N-Bridged Heterocycles. Part I. Synthesis and Chemistry of *NN'*-Polymethylene-*o*-phenylenediamines

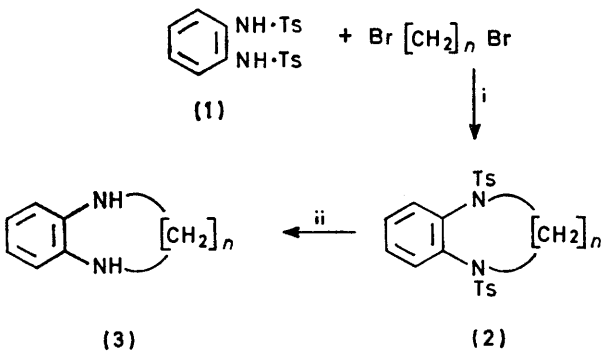
By **Roger J. Hayward** and **Otto Meth-Cohn,*** The Ramage Laboratories, University of Salford, Salford M5 4WT

Methods have been elaborated for the synthesis of the series of *NN'*-polymethylene-*o*-phenylenediamines with 5—10 and 12 methylene groups. The interaction of these compounds with formaldehyde, benzaldehyde, and other aldehydes (to give bridged 2,3-dihydro-1*H*-benzimidazoles), with di-acid chlorides such as phosgene, thiophosgene, and oxalyl, succinyl, and sebacoyl chloride (to give various bridged heterocycles), with hetero-cumulenes such as carbon disulphide, and phenyl isocyanate and isothiocyanate, and with oxidising agents are reported.

As part of a general study of *N*-bridged heterocycles we required as starting materials a series of *NN'*-polymethylene-*o*-phenylenediamine derivatives (**3**). The earlier members of this series ($n = 2$—6) have been prepared by Stetter [1] by the action of an αω-dibromoalkane on *NN'*-ditosyl-*o*-phenylenediamine (**1**), followed by hydrolysis of the ditosyl derivative (**2**) (Scheme 1). The reaction is of interest in that high dilution conditions were not necessary. However, the yields were only

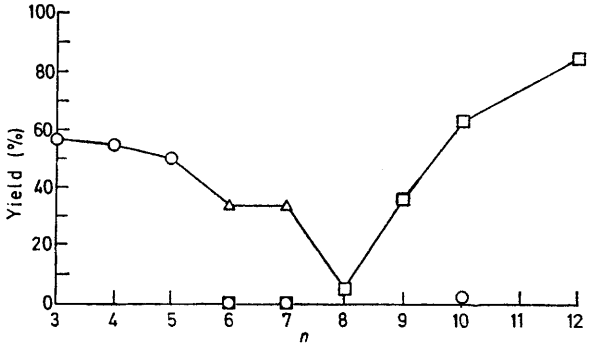
[1] H. Stetter, *Chem. Ber.*, 1953, **86**, 197.

significant for $n = 2$—5 (see Figure). We found that a low yield of the decamethylene derivative (3;



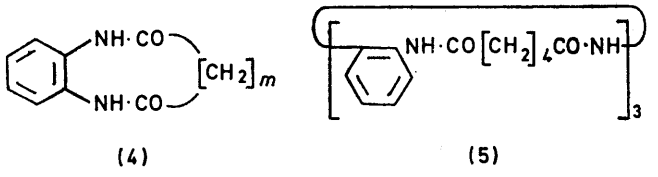
SCHEME 1 Reagents: i, Na–BuOH; ii, 70% H_2SO_4 or Na–BuOH

$n = 10$) is possible by this approach, but intermediate cases gave only polymeric products.



Yields of the *NN'*-polymethylene-*o*-phenylenediamines (3; $n = 3$—12) by: the tosyl method (○), the *N*-oxide method (△), the diacid chloride method (□)

Stetter has also reported [2] the high dilution interaction of *o*-phenylenediamine with an αω-diacid chloride which yields the cyclic diamides (4). Again the range



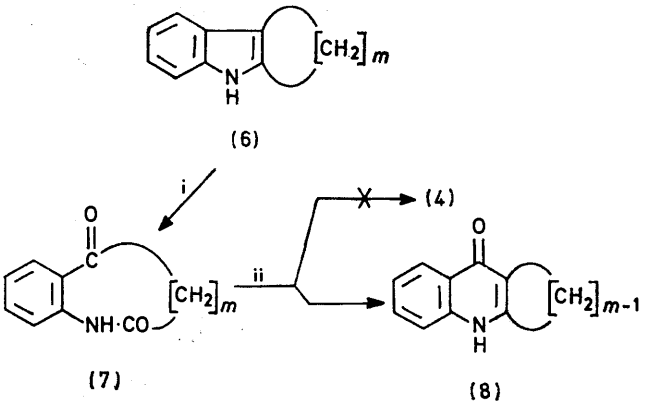
of this reaction is limited but Stetter reported significant yields of (4) for $m \geqslant 7$ [*i.e.* ⟶ (3); $n \geqslant 9$)] with a low yield (6·5%) for $m = 6$ and still lower for $m = 5$ and 4.

This reaction has two preparative drawbacks; (*a*) it is only effective on a very small scale using large amounts of solvent, and (*b*) the reaction requires the slow addition of two separate reagents at the same rates over a long period of time. We have been able to modify the conditions of this reaction with only a small loss of yield by changing the solvent (tetrahydrofuran instead of benzene) and varying reaction parameters such that the process can be conducted on a large scale (up to 1 molar: see Experimental section). However, the synthesis is of little value for the amides (4; $m = 4$ and 5). Indeed, repetition of Stetter's method with adipoyl chloride ($m = 4$) and *o*-phenylenediamine consistently gave only the trimer (5) and no monomer. Our product was of identical melting point and similar yield to Stetter's but was clearly the trimer by mass spectroscopy. The properties of this and other oligomers are considered later. Pimeloyl chloride ($m = 5$) and *o*-phenylenediamine gave only traces of monomer.

The amides (4) were readily reduced by lithium aluminium hydride in tetrahydrofuran to give the corresponding amines (3) in high yield, as low melting products which tended to discolour but gave stable hydrochlorides. However, the crucial members of the series (3; $n = 6$ and 7) were not available by this route.

Another potential route to these systems is outlined in Scheme 2 and is based on Witkop's observation [3] that ozonation of tetrahydrocarbazole (6; $m = 4$) gave the keto-amide (7). However, attempts to convert this ketone into the required diamides (4) by the Schmidt reaction gave only the quinolone (8).

Fortunately, a potential route to these diamines had already been elaborated in this Department. We recently observed that the *N*-oxides (10), readily prepared by action of aqueous hydrochloric acid on the nitroanilines (9), were easily transformed into the



SCHEME 2 Reagents: i, O_3; ii, NaN_3, H_2SO_4

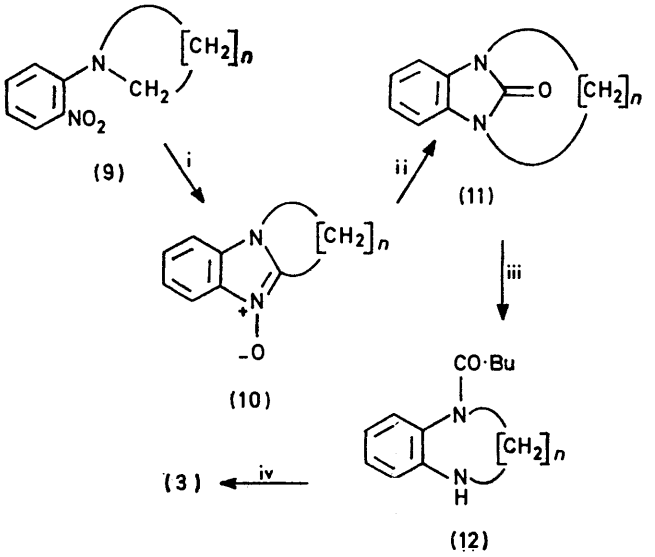
benzimidazolones (11) (Scheme 3).[4] This reaction has now been found to proceed in good yield for $n =$ 5—7. The benzimidazolones (11) are unaffected by hot acid or alkali but treatment with butyl-lithium in ether opens the ring to give (12) which is easily hydrolysed with acid to yield the required amines (3) (Scheme 3).

We have previously reported [5] the synthesis of (3; $n = 4$) as shown in Scheme 4. However, this reaction

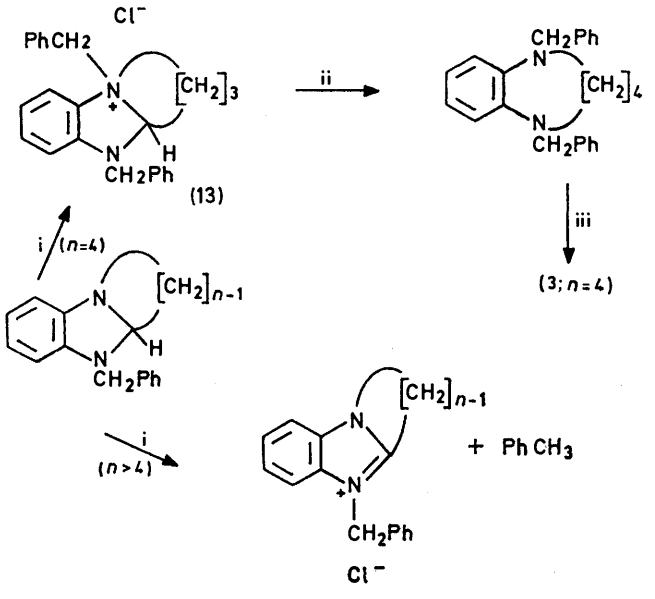
[2] H. Stetter and L. Marx-Moll, *Chem. Ber.*, 1958, **91**, 677.
[3] B. Witkop and J. B. Patrick, *J. Amer. Chem. Soc.*, 1951, **73**, 2188, 2196; B. Witkop, J. B. Patrick, and M. Rosenblum, *ibid.*, 2641.
[4] R. Fielden, O. Meth-Cohn, and H. Suschitzky, *J. Chem. Soc.* (*C*), 1970, 1658.
[5] R. K. Grantham and O. Meth-Cohn, *J. Chem. Soc.* (*C*), 1971, 1354.

was ineffective for the higher analogues of (3), since benzyl chloride and the dihydrobenzimidazole [homologue of (8)] did not give a salt analogous to (13) but caused aromatisation to a benzimidazolium salt.

The full range of diamines (3; $n \leqslant 12$) was now available in quantities sufficient to study their chemistry.



SCHEME 3 Reagents: i, HCl,Δ; ii, TsCl,NaOH; iii, BuLi; iv, H^+



SCHEME 4 Reagents: i, $PhCH_2Cl$; ii, $NaBH_4$; iii, Pd–C,H_2

In one case (3; $n = 10$) the amine was made in large quantities and this was used as the standard for most of the work described below. Some of the chemistry of these amines it outlined in Scheme 5. El'tsov [6] has reported the reaction of benzaldehyde with the amines (3; $n = 4$ and 5) and observed that reaction does not occur with the lower homologues. This reaction proceeds readily throughout the series yielding crystalline dihydrobenzimidazoles (14). Other aromatic aldehydes react similarly (*e.g.* pyridine-2- and -4-carbaldehyde).

The dihydrobenzimidazoles (14) appear consistently to form only one stereoisomer to which we assign the structure shown on the basis of n.m.r. chemical shifts (Table 2). Thus the lower members of the series ($n = 5$ and 6) show an upfield shift of their aliphatic CH-protons indicative of their being forced into the shielding cone of the phenylene-ring, while the phenyl substituents consistently appear as a singlet at τ *ca.* 2·7 throughout the series suggesting that no interaction of the π systems occurs as would be expected in the other isomer.

Formaldehyde gives polymers or mixtures of hydroxymethyl derivatives in every case except (3; $n = 5$) when a highly crystalline dihydrobenzimidazole (15) is isolated. This amine (3; $n = 5$) appears to have the amino-groups most favourably disposed for cyclisation. In no case was it possible to form an analogous dihydrobenzimidazole by the action of a ketone (*e.g.* acetone, cyclohexanone, or cyclopentanone). The use of a dialdehyde (terephthalaldehyde) gave the di-condensation product (16).

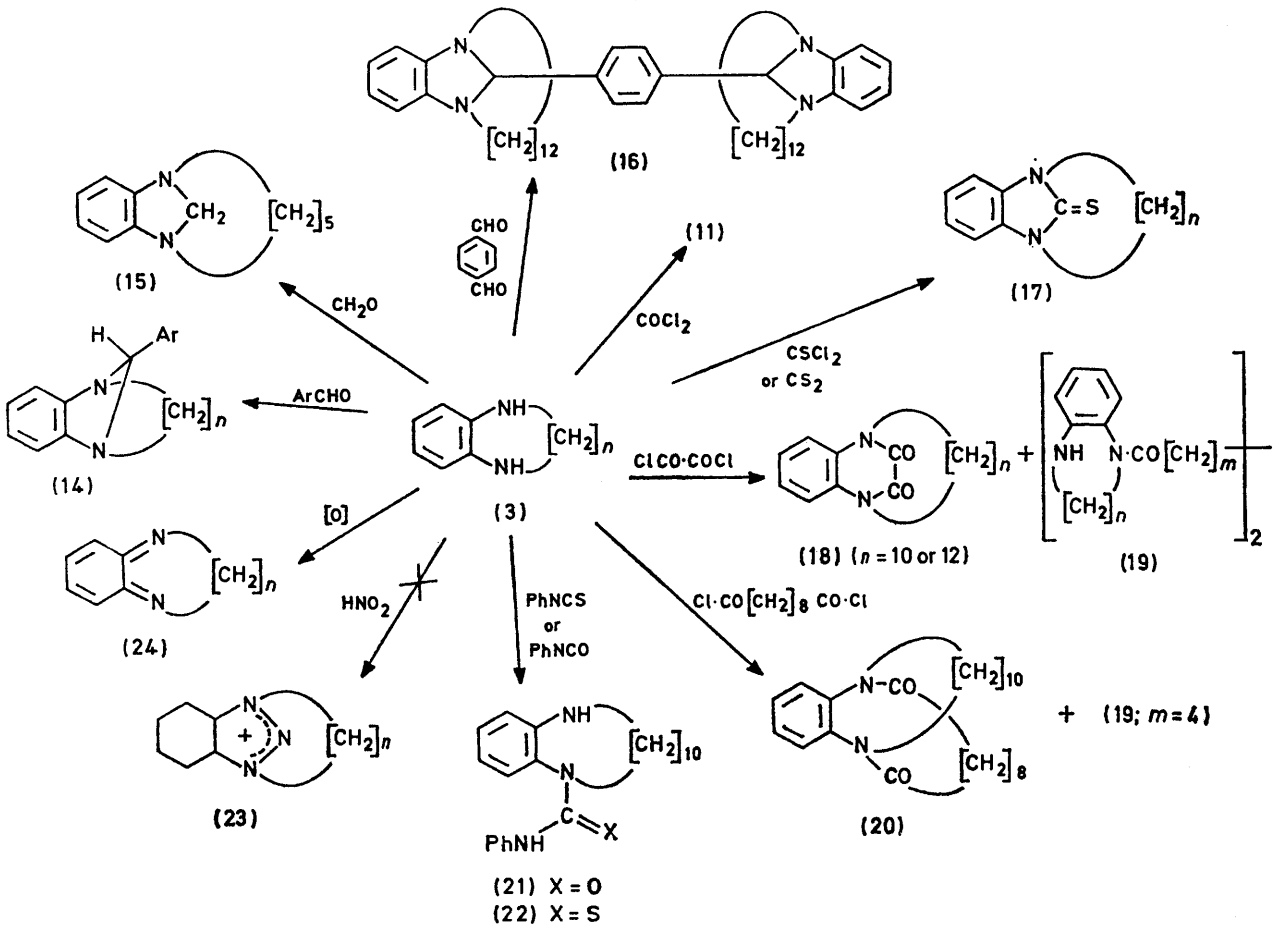
The action of diacid chlorides was of interest. Thus phosgene or thiophosgene rapidly produced the appropriate benzimidazol-one (11) or -thione (17) throughout the series from $n = 5$ to 12. In the case of the phosgene reaction we were able on one occasion to isolate a small amount of a product which, although not fully characterised, showed a high frequency carbonyl absorption (1730 cm^{-1}) in the i.r. spectrum, indicative of the benzimidazolone (11; $n = 4$). The thiones (17) were also slowly formed by the action of carbon disulphide on the amines (3; $n = 5$—12). In these reactions the molar amount of phosgene or thiophosgene must be added slowly to the amine in an inert solvent (toluene or methylene chloride) otherwise other reactions occur. Thus rapid addition of phosgene to the amine (3; $n = 5$) yields the dicarbamoyl chloride (25).

The action of oxalyl chloride gave a mixture of the quinoxalinedione (18) together with a trace of a product, probably the diamide (19; $m = 0$). Succinyl chloride gave solely the diamide (19; $m = 1$). Similarly, sebacoyl chloride gave the diamide (19; $m = 4$) but under high dilution conditions the unusual diamide (20) was isolated together with the diamide (19; $m = 4$). Phenyl isocyanate and isothiocyanate reacted rapidly with the amine (3; $n = 10$) to give the corresponding ureas (21) and (22), respectively, but these products showed no tendency to cyclise to the benzimidazol-ones or -thiones on heating.

The action of nitrous acid, with a view to preparing the triazolium salts (23), was of interest. While in no case was such a salt isolated, the reaction mixture became deep red. Similar red products were obtained by the action of air, alumina, and a variety of oxidants but in no case was a stable, pure product isolable. We

[6] A. V. El'tsov and Kh. L. Muravich-Alexsandr, *J. Org. Chem. U.S.S.R.*, 1965, 1695.

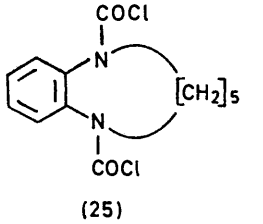
believe the red colour is associated with formation of the quinone-di-imine (24). Attempts to trap the di-imine by use of active manganese dioxide in ether containing oligomers were thermally unstable. Thus the trimer (5) at 195—200° gave the tricyclic benzimidazole derivative (26) in 35% yield. Attempts to simulate

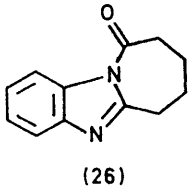


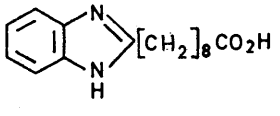
SCHEME 5

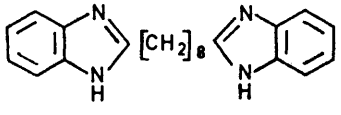
dimethyl acetylenedicarboxylate or tetracyanoethylene were unsuccessful as was the use of ethyl azodicarboxylate as both the oxidant and dienophile. In the latter case the hydrazodicarboxylate precipitated but no pure products could be isolated.

It was observed earlier that the interaction of *o*-phenylenediamine and adipoyl chloride gave mainly the trimeric product (5) rather than the expected monomer (3). These types of reaction always produce the oligomers together with the monomer, the proportion of oligomer increasing with reduction of the acid chloride chain length. However, their extreme insolubilities, while making separation from the monomer possible, rendered their purification tedious. The trimer (5) was reduced to the corresponding trimeric amine (5; CH_2 instead of CO) with lithium aluminium hydride and this was purified by chromatography on alumina to give a low melting product of correct analytical and mass spectral properties. Early attempts to separate the monomeric amides (4) from their oligomeric analogues by sublimation revealed that the this reaction from the monomer (4) were unsuccessful. The action of phosphoryl chloride on the amide (4;


(25)


(26)


(27)


(28)

$n = 8$) gave the 9-(benzimidazol-2-yl)nonanoic acid (27), possibly by way of the homologue of (26), while the

action of polyphosphoric acid gave 2,2′-octamethylenebisbenzimidazole (28), as shown by unambiguous synthesis from *o*-phenylenediamine and sebacic acid in polyphosphoric acid.

EXPERIMENTAL

U.v. spectra were recorded on a Unicam SP 800, i.r. spectra on a Perkin-Elmer 257, n.m.r. spectra on a Varian A60 A or HA 100, and mass spectra on an A.E.I. MS 12 instrument. Light petroleum refers to the fraction of b.p. 60—80° unless otherwise stated.

Preparation of the Phenylenediamines (3).—(a) *From NN′-ditosyl-o-phenylenediamine and an αω-dibromoalkane.* The method of Stetter [1] was employed, which with 1,10-dibromodecane (0·015 mol) and *NN′*-ditosyl-*o*-phenylenediamine (0·01 mol) in butanol (25 ml) and sodium (0·02 mol) gave a crude ditosyl product (2; $n = 10$) (0·6 g, 11%) after 6 h boiling and the usual work-up. This *amine* (4; $m = 10$) (95%), m.p. 221—222°; $\nu_{max.}$ (Nujol) 3290 (NH) and 1660 cm^{-1} (CO) (Found: C, 71·45; H, 8·65; N, 9·25%; M^+, 302. $C_{18}H_{26}N_2O_2$ requires C, 71·15; H, 8·5; N, 9·1%; *M*, 302). The reaction of *o*-phenylenediamine with sebacoyl chloride was conducted as above but on a 1 molar scale using a 20 l flask with an increase in yield (72%).

To lithium aluminium hydride (0·3 mol) in stirred, dry THF (200 ml) under nitrogen was added a suspension of the foregoing diamide (0·1 mol) in dry THF (100 ml) in portions from a separating funnel. When the addition was complete the mixture was boiled for 2 h and the excess of the hydride removed with ethanol and then a little water. The precipitate was filtered off and washed with ether, and the combined filtrate and washings were dried ($MgSO_4$) and evaporated. The remaining oil was rapidly eluted through a short alumina column with ether to give the products recorded in Table 1.

TABLE 1

Properties of the *NN′*-polymethylene-*o*-phenylenediamines (3)

Compound	Method of prepn.	Yield (%)	Found (%)			Formula	Required (%)			N.m.r. (τ values)					*M*$^+$
			C	H	N		C	H	N	Solvent [a]	NH	NCH_2	$[CH_2]_{n-2}$	Aromatic H	
(4) [b]	(a)	55	73·8	8·5	17·0	$C_{10}H_{14}N_2$	74·0	8·7	17·3						162
(5)	(a)	51	74·9	9·0	15·7	$C_{11}H_{15}N_2$	75·0	9·1	15·9	A	65·68, s	6·53—6·80	8·25—8·52	3·15, s	176
(6)	(c)	34	65·6	9·4	14·5	$C_{12}H_{18}N_2$	75·8	9·5	14·7	B	6·4br	6·75—7·04, t	8·20—9·10, m	3·22, s	190
(7)	(c)	34	76·2	9·6	13·5	$C_{13}H_{20}N_2$	76·4	9·9	13·7	B	6·33	6·15—7·20br, t	8·30—9·30	3·32	204
(8)	(b)	6	77·0	10·0	12·6	$C_{14}H_{22}N_2$	77·1	10·2	12·6	B	6·52—6·70br	6·88—7·14br, t	8·20—8·90, m	3·40	218
(9)	(b)	36	77·4	10·2	11·9	$C_{15}H_{24}N_2$	77·6	10·4	12·1	B	6·75—6·90br	6·99—7·20br, t	8·20—9·10, m	3·365	232
(10)	(b)	63	77·8	10·3	11·1	$C_{16}H_{26}N_2$	78·0	10·6	11·4	A–B	6·58—6·70br	6·73—7·00br, t	8·12—9·15, m	3·21s	246
(12)	(b)	84	78·7	10·8	9·9	$C_{18}H_{30}N_2$	78·9	11·0	10·2	A	6·80—710br	6·80—7·10br, t	8·15—9·10, m	3·37br, s	274

[a] A = $CDCl_3$, B = CCl_4. [b] Ref. 5.

derivative (0·6 g) on boiling with sulphuric acid (30 ml; 70% v/v) containing sulphurous acid (1 ml) for 4 h gave an oil (0·1 g, 40%) identical with the product reported later (Table 1).

(b) *From o-phenylenediamine and a diacid chloride.* Freshly purified *o*-phenylenediamine (0·05 mol) and freshly distilled diacid chloride (0·05 mol) were each separately dissolved in sodium-dried tetrahydrofuran (THF) (250 ml) in two dropping funnels fitted with drying tubes ($CaCl_2$). The funnels were placed in the vertical necks of a 3 l four-necked flask equipped with a stirrer, nitrogen inlet and thermometer, and a condenser. In the flask was placed dry THF (1500 ml) containing dry pyridine (40 ml; distilled over barium oxide) and the mixture was maintained at 55—60° on a water-bath. The two solutions were added at equal rates (1 drop every 5 s; during 20 h) with stirring and the heating was continued for a further 2 h after completion of the addition. The hot solution was filtered, the residue washed thoroughly with hot THF, and the filtrate evaporated to dryness. The remaining solid was washed with 1M-hydrochloric acid and then water, and dried, to yield the required diamide. Small samples could be recrystallised from ethanol. The yields are recorded in the Figure and m.p.s were as reported by Stetter and Marx-Moll.[2] From dodecanedioyl chloride and *o*-phenylenediamine was obtained *NN′-dodecanedioyl-o-phenylenediamine* (4; $m = 10$) (95%), m.p. 221—222°; $\nu_{max.}$ (Nujol) 3290 (NH) and 1660 cm^{-1} (CO) (Found: C, 71·45; H, 8·65; N, 9·25%; M^+, 302. $C_{18}H_{26}N_2O_2$ requires C, 71·15; H, 8·5; N, 9·1%; *M*, 302). The reaction of *o*-phenylenediamine with sebacoyl chloride was conducted as above but on a 1 molar scale using a 20 l flask with an increase in yield (72%).

(c) *From the benzimidazole N-oxides* (10). (i) *o*-Fluoronitrobenzene (17·4 g, 0·12 mol), perhydroazocine [7] (13·6 g, 0·12 mol), and sodium hydrogen carbonate (10·5 g, 0·12 mol) in ethanol (300 ml) were refluxed with stirring for 12 h. The solution was filtered and evaporated to yield *N*-(*o*-nitrophenyl)perhydroazocine (9; $n = 6$) (28·0 g, 100%), sufficiently pure for the next stage.

By a similar method using perhydroazonine,[7] *N*-(*o*-nitrophenyl)perhydroazonine (9; $n = 7$) was isolated (~100%) and used directly.

(ii) The above nitro-compounds (9) (60 g) in hydrochloric acid (400 ml; 36%) were refluxed for 50 h, cooled, and an equal volume of water was added. The solution was extracted with chloroform (3 × 400 ml), and the organic layer was treated with charcoal and evaporated to dryness, The remaining gum was washed thoroughly with ether, dissolved in water (300—400 ml), and decanted from any tarry material. The decanted solution was basified (Na_2CO_3) and extracted with ether (2 × 250 ml) (the extract containing mostly starting material) and then chloroform (3 × 250 ml) from which the *1,2-polymethylenebenzimidazole 3-oxides* (10) were obtained by drying ($MgSO_4$) and evaporation: (10; $n = 6$); 56%, m.p. 130—131° (Found: C, 72·85; H, 7·7; N, 12·0%; M^+, 230.

[7] L. Ruzicka, M. Kobelt, O. Haflinger, and V. Prelog, *Helv. Chim. Acta*, 1949, **32**, 544.

$C_{14}H_{18}N_2O$ requires C, 73·0; H, 7·9; N, 12·15%; *M*, 230); (10; $n = 7$); 56%, m.p. 126—127° (Found: C, 72·15; H, 7·4; N, 12·75%; M^+, 216. $C_{13}H_{16}N_2O$ requires C, 72·2; H, 7·45; N, 12·95%; M^+, 216).

(iii) To the benzimidazole *N*-oxides (10) (5 g) in chloroform (50 ml) was added aqueous sodium hydroxide (100 ml; 2M). Toluene-*p*-sulphonyl chloride (4·5 g) was added and the mixture shaken vigorously for 10 min, separated, and the aqueous phase further extracted with chloroform (2 × 50 ml). The combined chloroform layers were dried and evaporated and the residue was eluted through an alumina column with benzene. The benzimidazol-2-ones (11) obtained thereby were recrystallised from petroleum and their properties are recorded in Table 3.

(iv) The foregoing benzimidazolones (11) (3 g) in dry THF (50 ml) were stirred under nitrogen while an equimolar amount of butyl-lithium in hexane (Pfizer) was added. The mixture was refluxed for 1 h, after which water was added and the solution thoroughly extracted with ether. The ether extract was dried and evaporated to give an oil which was dissolved in sulphuric acid (50 ml; 50% v/v) and boiled for 2·5 h. The cooled solution was basified (NaOH) and extracted with ether. The dried extract was evaporated and the residue rapidly eluted through an alumina column with ether to give the *amines* (3; $n = 6$ and 7) recorded in Table 1.

(d) *Attempted preparation from tetrahydrocarbazole.* Tetrahydrocarbazole (10 g) was ozonised according to Witkop [3] to yield the keto-amide (7; $m = 4$) (60%). The keto-amide (1·3 g) in acetic acid (10 ml) and sulphuric acid (2 ml) was heated to 60—70°. Sodium azide (0·65 g) was added in small portions and the temperature raised to 100° for 3 h until nitrogen was no longer evolved. The mixture was poured into water and the solution was basified with ammonia to precipitate a white solid (1·0 g) which crystallised from ethanol to give the quinolone (8), m.p. 329—330° (lit.,[3] 330°).

Reactions of the Macrocyclic Diamines (3).—(a) *Reaction with aldehydes.* (i) *Formaldehyde.* The diamine (3) in ethanol was boiled with an equimolar quantity of paraformaldehyde for 1 h. Removal of the solvent generally gave an intractable oil. From *NN'*-pentamethylene-*o*-phenylenediamine (1·0 g) a white solid was obtained which was eluted from an alumina column with ether–light petroleum (1 : 1) as white plates of 1,8-*diazatricyclo*-[6.5.1.$0^{2,7}$]*tetradeca*-2,4,6-*triene* (15) (0·75 g, 70%), m.p. 106·5—107·5° (Found: C, 76·4; H, 8·5; N, 14·60%; M^+, 188. $C_{12}H_{16}N_2$ requires C, 76·6; H, 8·55; N, 14·87%; *M*, 188); τ (CCl_4) 3·25 (4H, s, ArH), 5·45 (2H, dd, *J* 10 Hz, CH_2), 6·30—7·40 (4H, m, NCH_2), and 8·40—8·90 (6H, m, $[CH_2]_3$).

(ii) *Benzaldehyde and pyridine-2- and -4-carbaldehyde.* Equimolar quantities of the amine (3) and benzaldehyde were treated as above in ethanol and chromatographed as above. Recrystallisation from light petrol gave the products recorded in Table 2.

(iii) *Terephthaldehyde.* The diamine (3; $n = 12$) (0·27 g, 0·001 mol) and terephthaldehyde (0·13 g, 0·001 mol) in ethanol (5 ml) were refluxed for 1 h. The product crystallised on cooling to give 21,21'-p-*phenylenebis*-(1,14-*diazatricyclo*[12.6.1.$0^{15,20}$]*heneicosa*-15,17,19-*triene*) (16) as an off-white solid (0·2 g, 31%). Further recrystallisation caused deterioration, m.p. 200—202° (decomp.) (Found: C, 80·6; H, 8·6; N, 7·9%; M^+, 646. $C_{44}H_{62}N_4$ requires C, 81·7; H, 9·7; N, 8·7%; *M*, 646); τ [$CDCl_3$–$(CD_3)_2SO$] 2·54 (4H, d, *J* 8·0 Hz), 3·68 (8H, m), 6·3—7·6 (8H, m), 8·00—9·20 (40H, m).

(b) *Reaction with acid chlorides.* (i) *Phosgene.* The diamine (3) (1·0 g) in dry toluene was slowly treated dropwise at ambient temperature with stirring, with an excess of phosgene solution in toluene. After a further 1 h stirring the precipitated amine hydrochloride [(3), HCl] (*ca.* 50%) was filtered off and the toluene solution evaporated to yield an oil which solidified on standing. Elution through an alumina column with ether–light petrol (1 : 1) gave the pure crystalline NN'-*polymethylenebenzimidazol*-2-*one* (11) in *ca.* 50% yield as recorded in Table 3. No improvement in yield was observed if triethylamine was added to the original mixture. In one case the rapid addition of phosgene in toluene to *NN'*-pentamethylene-*o*-phenylenediamine in toluene yielded NN'-*bischlorocarbonyl*-NN'-*pentamethylene*-o-*phenylenediamine*, m.p. 136—137° as white needles (from ethyl acetate), after removal of the toluene [Found: C, 55·1; H, 6·9; N, 8·3. $C_{16}H_{24}Cl_2N_2O_2$ requires C, 55·3; H, 7·5; N, 8·1%; M^+ (for ^{35}Cl), 346].

(ii) *Thiophosgene.* In a similar manner to the above method with phosgene, a solution of *NN'*-decamethylene-*o*-phenylenediamine (1·0 g) in methylene chloride (50 ml) was treated with thiophosgene (1·0 ml) in methylene chloride (20 ml). The solution was kept for 1 h and washed successively with water, dilute aqueous hydrochloric acid, aqueous sodium hydroxide, and water. The dried ($MgSO_4$) solution was evaporated and the residue eluted through an alumina column with light petroleum to give the product recorded in Table 3.

(iii) *Oxalyl chloride.* The diamine (3; $n = 10$ or 12) (0·3 g) in dry benzene containing an excess of triethylamine was rapidly treated dropwise with oxalyl chloride (1·1 mol. equiv.) with stirring at ambient temperature. After 1 h the solution was filtered to remove the precipitated hydrochloride and the filtrate evaporated to yield an off-white solid. From (3; $n = 10$), elution through an alumina column with ether–light petroleum gave the NN'-*decamethylenequinoxaline*-2,3(1H,4H)-*dione* (18; $n = 10$), m.p. 179—180° (62%) (Found: C, 71·7; H, 7·9; N, 9·1%; M^+, 300. $C_{18}H_{24}N_2O_2$ requires C, 72·0; H, 8·1; N, 9·3%; *M*, 300); $\nu_{max.}$ (Nujol) 1680 cm^{-1}; τ ($CDCl_3$) 2·72 (4H, s, ArH), 4·94 (2H, m, NCH_A), 6·15 (2H, NCH_B), and 7·9—9·5 (16H, m). Further elution with chloroform gave a trace of 2,2'-*oxalylbis*-(2,13-*diazabicyclo*[12.4.0]*octadeca*-14,16,18-*triene*) (19; $m = 0, n = 10$) (Found: M^+, 546. $C_{34}H_{50}N_4O_2$ requires *M*, 546); $\nu_{max.}$ (Nujol) 1655 (CO) and 3350 cm^{-1} (NH). From (3; $n = 12$) was obtained in the same manner the analogous *quinoxalinedione* (18; $n = 12$), m.p. 167—168° (60%) (Found: C, 73·0; H, 8·6; N, 8·4%; M^+, 328. $C_{20}H_{28}N_2O_2$ requires C, 73·2; H, 8·6; N, 8·5%; *M*, 328); $\nu_{max.}$ (Nujol) 1670 cm^{-1} (CO); τ ($CDCl_3$) 2·70 (4H, s, ArH), 4·95 (2H, m, NCH_A), 6·15br (2H, dt, NCH_B), and 7·9—9·3 (20H, m); and a trace of compound (19; $m = 0$, $n = 12$) (Found: M^+, 602. $C_{38}H_{58}N_4O_2$ requires *M*, 602); $\nu_{max.}$ (Nujol) 1660 (CO) and 3360 cm^{-1} (NH).

(iv) *Succinyl chloride.* When the diamine (3; $n = 10$) was treated as in (iii) with succinyl chloride, the crude product was chromatographed on alumina: elution with chloroform gave 2,2'-*succinylbis*-(2,13-*diazabicyclo*[12.4.0]-*octadeca*-14,16,18-*triene*) (19; $m = 1$, $n = 10$) (40%), m.p. 149°; $\nu_{max.}$ (Nujol) 1650 (CO), 3440 (NH), and 3460 cm^{-1} (NH) (Found: M^+, 547. $C_{36}H_{54}N_4O_2$ requires *M*, 574); τ ($CDCl_3$) 3·10 (8H, m, ArH), 4·62br (2H, NH), and 4·5—9·3 (44H, m).

TABLE 2

Properties of the *NN'*-polymethylene-2,3-dihydrobenzimidazoles (14)

Compound (14)				Found (%)				Required (%)			N.m.r. (τ values)					
n	Ar	Yield (%)	M.p. (°C)	C	H	N	Formula	C	H	N	Solvent [a]	Aromatic H	CH [b]	NCH_2 [c]	$[CH_2]_{n-2}$ [c]	M^+
5	Ph	90	266—267 [d]	81·6	7·4	10·3	$C_{18}H_{20}N_2$	81·8	7·6	10·6	A	2·68, m, 3·12, s	4·39	6·1—7·0	8·1—9·1	264
6	Ph	60	81—82	81·9	7·9	9·9	$C_{19}H_{22}N_2$	82·0	8·0	10·1	A	2·76, s 3·40, m	4·13	6·1—7·0	8·0—9·1	278
7	Ph	60	93—94	82·4	8·5	9·8	$C_{20}H_{24}N_2$	82·2	8·3	9·6	A	2·74, s, 3·54, m	3·74	6·2—7·1	8·2—9·1	292
8	Ph	72	90—91	82·1	8·6	9·1	$C_{21}H_{26}N_2$	82·4	8·6	9·1	A	2·80, s, 3·72, m	3·80	6·3—7·3	8·0—9·0	306
9	Ph	66	97—98	82·3	8·8	8·6	$C_{22}H_{28}N_2$	82·5	8·8	8·7	B	2·70, s, 3·69, m	3·72	6·3—7·4	7·9—9·1	320
10	Ph	76	118—119	82·5	9·1	8·1	$C_{23}H_{30}N_2$	82·7	9·1	8·4	B	2·66, s 3·63, m	3·66	6·3—7·5	8·2—9·0	334
12	Ph	60	100—101	82·8	9·5	7·7	$C_{25}H_{34}N_2$	82·9	9·5	7·7	A	2·70br, s, 3·80,m	3·84	6·5—7·5	8·2—9·0	362
10	2-Pyridyl	30	96—97	78·5	8·5	12·2	$C_{22}H_{29}N_3$	78·8	8·7	12·5	B	1·34 (1H, d), 2·5 (3H, m) 3·5 (4H, m)	2·50	6·2—7·3	7·9—9·1	335
10	4-Pyridyl	50	117—118	78·6	8·7	12·3	$C_{22}H_{29}N_3$	78·8	8·7	12·5	B	7·43 (2H, d) 2·73 (2H, d), 3·7 (4H, m)	3·77	6·55, 7·20	8·1—8·9	335

[a] A = CCl_4, B = $CDCl_3$. [b] All s. [c] All m. [d] Lit.,[6] 266—267°.

TABLE 3

Properties of the *NN'*-polymethylenebenzimidazol-2-ones (11) and -thiones (17)

Compound	*n*	Method of prepn. [a]	Yield (%)	M.p. (°C)	Found (%) C	H	N	Formula	Required (%) C	H	N	M^+	N.m.r. (τ values) Solvent [b]	Aromatic H	NCH_2	$[CH_2]_{n-2}$ [d]
(11)	5	i	43	80—81 [e]	71·2	6·8	13·6	$C_{12}H_{14}N_2O$	71·3	7·0	13·9	202	A	2·90	5·70br, t, 6·30br, d	8·2—9·2
(11)	6	ii	68	107—108	72·0	7·5	12·7	$C_{13}H_{16}N_2O$	72·2	7·5	13·0	216	B	3·00	5·85dt, 6·40,dt	7·7—9·8
(11)	7	ii	64	103—104	72·8	7·5	12·2	$C_{14}H_{18}N_2O$	73·0	7·9	12·2	230	B	3·00	5·85,m, 6·22, dt	8·2—8·9 10·8 (1H)
(11)	9	i	50	60—61	74·2	8·5	10·7	$C_{16}H_{22}N_2O$	74·4	8·6	10·8	258	A	2·95	5·70, m, 6·35, dt	7·9—9·8
(11)	10	i	45	109—110	75·1	8·8	10·1	$C_{17}H_{24}N_2O$	75·1	8·9	10·3	272	A	2·99	5·72, m, 6·38, dt	7·8—9·7
(11)	12	i	41	132—133	75·9	9·2	9·2	$C_{19}H_{28}N_2O$	76·0	9·4	9·3	300	A	2·97	6·05, t	7·9—9·2
(17)	5	iv	63	175—176	66·0	6·4	12·6	$C_{12}H_{14}N_2S$	66·0	6·5	12·8	218	A–B	2·78	4·96br, t, 5·81, br, d	7·6—9·4
(17)	6	iv	72	127—128	67·0	6·7	11·9	$C_{13}H_{16}N_2S$	67·3	6·9	12·1	232	B	2·87	5·16, m, 6·02, dt	7·6—9·9
(17)	7	iv	70	201—202	68·1	7·2	11·1	$C_{14}H_{18}N_2S$	68·3	7·4	11·4	246	A–B	2·75	4·61, m, 5·82br, d	7·7—9·3 11·2 (1H)
(17)	8	iv	53	133—134	68·9	7·6	10·6	$C_{15}H_{20}N_2S$	68·2	7·7	10·8	260	A–B	2·82	5·02, m, 5·96, m	7·6—9·9
(17)	9	iv	53	118—120	69·8	7·9	6·0	$C_{16}H_{22}N_2S$	70·0	8·1	10·2	274	B	2·88	5·12, m, 6·13, m	7·6—9·9
(17)	10	iii, iv	77	129—130	71·1	8·2	9·5	$C_{17}H_{24}N_2S$	70·9	8·4	9·7	288	A–B	2·83	4·77, m, 5·95, dt	7·5—9·9
(17)	12	iv	70	147—148	72·3	8·9	8·6	$C_{19}H_{28}N_2S$	72·2	8·9	8·9	316	B	2·90	5·10, m, 6·12, m	7·6—9·5

[a] i, phosgene method; ii, *N*-oxide method; iii, thiophosgene method; iv, carbon disulphide method. [b] A = $CDCl_3$, B = CCl_4. [c] All s. [d] All m. [e] Lit.,[4] 81°.

(v) *Sebacoyl chloride*. The diamine (3; $n = 10$) (1·0 g) in benzene (100 ml) and sebacoyl chloride (1·0 g) in benzene (100 ml) were added dropwise at an equal rate to a stirred mixture of pyridine (8 ml) and benzene (300 ml) at 50—55° over 6 h. The benzene solution was filtered at 50°, evaporated, and the residual oil treated with 2M-hydrochloric acid and ether. The ethereal phase was washed with sodium hydrogen carbonate solution and then water, dried ($MgSO_4$), and chromatographed on alumina. Elution with ether–light petroleum (1 : 1) gave first 1,12-*diazatricyclo*-[10.10.6.$0^{23,28}$]*octacosa*-23,25,27-*triene*-2,11-*dione* (20) as a white solid (0·08 g), m.p. 176°; $\nu_{max.}$ (Nujol) 1655 cm^{-1} (CO) (Found: C, 75·5; H, 9·8; N, 6·7%; M^+, 412. $C_{26}H_{40}N_2O_2$ requires C, 75·7; H, 9·8; N, 6·8%; *M*, 412). Further elution with the same solvent gave the unstable *compound* (19; $m = 4$, $n = 10$) (0·2 g); $\nu_{max.}$ (Nujol) 3360

(NH) and 1650 cm^{-1} (CO). A further quantity (0·16 g) of this product was obtained by basification of the acidic layer.

(c) *Reaction with heterocumulenes.* (i) *Carbon disulphide.* The diamines (3) in carbon disulphide were kept in a stoppered flask for *ca.* 1 month, the pressure being released each day. Evaporation of the solvent gave a crystalline residue which was eluted through a column of alumina covered with a layer (0·5 in) of activated charcoal with light petroleum to give high yields of the products recorded in Table 3.

(ii) *Phenyl isocyanate.* The diamine (3; $n = 10$) (0·5 g) and phenyl isocyanate (0·25 g) were mixed and kept overnight. Addition of light petroleum caused precipitation of the crude product (21) which was purified by elution through an alumina column with ether–light petroleum (1 : 1) to give *2-phenylcarbamoyl-2,13-diazabicyclo*[12.4.0]-*octadeca-14,16,18-triene* (21) (0·15 g, 20%), m.p. 110° (Found: C, 75·4; H, 8·4; N, 11·2%; M^+, 365. $C_{23}H_{31}N_3O$ requires C, 75·5; H, 8·6; N, 11·5%; *M*, 365); $\nu_{max.}$ (Nujol) 3420 (NH), 3278 (NH), and 1660 cm^{-1} (CO); τ ($CDCl_3$) 2·8 (10H, m), 6·3br (4H), 6·8br (1H), and 8·0—9·2 (16H, m).

(iii) *Phenyl isothiocyanate.* Reaction of the diamine (3; $n = 10$) as in (ii) but with phenyl isothiocyanate gave the *phenyl(thiocarbamoyl)-derivative* (22) (80%), m.p. 121—122° (Found: C, 72·55; H, 8·2; N, 11·1. $C_{23}H_{31}N_3S$ requires C, 72·3; H, 8·2; N, 11·0%); $\nu_{max.}$ (Nujol) 3330 and 3348 cm^{-1} (NH); τ ($CDCl_3$) 2·9 (10H, m), 5·15 (2H, m), 6·10br (1H), 6·70 (2H, m), and 8·0—9·1 (16H, m).

Thermolysis of the Amide (5).—The crude amide (5) (2·0 g) was distilled in a Kugel-röhr apparatus at 194—200° and 1 mmHg. The distillate (0·9 g) solidified on treatment with light petroleum and on redistillation (140—145° at 0·4 mmHg) gave *6,7,8,9-tetrahydroazepino*[1,2-a]*benzimidazol-10-one* (26) as a white solid, m.p. 51—52° (0·7 g, 35%) (Found: C, 72·2; H, 5·9; N, 13·7. $C_{12}H_{12}N_2O$ requires C, 72·1; H, 6·0; N, 14·0%); $\nu_{max.}$ (Nujol) 1715 cm^{-1} (CO); τ ($CDCl_3$) 1·72 (1H, m), 2·28 (1H, m), 2·60 (2H, m), 6·73br (2H, t), 7·04br (2H, t), and 8·0 (4H, m).

Reactions of the Diamide (4; $m = 8$).—(a) *With phosphoroyl chloride.* The diamide (0·5 g) was heated for 16 h with phosphoroyl chloride on a steam-bath. The mixture was cooled and poured into ice–water (50 ml). The solution was neutralised (pH 7) with aqueous sodium hydroxide solution and the precipitate filtered off. Recrystallisation from aqueous ethanol gave 9-(benzimidazol-2-yl)nonanoic acid, m.p. 116—117° (lit.,[8] 117—118°).

(b) *With polyphosphoric acid.* The diamide (1·0 g) in polyphosphoric acid (10 g) was heated at 200° for 2 h. The mixture was cooled, poured into water (100 ml), and the precipitate filtered off and recrystallised from ethanol to give 2,2′-octamethylenebisbenzimidazole (28), m.p. 276—278° (lit.,[9] 277—279°).

We thank Geigy (U.K.) Ltd. for a research grant.

[4/1316 *Received*, 1*st July*, 1974]

[8] P. R. Thomas and G. T. Taylor, *J. Chem. Soc.*, 1957, 2197.
[9] R. L. Shiner and R. W. Upson, *J. Amer. Chem. Soc.*, 1941, **63**, 2277.