic exchanges, involving the ions IO^+, I^{+++}, RI^{++} (of iodoso-salts) and R_2I^+ (iodonium), primarily $I^{+++} + RH \longrightarrow RI^{++} + H^+$, which when a *m*-directing substituent is present stops there; with an *op*-directing substituent present in the organic reagent, this wholly proceeds further, undergoing a second ionic exchange $RI^{++} + RH \longrightarrow R_2I^+ + H^+$.

In the direct formation of *m*-iodosonitrobenzene the missing 50—40% of yield is accounted for as *m*-iodonitrobenzene and iodonium salts, the latter mainly with the radical $(C_6H_3I{\cdot}NO_2)(C_6H_4{\cdot}NO_2)I^+$. These are experimentally traced to a relatively slow secondary decomposition of the primary iodoso-product by sulphuric acid, the same in nature as that of iodosobenzene in sulphuric acid whereby Hartmann and V. Meyer discovered iodonium salts as a class.

In a previous communication (Masson and Race, J., 1937, 1718) it was shown that iodous sulphate in moderately concentrated sulphuric acid acts upon chlorobenzene, forming quantitatively the diaryliodonium sulphate. A similar action occurs with benzene, toluene, bromobenzene, and iodobenzene; in short, with benzene derivatives which are not easily degraded by oxidation and in which the substituent is *op*-directing. In both aryl groups of the iodonium product, the tervalent iodine atom was found, in the case of chlorobenzene, to take the para-position respecting the substituent.

At the same time it was found by one of us that iodous sulphate acts in a different way upon benzene derivatives containing a meta-directing substituent, the product being essentially the iodoso-compound, RIO. This is the first time that the iodoso-group has been directly substituted for hydrogen in an organic compound. The reaction occurs with nitrobenzene, benzenesulphonic acid, and (less simply) with benzoic acid; and the iodoso-group takes the *m*-position. Nitrobenzene, which we have now studied more fully, readily gives yields of solid *m*-iodosonitrobenzene up to about 60%; the reaction is accomplished in less than an hour at room temperature.

Besides this main product, about 20—25% of the initial reagent appears as *m*-iodonitrobenzene, and the remainder as iodonium salts. The latter have iodine contents somewhat variable but corresponding with the " mixed " iodonitrophenyl–nitrophenyliodonium salt, together with the simple bisnitrophenyliodonium salt as a minor constituent: they are unstable when isolated as their iodides, largely decomposing within a few days of being purified. We find that all these products are formed by a secondary interaction between the primary iodoso-compound and the concentrated sulphuric acid, as quantitative experiments made by mixing these two substances showed. Here, in periods ranging from hours to days, besides *m*-iodonitrobenzene and an iodonium product, a little carbon dioxide (measured) was formed; and the oxygen of the initial iodoso-compound disappeared analytically *pari passu*, being consumed in degradative oxidation. The ratio of " mixed " to " simple " iodonium in these products was less than in those isolated from the major reactions, but, as far as their inconvenient instability allowed us to determine, they were otherwise the same material.

It is clear that the secondary reaction is of the same kind as that discovered by Hartmann and V. Meyer, who, by treating iodosobenzene with concentrated sulphuric acid, obtained (*p*-iodophenyl)phenyliodonium sulphate, together with degradative consumption of oxygen and the formation of iodo-compounds (*Ber.*, 1894, **27**, 426). This was a rapid reaction: in our case, the presence of the *m*-nitro-group in the iodoso-compound, the primary product of our main reaction, makes its decomposition slow, and thus it is easily isolated before much of it has been consumed.

In an explanation of all the main reactions, the iodous reagent, a solution of the yellow solid I_2O_3,SO_3, that is, $(IO)_2SO_4$, in concentrated sulphuric acid, is best regarded as a source of I^{+++} cations:

$$IO^+ + 2H^+ \rightleftarrows I^{+++} + H_2O \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Further, the organic product is always cationic: in the one set of cases it is the iodonium ion R_2I^+; in the other, the iodoso-compound is produced as its sulphate and can, in fact, be crystallised as such by limited dilution, and therefore is likewise formed as its cation, a bivalent ion RI^{++}. Thus the complete series of cationic radicals given by tervalent iodine and exhibited in the various compounds here dealt with is

IO^+	I^{+++}	RI^{++}	R_2I^+
Iodyl.	Iodous.	Iodoso-.	Iodonium.

The formation of an iodoso-compound by the interaction with an aromatic substance of the class to which nitrobenzene belongs is, accordingly, expressed as the partial ionic exchange:

$$I^{+++} + RH \longrightarrow H^+ + RI^{++} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

and, apart from the slow secondary decomposition already mentioned, the reaction with this class of reagent stops there. With an aromatic substance which is more reactive, however, by reason of its containing an *op*-directing substituent, the observed quantitative production of an iodonium salt is simply understood as due to reaction (2), followed at once and completely by a further step in ionic exchange, namely,

$$RI^{++} + RH \longrightarrow H^+ + R_2I^+ \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

the total reaction for this class of organic reagents being therefore $I^{+++} + 2RH \longrightarrow 2H^+ + R_2I^+$.

The respective orientations of the products are due, of course, to the same organic-electronic factors as influence the respective activities of the organic reagents, and this matter need not be elaborated here. We have not found in this work evidence for the obviously suggested final step

$$RH + R_2I^+ \longrightarrow H^+ + R_3I$$

The slow secondary decomposition which impairs the yield of an iodoso-compound from reaction (2) may be summarily formulated (though not completely explained) on lines similar to those here adopted. Taking, *e.g.*, Hartmann and Meyer's original reaction between iodosobenzene and concentrated sulphuric acid, which produces a "mixed" iodonium salt, we may express this as

$$2C_6H_5I^{++} + 2e \longrightarrow (C_6H_4I)(C_6H_5)I^+ + H^+$$

and in our case

$$2C_6H_4(NO_2)I^{++} + 2e \longrightarrow (C_6H_3I{\cdot}NO_2)(C_6H_4{\cdot}NO_2)I^+ + H^+$$

the neutralising electrons representing the slight breakdown-oxidation which is a necessary concomitant of the action.

EXPERIMENTAL.

Preparation of m-*Iodosonitrobenzene*.—Iodine (4·00 millimols.) and iodine pentoxide (6·00 millimols.), each well powdered, are shaken mechanically with 96% sulphuric acid (20 c.c.), and form quantitatively during about a day the yellow solid I_2O_3,SO_3, the solution being faintly yellow. To the whole, pure nitrobenzene (20 millimols.) is added from a burette, with shaking. As soon as the solid has disappeared, which may take an hour, the homogeneous liquid is diluted with pure ice. If the resulting solution is not less acidic than about 7N-sulphuric acid, crystals of a sulphate of *m*-iodosonitrobenzene are formed; further dilution hydrolyses these to the amorphous and bulky iodoso-compound, neutralisation of the liquor with sodium bicarbonate completes the precipitation, and the material is filtered off. Saturation with sodium acetate is a fairly satisfactory alternative to neutralisation with bicarbonate. From the filtrate, the "mixed" iodonium salt can be recovered as its iodide, which in this case cannot long be kept without spontaneously undergoing fission to iodo- and di-iodo-nitrobenzene. Much washing with water is needed to remove all sulphuric acid from the iodoso-compound, as it is more definitely basic than its phenyl analogue. The by-product, *m*-iodonitrobenzene (completely identified), is extracted with benzene from the dried iodoso-product, and the purified material is finally dried to constant weight in a vacuum over silica gel. Drying operations should be as rapid as possible, but no oxidisable washing agent such as alcohol is permissible; and no warmth may be used, nor should the substance be in bright light, in order to avoid the conversion $2RIO = RI + RIO_2$; it is not easy, perhaps impossible, wholly to prevent this. There is no solvent from which to crystallise an iodoso-compound as such.

The distinctive test for iodoso- and iodoxy-compounds is that they are reduced wholly to the corresponding iodo-compounds both by acidified potassium iodide and by aqueous hydrogen peroxide; the distinction between iodoso- and iodoxy-compounds is that the former are reduced at once (but not in all cases quantitatively) by potassium iodide in a saturated solution of borax at room temperature, whereas the latter remain unattacked. This negative result with iodoxy-compounds holds, at all events, for all those which the authors have examined, including that relevant to the present case, *m*-iodoxynitrobenzene, made by nitrating iodoxybenzene (Masson, Race, and Pounder, J., 1935, 1677). To these positive tests the present material answered unambiguously, and its reduction product was repeatedly identified, physically and analytically, as pure *m*-iodonitrobenzene, thus proving qualitatively that the substance is essentially *m*-iodosonitrobenzene.

In the quantitative verifications of this, however, the solid iodoso-compound was found to be associated with a small percentage of indifferent material, unidentifiable qualitatively, and explainable as water of hydration, though it was not removed by long exposure of the material to phosphoric oxide in a vacuum. The following are data for one preparation examined by ourselves and microchemically by different analysts :

					Resulting formula.				
Analyst.	C, %.	H, %.	N, %.	I, %.	C.	H.	N.	I.	O (by diff.).
M. & H.	—	—	—	44·1, 43·6	—	—	—	—	—
*	25·35	1·65	5·25	—	6	4·6	1·07	—	—
Weiler	25·9	1·9	4·9	43·4	6	5·3	0·97	0·95	4·1
Schoeller	25·25	1·9	4·8	43·1	6	5·4	0·98	0·97	4·4
Calc. for $C_6H_4(NO_2)\cdot IO$	27·2	1·5	5·3	47·9		$C_6H_4NIO_3$			
$C_6H_4(NO_2)\cdot I(OH)_2$	25·4	2·1	4·95	44·85		$C_6H_6NIO_4$			
$C_6H_4(NO_2)\cdot IO_2$	25·6	1·4	5·0	45·2		$C_6H_4NIO_4$			

* Through the kindness of Professor G. R. Clemo, this analysis was made in his laboratory.

These data agree with a monohydrate, the iodoso-base proper; the iodoxy-compound is excluded, not only qualitatively, but also by the oxidising equivalent weight [Found : 148·5, 148·0. Calc. for $C_6H_4(NO_2)IO_2$, 71·5; for $C_6H_4(NO_2)IO$, 132·5; for $C_6H_4(NO_2)I(OH)_2$, 141·5]. Other preparations gave an equivalent almost identical with the value 141·5, but in others again there was a definite variation either above or below this figure, as also in the iodine content (measured by Stepanow's method), and in the weight ratio (substance : reduction-product). Considering these fluctuations among about 15 independent preparations, we cannot state the existence of the monohydrate as more than a probability, and must regard this uncrystallisable compound as unusually difficult to purify.

Whatever the variable small additament may be, the identification of the substance is finally made satisfactory by treating it with acetic acid and acetic anhydride, which convert it all into a well-defined iodoso-diacetate, recrystallisable in rhombs from benzene (solubility, 2·5 g. per 100 c.c. at room temperature), and of m. p. 143—147° (decomp.). This gave an oxidising equivalent towards acidic potassium iodide of 184·3, 182·6 (Calc. : 183·5), and an iodine content of 33·85, 34·18% (Calc. : 34·6%); in semi-microanalysis (Weiler) it gave $C_{10}H_{10\cdot7}N_{1\cdot07}I_{1\cdot00}O_{(5\cdot84)}$ (Calc. : $C_{10}H_{10}NIO_6$), and an acetyl content of 25·4, 25·6% (Calc. : 23·4%).

The iodine contents of the iodonium by-products were determined by the Stepanow method applied to their precipitated iodides. They ranged from 53 to 60% [Calc. for $(C_6H_3I\cdot NO_2)(C_6H_4\cdot NO_2)I\cdot I$, 61·0; for $(C_6H_4\cdot NO_2)_2I\cdot I$, 51·0%].

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