

Studies on Carbamates

X. The Carbamates of Di-*n*-Propylamine and Di-*iso*-Propylamine

ARNE JENSEN, MOGENS BALLUND JENSEN and
CARL FAURHOLT

The Royal Danish School of Pharmacy, Copenhagen, Denmark

1. The equilibrium conditions and reaction mechanism of the formation and decomposition in aqueous medium of the carbamate formed by di-*n*-propylamine have been studied. Analogous experiments have been carried out with di-*iso*-propylamine. The experimental and theoretical conditions are analogous to those of the carbamates previously investigated; we refer to previous investigations¹ for the detailed information concerning method, theory, significance of constants *etc.* It should be noted, though, that "Am" means dipropylamine and "AmH⁺" dipropylammonium ion.

2. Di-*n*-propylamine and di-*iso*-propylamine, both from The British Drug Houses Ltd., were purified by distillation through a wiregauze column with 44 sets of platinum plates. The di-*n*-propylamine thus obtained boiled at 109.4—109.6° C (759 mm Hg) and by acidimetric titration we obtained a result corresponding to a content of 100.0 % (C₃H₇)₂NH. For the experiments with di-*iso*-propylamine we used a fraction with a boiling point 83.1—83.7° C, (750 mm Hg), $n_D^{20.0} = 1.3922$ and by acidimetric titration we obtained a result corresponding to a content of 100.0 % (C₃H₇)₂NH.

3. The carbamate of di-*n*-propylamine was prepared in solution only by leading a deficit of carbon dioxide to aqueous solutions of the amine, practically all of the carbon dioxide thus being converted to carbamate.

Contrary to this no carbamate is formed by a similar treatment of an aqueous solution of di-*iso*-propylamine.

An attempt was then made to obtain the carbamate of di-*iso*-propylamine as substance. Di-*iso*-propylamine when treated with dry carbon dioxide yields a white microcrystalline compound which is very soluble in water and ether. A content of approx. 85 % of amine was found by titration with 0.1 N HCl but since the substance was very deliquescent a constant composition was not found. The theoretical content of amine in (C₃H₇)₂NCOONH₂(C₃H₇)₂ is 82 %. After dissolving the substance in 0.1 N NaOH and immediately adding barium chloride a precipitate was formed. The precipitate and the liquid were separated as quickly as possible by filtration and the filtrate heated. No precipitate

was formed showing that no carbamate was present. If on the other hand the substance is dissolved in a *M* solution of dimethylamine no precipitate appears after the addition of sodium hydroxide and barium chloride thus showing that no carbonate is present in the substance; dimethylamine reacts as previously shown very fast with carbon dioxide to form a carbamate but not with carbonate². These facts indicate that the reaction product between di-*iso*-propylamine and carbon dioxide contains the carbon dioxide in a very labile form.

For both amines the solutions of carbonate were prepared by mixing equivalent amounts of solutions of dipropylammonium chloride and sodium carbonate.

4. The method of analysis was as in previous investigations precipitation with barium chloride, causing the precipitation of carbonate, but not of carbamate. All of the data presented in the later tables are corrected for blank experiments, *viz.* about 3 units of the percentage.

5. All of the experiments were done at 18° C, and the velocity constants were calculated by means of Briggs' logarithms, the unit of time being the minute. As in previous investigations, the activity coefficient *f* for a monovalent ion was calculated from the expression of Bjerrum, $-\log f = 0.3 \sqrt[3]{C_{\text{ion}}}$.

6. Bredigs³ corrected value of the basic dissociation constant for di-*n*-propylamine is $10^{-3.09}$ at 25° C. Hall and Sprinkle⁴ have found the basic dissociation constant for di-*iso*-propylamine to be $10^{-3.17}$ at 25° C. The heat effect of the reaction being very slight, these values may be used for 18° C as well.

ON THE REACTION "AMINE + CARBON DIOXIDE \rightleftharpoons CARBAMIC ACID"

The velocity constant for the reaction "amine + carbon dioxide" we usually determine by treating an aqueous solution of the amine and sodium hydroxide with a deficit of gaseous carbon dioxide mixed with atmospheric air. This method is also employed in this case. In the course of 5 minutes atmospheric air containing about 10 % of carbon dioxide was led into solutions containing both amine and sodium hydroxide. The mixture was immediately analysed. The analytical data obtained in the experiments with di-*n*-propylamine are listed in Table 1, where "% carbamate" indicates how many per cent of the carbon dioxide absorbed have been converted to carbamate. Fur-

Table 1. Carbon dioxide in di-*n*-propylamine + NaOH. 18°.

Initial solution		Absorb. mole CO ₂ litre	% carbamate	Final solution		Mean		kCO ₂ ·Am	
cNaOH	cAm			cNaOH	cAm	cNaOH	cAm		Mean
0.20	0.10	0.0209	58 ¹	0.17	0.09	0.19	0.09	10 ^{5.46}	
0.20	0.06	0.0211	47 ²	0.17	0.05	0.18	0.06	10 ^{5.48}	10 ^{5.47}
0.10	0.06	0.0145	63 ³	0.08	0.05	0.09	0.06	10 ^{5.47}	

^{1, 2, 3} found by the analysis: 55.2, 43.7 and 55.6 %, respectively. The listed values are corrected to zero time.

thermore, the velocity constant $k_{\text{CO}_2\text{Am}}$ for the reaction "amine + carbon dioxide \rightarrow carbamic acid" was calculated. In analogous experiments with di-*iso*-propylamine no carbamate was found, nor was it found in an experiment in a far less basic solution containing 0.11 *M* Am and 0.09 *M* AmH⁺ corresponding to a c_{OH^-} of about 10^{-3} .

In addition to the above, some experiments were carried out to illustrate that the percentage of carbamate formed in an aqueous solution of a definite amine (*in casu* ammonia) and sodium hydroxide when treated with carbon dioxide not only depends on the concentrations of amine and hydroxyl ion, but also on the manner of the treatment.

It has been previously observed that the calculated value of $k_{\text{CO}_2\text{Am}}$ in the case of ammonia² depends on the percentage of carbon dioxide in the employed air in the way that a higher percentage yields a higher value for $k_{\text{CO}_2\text{Am}}$.

Repeated experiments with ammonia have confirmed this phenomenon and analogous experiments with non-volatile amines as α -alanine and β -alanine gave a similar result, showing that the deviations observed in the case of ammonia are not entirely due to a side-reaction between gaseous ammonia and gaseous carbon dioxide.

The experiments were carried out in this way. Gaseous carbon dioxide or atmospheric air with an admixture of carbon dioxide was led into the solution in the form of fine bubbles.

In Table 2 are listed some of the experiments. It is seen that atmospheric air containing 1–10 % of carbon dioxide yields nearly the same value of

Table 2. Gaseous carbon dioxide in amine + NaOH. 18°.

Amine	% CO ₂ in the gas mixture	Initial solution		Absorbed CO ₂ mole litre	% carbamate	Final solution		Mean		$k_{\text{CO}_2\text{Am}}$
		cNaOH	camine			cNaOH	camine	cNaOH	camine	
NH ₃	100	0.10	1.0	0.0133	58	0.08	1.0	0.09	1.0	10 ^{4.12}
	80	—	—	0.0240	54	0.06	—	0.08	—	10 ^{4.01}
	35	—	—	0.0129	40	0.08	—	0.09	—	10 ^{3.80}
	11	—	—	0.0215	38	0.06	—	0.08	—	10 ^{3.73}
	7	—	—	0.0196	36	0.06	—	0.08	—	10 ^{3.69}
	5	—	—	0.0244	37	0.06	—	0.08	—	10 ^{3.69}
	3	—	—	0.0185	38	0.08	—	0.09	—	10 ^{3.73}
	2	—	—	0.0248	35	0.06	—	0.08	—	10 ^{3.66}
	1	—	—	0.0151	34	0.08	—	0.09	—	10 ^{3.66}
CH ₃	100	0.10	0.15	0.0112	60	0.09	0.14	0.09	0.15	10 ^{5.00}
CHNH ₂	10	—	—	0.0134	51	0.08	—	—	—	10 ^{4.82}
COOH	1	—	—	0.0113	48	0.08	—	—	—	10 ^{4.78}
CH ₂ NH ₂	100	0.10	0.10	0.0198	59	0.07	0.09	0.09	0.10	10 ^{5.15}
CH ₂	10	—	—	0.0245	54	0.06	—	0.08	0.09	10 ^{5.03}
COOH	1	—	—	0.0235	52	0.07	—	0.08	0.09	10 ^{5.00}

$k_{\text{CO}_2:\text{Am}}$, namely $10^{3.66}$ for ammonia, $10^{4.82}$ for α -alanine and $10^{5.04}$ for β -alanine which are the values published in earlier papers ^{2,1}, while air mixtures being richer in carbon dioxide yield higher values of $k_{\text{CO}_2:\text{Am}}$, most typical in the case of ammonia.

In order to eliminate the gas phase some experiments were carried out in which a saturated aqueous solution of carbon dioxide was added to the amine-sodium hydroxide solution. In carbon dioxide water being about 0.03 *M* as to total carbon dioxide, 99.5 % of the total carbon dioxide is present as CO_2^2 and that fraction of the carbon dioxide existing *a priori* as carbonate (*viz.* H_2CO_3 and HCO_3^-) can consequently be ignored in the present case.

The experiments were carried out in this way, that 100 ml of the amine-sodium hydroxide solution was placed in a beaker. The liquid was agitated by means of two mechanical stirrers each consisting of a hollow shaft and two blades. The blades of one were also hollow and perforated with fine holes, and the shaft of this one was placed in that of the other. The two stirrers circulated in opposite directions, and through the stirrer with the hollow blades the carbon dioxide water was allowed to flow out in the solution for about 2 minutes.

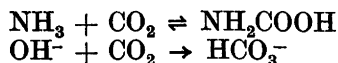
From the experimental data listed in Table 3 it is seen that the percentage of carbamate depends on the rotation rate of the stirrers, and it is remarkable that the value of $k_{\text{CO}_2:\text{Am}}$ in the experiments with ammonia decreases, while in the experiments with the alanines it increases with the rising rate of rotation. The value of $k_{\text{CO}_2:\text{Am}}$ for the alanines becomes, even at moderate rates of rotation, identical with the one obtained in the experiments with diluted gaseous carbon dioxide. It is remarkable that this is not the case with the value of $k_{\text{CO}_2:\text{Am}}$ for ammonia even at the most rapid rotation obtainable with the applied apparatus.

The deviations observed in the experiments with gaseous carbon dioxide mixed with small volumes of atmospheric air or in the experiments where slow agitation was employed must be due to incalculable changes in the relation between the concentrations of amine and sodium hydroxide during the addition of the carbon dioxide. Employing diluted gaseous carbon dioxide or rapid agitation during the admission of the carbon dioxide water this error must decrease.

In order to eliminate the above mentioned source of error, a third method for the admission of the carbon dioxide was examined. The carbon dioxide was admitted in the form of sodium methyl carbonate which after being dissolved in an aqueous solution containing ammonia and sodium hydroxide comparatively rapidly decomposed into methyl alcohol and carbon dioxide.



followed by



The velocity constant for the first reaction from left to right is at 18° C 0.024^5 , the velocity from right to left can be ignored, the concentration of methyl alcohol being very weak in comparison with the concentrations of

Table 3. Carbon dioxide water in amine + NaOH. 18°.

Amine	Number of revolutions per minute	Initial solution		c _{total} carbon dioxide	% carbamate	Final solution		Mean		k _{CO₂} ·Am
		c _{NaOH}	c _{amine}			c _{NaOH}	c _{amine}	c _{NaOH}	c _{amine}	
NH ₃	0	0.2	2.0	0.0148	56	0.08	1.0	0.14	1.5	10 ^{4.09} ¹
	20	—	—	0.0146	53	—	—	—	—	10 ^{4.04}
	40	—	—	0.0158	48	—	—	—	—	10 ^{3.96}
	60	—	—	0.0136	45	—	—	—	—	10 ^{3.90}
	65	—	—	0.0160	44	—	—	—	—	10 ^{3.88}
	160	—	—	0.0148	42	—	—	—	—	10 ^{3.86}
	170	—	—	0.0152	41	—	—	—	—	10 ^{3.82}
	210	—	—	0.0156	40	—	—	—	—	10 ^{3.82}
	220	—	—	0.0139	41	—	—	—	—	10 ^{3.83}
	260	—	—	0.0147	39	—	—	—	—	10 ^{3.80}
	275	—	—	0.0140	40	—	—	—	—	10 ^{3.81}
	700	—	—	0.0152	39	—	—	—	—	10 ^{3.78}
850	—	—	0.0139	40	—	—	—	—	10 ^{3.82}	
CH ₃	0	0.20	0.30	0.0163	45	0.08	0.14	0.14	0.22	10 ^{4.73}
	20	—	—	0.0156	46	—	—	—	—	10 ^{4.74}
CHNH ₂	55	—	—	0.0149	46	—	—	—	—	10 ^{4.76}
	115	—	—	0.0157	46	—	—	—	—	10 ^{4.74}
COOH	200	—	—	0.0163	48	—	—	—	—	10 ^{4.78}
	800	—	—	0.0134	48	—	—	—	—	10 ^{4.79}
CH ₃ NH ₂	0	0.20	0.20	0.0141	41	0.08	0.09	0.14	0.15	10 ^{4.84} ²
	15	—	—	0.0143	42	—	—	—	—	10 ^{4.86}
CH ₂	25	—	—	0.0151	49	—	—	—	—	10 ^{4.97}
	45	—	—	0.0148	51	—	—	—	—	10 ^{5.01}
COOH	115	—	—	0.0158	50	—	—	—	—	10 ^{5.00}
	700	—	—	0.0137	49	—	—	—	—	10 ^{4.99}
	700	—	—	0.0132	49	—	—	—	—	10 ^{4.99}

¹ Not reproducible. Other experiments gave values from 10^{3.90} to 10^{4.51} for k_{CO₂}·Am

² In an other experiments we found 10^{4.93}.

ammonia and hydroxylion. After about 150 minutes practically all of the monomethyl carbonate has disappeared and after this space of time the mixture was analysed, cf. Table 4. In calculation the listed values of k_{CO₂}·Am, the decomposition of the carbamate taking place during the 150 minutes, is taken into consideration.

Table 4. Sodium methyl carbonate in ammonia + NaOH. 18°.

Initial solution		c _{total} carbon dioxide	% carbamate	Final solution		Mean		k _{CO₂} ·Am
c _{NaOH}	c _{NH₃}			c _{NaOH}	c _{NH₃}	c _{NaOH}	c _{NH₃}	
0.10	2.0	0.0186	45	0.08	2.0	0.09	2.0	10 ^{3.61}
0.10	1.0	0.0100	31	0.09	1.0	0.10	1.0	10 ^{3.67}
0.05	0.50	0.0195	33	0.03	0.50	0.04	0.50	10 ^{3.66}

Table 5. The solution carbonate-carbamate in equilibrium. 18°.

	Initial solution				% carba- carba- mate	Equilibrium				K_{Eq}	
	c_{Am}	c_{AmH^+}	$c_{(AmH)_2CO_2}$	$c_{carba-mate}$		c_{Am}	c_{AmH^+}	$c_{carba-mate}$	$c_{HCO_3^-}$		Mean
di- <i>n</i> -	0.19	0.10	0.02		5.4	0.19	0.14	0.0011	0.00084	$10^{-0.83}$	$10^{-0.81}$
	0.22	0.11		0.02	5.6	0.22	0.12	0.0011	0.00072	$10^{-0.80}$	
di- <i>iso</i> -	0.19	0.10	0.02		0	0.19	0.14	0	0.0013		

It is seen from Table 4 that the value of $k_{CO_2, Am}$ determined by this method is identical with the one determined in the experiments where gaseous carbon dioxide was admitted mixed with abundant atmospheric air (Table 2).

THE EQUILIBRIUM "CARBAMATE \rightleftharpoons CARBONATE"

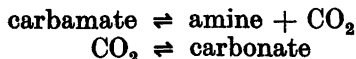
Experiments with di-*n*-propylamine have been done from the carbonate side as well as from the carbamate side. Experiments with di-*iso*-propylamine showed that no carbamate is formed. In Table 5 are listed the compositions of the solutions and the equilibrium constant K_{Eq} for the reaction $(CH_3 \cdot CH_2 \cdot CH_2)_2NCOO^- + H_2O \rightleftharpoons HCO_3^- + (CH_3 \cdot CH_2 \cdot CH_2)_2NH^+$.

THE VELOCITY OF THE CONVERSION "CARBAMATE \rightleftharpoons CARBONATE"

In Table 6 are presented the experiments on velocity, which have been carried out in a di-*n*-propylammoniumion-di-*n*-propylamine buffer, where an easily measurable equilibrium is established between carbamate and carbonate. In Table 7 are presented those experiments which have been carried out in a medium containing sodium hydroxide, where carbamate is converted almost completely to carbonate.

No experiments could be done with di-*iso*-propylamine since no carbamate is present in aqueous medium.

The velocity constants calculated from the experiments are listed in Tables 6 and 7. These velocity constants may, provided the decomposition takes place through the reactions



be calculated in advance.

In Table 8 is given a survey of the experimental and calculated values of the velocity constants.

Table 6. Velocity constants for the process "carbamate \rightleftharpoons carbonate"
 $p_{\text{H}} = \text{approx. } 11.6. 18^{\circ}$.

Initial solution			Min.	% carba- mate	$k_{\text{amate}} + k_{\text{onate}}$
$c_{\text{carba-}}\text{mate}$	c_{Am}	c_{AmH^+}			
0.019	0.22	0.11	99	70.4	0.00165
			237	45.3	0.00159
			352	32.6	0.00155
			468	23.5	0.00155
			∞	5.6	0.00159
			Mean:		0.0015
		k_{onate} :		0.00009	

Table 7. Velocity constants for the process "carbamate \rightarrow carbonate".
 $p_{\text{H}} = \text{approx. } 13. 18^{\circ}$.

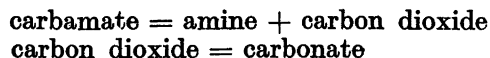
Initial solution			Min.	%carbamate	k_{amate}
$c_{\text{carba-}}\text{mate}$	c_{NaOH}	c_{Am}			
0.012	0.17	0.09	45	81.0	0.00206
			123	58.5	0.00190
			217	38.3	0.00192
			310	26.9	0.00184
			Mean:		0.0019
0.010	0.17	0.05	25	87.2	0.00240
			48	75.6	0.00254
			75	64.6	0.00254
			97	58.4	0.00241
			125	48.7	0.00250
			176	36.7	0.00248
Mean:		0.0025			
0.009	0.08	0.05	26	80.2	0.00370
			46	65.8	0.00396
			70	54.7	0.00374
			134	31.5	0.00374
Mean:		0.0038			

Table 8. Velocity constants, experimental and calculated.

Initial solution				k_{amate}		k_{onate}	
c_{Am}	c_{AmH^+}	c_{NaOH}	$c_{\text{carba-}}\text{mate}$	exp.	calc.	exp.	calc.
0.22	0.11		0.019	0.0015	0.0015	0.00009	0.00007
0.09		0.17	0.012	0.0019	0.0022		
0.05		0.17	0.010	0.0025	0.0029		
0.05		0.08	0.009	0.0038	0.0040		

SUMMARY

The velocity constant of the reaction $(\text{CH}_3\cdot\text{CH}_2\cdot\text{CH}_2)_2\text{NH} + \text{CO}_2 = (\text{CH}_3\cdot\text{CH}_2\cdot\text{CH}_2)_2\text{NCOOH}$ and the equilibrium constant for the reaction $(\text{CH}_3\cdot\text{CH}_2\cdot\text{CH}_2)_2\text{NCOO}^- + \text{H}_2\text{O} \rightleftharpoons \text{HCO}_3^- + (\text{CH}_3\cdot\text{CH}_2\cdot\text{CH}_2)_2\text{NH}$ have been determined. The velocity of the decomposition of $(\text{CH}_3\cdot\text{CH}_2\cdot\text{CH}_2)_2\text{NCOO}^-$ in basic medium was investigated and may be explained by assuming that the decomposition is a two stage reaction, *viz.*



Analogous experiments with di-*iso*-propylamine showed that this amine contrary to all the other secondary alifatic amines examined hitherto forms no carbamate in aqueous medium. Some experiments have proved that the percentages of carbamate and carbonate formed in an aqueous solution of an amine and sodium hydroxide when treated with carbon dioxide to some extent depend on the method of adding carbon dioxide.

REFERENCES

1. Jensen, A. and Faurholt, C. *Acta Chem. Scand.* **6** (1952) 385.
2. Faurholt, C. *J. Chem. phys.* **22** (1925) 1.
3. Bredig, G. *Z. physik. Chem.* **13** (1894) 297.
4. Hall, N. F. and Sprinkle, M. R. *J. Am. Chem. Soc.* **54** (1932) 3469.
5. *Not published.*

Received March 30, 1954.