Rearrangement of Aromatic *N*-Nitroamines. Part VII.[1] The Acid-catalysed Transformation of *N*-Methyl-*N*-nitro-9-aminoanthracene

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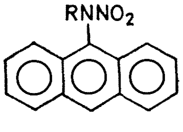
Treatment of *N*-methyl-*N*-nitro-9-aminoanthracene with sulphuric acid (*ca.* 7N) yielded 10-nitroanthrone (90%) together with nitrous acid (5%). The reaction which involved intramolecular shift of the nitro-group, was first order in substrate its rate was linearly correlated with the h_0 function; but, unexpectedly, the reaction had a solvent isotope effect (k_{D_2O}/k_{H_2O}) of less than unity.

It is proposed that rate-limiting protonation of the aromatic ring and either direct migration of the nitro-group or migration *via* the intermediacy of a tightly-bound ion or radical pair occurred.

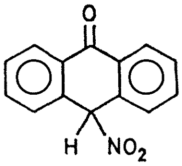
The present status of the ' radical-pair ' and ' cartwheel ' mechanisms for the nitroamine rearrangement is discussed.

THE acid-catalysed rearrangement of *N*-methyl-*N*-nitroaniline and various derivatives (and, by extension, all *N*-nitroarylamines) to form *C*-nitroamines has been considered to proceed by *N*-protonation followed by formation of a cation-radical pair ($\mathrm{Ph\overset{+\cdot}{N}HR\,\overset{\cdot}{N}O_2}$): this intermediate is supposed to form products by predominantly intramolecular (but also in some cases intermolecular) routes.[2,3] However, this interpretation cannot accommodate all the data for other substrates in a satisfactory manner.[4] For example, the complete lack of an intermolecular component for rearrangement of other types of *N*-nitroamines led to the proposal of a ' cartwheel ' mechanism whereby migration of the nitro-group to the C-2 ring position, and partition of the σ-complex thus formed between proton-loss and further migration to the C-4 position, occurred in concerted cyclic processes. A third proposal, that of the intermediate formation of a π-complex, is inconsistent with most of the available data.[5]

A distinction between the ' radical-pair ' and ' cartwheel ' mechanisms could possibly result from studies of rearrangement of *N*-nitro-9-aminoanthracenes (I). *N*-Methyl-*N*-nitro-9-aminoanthracene (I; R = Me) would not undergo rearrangement by a cartwheel process as the benzo-substituents on the central aromatic ring would prevent formation of a *o*-linked intermediate, but reaction by the radical-pair mechanism would be unimpeded. In the event, unexpected results were obtained which indicate that this substrate reacted by a mechanism atypical for the class.



(I)



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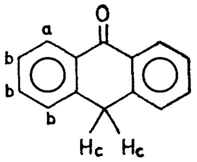

(III)

RESULTS

(a) *Kinetics.—Conditions.* The reactions were carried out in 60% dioxan–water at 25°. The acidities were above those at which formal ionic strengths can be taken to control properties of solutions independent of the nature of the ionic composition, and so ionic strength was not buffered by the addition of neutral salts. Pseudo-first-order rate constants (k_1/s^{-1}), recorded in Table 1, are the means of 2 to 3 determinations.

TABLE 1

Kinetics of decomposition of (I; R = Me) in 60% dioxan-water at 25°

N-H_2SO_4	7·21	7·21	6·73	6·37	5·71
$10^4[S_0]$/M [a]	3·97	1·07	3·97	4·80	3·97
10^4k_1/s^{-1}	2·96 ±0·01	2·97 ±0·01	1·75 ±0·02	1·06 ±0·04	0·45 ±0·05
H_0 (rel.)[b]	0·000	0·000	0·249	0·435	0·801

[a] $[S_0]$ is the initial concentration of substrate. [b] Relative H_0 values (see Experimental section).

Kinetic runs were also carried out at $[S_0]$, 4·80 × 10^{-4}M in 6·37N-H_2SO_4/H_2O and 6·44N-D_2SO_4/D_2O. The respective rate constants were (1·06 ± 0·04) and (0·95 ± 0·01) × 10^{-4} s^{-1}.

(b) *Products.*—Analyses recorded in Table 2 are the means of 2 or 3 determinations for reactions with 7N-H_2SO_4 in 60% dioxan–water at 25°. 10-Nitroanthrone (II) and methylamine were the only identified organic products.

(c) *Tracer Studies.*—Isotope abundances in 10-nitroanthrone isolated from reactions carried out in the presence of ^{15}N-labelled acids containing 98·5% atoms excess of tracer are recorded in Table 3. The abundances are accurate to ±1. The incorporation of tracer from [^{15}N]-nitric acid indicates a maximum of 7% intermolecular component. No significant incorporations resulted from the experiments using [^{15}N]nitrite, but the sensitivity of the test was impaired by the necessity of using low concentrations of the additive (see Experimental section).

(d) *Nitration of Anthrone.*—No conversion of anthrone into 10-nitroanthrone could be detected under the conditions of Table 3, line 1. However, on addition of nitrous acid equivalent to that liberated by acidolysis of the *N*-nitroamine under the same conditions a quantity of the 10-nitro-compound was formed equivalent to the amount of additive.

Similar experiments with *N*-methyl-9-aminoanthracene were complicated by autoxidation and decomposition of the

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[1] Part VI, D. V. Banthorpe and J. A. Thomas, *J. Chem. Soc.*, 1965, 7158.

[2] W. N. White in ' Mechanisms of Molecular Migrations,' ed. B. S. Thyagarajan, vol. 3, Wiley-Interscience, New York, 1971, p. 109.

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[4] D. V. Banthorpe in ' Chemistry of the Amino Group,' ed. S. Patai, Academic Press, London, 1968, p. 585.

[5] D. V. Banthorpe, *Chem. Rev.*, 1970, **70**, 295.

substrate and the 10-nitro-compound could not be unambiguously characterised. 9-Aminoanthracene was more stable under these conditions, and gave a mixture of products but no detectable 10-nitro-compound.

TABLE 2

Products of reaction of (I; R = Me); conditions as in Table 1: (7·21N-H_2SO_4)

$10^4[S_0]$/M [a]	Additive [10^3M]	t/°C	10-Nitroanthrone (%)	HNO_2 (%)	$MeNH_2$ (%)
6·3		25	63 ± 3	*b*	*b*
6·3	NaN_3 (8·3)	25	81 ± 1	*b*	*b*
6·5	Anisole (200)	25	65 ± 1	*b*	*b*
8·2		4	87 ± 2	5·3 ± 1·1	73 ± 5
8·2	Sulphamic acid (2·6)	4	88 ± 4	*b*	*b*
8·2	Urea (13)	4	89 ± 5	*b*	*b*

[a] As in Table 1. [b] Not estimated.

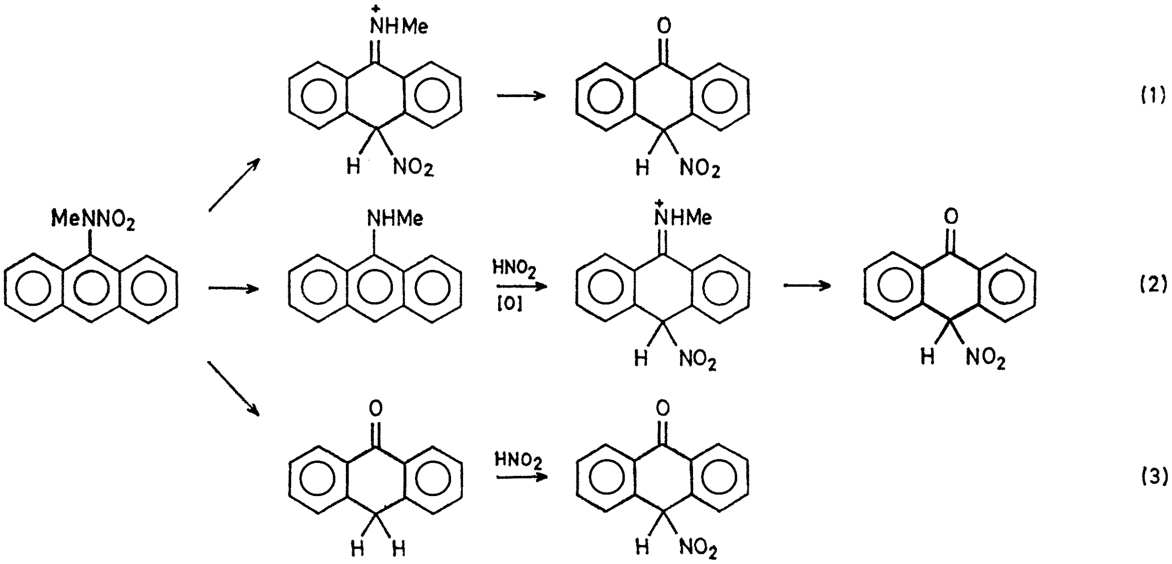
TABLE 3

Isotope abundances in 10-nitroanthrone [a]

Additive (10^3M)	$10^3[S]_0$/M [b]	Abundance
[^{15}N]-HNO_3 (15)	2·0	66
HNO_3 (15)	2·0	17·5
[^{15}N]-KNO_2 (0·35)	1·6	14·8
KNO_2 (0·45)	1·6	16·0
	2·0	15·9

[a] Conditions as in Table 2, line 1. [b] As in Table 1. 100(P + 1)/P: means of duplicate determinations.

(e) *Hydrogen Exchange in Anthrone.*—Anthrone (0·4 g) in dioxan (10 ml) was treated under nitrogen with deuteriosulphuric acid (36N; 4 ml) and deuterium oxide (2 ml) for 25 h at 25°. The substrate had n.m.r. peaks at τ 1·83 to 2·04 [m, 1H, H_a in (III)], 2·73 to 2·98 [m, 3H, H_b in (III)] and 5·97 [s, 2H, H_c in (III)]. The product showed no absorption at τ 5·97 but the relative intensities of the other peaks were unchanged.



DISCUSSION

The main product of these reactions is 10-nitroanthrone. This could result from (a) hydrolysis of the intramolecular rearrangement product *N*-methyl-9-amino-10-nitroanthracene; (b) Fischer–Hepp-type rearrangement involving the amine formed by disproportionation of the substrate; or (c) cleavage of the substrate to anthrone and nitration (*via* nitrosation by concomitantly-produced nitrous acid). These possibilities are shown in mechanisms (1) to (3). Our experiments on nitration of anthrone show that the reactions of the last mechanism are possible under the ' rearrangement ' conditions. There was no kinetic or spectral evidence for any build up of intermediate between the substrate and 10-nitroanthrone.

The intermolecular pathways of mechanisms (2) and (3) are ruled out (except for possible minor components of reaction) by the lack of influence on product proportions of scavengers for nitrous acid (urea, sulphamic acid, Table 2) which were added in molar excess, and any intermolecular route involving an electrophile (*e.g.* $\overset{+}{N}O_2$, $\overset{+}{N}O$) is eliminated by the similar lack of effect of added anisole. The addition of sodium azide, another scavenger of nitrous acid, does effect the product of a run carried out at higher temperature: however, the yield of 10-nitroanthrone is now increased and presumably the additive destroyed nitrous acid formed by disproportionation of the substrate that would otherwise have reacted with substrate, intermediates, or product.

The tracer work with [^{15}N]nitric acid confirms the intramolecular picture, allowing at most 7% intermolecular components [that would arise *via* routes (2) and (3)], as nitrate ion would be an efficient trap for any nitrating or nitrosating species.[6] The lack of uptake of tracer from sodium [^{15}N]nitrite ion is less significant as a molar excess of sodium nitrite could not be added to the reaction mixture without destroying substrate and

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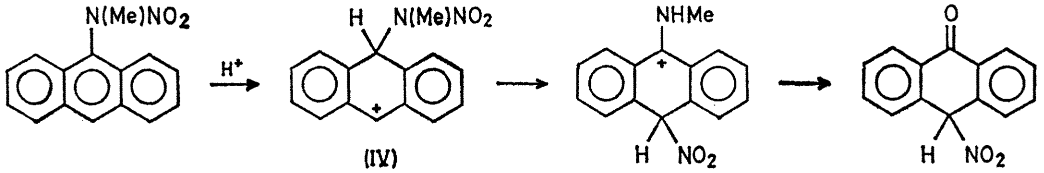
[6] D. V. Banthorpe, J. A. Thomas, and D. L. H. Williams, *J. Chem. Soc.*, 1965, 6135.

products. The conclusion is that, in common with most other nitroamine rearrangements, this acid-catalysed transformation is predominantly intramolecular in nature.

A product balance was not obtained in these experiments, but the formation of nitrous acid was proved in one case and the *N*-methyl-9-aminoanthracene that was probably formed in equivalent quantities to the latter would have been nitrosated, autoxidised, or otherwise destroyed[7] and probably contributed to the tars that always accompanied reaction. Methylamine was also recovered in up to 73% of the theoretical yield from one reaction.



(4)

The reaction is first order in substrate and, showed a Hammett-dependence of rate on acidity ($\Delta \log k/\Delta H_0$, $-1{\cdot}03 \pm 0{\cdot}05$). The range of acidity used in the latter correlation was small (Table 1) but the conclusion is justified as H_0 and pH diverge widely at these acidities. The relative rates for rearrangement of *N*-methyl-*N*-nitroaniline, *N*-methyl-*N*-nitro-1-naphthylamine, and our anthracene derivative[2,8] are 1·0 : 0·11 : 0·0095, and these correlate well with the pK_a values of the corresponding arylamines, *viz.* 1·0 : 0·06 : 0·013.[9,10] The values for the *N*-methylarylamines are unavailable.

Thus the reaction of the anthracene derivative appears to fall in line with those of its analogues, and this 'normal' behaviour appears to favour the 'radical-pair' theory (see opening paragraphs). Although on the basis of the latter theory, it is difficult to see why migration into the flanking benzene rings did not occur to some extent.

The solvent isotope effects reveals, however, an unexpected situation. k_{D_2O}/k_{H_2O} had a value (corrected for the differing acidities of the two runs) of 0·84 and this compares with values of 2·5 to 3·3 for *N*-nitroaniline and *N*-nitro-1-naphthylamine and their *N*-methyl homologues,[2,8,11] and indicates a mechanistic difference, for it is difficult to see how this effect can be a secondary solvent effect. Either rate-determining protonation of the substrate occurred in the presently studied situation or carbon-bonded hydrogen must have exchanged with the deuteriated solvent and deuterium must then have been lost from the substrate or its derivative in the rate-limiting step[12] following an initial pre-equilibrium proton transfer. The former mechanism would give a Hammett correlation providing the protons were practically transferred to the substrate in the transition state of the rate-limiting step.[13]

Our exchange studies do suggest that hydrogen linked at C-10 could be exchanged before reaction, but the tendency of the anthracene to acquire the quinonoid condition[14] suggests that a novel mechanism may here be operative. Slow proton-transfer to the ring could give the species (IV), reaction (4), in which the hybridisation at C-9 facilitates intramolecular transfer of the nitro-group to C-10 and this could be followed by hydrolytic cleavage of the methylamino-group. Several details of this mechanism are adjustable: the N to C migration could be *via* direct spanning, a tightly-bonded ion-pair,[11] or a radical-ion pair. Similar ring-protonation and 1,4-migrations have been suggested (but with no supporting evidence) for certain sulphanilic acid rearrangements[15] and they may occur in the recently-discovered[16] intramolecular Fischer–Hepp rearrangements.

If a unique mechanism obtains for anthracene derivatives, the skeleton is not a suitable structure to use as a criterion for the validity of the cartwheel and radical-pair theories. One possible method of characterising the latter would be observation of a c.i.d.n.p. effect during rearrangement. We have carried out preliminary studies to this end using *N*-nitroaniline and *N*-methyl-*N*-nitroaniline in dioxan : deuterium oxide and the reactions of the corresponding 2,6-dideuterio- and 2,4,6-trideuterio-compounds in isotopically normal media, but have been unable to detect the characteristic signals. Others have had a similar experience.[17]

The present situation is that the nitroamine rearrangement is symmetry-allowed[18] and so, energy, stereochemistry, and geometry permitting, could progress by a concerted cartwheel route. Much of the available data can, indeed, only be rationalised thus.[4] On the other hand, considerable data has been collected to support a radical-pair mechanism in other examples.[2,3] If the latter mechanism were to be general, the radical pairs would have to be extremely tightly-bonded to account for the general strict intramolecularity of rearrangement: other reactions in which radical pairs are

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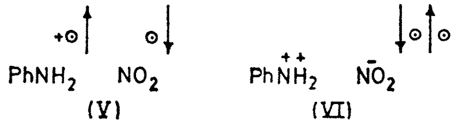
formed typically show a high rate of leakage from the solvent cage and a relatively low rate of primary recombination.[19] Another argument for tight bonding of the fragments is the predominance of *o*-linked product rather than the statistical distribution of isomers expected if the moieties were free within the solvent cage. Consequently, such intermediates must probably be spin-paired and there can be little difference between the representations (V) and (VI): *i.e.* spin-paired radicals or ion pairs.



The difference between the cartwheel and such restricted radical-pair mechanisms is thus that the former involves covalently-bonded *o*- and *p*-linked intermediates, whereas the latter requires ' intermediates ' that are electrostatically or quantally bonded at the same ring positions. The latter would require some type of spin–spin interaction without covalent bonding. π-Complexing between the radical or ionic moieties has been explicitly rejected on theoretical and experimental grounds.[2,3] Studies of product isotope-effects support the existence of the first type of (covalent) intermediates in certain rearrangements,[4] but the two descriptions are clearly very similar on energetic and stereochemical grounds, and a spectrum of mechanisms ranging from fully concerted cartwheel types to those involving loosely-bonded, spin-unpaired radical pairs or ion-pairs is conceivable. There is no reason to expect a single mechanism to apply for all substrates and conditions.

EXPERIMENTAL

Unless otherwise stated, all m.p.s were within ±1° of accepted values. Light petroleum refers to the fraction of b.p. 40—60°. N.m.r. spectra were measured at 60 MHz in $[^2H_6]$acetone or $[^2H]$chloroform with Me_4Si as internal standard.

(i) *Preparations*.—9-Nitroanthracene [20] was rapidly crystallised from acetic acid (to avoid oxidation): yield 56%, m.p. 146°; and converted [21] into 9-aminoanthracene: yield 70%, m.p. 140°(d) (lit.,[21] 145—150°). Attempts to recrystallise the latter led to the isolation of detonatable autoxidation products,[7] m.p. 125°(d) and 225°(d). The crude product contained >90% of the required amine as indicated by the n.m.r. spectrum. Conversion into N-*methyl*-N-*nitro*-9-*aminoanthracene* was by the method for preparing *N*-methyl-*N*-nitroanilines: [22] the ethereal product was decolourised and worked-up to yield yellow crystals: yield 2%, m.p. 163°(d) (Found: C, 70·4; H, 4·8; N, 11·1. Calc. for $C_{15}H_{12}N_2O_2$: C, 71·4; H, 4·8; N, 11·1%), τ 5·90 (s, 3H, C*H*$_3$), 1·30 (s, 1H, 10-H), and 1·78—2·59 (m, 8H, other C-*H*).

10-Nitroanthrone was prepared as described [23] save that the initially formed precipitate was rejected and crystals were precipitated by addition of water to the mother liquor: yield 40%; m.p. 152°(d) (from benzene–light petroleum; lit.,[24] 146°) (Found: C, 70·8; H, 3·9; N, 5·8. Calc. for $C_{14}H_9NO_3$: C, 70·3; H, 3·8; N, 5·9%).

N-Methyl-9-aminoanthracene was prepared: [25] yield 40%; m.p. 80—90° [lit.,[25] 90°(d)]. The n.m.r. spectrum indicated over 90% of the required amine but purification was impracticable because of ready autoxidation.

(ii) *Kinetic Methods*.—Aliquot portions (5 ml) were made basic with sodium hydroxide (5N; 20 ml) at *ca.* 0° with precautions (ice–salt bath, rapid stirring, addition down side of beaker) to prevent side reactions and the resulting solution was extracted with chloroform (2 × 20 ml) to give aqueous and organic fractions (A and B).

The latter contained unchanged substrate, tars, and various minor (<2%) reaction products and was chromatographed on thin layers of silica gel H with ether–benzene (3 : 7 v/v) or chloroform to give substrate (R_F 0·60, 0·65) which was eluted from the plate (>98% recovery in blanks) and assayed spectrophotometrically ($\lambda_{max.}$ chloroform 274 nm; ε 11,500). No *C*-nitroamines or 9-aminoanthracene could be detected. The sodium salt of the enol form of 10-nitroanthrone remained in extract A, and could be converted into the keto-form by cautious acidification and this could then be extracted into chloroform. This keto-compound was shown to be the only component in the extract A (t.l.c. systems as above; R_F 0·44, 0·48), and was assayed spectrophotometrically ($\lambda_{max.}$ chloroform 367 nm; ε 9480). The Beer–Lambert law applied to the solutions of substrate and product.

Good first-order plots could be obtained for either the rate of disappearance of substrate or the rate of formation of products, and linear plots were obtained up to 80% of the reaction. The component of the rate of disappearance of the former to give 10-nitroanthrone was equal (±1%) to the rate of formation of this product, and no build up of intermediates could be detected, at the range of acidities used, by spectrometric scanning of the reaction mixtures. Thus either ($-$ds/d*t*) or (d*p*/d*t*) (s = substrate, p = product) could be measured as an equivalent index of the rate of the ' rearrangement ' reaction: the latter was more convenient to do and the results of Table 1 are so based.

H_0 Values relative to that of the most concentrated acid solution were measured by indicator studies using 2-nitroaniline.

(iii) *Product Analyses*.—Products were extracted from large scale runs by the method described in the previous section. Nitrous acid was estimated by measurement of the optical density at 528 nm after diazotisation of 4-nitroaniline and coupling with *NN'*-dimethyl-1-naphthylamine, and methylamine was aspirated (in one experiment) from the basic reaction mixture and was collected in dilute acid and characterised spectrometrically. Recovery in blank experiments was 80—90% of the theoretical, and so the value recorded in Table 1 considerably underestimates the actual value.

The reactions in the presence of additives were carried

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out in three-necked flasks. A ten-fold, or greater, excess of the additive was put into one of the arms, the acid was put in another, and the substrate dissolved in solvent suitable to give a final composition of 60% dioxan–water was put in the third. The flask was deoxygenated and mixed by shaking. Controls were carried out in all cases.

(iv) *Isotope Experiments*.—The relative proportions of nitric and nitrous acids that were added had to be carefully controlled to prevent side reactions, and, in particular, destruction of substrate and product by the latter additive. The last reaction necessitated the use of concentrations of [^{15}N]nitrite such that an intermolecular component of less than *ca.* 40% of the total reaction would not have been detected. Two sets of experiments were carried out, each in duplicate.

(a) A cooled (*ca.* 5°) mixture of dioxan (50 ml), sulphuric acid (23N, 37·5 ml), and [^{15}N]nitric acid (0·6N; 2·5 ml; 98% atoms excess: ex Merck, Montreal, Canada) was added to the substrate ($2{\cdot}04 \times 10^{-2}$ mol) in dioxan (10 ml) under nitrogen, and the mixture was left 24 h at 25° before work-up.

(b) A solution (*ca.* 5°) of the substrate ($1{\cdot}65 \times 10^{-2}$ mol) in dioxan (10 ml) was added to a mixture of sodium[^{15}N]-nitrite (7×10^{-3} mol) in water (4 ml) and dioxan (50 ml) that also contained sulphuric acid (23N; 35 ml), and was treated as in (a).

The 10-nitroanthrone was isolated and the nitrogen-15 content was determined mass spectrometrically using a modified A.E.I. MS9 instrument.

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