122. *The Ullmann Biaryl Synthesis. Part VI.*[1] *The Scope and Mechanism of the Reaction.*

By James Forrest

Optimum conditions for formation of unsymmetrical biaryls in the Ullmann reaction and some limiting factors in this respect are suggested. The mechanisms of the normal condensation and the atypical side-effects are discussed.

As shown in this series of papers,[1] it is evident that several factors, apart from the choice of aryl halide, can influence the product pattern of unsymmetrical Ullmann syntheses, particularly when an electronegative group such as nitro is present in a reactant. This communication describes, primarily, experiments on the scope of syntheses of this type and concludes with a discussion of the mechanism of the reaction.

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[1] Parts I—V, preceding papers.

Component	Component	Ratio	Reaction		Yield (%) of biaryls	
A	B	A : B	temp.	time (hr.)	A–A	A–B
o-$C_6H_4I\cdot NO_2$	C_6H_5I	1 : 1·25	195°	2	65	10
o-$C_6H_4I\cdot CO_2Me$	,,	,,	,,	4	65	10
o-$C_6H_4I\cdot CN$	,,	,,	,,	2·5	30	—
m-$C_6H_4I\cdot NO_2$	,,	1 : 1	,,	6	15	25
p-$C_6H_4I\cdot NO_2$	,,	1 : 1·25	,,	,,	20	35
,,	,,	1 : 1	,,	,,	20	25
o-$C_6H_4Br\cdot NO_2$	*m*-$C_6H_4I\cdot NO_2$	,,	,,	2	*	35
,,	*p*-$C_6H_4I\cdot NO_2$	,,	,,	,,	*	35
,,	*p*-$C_6H_4I\cdot CO_2Me$	,,	190	,,	20	35
m-$C_6H_4Br\cdot NO_2$	C_6H_5I	1 : 1·25	195	6	0 †	0
p-$C_6H_4Br\cdot NO_2$	,,	,,	,,	,,	0	2·5
1,3,4-$C_6H_3Br_2\cdot NO_2$	,,	,,	,,	3·5	10	55
o-$C_6H_4Br\cdot NO_2$	*p*-$C_6H_4I\cdot OMe$	,,	175	,,	10	40
1,2,4-$C_6H_3Cl(NO_2)_2$	*m*-$C_6H_4Br\cdot NO_2$	1 : 1	195	5	0	15
,,	*p*-$C_6H_4Br\cdot NO_2$	,,	,,	,,	0	20
,,	*o*-$C_6H_4Br\cdot OMe$	,,	,,	,,	*	30
,,	*m*-$C_6H_4Br\cdot OMe$	,,	,,	,,	*	20
,,	*p*-$C_6H_4Br\cdot OMe$	,,	,,	,,	*	20
,,	,,	1 : 2	,,	,,	*	25
1,2,4-$C_6H_3Br(NO_2)_2$	*o*-$C_6H_4Br\cdot OMe$	,,	,,	3·5	40	20
,,	*m*-$C_6H_4Br\cdot OMe$	,,	,,	,,	55	15
,,	*p*-$C_6H_4Br\cdot OMe$	,,	,,	,,	55	15
1,4,3-$C_6H_3MeBr\cdot NO_2$	*p*-C_6H_4MeI	1 : 1·25	175	,,	20	40

* Not isolated. † Biphenyl (15%) obtained.

Optimum formation of unsymmetrical biaryls in the Ullmann reaction has been based theoretically on the equal rates of reactivity towards copper of the halides involved. Exceptions have, however, long been recognised.[2] Although this equality may apply to some pairs of aryl halides (for the most part in the absence of electronegative substituents), Parts I [3] and IV [4] of this series, the Table of the present paper, Fanta's review,[2] and direct comparison of the reactivities (Mascarelli *et al.*[5] and Part V of this series) show widespread inequality. The syntheses carried out suggest that formation of unsymmetrical biaryls depends rather on the greater reactivity towards copper of the reactant containing the more powerful electronegative substituent (subsequently referred to as the A component) than that of the second reactant (B component). Generally the A component must contain at least one electronegative group, such as nitro or methoxycarbonyl, *ortho* to the halogen atom. Successful syntheses depended largely on the choice of the halogen atom. Bromo-compounds, and to a smaller extent chloro-compounds, have been most useful as A components: the iodo-compounds were of little use owing to predominant self-condensation (*i.e.*, formation of symmetrical biaryls). Iodo-compounds, however, found general application as B components, although in specific instances bromo- and even chloro-compounds have been successfully employed.

Electronegative substituents *meta* and *para* to halogen normally failed to activate the latter sufficiently for A components. Limited use, however, can be made of the more active compounds of this type in condensations of weakly reactive B components. For example, *m*- and *p*-iodonitrobenzene with iodobenzene afforded respectively 3- and 4-nitrobiphenyl, in both cases with relatively large quantities of the dinitrobiphenyl. The bromo-nitro-analogues were insufficiently reactive: 3-nitrobiphenyl could not be isolated on attempted reaction of the *m*-bromonitrobenzene with iodobenzene—only a small quantity of biphenyl was obtained. *p*-Bromonitrobenzene, in similar circumstances, furnished traces of 4-nitrobiphenyl, and the product of reductive arylation, 4-bromotriphenylamine.

In unsymmetrical Ullmann syntheses electronegative substituents *meta* and *para* to the halogen atom in A components seemed to have approximately the same influence. For example, similar product patterns were obtained from *m*- and *p*-iodonitrobenzene

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[2] Cf. Fanta, *Chem. Rev.*, 1946, **38**, 139.
[3] Part I, *J.*, 1960, 566.
[4] Part IV, *J.*, 1960, 589.
[5] Mascarelli, Longo, and Ravera, *Gazzetta*, 1938, **68**, 33.

with iodobenzene; and with *o*-bromonitrobenzene they afforded comparable yields of 2,3′- and 2,4′-dinitrobiphenyl. Further, *m*- and *p*-bromonitrobenzene behaved similarly as B components on condensation with 1-chloro-2,4-dinitrobenzene, as did methyl *m*-[6] and *p*-iodobenzoate with *o*-bromonitrobenzene. On this evidence, together with the similarity shown on self-condensations of isomeric halides of this type,[1] it seems clear that the concept of activation of *o*- and *p*-halogen atoms by an electronegative group[2] is unsupportable, the effect of such substituents being confined to the *ortho*-position. The influence of *m*- and *p*-halogen atoms is apparently of the same order and may well be related to the general effect of the substituent on the ring.

The almost negligible activation of a halogen atom by a *m*- or *p*-nitro-group is further exemplified by the condensation of 2,4-dibromonitrobenzene with iodobenzene, which afforded 3-bromo-6-nitrobiphenyl as the sole unsymmetrical product. In addition, a *p*-nitro-group did not augment materially the influence of an *o*-nitro-group already present: similar product patterns were afforded from 1-bromo-2-nitro- and 1-bromo-2,4-dinitro-benzene with (*a*) iodobenzene and (*b*) *p*-iodoanisole (Part IV; Table of the present paper).

Recovery of the greater part of the *p*-bromonitrobenzene after attempted condensation with iodobenzene, together with the very poor yield of biaryl obtained, indicated that in this instance the A component acted mainly as a diluent for the B component. It is clear that here initial reaction of the B component with copper did not lead to the unsymmetrical biaryl, although the bromonitro-compound could be condensed as the B component with 1-chloro-2,4-dinitrobenzene under similar conditions. Considerable evidence exists for the general inference that in this type of Ullmann condensation preferential attack by the condensing agent on the A component is essential for successful reaction. For example, the abnormal products described in Part I are evidently the result of initial reaction of B components. Further, the variations in the product patterns of condensations in which the relative reactivities of A–B components could be modified showed that formation of unsymmetrical biaryl was favoured by A components of greater disproportionate reactivity. Thus 1-bromo-2,4-dinitrobenzene[4] condensed more effectively than the relatively inert chloro-analogue[3] with iodobenzene, *p*-iodoanisole, etc. In the same way a marked improvement in the homogeneity of the product from *o*-bromonitrobenzene and α-iodonaphthalene was obtained at a low temperature where the reactivity of the B component with copper was disproportionately reduced.

It is characteristic of mixed Ullmann reactions that an aryl halide can function as the B component more readily than as the A component, and at a lower temperature than that at which the halide *per se* is attacked by copper. For example, 1-chloro-2,4-dinitrobenzene reacts readily with a trinitrohalogeno-compound[7] at 160° although the former is largely unaffected at 165° on attempted reaction with iodobenzene; iodobenzene condenses with picryl chloride[8] under milder conditions than those required for reaction of the iodide with copper alone; the relatively inert *m*- and *p*-bromonitrobenzene are capable of condensations as B components with 1-bromo- and 1-chloro-2,4-dinitrobenzene respectively, at temperatures below those at which their individual self-condensations could occur. In the same way the isomeric bromoanisoles, unattacked by copper at 195°, condense with these dinitrohalogeno-compounds at that temperature. It seems clear, therefore, that optimum conditions for formation of unsymmetrical biaryls in Ullmann reactions include a temperature immediately below that at which the B component is independently attacked by copper. Reaction of the B component with the metal can rarely be suppressed entirely; therefore, as in the synthesis of 1-*o*-nitrophenylnaphthalene,[4] operation at the lowest practicable temperature for the reaction of the A component with copper furnishes the best results. The frequent practice of raising the temperature to

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[6] Adams and Cairns, *J. Amer. Chem. Soc.*, 1939, **61**, 2179.
[7] Stearns and Adams, *J. Amer. Chem. Soc.*, 1930, **52**, 2070.
[8] Rule and Smith, *J.*, 1937, 1096.

complete the reaction is deleterious, particularly when the A component partly condenses with itself. For example, the synthesis of 2-nitro-*p*-ditolyl[9] from 4-bromo-3-nitrotoluene and *p*-iodotoluene was significantly improved at a low temperature. Under ideal conditions excess of the B component may be used with impunity, otherwise a greater excess than that required to replace losses by halogen transfer is undesirable, particularly when nitro-groups are present in a reactant.

The satisfactory preparation of unsymmetrical biaryls free from impurities derived from the B components, under conditions in which the latter were unable to react independently with copper, suggests that biaryl formation takes place without initial attack by the condensing agent on the B component. The absence of halogen-transfer products from the low-temperature condensation of *o*-bromonitrobenzene with α-iodonaphthalene, which normally gives a high proportion of transfer halide, further supports the idea of the reaction of the B component *per se*. This is irreconcilable with the free-radical mechanism for the Ullmann reaction suggested by Rapson and Shuttleworth.[10] The formation of traces of biphenyl-2- and -4-carboxylic acid from the forced Ullmann reaction (sealed tube) of iodobenzene dissolved in ethyl benzoate, on which the free-radical theory is based, may well be related to the atypical behaviour of iodobenzene on reaction in *m*-dinitrated diluents.[11] Furthermore, ester diluents such as methyl benzoate have been shown to suppress the normal reaction of iodobenzene with copper,[12] although biphenylcarboxylic esters have not been isolated from such reactions at atmospheric pressure. The acceptance of condensations of this nature as a basis for theoretical concepts of the Ullmann reaction must therefore be treated with reserve. The halogen-transfer effect may well provide the key to the mechanism of the reaction. It seems clear therefrom that the initial stage of the halide–copper interaction does not involve direct removal of the halogen atom to form a cuprous halide, with the resultant formation of a free aryl radical, but suggests attack by the metal on the bond between the halogen atom and the aryl nucleus on the lines suggested by Fanta.[2] The formation of halogen-transfer products, which appears dependent on initial attack by copper on the acceptor halide, may well be related to the fission of Grignard reagents by halogens[13] although the precise nature of the transfer reaction is not yet definable.

Preparative evidence in the Ullmann reaction also militates against the free-radical mechanism. For example, self-condensation of iodobenzene gives biphenyl free from polymer. Nitrobiphenyls cannot be isolated from the reactions of iodobenzene in nitrobenzene and analogous compounds. It has been observed in our work that a heterogeneous product, which would be expected if the radical mechanism obtained, is a characteristic of slow or sterically impeded reactions involving nitro-compounds: reactions in the absence of nitrated material normally give negligible amounts of by-products of this nature. The attack on the nitro-group may also provide additional support for initial nuclear attack by copper on the aryl halide, since the complex reaction between phenylmagnesium bromide and nitrobenzene has been reported to yield diphenylamine.[14] In Ullmann reactions, however, the attack on the nitro-group, affording in most cases derivatives of triphenylamine and less frequently secondary amines or azo-compounds, is a secondary effect of slow reactions. For example, reductive arylation in the sterically hindered self-condensation of 1-chloro-2,6-dinitrobenzene in nitrobenzene solution, which has been shown to give 2,6-dinitrodiphenylamine predominantly,[15] is eliminated by the addition of a molar equivalent of iodobenzene to the reaction, the unsymmetrical biaryl alone then being obtained.

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[9] Marler and Turner, *J.*, 1932, 2391.
[10] Rapson and Shuttleworth, *Nature*, 1941, **147**, 675.
[11] Part II, *J.*, 1960, 574.
[12] Part III, *J.*, 1960, 581.
[13] Gilman and Brown, *J. Amer. Chem. Soc.*, 1930, **52**, 1181.
[14] Gilman and McCracken, *J. Amer. Chem. Soc.*, 1929, **51**, 821.
[15] Borsche and Rantscheff, *Annalen*, 1911, **379**, 152.

The mechanism of the abnormal arylation of *m*-dinitro-compounds in Ullmann reactions, affording derivatives of 2,6-dinitrobiphenyl, is not clear. It seems unlikely that free aryl radicals are involved, the product pattern of the reaction of free phenyl radicals with *m*-dinitrobenzene being different. Thus repetition of the phenylation of 1-tritio-2,4-dinitrobenzene by phenyl radicals derived from benzoyl peroxide,[16] which has been reported to yield only 2,4-dinitrobiphenyl and its 5-tritio-derivative, furnished (from the untritiated material) a 9 : 1 mixture of 2,4- and 2,6-dinitrobiphenyl. In the same way, phenyl radicals derived from the decomposition of benzenediazonium zinc chloride by Waters's technique[17] gave, in the presence of *m*-dinitrobenzene, *inter alia*, a similar mixture of the same dinitrobiphenyls.

EXPERIMENTAL

For general directions see Parts I and II.

General Technique.—Reactions were normally carried out as described in Part I of this series. The various Ullmann condensations are given below under the headings of the reactants.

o-*Iodonitrobenzene–Iodobenzene.*—Copper (10 g.) was added portionwise in *ca.* 0·5 hr. to a mixture of 12·5 g. of each reagent at 195°. The temperature was maintained for a further 1·5 hr. The organic extracts (copper salts etc., 18 g.) were evaporated and kept overnight at 20°, then 2,2′-dinitrobiphenyl (2·7 g.), m. p. 127°, was filtered off and washed with a little cold methanol. The combined filtrates and washings were fractionally distilled, affording (1) unchanged iodobenzene (6·5 g.), b. p. 45—50°/1 mm., (2) a yellow oil (1·75 g.), b. p. 125—130°/1 mm., and (3) a semi-solid distillate (2 g.), b. p. 165—170°/1 mm. Fraction (2), when cooled to 0° for 2—3 hr. and seeded, gave 2-nitrobiphenyl (1 g.), m. p. 37°. Crystallisation of fraction (3) from benzene–light petroleum furnished more of the dinitrobiphenyl (1·3 g.).

Methyl o-*Iodobenzoate–Iodobenzene.*—Copper (18 g.) was added gradually to a mixture of the ester (26 g.) and iodobenzene (25 g.) at 195°. After 4 hr. the products were separated, giving copper salts, etc. (34 g.), iodobenzene (16 g.), an oil (3·5 g.), b. p. 105—115°/0·4 mm., and crude methyl biphenate (10·5 g.), b. p. 135—145°/0·3 mm., which gave the pure ester (9 g.) as colourless prisms (from methanol), m. p. 73°. The second fraction was hydrolysed by methanol (25 ml.) and 40% aqueous potassium hydroxide (5 ml.) at 20° for 15 hr. The mixture was evaporated, and the residue dissolved in water (75 ml.), extracted with benzene and then light petroleum, and acidified with dilute hydrochloric acid; the precipitate gave an oil which solidified at 0° overnight. Three crystallisations from benzene–light petroleum gave biphenyl-2-carboxylic acid (2 g.) as needles, m. p. and mixed m. p. 110—111°.

o-*Cyanoiodobenzene–Iodobenzene.*—The nitrile (11·5 g.), iodobenzene (12·5 g.), and copper (10 g.) reacted at 195° for 2·5 hr. Separation of the product yielded copper salts, etc. (17·5 g.), iodobenzene (7 g.), an oil (1·5 g.), b. p. 90—110°/0·5 mm., and a sticky solid (4·3 g.), b. p. 130—150°/0·8 mm. A black residue (1·5 g.) was discarded. Crystallisation of the solid from methanol–ethyl acetate gave 2,2′-dicyanobiphenyl (1·6 g.), m. p. 170—171° (lit., 172°).

m-*Iodonitrobenzene–Iodobenzene.*—Iodobenzene (10 g.), *m*-iodonitrobenzene (12·5 g.), and copper (10 g.), reacting at 190° for 6 hr., gave copper salts (22 g.), iodobenzene (2·2 g.), a yellow oil (3·5 g.), b. p. 138—145°/0·8 mm., and a solid fraction (1·2 g.), b. p. 160—185°/0·8 mm. A small residue (0·5 g.) was discarded. The oil crystallised readily from methanol in almost colourless plates of 3-nitrobiphenyl (2·4 g.), m. p. and mixed m. p. 61° (Found: N, 7·2. Calc. for $C_{12}H_9O_2N$: N, 7·0%). The less volatile solid fraction furnished colourless needles (from ethyl acetate) of 3,3′-dinitrobiphenyl (1 g.), m. p. 200°.

p-*Iodonitrobenzene–Iodobenzene.*—Iodonitro-compound (12·5 g.), iodobenzene (10 g.), and copper reacted at 195° for 6 hr. Extraction with chloroform followed by warm acetone gave inorganic material (22·5 g.). Removal of the acetone afforded 4,4′-dinitrobiphenyl (0·7 g.), m. p. 232°. Distillation of the chloroform extract gave a fraction (1·5 g.), b. p. 40—50°/0·5 mm. (which had the odour of nitrobenzene), *p*-iodonitrobenzene (0·3 g.), subliming at 100—110°/0·5 mm., and a yellow oil (3·2 g.), b. p. 140—160°/1·5 mm., which solidified. A dark resin (3 g.) decomposed on further heating. Crystallisation of the main fraction from methanol afforded pale yellow needles of 4-nitrobiphenyl (2·75 g.), m. p. and mixed m. p. 113° (Found: N, 7·2%). A further small quantity of 2,2′-dinitrobiphenyl (0·5 g.) was obtained from the

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[16] Price and Convery, *J. Amer. Chem. Soc.*, 1957, **79**, 2941.

[17] Waters and Hanby, *J.*, 1939, 870.

distillation residue by successive crystallisations from glacial acetic acid and methanol. Repetition of the condensation with 12·5 g. (1·25 mol.) of iodobenzene raised the yield of unsymmetrical biaryl to 3·4 g.; that of the dinitrobiphenyl (1·25 g.) was unaltered.

m-*Bromonitrobenzene–Iodobenzene.*—The bromo-compound (24 g.), iodobenzene (30 g.), and copper (24 g.) at 195° (6 hr.) afforded inorganic material (41 g.) and, on fractional distillation, (1) iodobenzene (5 g.), (2) a pale yellow oil (14 g.), b. p. 80—110°/mm., (3) a red oil (2 g.), b. p. 140—165°/1 mm., and (4) a dark red viscous oil (4 g.), b. p. 170—190°/0·5 mm. A black residue (2 g.) was discarded. Fraction (2) furnished *m*-bromonitrobenzene (9 g.) on cooling to 15°. After separation of the solid, the oily mother-liquor was reduced with iron powder in aqueous acetic acid, then treated with excess of concentrated hydrochloric acid. Crystallisation of the precipitate from aqueous methanol afforded biphenyl (1·75 g.). Fractions (3) and (4) gave strong blue colours in warm concentrated sulphuric acid, indicating reductive arylation of the nitro-group. No crystals, however, were isolated from either fraction after chromatography in light petroleum.

p-*Bromonitrobenzene–Iodobenzene.*—The iodide (75 g.), *p*-bromonitrobenzene (60 g.), and copper (60 g.), reacting at 195° for 6 hr., gave inorganic material (101 g.). Concentration of chloroform extracts to small bulk afforded unchanged *p*-bromonitrobenzene (25·5 g.). Fractional distillation of the residues gave (1) iodobenzene (15·5 g.), (2) a further quantity of the bromonitro-compound (14·5 g.), b. p. 160—170°/40 mm., (3) an orange red oily solid (3·5 g.), b. p. 160—165°/0·6 mm., and (4) a viscous red oil (3·5 g.), b. p. 170—195°/0·6 mm. A black residue (7·5 g.) was discarded. Crystallisation of fraction (3) from benzene–light petroleum gave pale yellow needles of 4-nitrobiphenyl (1·75 g.), m. p. and mixed m. p. 113° (Found: N, 7·0%). After the solvent had been stripped from the mother-liquors, the residue was dissolved in warm glacial acetic acid (15 ml.), then zinc dust added portionwise with shaking to the yellow solution until decolorisation was complete. The solid which separated on pouring the whole into 5% aqueous hydrochloric acid (100 ml.) was separated and recrystallised from methanol, giving white needles of 4-*bromotriphenylamine* (1 g.), m. p. 115° (Found: C, 66·5; H, 4·3; N, 4·6. Br, 25·0. $C_{18}H_{14}NBr$ requires C, 66·7; H, 4·3; N, 4·3; Br, 24·7%). Similar treatment of fraction (4) with benzene–light petroleum afforded orange feathery needles (0·05 g.). m. p. 180—210°, which were not further examined. Crystallisation of the residue, after removal of solvent, from methanol gave a further quantity of bromotriphenylamine (1·8 g.). Biphenyl was not obtained from the residues of fraction (2) after exhaustive crystallisation of the bromonitro-compound from methanol.

o-*Bromonitrobenzene*–m-*Iodonitrobenzene.*—Copper (7·5 g.), *o*-bromonitrobenzene (7·5 g.), and *m*-iodonitrobenzene (9·4 g.) reacted at 195° for 2 hr., giving inorganic material (13·5 g.), unchanged halides (3·5 g.), b. p. 90—110°/1 mm., and a viscous oil (6 g.), b. p. 180—185°/1 mm., which solidified. There was no distillation residue. Successive crystallisations of the main fraction from methanol–ethyl acetate and benzene–light petroleum gave almost colourless needles of 2,3′-dinitrobiphenyl (2·75 g.), m. p. 119—120° (lit., 120°) (Found: N, 11·7. Calc. for $C_{12}H_8O_4N_2$: N, 11·5%). Repeated crystallisation of material obtained from the mother-liquors afforded a further quantity of the unsymmetrical biaryl (0·5 g.).

o-*Bromonitrobenzene*–p-*Iodonitrobenzene.*—An analogous reaction with the *p*-iodonitro-isomer on the same scale gave copper salts (14 g.), unchanged halides (mostly the iodonitro-compound) (3 g.), b. p. <120°/0·5 mm., and a yellow oil (5·7 g.), b. p. 185—195°/0·5 mm., which solidified. A small residue (0·5 g.) was discarded. After 2 crystallisations from benzene–light petroleum the main fraction yielded yellow needles of 2,4′-dinitrobiphenyl (2·5 g.), m. p. 93—94° (lit., 92·5—93·5°) (Found: N, 11·5%). Repeated crystallisation (from the same solvent) of material obtained by concentration of the mother-liquors afforded a further quantity of the unsymmetrical biaryl (0·5 g.).

1-*Chloro*-2,4-*dinitrobenzene*–m-*Bromonitrobenzene.*—Equal weights (7·5 g.) of the halogeno-nitro-compounds reacted with copper (7·5 g.) at 195° for 5 hr. Separation of the products gave copper salts (9·8 g.), unchanged *m*-bromonitrobenzene (4·7 g.), b. p. 75—80°/0·3 mm., and 1-chloro-2,4-dinitrobenzene (5 g.), b. p. 110—120°/0·3 mm., and a very viscous pale orange oil (2·5 g.), b. p. 230—240°/0·3 mm. A small residue (0·5 g.) was discarded. From methanolic solution the viscous oil slowly gave ill-defined yellow crystals, m. p. 128—133°. Further crystallisation from glacial acetic acid afforded very pale yellow fluffy needles of 2,4,3′-*trinitrobiphenyl* (1·5 g.), m. p. 135° (Found: C, 49·8; H, 2·6; N, 14·6. $C_{12}H_7O_6N_3$ requires C, 49·8; H, 2·4; N, 14·5%).

1-*Chloro*-2,4-*dinitrobenzene*–p-*Bromonitrobenzene*.—Equal weights (10 g.) of the reactants, treated with copper (10 g.), as for the *m*-bromonitro-isomer, gave inorganic material (13·2 g.), unchanged halides (9·5 g.), b. p. 80—125°/0·5 mm., and a clear pale orange resin (4 g.), b. p. 230—245°/0·5 mm. An undistillable residue (1 g.) was discarded. Crystallisation of the halides from methanol afforded *p*-bromonitrobenzene (5 g.). The resin, after 3 crystallisations from glacial acetic acid, gave pale yellow cubes of 2,4,4′-trinitrobiphenyl (2·5 g.), m. p. 174—175° (lit., 174—175°) (Found: N, 14·3%).

o-*Bromonitrobenzene–Methyl* p-*Iodobenzoate*.—The bromonitro-compound (5 g.), the iodo-ester (6·5 g.), and copper (5 g.) reacted at 190° for 2 hr., giving inorganic material (9 g.), crude methyl *p*-iodobenzoate (2·5 g.), b. p. 100—115°/0·5 mm., and a viscous oil (3·7 g.), b. p. 175—180°/0·5 mm. A small residue (0·5 g.) was discarded. Crystallisation of the crude iodo-ester from methanol gave the pure material (2 g.), m. p. 115°. The oil was dissolved in methanol (50 ml.) containing potassium hydroxide (2·5 g.). After 18 hr. at 20° the methanol was distilled off and the residue extracted with water (100 ml.). The insoluble material, from which 2,2′-dinitrobiphenyl (0·6 g.) was obtained by crystallisation from benzene–light petroleum, was separated, then the aqueous extract was acidified with dilute hydrochloric acid. The precipitate was filtered off, dried, and re-esterified in 3% methanolic sulphuric acid. Crystallisation of the product afforded greenish-yellow needles (from methanol) of *methyl* 2′-*nitrobiphenyl*-4-*carboxylate* (2·3 g.), m. p. 84—85° (Found: C, 65·5; H, 4·4; N, 5·5. $C_{14}H_{11}O_4N$ requires C, 65·4; H, 4·3; N, 5·4%).

2,4-*Dibromonitrobenzene–Iodobenzene*.—The bromonitro-compound (5 g.), iodobenzene (4·5 g.), and copper (3·5 g.), at 195° (1·5 hr.), gave inorganic material (6·5 g.). The organic product was treated with cold methanol (10 ml.). The crystals precipitated were dissolved in acetone, filtered from a little suspended material, and after removal of solvent crystallised from ethyl acetate in pale yellow prisms of 5,5′-*dibromo*-2,2′-*dinitrobiphenyl* (0·4 g.), m. p. 204—205° (Found: C, 35·7; H, 1·8; N, 7·3; Br, 40·2. $C_{12}H_6O_4N_2Br_2$ requires C, 35·8; H, 1·5; N, 7·0; Br, 39·8%). The original methanolic mother-liquors were concentrated, then distilled, affording a clear yellow viscous oil (3·5 g.), b. p. 155—160°/0·8 mm. A higher-boiling residue (0·5 g.) was discarded. After 2 crystallisations from benzene–light petroleum the oil furnished pale yellow needles of 5-*bromo*-2-*nitrobiphenyl* (2·6 g.), m. p. 50—51° (Found: C, 51·5; H, 2·9; N, 5·3; Br, 29·1. $C_{12}H_8O_2NBr$ requires C, 51·8; H, 2·9; N, 5·0; Br, 28·8%). Reductive acetylation of this material by zinc dust in acetic acid–acetic anhydride furnished 2-acetamido-5-bromobiphenyl, m. p. and mixed m. p. 129—130° (Found: N, 5·1. Calc. for $C_{14}H_{12}ONBr$: N, 4·8%).

o-*Bromonitrobenzene*–p-*Iodoanisole*.—The halogenonitro-compound (10 g.), the iodo-ether (14·6 g.), and copper (9·5 g.) at 175° (3·5 hr.) afforded copper salts (18 g.), a distillation fore-run (6 g.), b. p. 60—80°/0·4 mm. (discarded), a clear orange oil (6·9 g.), b. p. 150—155°/0·5 mm., and a yellow viscous oil (2 g.), b. p. 165—170°/0·5 mm. The main fraction gave yellow prisms (from methanol) of 4-*methoxy*-2′-*nitrobiphenyl* (4·8 g.), m. p. 61—62° (Found: C, 68·1; H, 4·7; N, 5·8. $C_{13}H_{11}O_3N$ requires C, 68·1; H, 4·8; N, 6·1%). Crystallisation of the viscous oil from benzene–light petroleum gave yellow needles of 2,2′-dinitrobiphenyl (0·6 g.), m. p. 127°.

1-*Chloro*(*and* 1-*Bromo*)-2,4-*dinitrobenzene*–o-*Bromoanisole*.—The reaction between 1-chloro-2,4-dinitrobenzene (8 g.), *o*-bromoanisole (7·5 g.), and copper (7·5 g.) at 195° for 5 hr. furnished inorganic material (11 g.), unchanged bromo-ether (3·3 g.), b. p. 60—70°/0·8 mm., and nitro-halide (2·3 g.), crude unsymmetrical biaryl (3·8 g.), b. p. 185—195°/0·5 mm., and a higher-boiling residue (2 g.), consisting largely of tetranitrobiphenyl, which in this instance was not further examined. Crystallisation of the resinous main fraction from methanol afforded yellow prismatic needles of 2′-*methoxy*-2,4-*dinitrobiphenyl* (3·4 g.), m. p. 125—126° (Found: C, 57·0; H, 3·6; N, 10·1. $C_{13}H_{10}O_5N_2$ requires C, 56·9; H, 3·6; N, 10·2%).

A similar reaction with 1-bromo-2,4-dinitrobenzene, but with *o*-bromoanisole (15 g., 2 mol.) at 195° for 3·5 hr., in which both reaction products were isolated, furnished the unsymmetrical biaryl (22%) and tetranitrobiphenyl (40%) as a yellow resin, b. p. 245—260°/0·5 mm., giving yellow-brown prisms, m. p. 165° (from methanol–ethyl acetate).

1-*Chloro*(*and* 1-*Bromo*)-2,4-*dinitrobenzene*–m-*Bromoanisole*.—In the same way as with the *o*-isomer, equimolar reaction of *m*-bromoanisole and the chlorodinitro-compound afforded yellow prisms (from methanol) of 3′-*methoxy*-2,4-*dinitrobiphenyl* (20%), m. p. 96—97°, from a crude fraction, b. p. 180—200°/0·4 mm. (Found: C, 57·1; H, 3·8; N, 10·4%). A comparable reaction with the bromonitro-analogue and the bromo-ether (2 mol.) at 195° for 3·5 hr. gave the unsymmetrical biaryl (15%) and the tetranitro-compound (55%).

1-*Chloro*(*and* 1-*Bromo*)-2,4-*dinitrobenzene*–p-*Bromoanisole*.—Similar treatment of an equimolar mixture of the chlorodinitro-compound and *p*-bromoanisole gave yellow needles (from methanol) of 4′-methoxy-2,4-dinitrobiphenyl (20%), m. p. and mixed m. p. 94—95° (Found: N, 10·2%). The yield of unsymmetrical biaryl was raised (to 25%) by repetition of the above reaction with the bromo-ether (2 mol.).

Reaction of the bromodinitro-analogue and the bromo-ether (2 mol.) at 195° for 3·5 hr. gave the unsymmetrical biaryl (15%) and tetranitrobiphenyl (55%).

4-*Bromo*-3-*nitrotoluene*–p-*Iodotoluene*.—The bromonitro-compound (23 g.) and *p*-iodotoluene (29 g., 1·25 mol.) reacted with copper (21 g.) at 175—180° for 3·5 hr. Fractional distillation of the organic products after separation of copper salts, etc. (37 g.), gave unchanged *p*-iodotoluene (12·5 g.), an orange yellow oil (12·5 g.), 150—165°/1 mm., and a higher-boiling residue (2·5 g.). Redistillation of the oil gave a fraction (10·5 g.), b. p. 212—216°/20 mm., which crystallised from methanol in lemon-yellow plates of 2-nitro-*p*-bitolyl (9·7 g.), m. p. 69—70° (lit., 69—70°). The combined distillation residues (4 g.) gave yellow needles (from methanol) of 2,2′-dinitrobitolyl (3 g.), m. p. 140—141°.

Phenylation of m-*Dinitrobenzene*.—(a) *With benzoyl peroxide.* A mixture of benzoyl peroxide (2·2 g.) and *m*-dinitrobenzene (15 g.) in a long-necked flask (100 ml.) was immersed in a water-bath and the temperature of the reactants raised to 90° during 1 hr. The mixture was then transferred to a steam-bath and heated at 100° for a further 4 hr. The product was dissolved in chloroform (200 ml.), and washed with aqueous sodium hydrogen carbonate and water, recovered, and distilled, yielding *m*-dinitrobenzene (12·5 g.), b. p. 110—115°/0·6 mm., and a red oil (1·3 g.), b. p. 150—165°/0·5 mm., which partly solidified. A resinous residue (1 g.) was discarded. Crystallisation of the red oil from methanol (15 ml.) gave, primarily, fine very pale yellow needles of 2,6-dinitrobiphenyl (0·02 g.), m. p. and mixed m. p. 188° (Found: N, 11·5. Calc. for $C_{12}H_8O_4N_2$: N, 11·5%), which was separated from the mother-liquors by decantation. On further storage the latter yielded the 2,4-isomer (0·2 g.) (Found: N, 11·4%). Repetition of the procedure after concentration of the mother-liquors afforded further quantities of the 2,6- (0·02 g.) and 2,4-isomer (0·16 g.) successively.

Repetition of the reaction with the addition of chlorobenzene (25 ml.) gave 2,6-dinitrobiphenyl (0·03 g.) and the 2,4-isomer (0·21 g.) from a crude distillation fraction (0·55 g.) obtained as previously described.

(b) *With benzenediazonium zinc chloride.* The double salt prepared [17] from aniline (4·65 g.) was filtered from the aqueous mother-liquors, washed with acetone, then immediately transferred to a solution of *m*-dinitrobenzene (19 g.) in acetone (25 ml.). Powdered calcium carbonate (10 g.) was added to the stirred solution, followed by zinc dust (2·5 g.). An exothermic reaction with evolution of nitrogen ensued and the liquors became deep crimson. After the reaction had subsided, water (300 ml.) was added, and the organic material extracted with chloroform (2 × 100 ml.). The combined extracts were washed with water then evaporated, finally under reduced pressure. The residue was dissolved in benzene (150 ml.) and filtered while warm by suction through alumina, which was finally washed with benzene (50 ml.). The combined filtrates were concentrated and fractionally distilled, giving *m*-dinitrobenzene (14 g.) and a red viscous oil (1·5 g.), b. p. 145—185°/0·5 mm. A black residue (2 g.) was discarded. The red oil was chromatographed in benzene–light petroleum (1 : 2), furnishing as the initial eluate a red oil which crystallised from methanol in red-orange feathery plates of 4-phenylazobiphenyl (?) (0·25 g.), m. p. 153—154° (lit., 150°) (Found: C, 83·5; H, 5·4; N, 10·9. Calc. for $C_{18}H_{14}N_2$: C, 83·7; H, 5·4; N, 10·9%). Further elution of the chromatogram yielded successively 2,4-dinitrobiphenyl (0·35 g.), m. p. 110° (Found: N, 11·4%), and 2,6-dinitrobiphenyl (0·03 g.), m. p. 188° (Found: N, 11·6%). The m. p.s of the isomeric dinitrobiphenyls were undepressed on admixture with authentic specimens.

1-*Chloro*-2,6-*dinitrobenzene*–*Iodobenzene* (*in Nitrobenzene Solution*).—Iodobenzene (5 g.) was added to a solution of the nitro-halide (5 g.) in nitrobenzene (25 ml.) containing suspended copper (5 g.). After 1·5 hours' refluxing, the liquors were cooled, filtered from inorganic material, and evaporated under reduced pressure. The residue crystallised readily in pale yellow needles (from ethyl acetate) of 2,6-dinitrobiphenyl (5 g.), m. p. 188°. 2,6-Dinitrodiphenylamine could not be isolated.

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