extracts were dried over anhydrous sodium sulfate and distilled. The product (light yellow) boiled sharply at 142–143° (1 mm.). The yield was 89 g. (77%), $n^{20}D$ 1.4971; d^{20}_{20} 0.980; M_D calcd. 78.1; found 78.0.

5-Diethylaminopentanol-1.—One hundred grams (0.38 mole) of the benzoate of 5-diethylaminopentanol-1, 200 ml. of water, 50 ml. of alcohol and 20 g. of potassium hydroxide were refluxed for four hours with vigorous stirring. The amino alcohol was salted out with potassium carbonate. After the addition of 50 ml. of benzene to the mixture, the potassium benzoate was filtered and washed with 50 ml. of benzene. The aqueous phase was extracted with a fresh 50-ml. portion of benzene. The combined benzene layers were dried over anhydrous potassium carbonate and distilled. The product, weighing 41 g. (68%), was collected at 125–130° (20 mm.). This material, on redistillation at 23 mm., boiled sharply at 130–131°; $n^{20}D$ 1.4544; lit.[6] b. p. 131° (23–24 mm.); $n^{20}D$ 1.4542.

Acknowledgment.—The author is grateful to E. I. du Pont de Nemours and Co., Inc., Wilmington, Delaware, for the sample of tetrahydropyran.

Summary

1. Acid chlorides react readily in the presence of zinc chloride to cleave the tetrahydropyran ring, forming 5-chloroamyl esters.

2. 5-Diethylaminopentanol-1 has been prepared in 44.5% over-all yield in three steps starting with benzoyl chloride and tetrahydropyran in the presence of zinc chloride, followed by replacement of the chlorine atom by a diethylamino group and hydrolysis.

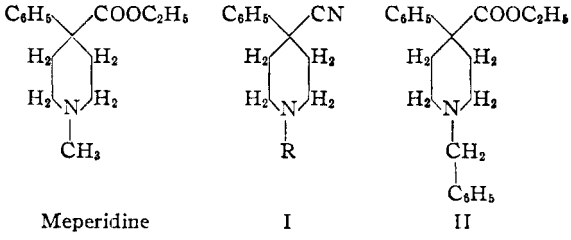
YONKERS 3, N. Y. RECEIVED MAY 12, 1947

[CONTRIBUTION FROM THE STERLING-WINTHROP RESEARCH INSTITUTE]

The Preparation of Substituted 4-Aminomethylpiperidines and their Straight Chain Analogs[1]

BY CHARLES E. KWARTLER AND PHILIP LUCAS[2]

There are many references in the literature to the preparation[3] and pharmacological properties[4] of ethyl 1-methyl-4-phenylpiperidine-4-carboxylate hydrochloride (meperidine, isonipecaine, Demerol,[5] Dolantin, Dolantal, Pethidine). The various pharmacological reports on meperidine hydrochloride emphasize its properties as an analgesic and spasmolytic agent. It appeared to be desirable, therefore, to institute a research program for the purpose of preparing compounds structurally similar to meperidine hydrochloride, or to incorporate into the meperidine nucleus various groupings which might result in compounds of significant pharmacological activity.



Meperidine I II

a, R = benzyl
b, R = methyl

During the synthesis of meperidine hydrochloride, several intermediates are prepared which readily lend themselves to further synthetic work. Among these compounds are 1-benzyl-4-cyano-4-phenylpiperidine (Ia), 1-methyl-4-cyano-4-phenylpiperidine (Ib) and ethyl 1-benzyl-4-phenylpiperidine-4-carboxylate (II).

The following series of catalytic reductions beginning with 1-benzyl-4-cyano-4-phenylpiperidine (Ia) has been carried out

By a procedure similar to that shown in Diagram I, 1-methyl-4-cyano-4-phenylpiperidine (Ib) is reduced with Raney nickel in the presence of an excess of ammonia[5a] to form 1-methyl-4-aminomethyl-4-phenylpiperidine. The reduction of ethyl 1-benzyl-4-phenylpiperidine-4-carboxylate (II) in the presence of palladium sponge resulted in the formation of ethyl 4-phenylpiperidine-4-carboxylate. Table I furnishes a summary of the amines prepared and studied in this paper. Some of the compounds reported in the present paper include the ureides, guanidino derivatives and urethans of the amines described in Table I.

In order to prepare the urea derivatives, nitrourea was used according to the method of Davis and Blanchard.[6]

As indicated in Diagram II, compounds VI, VII or VIII were obtained depending upon whether R was benzyl, methyl or hydrogen. By a procedure similar to that shown in Diagram II, ethyl 4-phenylpiperidine-4-carboxylate was converted to ethyl 1-carbamyl-4-phenylpiperidine-4-carboxylate. Table II furnishes a summary of the

(1) This paper was presented before the Medicinal Chemistry Division at the Chicago meeting of the American Chemical Society, September, 1946.

(2) Present address: Massengill Chemical Co., Bristol, Tennessee.

(3) (a) Eisleb, U. S. Patent 2,167,351 (1939); (b) Eisleb, *Ber.*, **74B**, 1433 (1941); (c) Bergel, Morrison and Rinderknecht, *J. Chem. Soc.*, 265–269 (1944).

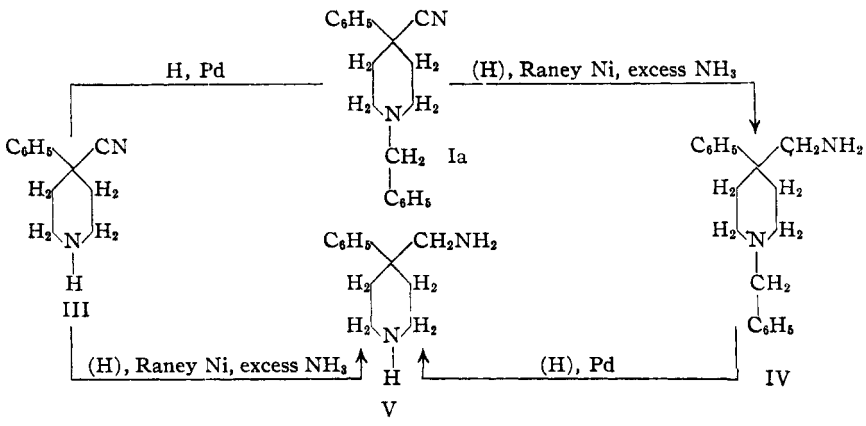
(4) (a) Eisleb and Schaumann, *Deut. med. Wochschr.*, **65**, 967–968 (1939); (b) Schaumann, *Arch. expil. Path. Pharmakol.*, **196**, 109–136 (1940); (c) Gruber, Hart and Gruber, *J. Pharmacol. Expil. Therap.*, **73**, 319 (1941); (d) Barlow, Climenko and Homburger, *Proc. Soc. Expil. Biol. Med.*, **49**, 11 (1942); (e) Climenko, *Federation Proc.*, [Pt. 11] **1**, 15 (1942); (f) Batterman, *Arch. Int. Med.*, **71**, 345 (1943); (g) Batterman and Himmelsbach, *J. Am. Med. Assoc.*, **122**, 222 (1943).

(5) Registered mark of the Winthrop Chemical Company, Inc.

(5a) Huber, THIS JOURNAL, **66**, 876 (1944).

(6) Davis and Blanchard, *ibid.*, **51**, 1790 (1929).

DIAGRAM I



ureides that have been prepared. Contributions by Whitmore and co-workers[7] indicate that some ureides containing a quaternary carbon atom have application as sedatives, soporifics and hypnotics. Compounds VI, VII, VIII and IX are ureides and each contains a quaternary carbon atom (*).

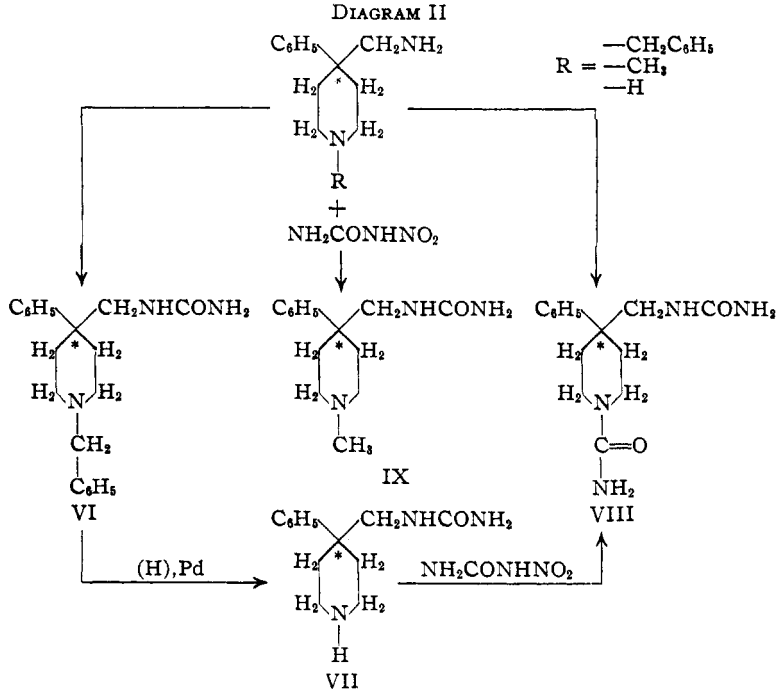
The action of methylisothiourea sulfate on some of the amines in Table I led to the formation of 1-benzyl-4-guanidinomethyl-4-phenylpiperidine, 1-methyl-4-guanidinomethyl-4-phenylpiperidine, and ethyl 1-guanyl-4-phenylpiperidine-4-carboxylate.[8] Tables III and IV furnish a summary of the guanidine derivatives studied in this paper.

The reactions of alkyl chlorocarbonates with 1-benzyl-4-aminomethyl-4-phenylpiperidine were found to yield the corresponding urethan derivatives. The alkylchlorocarbonates from methyl to hexyl were used and Table V gives a summary of the urethans obtained. Similarly the reaction between ethyl chlorocarbonate and 1-methyl-4-aminomethyl-4-phenylpiperidine led to the formation of 1-methyl-4-carbethoxy-aminomethyl-4-phenylpiperidine.

Straight Chain Analogs.—A study of the patents issued to Kulz[9] on N-phenylalkyl-dihydroxyphenylalkyl amines indicates that a breakdown of an analog of meperidine resulted in the formation of a straight chain compound possessing analgesic activity. One of the active compounds described is 3,4-dihydroxybenzyl-1-methyl-3-phenylpropylamine. The skeleton (-benzyl-3-phenylpropylamino-) is included in the structure of ethyl 1-benzyl-4-phenylpiperidine-4-carboxylate (II). In some later formulas, the hypothetical ring rupture and subsequent hydrolysis and decarboxylation could result in the formation of ethylbenzyl-3-phenylpropylamine.

In view of the activity of this type of straight chain amine, it was of interest to us to prepare the straight chain analogs of the piperidine compounds previously described. The following synthetic scheme was employed for the preparation of the desired compounds; the reaction between β-chlorethyldiethylamine and benzyl cyanide[3b] led to the formation of γ-diethylamino-α-phenylbutyronitrile. This compound on hydrolysis and esterification led to the formation of ethyl γ-diethylamino-α-phenylbutyrate. By a similar series of reactions beginning with β-chlorethyldimethylamine, there was obtained ethyl γ-dimethylamino-α-phenylbutyrate. The hydro-

DIAGRAM II

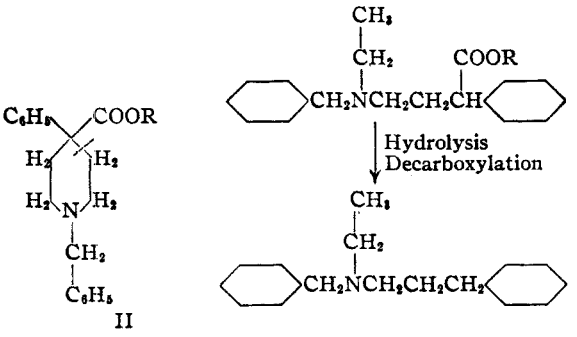


* Is quaternary carbon atom.

(7) Whitmore, Homeyer and Noll, U. S. Patent 2,135,064 (1938).

(8) Various guanidines in the pyridine series have been prepared as anesthetics, *e. g.*, Gebauer, German Patent 665,510 (1938). It was thought to be of interest to prepare and study the pharmacological properties of a group of guanidine derivatives in this piperidine series.

(9) Kulz, U. S. Patents, 2,276,618, 2,276,619 (1942).



II

chlorides of these esters were found to have markedly less analgesic action than meperidine hydrochloride.[10]

Reduction of γ-diethylamino-α-phenylbutyronitrile with Raney nickel in the presence of ammonia resulted in the formation of 4-diethylamino-2-phenylbutylamine. The ureides and guanidino derivatives of this amine were prepared and they are included in the respective tables. The *p*-chlorophenyl and 3,4-dichlorophenyl analogs of the guanidino compound were also prepared. The preparation and properties of the nitriles and amines necessary for these syntheses have already been reported.[11]

The compounds described in this paper have been tested for antispasmodic activity employing both intestinal and uterine strips. The observations included their effect upon normal muscle as well as their neurotropic and musculotropic effect. The majority of the compounds were found to show mild spasmolytic action and negative analgesic action. The effect against acetylcholine spasms of the isolated rabbit ileum was negligible in all cases. Against barium chloride induced spasms, the ethyl 1-guanyl-4-phenylpiperidine-4-carboxylate sulfate was approximately two and one-half times as active as papaverine. The remaining compounds were less active than papaverine.

1-Guanidino-2-phenyl-4-diethylaminobutane sulfate, 1-guanyl-4-guanidinomethyl-4-phenylpiperidine sulfate and 1-benzyl-4-carbethoxyaminomethyl-4-phenylpiperidine hydrochloride were of the same order of activity as papaverine against barium chloride induced spasms of the isolated virgin guinea pig uterus. All of the other compounds studied were less active.

Experimental

The following compounds were prepared according to the methods described in U. S. Patent 2,167,351.

1-Benzyl-4-cyano-4-phenylpiperidine (Ia)
1-Methyl-4-cyano-4-phenylpiperidine (Ib)
Ethyl 1-benzyl-4-phenylpiperidine-4-carboxylate (II)
4-Cyano-4-phenylpiperidine (III)
Ethyl 4-phenylpiperidine-4-carboxylate

(10) The diethylaminoethyl ester of γ-diethylamino-α-phenylbutyric acid was described recently by Billman and Rendall, THIS JOURNAL, **66**, 745 (1944).

(11) Kwartler and Lucas, *ibid.*, **68**, 2395 (1946).

Ethyl γ-Dimethylamino-α-phenylbutyrate.—B. p. 108 (2 mm.); hydrochloride, m. p. 115–117°.

Anal. Calcd. for $C_{14}H_{21}NO_2 \cdot HCl$: N, 5.16. Found: N, 5.11.

Ethyl γ-Diethylamino-α-phenylbutyrate.—B. p. 132–133° (3 mm.), hydrochloride, m. p. 89–90°.

Anal. Calcd. for $C_{16}H_{24}NO_2 \cdot HCl$: N, 4.67. Found: N, 4.65, 4.97.

1-Methyl-4-aminomethyl-4-phenylpiperidine Dihydrochloride.—A solution of 36 g. (0.18 mole) of 1-methyl-4-cyano-4-phenylpiperidine (Ib) in 400 cc. of 15% methanolic ammonia was hydrogenated for twenty hours in the presence of 10 g. of Raney nickel at 500 lb. pressure and room temperature. Catalyst was filtered off and the filtrate distilled to give 24.5 g. (66.7%) of product, b. p. 170–172° (12.5 mm.). The dihydrochloride of this diamine was prepared from an ether solution of the amine by treatment with dry hydrogen chloride, m. p. 287–288°.

4-Aminomethyl-4-phenylpiperidine Dihydrochloride (V). Method A.—Fifty-five grams of 4-cyano-4-phenylpiperidine (III) in 500 cc. of 10% methanolic ammonia was hydrogenated for fourteen hours in the presence of 20 g. of Raney nickel at 500 lb. pressure and room temperature. Catalyst was removed by filtration and the filtrate distilled *in vacuo* to give 47 g., b. p 154° (4 mm.).

Anal. Calcd. for $C_{12}H_{18}N_2$: N, 14.72. Found: N, 14.63.

The dihydrochloride was prepared by treatment of the distilled base in ether solution with alcoholic hydrogen chloride and obtained in theoretical yield, m. p. 252–254°.

Method B.—A solution of 31 g. (0.111 mole) of 1-benzyl-4-aminomethyl-4-phenylpiperidine (IV) in 78 cc. of alcohol and 6 cc. of acetic acid was hydrogenated in the presence of 0.5 g. of palladium catalyst at 40 pounds pressure and 55°. The catalyst was removed by filtration and the solvent distilled. The gummy residue was dissolved in water and made alkaline to phenolphthalein to give an insoluble base which was dissolved in ether. The ether solution was dried over potassium carbonate and vacuum distilled to give 17.5 g. (83.2%).

1-Benzyl-4-uraminomethyl-4-phenylpiperidine (VI).—A mixture of 30 g. (0.107 mole) of 1-benzyl-4-aminomethyl-4-phenylpiperidine (IV) and 14.4 g. (0.137 mole) of nitrourea was dissolved in 450 cc. of warm water and heated to 90° until evolution of gas ceased. A solid separated and after cooling it was collected by filtration and recrystallized from acetone–water to yield 19 g. (55%) of a material of m. p. 172–174°.

1-Carbamyl-4-uraminomethyl-4-phenylpiperidine (VIII).—To a mixture of 11.2 g. (0.059 mole) of 4-aminomethyl-4-phenylpiperidine (V) and 14 g. of nitrourea was added 140 cc. of water and the mixture kept at 70° for thirty minutes when gas evolution and solution resulted. Solvent was removed *in vacuo* and the residue crystallized from pyridine. Yield was 13 g. (80%); m. p. 201–203° dec. Recrystallization from pyridine raised the m. p. to 205–206° dec.

4-Uraminomethyl-4-phenylpiperidine (VII).—A solution of 12.5 g. of 1-benzyl-4-uraminomethyl-4-phenylpiperidine (VI) in 10 cc. of water, 50 cc. 2-B alcohol and 8 cc. of glacial acetic acid was hydrogenated over 0.4 g. of palladium chloride and 2 g. of charcoal at 45 lb. and 50–60°. Catalyst was removed by filtration and the filtrate concentrated *in vacuo*. The residue was dissolved in water and made strongly alkaline to bring about crystallization. The yield was 4 g. of product, m. p. 175–177° dec.; recrystallization from water raised the m. p. to 186–187°.

1-Carbamyl-4-uraminomethyl-4-phenylpiperidine (VIII).—A solution of 2.5 g. of 4-uraminomethyl-4-phenylpiperidine (VII) and 1.25 g. of nitrourea in 25 cc. of water was kept at 70° until gas evolution cleared. Solvent was removed *in vacuo* and the residue crystallized twice from pyridine; m. p. 205–206°. A mixture melting point with an authentic sample gave no depression.

1-Benzyl-4-guanidinomethyl-4-phenylpiperidine Sulfate.—A mixture of 14 g. (0.05 mole) of 1-benzyl-4-aminomethyl-4-phenylpiperidine, 7 g. (0.025 mole) of methyl-

TABLE I

AMINES

4-Phenylpiperidine	Base b. p., °C.	Mm.	Dihydrochloride M. p., °C.	Formula	Analyses, % Nitrogen Calcd.	Nitrogen Found	Chloride Calcd.	Chloride Found
4-Cyano-[a]	145–146	2						
1-Benzyl-4-aminomethyl-	201–202	0.5	229–231	$C_{19}H_{24}N_2.2HCl$	7.94	7.83		
1-Methyl-4-aminomethyl-	170–172	12.5	287–288	$C_{12}H_{20}N_2.2HCl$	10.11	10.32	25.63	25.1
4-Aminomethyl-	154	4	252–254	$C_{12}H_{18}N_2.2HCl$	10.64	10.84	27.0	26.65
4-Carbethoxy-	154–155	3	112–113	$C_{14}H_{19}NO_2.HCl$	5.19	5.31	13.17	12.8

[a] *Anal.* (titration). Calcd. for $C_{12}H_{14}N_2$: N, 7.53. Found: N, 7.49. Picrate, m. p. 205–206°. *Anal.* Calcd. for $C_{12}H_{14}N_2 \cdot C_6H_3N_3O_7$: N, 16.88. Found: N, 16.36.

TABLE II

UREIDES

4-Phenylpiperidine	M. p., °C.	Formula	N anal., % Calcd.	N anal., % Found
1-Benzyl-4-uramino-methyl-	172–174	$C_{20}H_{25}ON_3$	13.0	13.1
1-Methyl-4-uramino-methyl-	200–201	$C_{14}H_{21}ON_3$	17.0	17.15
1-Carbamyl-4-carbethoxy-	119–120	$C_{15}H_{20}O_3N_2$	10.15	10.28
1-Carbamyl-4-uraminomethyl-	205–206 dec.	$C_{14}H_{20}O_2N_4$	20.3	20.35
4-Uraminomethyl-	186–187	$C_{13}H_{19}O_2N_3$	11.15	10.7
Straight Chain Ureide				
1-Diethylamino-3-phenyl-4-uramino-butane	83–84	$C_{15}H_{25}ON_3$	15.98	16.1

TABLE III

GUANIDINE SULFATES

4-Phenyl-piperidine	M. p., °C.	Formula	N anal., % Calcd.	N anal., % Found
1-Benzyl-4-guanidino-methyl-	150	$C_{20}H_{26}N_6 \cdot {}^1/_2H_2SO_4$	15.1	14.92
1-Guanyl-4-carbeth-oxy-	276–277 dec.	$C_{15}H_{21}N_5O_2 \cdot {}^1/_2H_2SO_4$	12.96	13.22
1-Guanyl-4-guanidino-methyl-	363–365 dec.	$C_{14}H_{22}N_6 \cdot H_2SO_4$	22.6	22.4

isothiourea sulfate and 50 ml. of water was stirred at room temperature for fifteen hours and then heated on a steam-bath for one hour. The resultant solution was clarified with charcoal and crystallized on cooling. There separated a solid which had a melting point of 122–125° after recrystallization from water. This solid was dried at 100° to give 5.6 g. of product (30–32%), as a vitreous solid melting at 150°.

1-Guanyl-4-guanidinomethyl-4-phenylpiperidine Sulfate.—A mixture of 3.8 g. (0.02 mole) of 4-aminomethyl-4-phenylpiperidine (V) and 5.6 g. (0.02 mole) of methylisothiourea sulfate in 10 cc. of water was kept at room temperature for fifteen hours and then slowly heated to boiling during which time crystallization occurred to yield 3.5 g. (47%), m. p. 363–365° dec. Recrystallization from water did not affect the melting point.

1-Methyl-4-carbethoxyaminomethyl-4-phenylpiperidine.—To a suspension of 8.3 g. of powdered anhydrous potassium carbonate in 75 ml. dioxane, with 8.16 g. (0.04 mole) of 1-methyl-4-aminomethyl-4-phenylpiperidine was added dropwise a solution of 4.34 g. (3.82 ml., 0.04 mole) of ethyl chlorocarbonate in a small amount of ether. The mixture was caused to reflux for ninety minutes and filtered hot. The solvent was distilled off *in vacuo*, and the residue treated with petroleum ether to induce crystallization; yield was 5 g. (45.3%) of melting point 86–88°.

Anal. Calcd. for $C_{16}H_{24}O_2N_2$: N, 10.14. Found: N, 10.16.

1-Benzyl-4-carbethoxyaminomethyl-4-phenylpiperidine Hydrochloride.—A solution of 8.68 g. (0.08 mole) of ethyl

TABLE IV

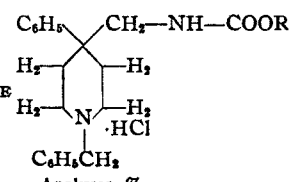
2-R-4-DIETHYLAMINOBUTYLGUANIDINE HYDRIODIDE

R	M. p., °C.	Formula	Analyses, % Nitrogen Calcd.	Nitrogen Found	Iodine Calcd.	Iodine Found
Phenyl-	91–93	$C_{15}H_{26}N_4 \cdot HI \cdot H_2O$[a]	13.73	13.60	31.13	30.85
p-Chlorophenyl-	93–95	$C_{15}H_{25}ClN_4 \cdot HI$	13.19	13.05	29.92	30.2
3,4-Dichlorophenyl	122–123	$C_{15}H_{24}Cl_2N_4 \cdot HI \cdot H_2O$[b]	11.74	11.87 11.90	26.62	26.4 26.38

[a] Calcd. for moisture: 4.41. Found: 4.35. [b] Moisture retained too tenaciously to be determined accurately.

TABLE V

1-BENZYL-4-CARBALKOXYLAMINOMETHYL-4-PHENYLPIPERIDINE HYDROCHLORIDE



R	M. p., °C.	Formula	Analyses, % Nitrogen Calcd.	Nitrogen Found	Chlorine Calcd.	Chlorine Found
Methyl	210.6–211.2 dec.	$C_{21}H_{26}N_2O_2 \cdot HCl$	7.48	7.54	9.47	9.21
Ethyl	232 –233 dec.	$C_{22}H_{28}N_2O_2 \cdot HCl$	7.2	7.46	9.13	9.16
n-Propyl	219 –227 dec.	$C_{23}H_{30}N_2O_2 \cdot HCl$	6.96	6.83	8.83	8.79
n-Butyl	208 –208.8	$C_{24}H_{32}N_2O_2 \cdot HCl$	6.73	6.83	8.52	8.26
Isobutyl	226.6–227.4	$C_{24}H_{32}N_2O_2 \cdot HCl$	6.50	6.47	8.24	8.49
n-Hexyl	193 –194	$C_{26}H_{36}N_2O_2 \cdot HCl$	6.30	6.12	7.98	7.93

chlorocarbonate in a small amount of ether was added dropwise to a solution of 22.4 g. (0.08 mole) of 1-benzyl-4-aminomethyl-4-phenylpiperidine (IV) in 100 ml. of pyridine at room temperature; a solid settled out. The mixture was kept at room temperature for sixteen hours and then at 60° for one hour; this heating caused the solid to dissolve; on cooling 13 g. of crystallized solid of m. p. 228–229° was obtained, as well as an additional 9 g. (m. p. 225–227°) by precipitation with ether; total yield was 22 g., 71%. Recrystallization from alcohol–ether raised the m. p. to 232–233° dec.

Acknowledgment.—The authors wish to acknowledge, with appreciation, the advice of Dr. C. M. Suter and Dr. J. S. Buck. We wish to thank Dr. T. J. Becker for the pharmacological data and the Misses Bass, Raney and Curran for the microanalyses recorded.

Summary

A series of amines and diamines in the 4-phenylpiperidine series have been prepared. The ureido, guanidino and urethan derivatives of these various amines have been synthesized. Straight chain analogs of several piperidine derivatives have been prepared. The compounds described in this paper have been submitted for pharmacological assay and many of them were found to show a mild spasmolytic but negative analgesic action.

RENSSELAER, N. Y. RECEIVED MAY 21, 1947

[CONTRIBUTION FROM THE FRICK CHEMICAL LABORATORY, PRINCETON UNIVERSITY]

The Ignition of *n*-Butane by the Spontaneous Oxidation of Zinc Dimethyl[1]

BY ELMER J. BADIN, DAVID R. WALTERS AND ROBERT N. PEASE

It is well known that zinc dimethyl inflames spontaneously in air or oxygen at room temperature. This fact suggests that zinc dimethyl oxidation might be used to ignite a hydrocarbon such as *n*-butane. Our experiments show that this can be accomplished.

The oxidation of zinc dimethyl vapor has been previously studied by Thompson and Kelland[1a] and Bamford and Newitt.[2] At room temperature there is a fast but non-explosive reaction at pressures of a few millimeters of mercury. This reaction gives rise to a white mist which consists of a solid of approximate composition $2[(CH_3)_2Zn]\cdot O_2$, as judged by the pressure decrease, and the ratio of zinc dimethyl and oxygen consumed. No appreciable amounts of gaseous products are detected.

With an increase of pressure there is a transition to explosion after an induction period of several seconds. As in the slow reaction the white mist is first formed. Explosion is accompanied by a very brilliant white flash when oxygen is in excess, shading off to a less brilliant blue-green color at intermediate compositions. With an excess of zinc dimethyl the flash is fainter and reddish, in some cases visible only in a darkened room. A solid deposit forms on the reaction vessel walls which varies from grey-white to black, sometimes appearing as a bright metallic mirror.

We have repeated some of this work, and have in addition studied the induced oxidation of *n*-butane.

Experimental

Reactions were carried out in spherical Pyrex bulbs of 6.6 cm. diameter. Before each experiment, a bulb was washed with boiling nitric acid, rinsed with distilled water, dried for fourteen hours or more at 135° and then blown out with dry air. Bulbs were connected to the apparatus by a ground glass joint, and were thermostated at 20°.

The apparatus was of conventional design, including the reaction bulb, a bulb for liquid zinc dimethyl, a mercury manometer, and Langmuir and Hyvac pumps. After evacuation, zinc dimethyl vapor was admitted to the desired pressure. Dry oxygen (or air) was then introduced as quickly as possible from a reservoir previously adjusted to the proper pressure. When *n*-butane was to be included, it was admitted after the zinc dimethyl. No reaction occurred between the two.

Stopcocks and the ground glass joint were lubricated with Apiezon grease. No reaction between the grease and zinc dimethyl was apparent.

When the gaseous products were to be analyzed, samples were withdrawn by means of a modified Töpler pump. They were analyzed by absorption in 30% aqueous potassium hydroxide (carbon dioxide), bromine water (olefins), Oxsorbent (oxygen), Cosorbent (carbon monoxide). Hydrogen was determined by combustion over copper oxide at 310°, and paraffins at 570°.

Zinc dimethyl was prepared from methyl iodide and zinc dust containing 5% cupric oxide, which was reduced in hydrogen before use. Last traces of methyl iodide were removed by treating with anhydrous silver oxide followed by fractionation in a 20-plate column (nitrogen atmosphere). This point received special attention since preliminary experiments indicated some inhibition by methyl iodide.

Results and Discussion

A set of data for the non-explosive reaction are given in Table I. Runs with foreign gases present are included.

A white mist appeared immediately on adding oxygen, though there was a short induction period with the rate passing through a maximum (Fig. 1). The pressure decreased quite rapidly to a value roughly equivalent to a loss of 1 to 1.5 times the zinc dimethyl present. Gas analysis revealed no gaseous products. Thus the result is consistent with the assumption that the solid product is equivalent to 2 molecules or more of zinc dimethyl to 1 molecule of oxygen.

(1) The work described in this paper was done in connection with Contract NOrd 7920 with the United States Naval Bureau of Ordnance, as coördinated by the Applied Physics Laboratory, The Johns Hopkins University. Acknowledgment is also due to Dean Hugh S. Taylor, who has general supervision of this project.

(1a) Thompson and Kelland, *J. Chem. Soc.*, 746 (1932).

(2) Bamford and Newitt, *ibid.*, 695 (1946).