932. *Properties and Reactions of Free Alkyl Radicals in Solution. Part XII.* Evidence for Radical-catalysis of Hydrogen Transfer.*

By R. A. JACKSON and WILLIAM A. WATERS.

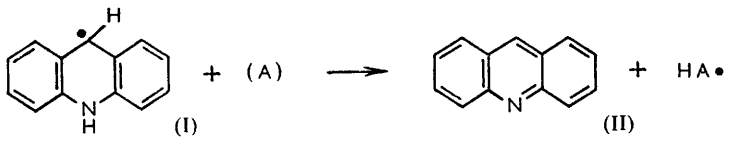
2-Cyano-2-propyl radicals attack acridan, giving acridine, di-9-acridanyl, and 9-(2-cyano-2-propyl)acridan. Mercaptoacetic acid promotes the reaction.

In the presence of 2-cyano-2-propyl radicals at 80—100° the conversion of acridan into acridine is effected by azobenzene, *m*-dinitrobenzene, and 1 : 3 : 5-trinitrobenzene; at this temperature there is little hydrogen transfer in the absence of the cyanopropyl radicals. Catalysed reduction of tetrazolium salts has also been noted.

Diphenylnitrogen radicals have only weak hydrogen-abstracting power.

2-CYANO-2-PROPYL and related radicals scarcely dehydrogenate aliphatic aldehydes (Part IV [1]) except in the presence of a thiol,[2] and in the absence of a thiol do not attack 9 : 10-dihydroanthracene.[3,4] We find, however, that acridan (9 : 10-dihydroacridine) is attacked by 2-cyano-2-propyl radicals giving, under optimum conditions, 14% of acridine, 27% of di-9-acridanyl, and 48% of 9-(2-cyano-2-propyl)acridan, the formation of the last two showing that radical dehydrogenation occurs at the *meso*-CH_2 group and not at >NH. Mercaptoacetic acid appreciably catalyses this dehydrogenation. 9-Phenylacridan is less easy to dehydrogenate, whereas diethyl 1 : 4-dihydrocollidine-3 : 5-dicarboxylate is not dehydrogenated even in the presence of mercaptoacetic acid.

In the presence of a hydrogen atom acceptor, such as azobenzene, *m*-dinitrobenzene, or 1 : 3 : 5-trinitrobenzene, much more hydrogen can be removed from acridan at temperatures that are far too low for appreciable direct hydrogen-transfer to the ultimate oxidant. Thus no reaction occurred when a solution of acridan and azobenzene in benzene was refluxed for 4 hours, but in presence of excess of αα′-azo*iso*butyronitrile 85% of the azobenzene was reduced. (2-Cyano-2-propyl radicals did not react directly with azobenzene.) When a solution of acridan and *m*-dinitrobenzene in benzene was refluxed for 8 hours, only 0·4% of acridine was produced, but on addition of αα′-azo*iso*butyronitrile 31% of acridine was formed, only 11% of which corresponds to the direct attack of 2-cyano-2-propyl radicals on the acridan. With 1 : 3 : 5-trinitrobenzene over a similar period there was only 4% of direct reaction, and a 64% conversion in the presence of 2-cyano-2-propyl radicals, corresponding to 49% of radical-catalysed hydrogen transfer. Colour tests with 2 : 3 : 5-triphenyltetrazolium chloride, and with 3 : 3′-dimethoxydiphenyl-4 : 4′-bis-(3 : 5-diphenyltetrazolium) dichloride (" blue tetrazolium salt ") have given further evidence of a radical-catalysed hydrogen transfer which can be promoted by the addition of mercaptoacetic acid, though the occurrence of side reactions has made it difficult to obtain quantitative data.



It is thus evident that, when 2-cyano-2-propyl radicals have attacked acridan to give the 9-acridanyl radical (I), the latter can then transfer a hydrogen atom to a suitable acceptor

* Part XI, *J.*, 1958, 3221.

[1] Harris and Waters, *J.*, 1952, 3108.
[2] *Idem*, *Nature*, 1952, **170**, 212.
[3] Bickel and Kooyman, *ibid.*, p. 211.
[4] Beckwith and Waters, *J.*, 1957, 1001.

molecule (A), such as azobenzene or a polynitro-compound, the extra resonance energy of the anthracene-type ring system being available from the conversion of (I) into (II) to provide a driving force for the reaction.

Radiochemical evidence for homolytic hydrogen-transfer to certain heterocyclic molecules is now definite,[5] but attempts to set up radical chains:

$$HX\cdot + A \longrightarrow X + HA\cdot\ ;\quad HA\cdot + XH_2 \longrightarrow HX\cdot + H_2A$$

by the generation of semiquinone radicals [6] have failed, probably because in these selected systems at least one of the radicals concerned (HA· or HX·) has a resonance structure of too low energy content for attack on C–H bonds. Chain processes of this type occur, of course, in autoxidations where A is oxygen (O_2).

Chain dehydrogenation by the radical $(CH_2{\cdot}CO)_2N\cdot$, which has little resonance stabilisation, is undoubtedly involved in the homolytic reaction of *N*-bromosuccinimide. We have attempted to dehydrogenate other molecules with the diphenylnitrogen radical $Ph_2N\cdot$ and find that it will attack hydrazobenzene giving azobenzene, and 9 : 10-dihydroanthracene giving anthracene. It does not attack cumene, tetralin, or *cyclo*hexene. Here again, as with diphenylpicrylhydrazyl,[7] we have an inactive radical.

Experimental

Free-radical experiments were carried out under oxygen-free nitrogen. M. p.s are corrected.

Reaction of αα′-Azoisobutyronitrile with Acridan.—Acridan (5·0 g.) and αα′-azo*iso*butyronitrile (9·0 g.) in dry benzene (250 ml.) were refluxed for 7 hr. Colourless crystals of insoluble di-9-acridanyl, m. p. 252° (0·58 g., 12%), separated (Found: C, 86·9: H, 5·4; N, 7·4. Calc. for $C_{26}H_{20}O_2$: C, 86·6; H, 5·6; N, 7·8%) and were identified by conversion with sulphuric acid into 1 : 2-di-(*o*-anilinophenyl)ethylene oxide,[8] m. p. 165°. The solvent was removed from the remainder, which was then steam-distilled. The distillate was extracted with benzene, and the benzene solution was extracted with 2N-hydrochloric acid. On evaporation of the benzene solution, tetramethylsuccinonitrile (3·4 g.) was obtained, whilst the acid extracts, after neutralisation and extraction with ether, gave acridine (0·28 g.). The involatile residue was fractionally crystallised from benzene and light petroleum (60—80°), giving acridan, m. p. 169° (1·53 g., 30%), more acridine (0·73 g., total 20%) and 9-(2-*cyano*-2-*propyl*)*acridan* (1·1 g., 16%), m. p. 164° (decomp.) (Found: C, 82·4; H, 6·4; N, 11·6. $C_{17}H_{16}N_2$ requires C, 82·2; H, 6·5; N, 11·3%). The ultraviolet spectrum of this compound in alcohol resembled that of acridan, having $\varepsilon_{max.} = 1{\cdot}8 \times 10^4$ at 279 mμ whilst its infrared spectrum (Nujol mull) had absorption at 4·49 (·CN), 7·20 and 7·29 (·CMe_2), and 2·97 μ (·NH).

By addition during 24 hr. of the azo-nitrile (3·6 g., 2 mol.) in benzene (100 ml.) to a refluxing solution of acridan (2·0 g., 1 mol.) in benzene (100 ml.), 0·54 g. (27%) of insoluble di-9-acridanyl was obtained. Spectroscopic analysis of the remaining solution indicated yields of 14% of acridine and 48% of 9-(2-cyano-2-propyl)acridan, with no remaining acridan.

To acridan (2·0 g.) and the azo-nitrile (3·6 g.) in boiling benzene (60 ml.), mercaptoacetic acid (0·36 g.) in benzene (40 ml.) was added in small portions during ½ hr. and heating was continued for a further 7 hr. From this mixture 9% of di-9-acridanyl, 12% of acridine, 5% of unchanged acridan, and 44% of 9-(2-cyano-2-propyl)acridan were isolated, so that addition of the thiol had markedly increased the yield of the last compound and decreased the amount of unchanged acridan.

Reaction of αα′-Azoisobutyronitrile with 9-Phenylacridan.—A solution of 9-phenylacridan [9] (0·42 g.) in benzene (250 ml.) was prepared. To 50 ml. (1 mol.) portions of this were added (*A*) αα′-azo*iso*butyronitrile (0·21 g., 4 mols.), (*B*) mercaptoacetic acid (0·03 g., 1 mol.), and (*C*) αα′-azo*iso*butyronitrile (0·21 g.) and mercaptoacetic acid (0·03 g.). The three solutions were refluxed for 8 hr. and then diluted to 100 ml. with benzene. Analysis of the ultraviolet spectra

[5] Stein and Swallow, *J.*, 1958, 306.
[6] Moore and Waters, *J.*, 1953, 3405.
[7] Braude, Brook, and Linstead, *J.*, 1954, 3574.
[8] Lehmstedt and Hundertmark, *Ber.*, 1930, **63**, 1229.
[9] Acheson, Hoult, and Barnard, *J.*, 1954, 4142.

of these solutions at 289, 355, and 385 mμ indicated that 9-phenylacridine had been produced in the following amounts: *A* 5%, *B* 11%, and *C* 22%.

Reaction of αα′-Azoisobutyronitrile with Diethyl 1 : 4-*Dihydrocollidine*-3 : 5-*dicarboxylate.*—A solution of diethyl 1 : 4-dihydrocollidine-3 : 5-dicarboxylate [10] (3·5 g.) and the azo-nitrile (4·3 g.) in benzene (100 ml.) was refluxed for 7½ hr. Tetramethylsuccinonitrile (2·8 g.) and unchanged dihydrocollidine ester (3·15 g., 90%) were recovered. Addition of mercaptoacetic acid (0·43 g.) to a similar mixture merely reduced the recovery of tetramethylsuccinonitrile to 2·38 g.; 2·44 g. were obtained in a control experiment without the ester.

Reaction of Acridan with Azobenzene in the Presence of αα′-Azoisobutyronitrile.—A solution of acridan (3·62 g., 2 mol.), azobenzene (1·82 g., 1 mol.), and αα′-azo*iso*butyronitrile (6·57 g., 4 mol.) in benzene (250 ml.) was refluxed for 4 hr. The solution was then still orange, with no appreciable precipitate, showing that the formation of di-9-acridanyl had been almost completely inhibited. The light absorption at 444 mμ of a sample, compared with that of a sample of the initial solution, showed that the azobenzene concentration was only 15% of its original value. The bulk of the product was recovered by evaporation and dissolved in ether, and the presence of hydrazobenzene was shown (*a*) by the intensification of the absorption at 444 mμ after oxidation with sodium hypobromite and (*b*) by the chromatographic isolation of a small quantity of benzidine after treatment with 6N-hydrochloric acid. The benzidine (m. p. 126—127°) was characterised by its mixed m. p. and infrared spectrum.

Control experiments showed that azobenzene did not react directly with acridan or αα′-azo-*iso*butyronitrile.

Reaction of Acridan with Nitro-compounds in the Presence of αα′-Azoisobutyronitrile.—A solution of 1 : 3 : 5-trinitrobenzene (0·85 g., 0·72 mol.), acridan (1·00 g., 1 mol.), and αα′-azo*iso*-butyronitrile (1·81 g., 2 mol.) in benzene was refluxed for 8 hr., cooled, and extracted with 2N-hydrochloric acid until the extracts were colourless. The hydrochloric acid solution was made alkaline with ammonia and extracted with ether, and the ethereal extracts were dried ($MgSO_4$) and made up to 250 ml. Half of this solution was evaporated and the residue was sublimed at 100° in a vacuum, giving acridine (0·318 g., 64%), m. p. 107—108°, characterised by its mixed m. p. and infrared spectrum.

Similar experiments were carried out with nitrobenzene and *m*-dinitrobenzene. In addition, control experiments without the azo-nitrile were conducted. In these experiments, acridine was estimated by its absorption at 250 mμ in ethanol solution. The results are shown in the Table.

Azonitrile (mol.)	Nitro-compound (mol.)	Acridine produced (%)	" Excess " of acridine (%)
2	Nil	11	—
2·2	Nitrobenzene (1 mol.)	14	3
Nil	*m*-Dinitrobenzene (1 mol.)	0·4	—
2	*m*-Dinitrobenzene (1 mol.)	31	20
Nil	1 : 3 : 5-Trinitrobenzene (0·72 mol.)	4	—
2	1 : 3 : 5-Trinitrobenzene (0·72 mol.)	64	49

1 mol. of acridan was used in each experiment.

Reaction of Acridan and Tetrazolium Chlorides in the Presence of αα′-Azoisobutyronitrile.—Decomposition of the azo-nitrile in water or ethanol does not produce reductive coloration of 2 : 3 : 5-triphenyltetrazolium chloride or of the analogous " blue tetrazolium salt." [11] Heating the tetrazolium salts in ethanol with acridan produces some colour, but much less than that in a mixture of all three components. With the " blue tetrazolium salt " the colour enhancement at 510 mμ due to the reduction of the salt was, with addition of the azo-nitrile, 27 times that without it.

Dehydrogenations with Diphenylnitrogen Radicals.—A solution of 9 : 10-dihydroanthracene (2·0 g.) and tetraphenylhydrazine (5·0 g.) in benzene (100 ml.) was refluxed for 4½ hr. After cooling, the solution was extracted with 6N-hydrochloric acid to remove diphenylamine (2·4 g.). The benzene was removed and the residue was separated chromatographically, giving anthracene, m. p. 213° (1·45 g., 73%), and unchanged 9 : 10-dihydroanthracene (0·47 g., 23%).

After refluxing for 4½ hr., a solution of hydrazobenzene (1 g.) and tetraphenylhydrazine

[10] Hantzsch, *Annalen*, 1882, **215**, 1.
[11] Haines and Waters, *J.*, 1955, 4256.

(2 g.) in benzene became deep orange. Spectroscopic analysis (visible absorption at 450 mμ) indicated 99% conversion into azobenzene; 87% of azobenzene, m. p. 67—68°, was recovered chromatographically.

Similar experiments with cumene, *cyclo*hexene, tetralin, and dimethyl succinate gave no evidence of hydrogen transfer.

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THE DYSON PERRINS LABORATORY, OXFORD UNIVERSITY. [*Received, July 17th,* 1958.]