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DIELECTRIC CONSTANT AND MOLECULAR STRUCTURE

Part III. Dielectric Constants of Amino Acids and other dipolar ions

BY

S. K. KULKARNI JATKAR AND B. R. YATHIRAJA IYENGAR

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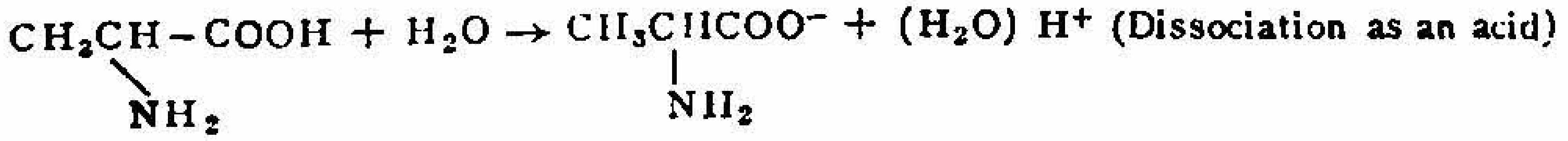
INTRODUCTION

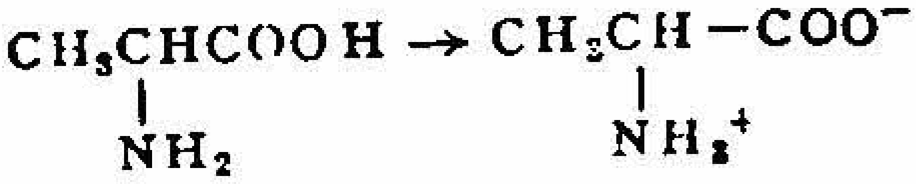
Amino acids, the amino derivatives of the monobasic fatty acids produced by the replacement of one hydrogen atom in the latter by the amino group are very interesting to study since they contain both a basic (NH_2) and an acidic (–COOH) group.

$$\underset{\displaystyle COOH}{CH_3CHNH_2} + H_2O \rightarrow \underset{\displaystyle COOH}{CH_3CHNH_3^+} + OH^- \text{ (Dissociation as a base)}$$



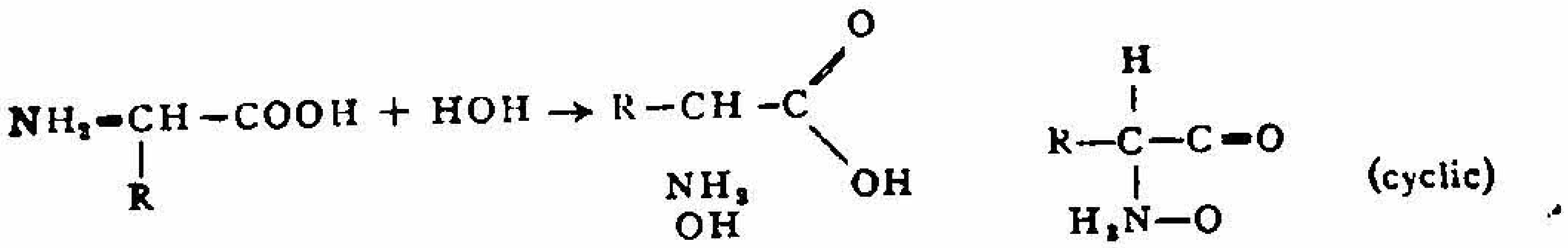
$$\underset{\displaystyle NH_2}{CH_2CH}-COOH + H_2O \rightarrow \underset{\displaystyle NH_2}{CH_3CHCOO^-} + (H_2O)\,H^+ \text{ (Dissociation as an acid)}$$

Alternatively amino acids may be dissociated in neutral solutions to give the so-called " zwitterions " or " dipolar ions " carrying both a positive and a negative charge



$$\underset{NH_2}{CH_3CHCOOH} \rightarrow \underset{NH_3^+}{CH_3CH}-COO^-$$

Recent views support the existence of this structure rather than the older classical cyclic structure supposed to be formed by the neutralisation of the basic amino group by the carboxyl to form an internal salt as shown below:



The postulate of a dipolarionic structure was first inferred by Bredig in the case of betaine. Later Adams pointed out that the dissociation constants of amino acids could be satisfactorily explained only on the basis of a zwitterion hypothesis. In 1922 Pleiffer showed clearly, from stearic considerations and melting points, that the betaines must be dipolar ions. Bjerum's work further supports this view. Cohn and Edsall[8] have enumerated evidences in support of the zwitterion hypothesis in view of recent work associated with molecular structure. First of all, the dipolar-ions are characterised by virtue of the abnormalities in their physical properties which render them more akin to ionized salts. Thus they possess a high m.p., generally decomposing on melting; are extremely insoluble in non-polar solvents and relatively more soluble in water or in salt solutions. Raman spectra studies revealing, (1) a strong Raman frequency near 1,400 cm.$^{-1}$ due to the ionized carboxyl group, (2) Raman lines due to the NH group thus provide direct support to a dipolar-ion structure. Infra-red and ultraviolet spectra further lend support to this view. Further the application of Bronsted's theory to the study of acid-base equilibria as well as an investigation into thermo-dynamical properties like the heats of ionization all go to substantiate the view that the amino acids are dipolar ions.

The most important physical property which has been widely cited as evidence in support of the zwitterion hypothesis is the dielectric constant. Since the dipolar ions are insoluble in non-polar liquids all of them so far studied have been in polar solvents (mainly water). A striking feature of these observations was that all these substances enhanced the dielectric constant of water. Apart from an estimation of this dielectric increment the results could not be of much use in throwing any light on the structure of these molecules since a satisfactory relationship backed by theory to interpret the dielectric constants of polar liquids was lacking. Nevertheless attempts have been made to calculate dipole moments by the following empirical equations by Wyman[34-35] and others.

(1) Wyman[35] pointed out that the Debye's theory developed for gases and dilute solutions in non-polar liquids would be a thorough failure especially in the case of substances having so high dielectric constants as amino acids, in view of the fact that (*a*) the expression for the internal field $F = E + 4\pi I/3$ can hardly be expected to hold good in such systems. (*b*) The expression for polarisation $\frac{(\epsilon - 1)}{(\epsilon + 2)}\frac{1}{d}$ set an arbitrary limitation so that $\underset{\epsilon \to \infty}{p} = \frac{1}{d}$ and hence in the case of liquids of high dielectric constants very small values of 'p' are got. (*c*) An expression of the type $\frac{(\epsilon - 1)}{(\epsilon + 2)}\frac{1}{d}$ would not, when applied to solutions, explain the linear observed increment of dielectric constant with increase in concentration of solute. To eliminate these discrepancies Wyman found it necessary to assume in the original field equation $F = E$ instead of $E + 4\pi I/3$ (Clausius-Mosotti). To account for the elimination of the term $+ 4\pi I/3$, Wyman arbitrarily wrote $F_3 = - F_2 = - 4\pi I/3$ in the original field equation $F = F_1 + F_2 + F_3$. Thus assuming $F = E$ he derived for polarisation the expression $p = \frac{(\epsilon - 1)}{3}$, using which he calculated the dipole moments of glycine, 'α' amino-butyric acid, glycine hexa and heptapeptides, betaines and two other tetrapoles. Though this expression is based on arbitrary deductions from observed facts, regarding the internal field, yet it is interesting to find that the same relation, *viz.*, $F = E$ which forms the basis of the derivation of the new equation has been arrived at. When $F = E$ is assumed it is not necessary to write for p, $\frac{(\epsilon - 1)}{3}$; in fact more appropriately $p = \frac{(\epsilon - 1)}{3} = \frac{4\pi n \alpha}{3}$. Lastly Wyman's equation does not at all deal with the expression for orientation polarization (P_0). Evidently it has been assumed to be identical with P_0 (D.C.M.) which has no justification.

(2) For the same reasons which necessitated the abandonment of Debye's equation for substances of high dielectric constant, Wyman[34] was led to assume a linear relationship between dielectric constant and p, polarisation per c.c. $\epsilon = a + bp$, where a and b are constants. This explains the observed linear variation of ϵ with concentration of solute, for, differentiating with respect to the concentration c, $\frac{d\epsilon}{dc} = \frac{bP - V(\epsilon_0 - a)}{1000}$, where P and V

are the molecular polarisation and partial molar volume of solute and ϵ_0 the dielectric constant of the solvent. Since it is usually found that $\frac{V(\epsilon_0 - a)}{1000}$ is very small compared with $d\epsilon/dc$, the observed increment, it is obvious that the dielectric increment is equal to $bP/1000$ which is a constant for each substance. The constants a and b in equation (1) were determined empirically by Wyman by calculating hypothetical values of volume polarisation (P) of liquids from the dipole moments found in the vapour or in dilute solutions of non-polar solvents. Wyman's consideration of 140 liquids on which data of dielectric constants as well as dipole moments are available gave for b values between 6 and 10, the best value being 8·5 and for 'a' $= -1$· Thus the equation for polarisation becomes $p = \frac{\epsilon + 1}{8 \cdot 5}$ c.c. This equation has been applied to calculate the moments of glycine and homologous mono amino acids and peptides. Wyman's equation, while accounting for many observed facts, suffers from a lack of theroetical background. Again here the Debye's expression has been used for orientation polarisation ($P_0 = 4\pi N\mu^2/9kT$), knowing full well that this has been derived for gases and dilute solutions in non-polar solvents. The same reasons which necessitated the modification of the expression for total polarisation should obviously have necessitated the modification of the equation for P_0. This fact has been overlooked by Wyman.

(3) A convenient approximate relation has been used to calculate moments by Cohn[7] $\delta = A\mu^2 - K$, where $\delta =$ dielectric increment, $\mu =$ dipole moment; A and K are constants. K is small and often neglected. A has been evaluated by substituting $\mu = 15$ D for glycine whose δ is known. This equation is convenient to make approximate estimates of the dipole moments of the dipolar ions.

(4) Moments have also been evaluated by the well-known D.C.M. equation which, for obvious reasons, is a thorough failure for the case of the dipolar ions. Wyman calculated μ (D.C.M.) for amino acids and found them unreasonably small and even less than that for the corresponding esters.

(5) The fact that the amino acids exist as dipolar ions in solutions affords another method of directly calculating their moments using statistical methods which estimate the value of $\bar{C}^2$ the mean square distance between the ends of a chain. Eyring[19] calculated $\bar{C}^2$ in terms of n the number of valence bonds each of length C_1, separating the ends of the chain as $\bar{C}^2 = C_1^2\,[n + 2(n-1)\cos\theta + 2(n-2)\cos^2\theta + \ldots + 2\cos^{n-1}\theta]$, where $\theta =$ supplement of the valence angle. This expression approximates to

that of Kuhn[26] for higher values of n, $C^2 = nC_1^2\left(\frac{1+\cos\theta}{1-\cos\theta}\right)$. These equations are derived for the case of uncharged molecules. Recently Kuhn[27] has derived a formula for the mean square distance of separation of charged groups. However, these values seem to be rather low in view of other evidence offered by certain established factor (like the moment of glycine). Wyman has used Kuhn's equation to calculate $\overline{C^2}$ and thence the moments μ ($\mu = 4\cdot8 \sqrt{C^2}$) for some amino acids and peptides.

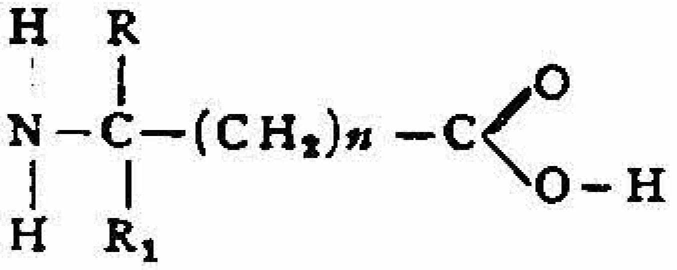
In this paper the dipole moments of the various amino acids and peptides have been calculated by means of the new equation $(\epsilon - n^2)\, M/d = 4\pi N\mu^2/kT$ extended to solutions in the form

$$P_{12} = \frac{(\epsilon_{12}-1)(M_1f_1+M_2f_2)}{d_{12}} = P_1f_1 + P_2f_2 = (\epsilon_1-1)\, M_1f_1/d_1 + P_2f_2.$$

The other quantities being known, P_2, the polarisation of the solute is calculated from the above equation. The moment μ is then evaluated as $\sqrt{P_2\cdot kT/4\pi N}$.

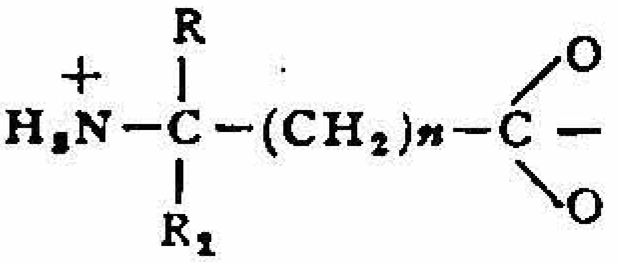
1. AMINO ACIDS

Amino acids differ from one another either in the number of carbon atoms in the chain or in the position of the carboxyl and amino group or both. The general formula may be written as



$$\underset{\underset{H}{|}}{\overset{H}{N}}-\underset{\underset{R_1}{|}}{\overset{\overset{R}{|}}{C}}-(CH_2)_n-C\begin{matrix}\nearrow O\\ \searrow O-H\end{matrix}$$

where $n = 0, 1, 2, \ldots$ etc., and R is a hydrogen atom on C_nH_{2n+1} group. The corresponding dipolar ionic structure is



$$\overset{+}{H_3N}-\underset{\underset{R_1}{|}}{\overset{\overset{R}{|}}{C}}-(CH_2)_n-C\begin{matrix}\nearrow O\\ \searrow O\end{matrix}-$$

The available data on the dielectric constants of the aqueous solutions are due to Wyman and Devoto.[11] A common feature of the studies is the fact that the dielectric constant of the solution increases linearly with concentration of solute. This linearity could be explained on the basis of the new equation which for binary solutions can be writtten

$\frac{(\epsilon_{12}-1)}{d_{12}} = \frac{(\epsilon_1-1)}{d_1}W_1 + p_2W_2$, W_1 and W_2 being weight frcations.

Since in dilute aqueous solutions $d_{12} \simeq d_1 \simeq 1$, $(\epsilon_{12}-1) = (\epsilon_1-1) \times (1-W_2) + p_2W_2$ and $\Delta\epsilon = \frac{(\epsilon_{12}-\epsilon_1)}{W} = (p_2 - \epsilon_1 + 1)$. (1)

$\Delta\epsilon$ corresponds very closely to Wyman's δ the dielectric increment, differing by it from a constant. Since p_2 and ϵ_1 are constants independent of concentration it is clearly seen that the dielectric increment is constant in dilute solutions. Equation (1) also explains the observed fact that the dielectric increment is independent of the dielectric constant ϵ_1 of the solvent employed for, ϵ_1 the dielectric constant of solvent being very small compared to p_2 proves ineffective in altering the values of $\Delta\epsilon$ to any measurable extent.

Wyman and Mcmeekin[31] have interpreted the dielectric constant data in the light of the zwitterion hypothesis. Since the addition of even small amounts of the solute enhanced the dielectric constant to a considerable extent, they concluded that the dielectric constant of the solute and hence its dipole moment was unusually high and larger than any of the 'non-ampolytes' studied till then. Their observations indicate (1) the dielectric increment

$$\delta = \left\{\frac{[\epsilon_{\text{solution}} - \epsilon_{\text{solvent}}]}{\text{concentration of solute in mols/litre}}\right\} \text{ increases}$$

linearly with n the number of CH_2 groups between the carboxyl and amino groups. (2) The dielectric increment is the same for a given type of amino-acid. Thus the four α amino acids and the two β amino acids studied give the same δ.

Wyman concluded from the first observation that μ is proportional to n on the assumption that the increment δ was a measure of the dipole moment. He even cited this linear increase of δ with n in support for the assumption that the molecules existed in solutions like straight rods so that the addition of each group, regularly increases the dipole distance and hence the moment. However, Wyman's assumption that δ gives a measure of dipole moment is wrong. δ in fact is proportional to polarisation and hence to the square of the moment as seen from equation (1). Attempts have been made to evaluate μ for glycine and some amino-acids. The moment calculated from Wyman's equation (1) using for $p = \frac{(\epsilon - 1)}{3}$ are always $\sqrt{3}$ times higher while those calculated from Wyman's latter equation (2) based on $p = \frac{(\epsilon + 1)}{8 \cdot 5}$ are very near to that given by the new equation. The latter fact has been shown in a previous paper to be due to fortuitous coincidence arising out of Wyman's equation arithmetically approximating to the new equation, moments calculated according to which have been tabulated as below:

TABLE I

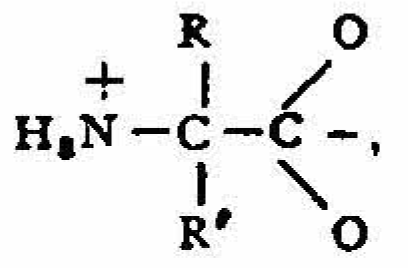
Glycine

Solvent	$f_2 \times 10^2$	ϵ_{12}^{31}	P_0	μ
Water	4·06	123·7	25110	11·6
20% aq. alcohol	2·17	101·1	21490	10·7
40% aq. alcohol	2·57	100·3	27950	12·3
60% aq. alcohol	2·98	100·2	30560	12·8

TABLE II

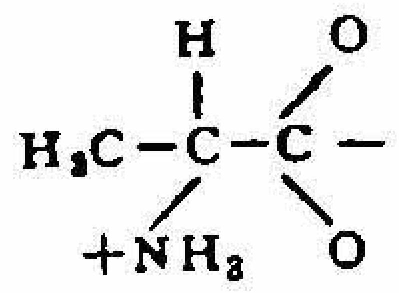
Amino-acids	$f_2 \times 10^2$	ϵ_{12}^{31}	d_{12}	P_0	μ
α-alanine	1·94	101·7	1·032	28070	12·3
α-aminobutyric	19·7	101·7	1·025	29170	12·5
α-aminovaleric	0·61	85·97	1·005	30381	12·8
β-alanine	1·94	113·1	1·021	39223	14·5
β-aminobutyric	1·52	103·9	1·013	37972	14·3
γ-aminobutyric[14]	0·081	80·12	1·000	57809	17·6
γ-aminovaleric	0·33	88·55	1·002	84554	18·4
δ-aminovaleric[14]	0·046	79·52	1·000	73601	19·8
ε-aminocaproic	2·03	156·0	1·013	84548	21·3
ζ-aminoheptylic[14]	0·015	78·57	1·000	95452	22·6

On the zwitterion hypothesis moments of amino acids could easily be calculated knowing the distance of separation of the charged carboxyl and amino groups. A model of glycine based on X-ray diffraction studies gives the distance between the positive charge (*i.e.*, the nitrogen atom) and the negative charge (midway between the two oxygens of the carboxyl group) as 2·96 Å. Thus the moment is 2·96 × 4·77 = 14·2 D as compared with the observed 12·2 D. It is to be borne in mind that the X-ray values are from studies of crystal glycine and that the distance between the changed group need not be the same when the molecules are in solution. A tendency for bending will result in a reduction of the dipole distance and hence of the moment. However the agreement between the calculated and observed values is more than satisfactory in view of the limitations involved in the work in dilute solutions especially with a solvent like water. From the general structure of the α amino acids

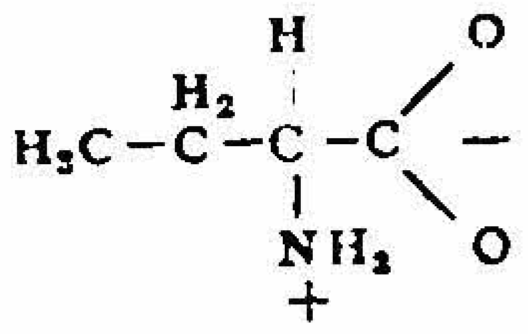


$$\overset{+}{H_3N}-\underset{R'}{\overset{R}{C}}-C(=O)O^{-},$$

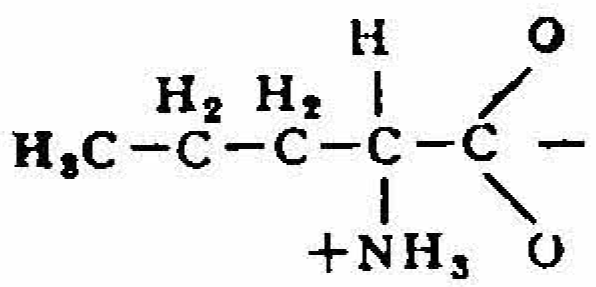
it is obvious that irrespective of the nature of the groups R, R′ the dipole distance and hence the moment ought to be the same for all α amino-acids. This indeed is the case as revealed by Table II. Glycine and alanine



α aminobutyric acid



α amino-valeric acid

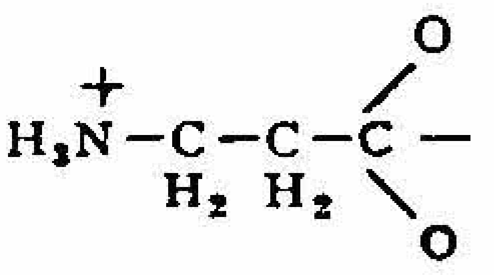


have all the same moment (12·2 ± 0·5). In the case of glycine the dipole moments have also been calculated from Wyman's data on alcohol solution of various concentrations. In the calculation P_2 was evaluated by using the following equation

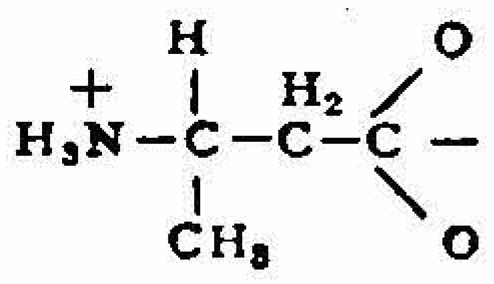
$$P_{12}=\frac{(\epsilon_{12}-1)}{d_{12}}(M_1f_1+M_2f_2)=\frac{(\bar{\epsilon}_1-1)}{d_1}\bar{M}_1f_1+P_2f_2$$

where $\bar{\epsilon}_1$ dielectric constant of the water-alcohol mixture used as solvent, $\bar{M}_1$ = mean molecular weight calculated as $(M_1f_1'+M_2'f_2')$ where M_1' = molecular weight of water, f_1' = mole fraction of water ; M_2' = molecular weight of alcohol, f_2' = mole fraction of alcohol in the water-alcohol mixture. The moments obtained in 20, 40 and 60 per cent. alcohol solutions are all the same as obtained in water[12], a fact which not only establishes the applicability of the new equation even to an extremely limiting case of a ternary system with a binary polar mixture as solvent, but also provides evidence that even in alcohol solutions the zwitterion structure is predominant. Similarly, as expected on the dipole ion structure basis, the two β amino-acids studied;

β alanine

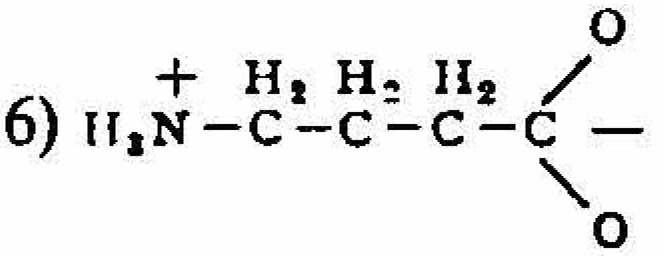


and β aminobutyric acid

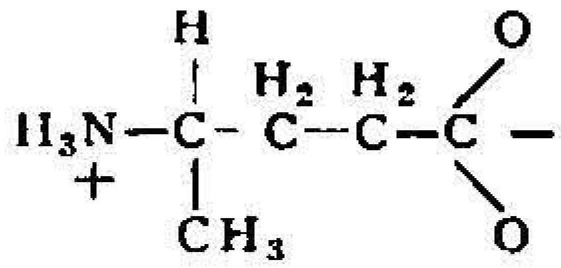


have the same moments (14·5 and 14·3 respectively). So also the two γ amino-acids,

γ amino butyric acid (μ = 17·6)



and γ amino valeric acid (μ = 18·4)



Only one member each belonging to δ, ϵ, ξ amino-acids (with 4, 5, and 6 CH_2 groups between the $\overset{+}{N}H_3$ and $C\begin{smallmatrix}\diagup O\\ \diagdown O\end{smallmatrix}$ —) have been studied.

The studies on the amino acids series thus reveal:

(1) The moments of the amino-acids of the same type are the same (μ = 12·5, μ = 14·5 μ = 18).
(α) (β) (γ)

(2) There is a gradual increase of moment from the α to the ξ as the number of CH_2 groups separating the NH_3^+ and $CO\bar{O}$ groups increases

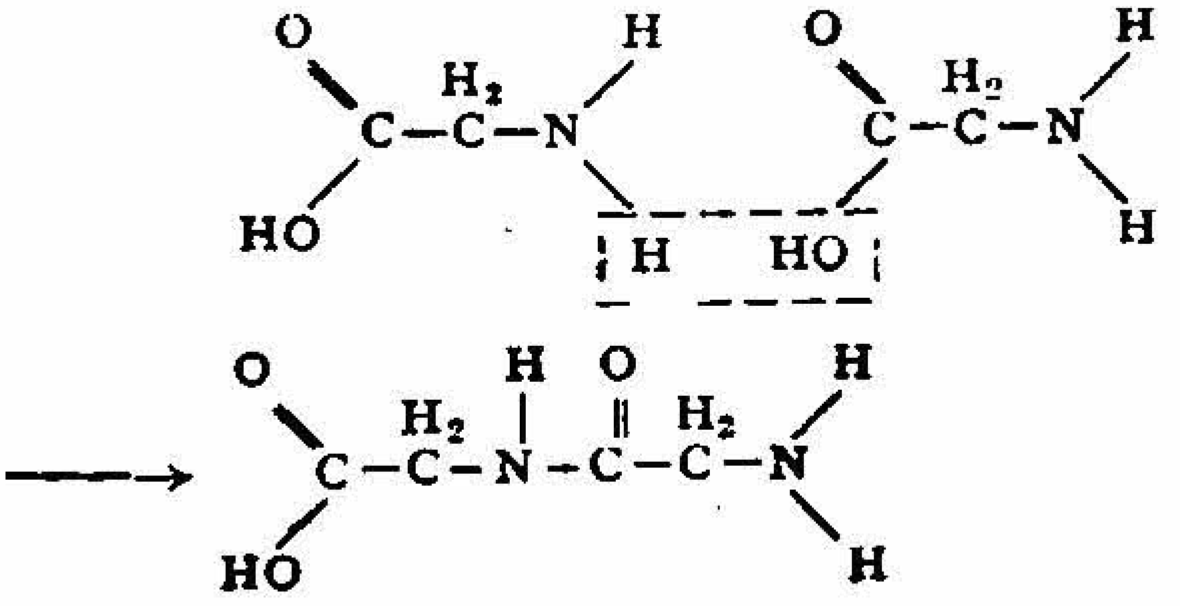
	α	β	γ	δ	ϵ	ξ
μ	12·5	14·5	18	20	21	23

2. PEPTIDES

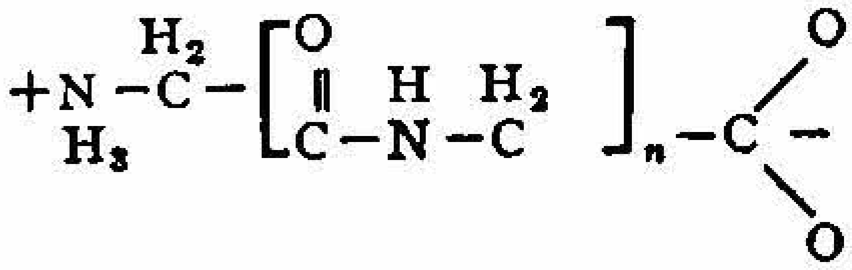
Under this heading are the amide-like amino acid derivatives formed by the amino group of an amino-acid molecule combining with the carboxyl of another molecule with the elimination of water. The amino linking is not confined to two amino-acid molecules and the single constituents need not be of the same kind.

(a) *Glycine peptides*

Glycine peptides are obtained by the condensation of two or more molecules of glycine with the elimination of water. Thus glycine dipeptide is formed by two glycine molecules



The general formula (zwitterion) for glycine peptides is



$$+\underset{H_3}{N}-\overset{H_2}{C}-\left[\overset{\overset{O}{\|}}{C}-\overset{H}{N}-\overset{H_2}{C}\right]_n-C\begin{smallmatrix}\diagup O\\ \diagdown O\end{smallmatrix}-$$

Moments calculated by the new equation have been tabulated below:

TABLE III

n peptides	$f_2 \times 10^4$	$\epsilon_{12}{}^{31}$	P_0	μ
di ..	19·3	86·02	78771	20·6
tri ..	11·3	85·59	125500	25·9
tetra ..	10·9	88·03	174701	30·6
penta ..	4·79	84·20	238212	35·7
hexa ..	2·38	81·62	260698	37·4

Wyman and Mcmeekin have studied the ' di ', ' tri ', ' tetra ' and ' penta ' peptides and find that as in the case of the amino-acids the dielectric increment is independent of concentration and increases linearly with n the number of glycine units between the terminal $CO\bar{O}$ and $\overset{+}{N}H_3$ groups. As usual these results are cited as affording direct evidence to the existance of these as dipolar ions.

Wyman has observed that the dielectric increment of glycyl glycine (70·5) is about midway between that of ε caproic acid (73·7) and δ amino-valeric acid whereas the distance along the chain between the charged groups of the dipeptide is about the same as in a ε amino-acid. This discrepancy is attributed by Wyman to the additional contribution to the moment from the amide group in the peptide. The new equation gives the same moment[20] for diglycine and δ amino-acid in conformity with their equal dipolar distances.

When the square of moments calculated by the new equation for the five glycine peptides are plotted against the molecular weight a straight line is obtained. It is interesting to consider the implications of this linear relationship in light of the statistical deductions of Kuhn, Eyring[19] and others who have calculated C^2 " mean square distance between the ends of a straight chain structure " in terms of n the number of atoms in the chain. According to Eyring's equation which is more general than Kuhn's C^2 is given by $\bar{C}^2 = C_1^2\ [n + 2(n-1)\cos\theta + 2(n-2)\cos^2\theta + \ldots.\ 2\cos^{n-1}\theta]$, θ, being the valence angle and C_1 the distance between the centres of adjacent atoms

$$= C_1^2\,[n + 2n(\cos\theta + \cos^2\theta + \cos^3\theta + \ldots.\cos^{n-1}\theta) -$$
$$2(\cos\theta + 2\cos^2\theta + 3\cos^3\theta + (n-1)\cos^{n-1}\theta]$$

$$= C_1^2\left\{n + 2n\left[\frac{\cos\theta\,(1-\cos^{n-1}\theta}{1-\cos\theta}\right] -\right.$$
$$\left.\left[\left(\frac{1-\cos^{n-1}\theta}{1-\cos\theta} - (n-1)\cos^{n-1}\theta\right)\frac{\cos\theta}{1-\cos t}\right]\right\}$$

When n is large

$$\overline{C}^2 = C_1^2\left[n + \frac{2n\cos\theta}{1-\cos\theta} - \frac{\cos\theta}{(1-\cos\theta)^2}\right]$$

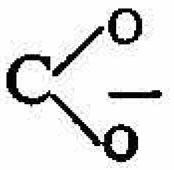
since

$$(n-1)\cos^{n-1}\theta = \frac{n-1}{\sec^{n-1}\theta} \underset{n\to\infty}{\rightarrow} 0.$$

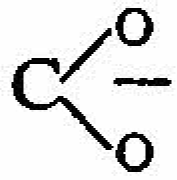
Assuming a tetrahedral valence angle, $\cos\theta = \frac{1}{3}$

$$\overline{C}^2 = C_1^2\,[2n - 1\cdot5] \simeq 2nC_1^2$$

which is identical with Kuhn's expression derived for the case of large n.

The entire graph of C^2 versus n (according to Eyring's equation) is a curve starting from the origin approximating to a straight line when n is high ($n \geqslant 3$). In discussing the dielectric increments of peptides Conner, Clerk and Smyth have been unable to explain as to why δ, the dielectric increment (assumed to be proportional to $\overline{C}^2$) should linearly vary with n ' even for smaller peptides like the di. tri and tetra inasmuch as the straight line relationship holds only for larger values of n. It is to be pointed out that these authors as well as Wyman have plotted n as the number of glycine residues while actually n in the equations of Kuhn and Eyring is the number of atoms separating the NH_3^+ and  groups. Thus even in the lowest member, the dipeptide $n = 4$ () so that the δ of this together with those of the higher members of the series which have $n = 8, 12, 16$ fall on a straight line when plotted against n since n is large enough to justify such a linear relation for this series. More recently Kuhn has calculated $\overline{C}^2$ taking into account electrostatic attraction between the carboxyl and amino group, and also assuming a value of 1·5 Å for the distance of closest approach of the charged groups. These values however are smaller than those given by Kuhn and Eyring and increase less rapidly than in proportion to n.

The results from the new equation reveal that the moment μ is related to molecular weight (M) by $\mu^2 = 5M - 230$ (1)

(μ in Debye units). Expressing M, the molecular weight in terms of n the number of valence bonds separating the two terminally charged groups NH_3^+ and 

$$M = 19n + 18 \qquad (2)$$

($n = 3, 6, 9 \ldots.$ for di, tri, tetra.... peptides).

Substituting (2) in (1) $\mu^2 = 95n - 140.$ (3)

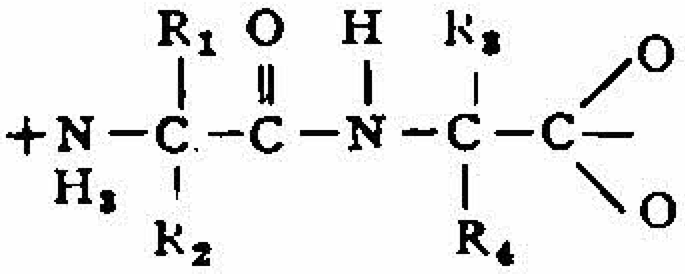
Now if D is the dipole distance of the zwitterion (*i.e.*, distance between the charged groups), $\mu = D \times 4 \cdot 77 \times 10^{-10}$. (3) becomes now

$$D^2 = 4 \cdot 2n - 6 \cdot 1 \qquad (4)$$

Eyring's equation $C^2 = C_1^2\,(2n - 1 \cdot 5)$ can be written as $C^2 = 4 \cdot 6\, n - 3 \cdot 5$ (5) taking $C_1 =$ the distance between adjacent atoms as $1 \cdot 5$ Å. The equations (5) and (4) show close resemblance indicating that the square of the dipole distance (μ/e) corresponds to the average square of the distance between charged groups calculated on the basis of statistical methods of Eyring.[19] The slight discrepancy between (5) and (4) is perhaps due to a hindrance of rotation which has been unaccounted for by Eyring. Considering this fact the agreement obtained is very satisfactory. A correction for hindrance, which has been taken into account by Taylor[33] in a recent paper would result in changing the value of the constants K and K′ in Eyring's equation $C^2 = Kn + K'$.

(*b*) *Mixed dipeptides*

The peptides studied so far were entirely composed of glycine units. In the present case are considered the peptides which are made up of different amino-acid units. Those in which only two such units are considered, *i.e.*, the dipeptides can be depicted by a general formula



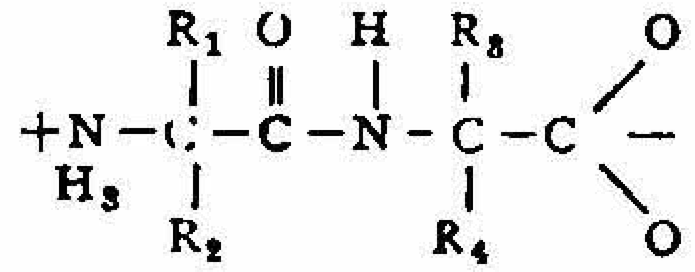
$$\overset{+}{N}H_3-\underset{R_2}{\overset{R_1}{C}}-\overset{O}{\overset{\|}{C}}-\overset{H}{N}-\underset{R_4}{\overset{R_3}{C}}-C\begin{smallmatrix}\nearrow O\\ \searrow O\end{smallmatrix}$$

where R_1 and R_2, R_3 and R_4 are either H, aliphatic or aromatic radicals. Belonging to this class are leucyl glycine, glycylleucine, glycylalanine, alanylglycine, leucylalanine, methylleucylglycine and phenylglycine whose dielectric constants in dilute aqueous solutions have been investigated by Greenstein and Wyman[22] and Conner, Clarke and Smyth.[5] No attempts have been made so far to evaluate the moments of these peptides. Greenstein and Wyman have discussed the results in terms of the dielectric increments. They observed that the very nearly same δ values for leucylglycine, glycylleucine and methylleucylglycine suggested that their moments might be expected to be the same. Moments have been calculated by the new equation and tabulated as follows:

TABLE IV

Dipeptide	$f_2 \times 10^4$	ϵ_{12}^{22}	P_0	μ
Leucylglycine ..	9·08	81·84	81812	21·1
Glycylleucine ..	1·80	79·29	88838	21·8
Glycylalanine .	1·80	79·26	83221	21·1
Alanylglycine ..	1·80	79·25	83222	21·1
Leucylalanine[5] ..	5·43	80·28	73672	19·9
Methylleucylglycine ..	1·80	79·21	88717	21·8
Glycylphenylalanine ..	1·80	79·24	88694	21·8
Phenylalanylglycine ..	1·80	79·11	77606	20·4

All the seven mixed dipeptides show very nearly the same moment.[21] This is expected because irrespective of the nature of the group R_1, R_2, R_3 and R_4 in the general structure

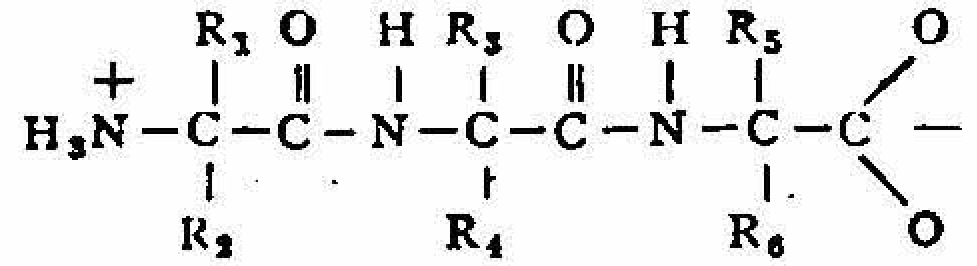


$$ {}^{+}\underset{H_3}{N}-\underset{R_2}{\overset{R_1}{C}}-\overset{O}{\overset{\|}{C}}-\overset{H}{N}-\underset{R_4}{\overset{R_3}{C}}-C\begin{cases}O\\O^-\end{cases} $$

the dipole distance is the same in all the peptides since the $\overset{+}{N}H_3$ and $C\begin{cases}O\\O^-\end{cases}$ are separated in all the cases by the same $C\diagup C\diagdown N\diagup C$ link. Hence the moment being directly proportional to the dipole distance is the same for all these dipeptides. Further the moments of all these peptides are equal to that of glycine dipeptide, which being a dipeptide has the same dipolar distance as the former.

(*c*) *Mixed tripeptides*

These are peptides got by condensation of three amino-acid molecules. The general formula may be written as



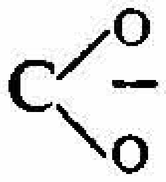
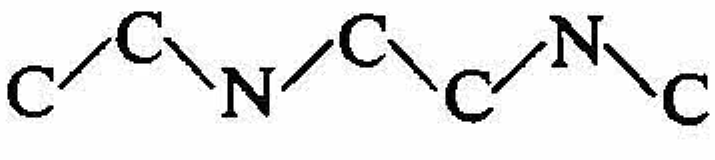
$$ \overset{+}{H_3N}-\underset{R_2}{\overset{R_1}{C}}-\overset{O}{\overset{\|}{C}}-\overset{H}{N}-\underset{R_4}{\overset{R_3}{C}}-\overset{O}{\overset{\|}{C}}-\overset{H}{N}-\underset{R_6}{\overset{R_5}{C}}-C\begin{cases}O\\O^-\end{cases} $$

R_1, R_2 .... = H.

aliphatic or aromatic groups. The dielectric studies in aqueous solutions of four of these tripeptides leucylglycylglycine, alanylglycylglycine, analylleucylglycine and glycylleucylalanine have been done by Conner, Clerk, and Smyth[5] and Greenstone and Wyman.[22] Apart from the evaluation of the dielectric increments no further attempts have been made by these authors to calculate the dipole moments. The new equation has been used to evaluate the moments as shown in the following tables:

TABLE V

	$f_2 \times 10^4$	$\epsilon_{12}{}^{5}$	$P_2 \times 10^{-2}$	μ
Leucylglycylglycine ..	1·80	79·74	1441	27·8
Alanylglycylglycine ..	3·61	80·88	1328	26·6
Alanylleucylglycine ..	1·80	79·79	1496	28·3
Glycylleucylalanine ..	1·80	79·65	1441	27·7

The four peptides studied show very nearly the same moment 27–28 equal to that of the glycine tripeptide (26). This is expected on the basis of their structural similarity whereby in all these the dipolar distance is the same, since the NH_3^+ and  $C\begin{smallmatrix}\nearrow O \\ \searrow O\end{smallmatrix}{}^{-}$ are separated by the same  link.

3. BETAINES

The betaines form a class closely akin to the amino acids. For any given amino acid there is a corresponding betaine which differs from the former in that the three hydrogen of the amino group are replaced by organic radicals. Their dissociation constants and other properties indicate that they are dipolar ions. The moments calculated by the new equation for some betaines have been tabulated as follows:

TABLE VI

Betaines	$f_2 \times 10^4$	$\epsilon_{12}{}^{18}$	P_0	μ
Glycine– ..	5·42	79·09	27681	12·2
Pyridine– ..	9·06	79·47	29803	12·6
Thio–[15] ..	4·84	78·44	28944	12·5
o-benz– ..	9·07	79·48	33072	13·5
m-benz– ..	5·43	79·98	62658	18·3
p-bnz– ..	3·61	79·98	88591	21·8
Dimethylanthranilic acid ..	9·07	79·14	26472	11·9

(*a*) *Glycine betaine* $(CH_3)_3N^+CH_2CO\bar{O}$

Edsall and Wyman got a value of 18·5 for dielectric increment and Devoto, a slightly higher value of 24. Assuming the relation $p = \frac{(\epsilon - 1)}{3}$ Edsall and Wyman[18] have calculated the dipole moment as 10·7. Since the glycine betaine has essentially the same structure as glycine and the positive charge could be considered to be located at or near the centre of the nitrogen atom as in the case of glycine it is expected that the moment of glycine and its betaine should be the same. The new equation gives the same moment (12·2) for betaine as for glycine ($\mu = 12 \cdot 0$).

(*b*) *Pyridine and thiobetaine*

For pyridine betaine Edsall and Wyman[18] gave a dielectric increment of 18·5 whereas Hausser[23] reports a value 20·5 D. The moment calculated by the new equation is 12·6 D. The only available data on dielectric constants of thiobetaine is the investigation of Devoto who reported a value of 23 for the dielectric increment. The moment calculated according to the new equation is 12·5 D. Wyman predicted on the basis of the dielectric increment and the structural similarity that the moments of pyridine betaine $C_6H_5\overset{+}{N}CH_2CO\overset{-}{O}$ and thiobetaine $(CH_3)_2\,\overset{+}{S}CH_2CO\overset{-}{O}$ should be the same as for glycine. The moments calculated by the new equation for the two betaines (12·5 and 12·6) confirm this fact.

(*c*) *Benz betaines* (ortho, meta and para). $(CH_3)_3N^+\,C_6H_4COO$

In the compounds belonging to this series the amino and carboxyl groups are attached to the rigid benzene ring in the three possible (ortho, meta and para) positions respectively. The dielectric studies of Wyman and Edsall[18] resulted in a value of 19, 48 and 72 for the dielectric increment of ortho, meta and para benz betaines for which Devoto reported $\delta = 20$, 58 and 68 respectively. Using the expression $\frac{(\epsilon-1)}{3}$ for polarisation Wyman and Edsall have calculated the moment of the ortho, meta and para benz betaines as 22, 31 and 36 respectively. The new equation gives the moments as 13·5, 18·3 and 21·8 rspectively as shown in Table VI. Wyman and Edsall have had to assume a distorted valence group in the case of ortho benz-betaine since this was the only way of accounting for a moment[20] obtained by their equation ($\frac{\epsilon-1}{3} = p$) higher than that based on a rigid undistorted model. Though such a consideration accounts for the discrepancy mentioned above yet the assumption involved in their postulate of valence distortion, *viz*., that of free rotation of both the carboxyl carbon and nitrogen atoms about the valence line joining them with the carbon atom of the ring, calls for a deformed structure existing in a state of strain. Assuming for the ortho compound the dipole distance 3·23Å calculated on the basis of rigid models based on data from recent X-ray and electron diffraction, the moment $= 3{\cdot}23 \times 4{\cdot}77 \times 10^{-18} = 14{\cdot}3$ D which shows good agreement with the value 13·5 obtained by the new equation. The calculated value based on the X-ray model for the meta and para compounds (26·2 and 30·4 respectively) are higher than the moment got by the new equation and lower than that given by Wyman (31 and 36 respectively) using the $\frac{(\epsilon-1)}{3}$ law for polarisation. Wyman and Edsall are however content with the fact that their moments are " closely proportional to the true values though probably too high ". The lower moments of the meta and para compounds may possibly be due to a distortion of valence bonds uniting the carboxyl carbon and nitrogen atoms to the corresponding carbons of the ring.

(*d*) *Dimethylanthranilic acid* $(CH_3)_2NC_6H_4COOH$

Dimethylanthranilic acid shows unusual properties. Unlike amino-acids and betaines it has got a low melting point (70°), has small electrostriction and is soluble to a good extent in non-polar solvents. These differences in properties from typical dipolar ions seem to suggest that the acid does not exist in zwitterion form. On the other hand the dissociation constant and dielectric constant studies give strong support for a dipolar ion structure.

Edsall and Wyman's[18] studies on the dielectric constants of aqueous solutions of the acid give a value 12 for the dielectric increment. Devoto[16] gives a higher value 16·7. The studies of the former are more extensive than the latter. Application of Wyman's equation $\frac{(\epsilon-1)}{3}$ for polarisation per c.c. gives for the moment a value 18·9. The new equation gives $\mu = 12$ (Table VI) which is slightly less than that for '*o*' benz betaine ($\mu = 13 \cdot 5$) with which it structurally resembles. The substitution of one of the CH_3 by H causes the positive and negative radicals to pack more closely in dimethylanthranilic acid than in the bulky ortho benz betaine and thus the dipolar distance and hence the moment of the former might be expected to be slightly lower than that of the latter, though it is equally probable that view of the higher value given by Devoto for δ the moment calculated on the basis of Edsall and Wyman's data might be too low.

Edsall and Wyman[18] have calculated the moment in benzene as 6·31 and concluded that such a high value might be, as suggested by Pauling, due to the formation of a hydrogen bond between the carboxyl and methylated amino groups, but not possibly due to a dipolar ionic structure which evidently is improbable in a non-polar solvent like benzene. It has to be borne in mind that the value 6·31 has been calculated on the basis of Wyman's equation for $p = \frac{(\epsilon-1)}{3}$. The new equation would on the other hand give a moment $1/\sqrt{3}$ times, *i.e.*, $6 \cdot 31/1 \cdot 73 = 3 \cdot 65$. A moment of this magnitude can be easily accounted for even on the basis of a normal (non-dipolar) structure since strongly polar C–N, C=O groups constitute the compound.

4. UREA AND ITS DERIVATIVES

In this series urea, thiourea and four other homologues of urea, *viz.*, methyl, ethyl, propyl and dimethyl urea have been considered with a view to discuss their molecular structure on the basis of the dielectric constant studies. The new equation has been applied to calculate moments for the compounds. The results are tabulated as follows:

TABLE VII

Substance	$f_2 \times 10^{+3}$	ϵ_{12}	P_0	μ
Urea[12] ..	3·63	78·53	7989	7·24
,, * ..	0·57	2·286	9·22	7·24
Thio urea[12] ..	3·09	78·58	9709	7·21
,, * ..	2·13	2·399	6995	6·34
Methyl[13] urea ..	5·68	78·84	8628	6·79
Ethyl[14] ,, ..	2·62	77·99	8021	6·55
Propyl[14] ,, ..	2·31	77·99	9088	6·97
Dimethyl[13] ,, ..	4·30	78·53	9997	7·30

* In dioxane solution :

(*a*) *Urea*

Bergmann and Weizmann's[2] study in dilute dioxane solutions reveals a dipole moment of 8·6 (D.C.M. equation) whereas Kumler and Fohlen's[20] studies in the same solvent show a considerably smaller moment of 4·6. The latter authors have employed a graphical method of calculating P_2 at infinite dilution. This method is claimed to be more accurate than the usual methods and to be particularly useful in dilute solutions where solvent polarisation error may have a large effect on μ. Unfortunately the reference to the communication giving details of the derivation was not available. The equation has been written as follows:

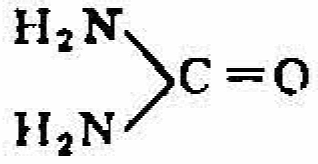
$$p_{2(\infty)} = \frac{3\,V_1 a}{(\epsilon_1 + 2)^2} + (V_1 + \beta)\,\frac{(\epsilon_1 - 1)}{(\epsilon_1 + 2)}. \tag{1}$$

From the tables given by the author it is obvious that V_1 refers to the specific volume and a, the change in dielectric constant of solution per mole of solute and β the change in density per mole of solute. It will be interesting to compare this equation with that derived by Le Fevre and Vine,[29] *viz.*,

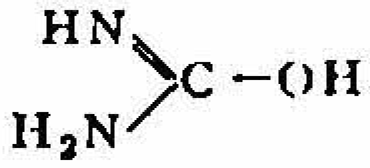
$$p_{2(\infty)} = \frac{3}{(\epsilon_1 + 2)^2}\,V_1 a\,\epsilon_1 + \frac{(\epsilon_1 - 1)}{(\epsilon_1 + 2)}\,V_1\,(1 - \beta). \tag{2}$$

Since the second term is usually found very small than the first it can be neglected in both the above equations (1) and (2). It is then seen that the polarisation at infinite dilution $P_{2(\infty)}$ given by Le Fevre and Vines, equation is ϵ times that given by Kumler and Fohlen's equation. Since the full knowledge of the assumptions involved in the latter's relationship is not known it is not advisable to accept the value of the moment calculated by their equation. Bergmann and Weizmann's data recalculated by the new equation gives a moment of 7·2. This agrees very well with the moment of 6·5 observed in water; the agreement being considered quite satisfactory in view of the fact that the moment calculated from the only available value of Bergmann on the dielectric constant of a very dilute solution (0·0006 molar) is subject to uncertainty.

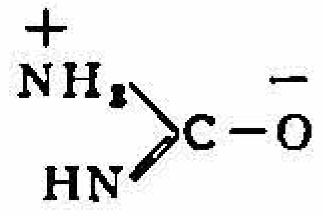
For many years it has been the object of consideration whether urea has the classical formula


(1)

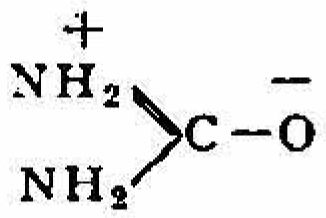
or an isomeric one


(2)

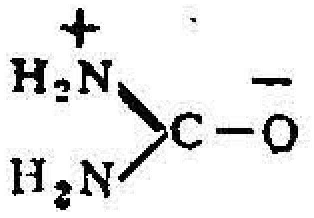
or the charged structures

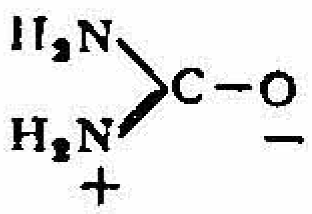

(3)

and


(4)

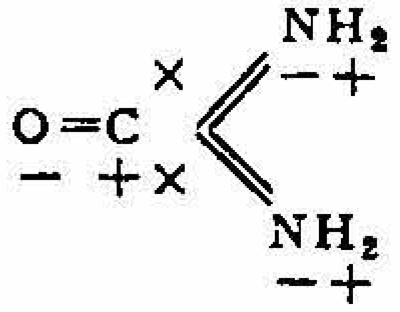
Strictly speaking the structure (3) alone of the two structures could be termed as a zwitterion, since the structure has two typical characteristics of a zwitterion, *viz.*, (1) a separation of charge (2) a shift of proton necessary to form it from the normal form. Structure (4) involves a separation of charges but no shift of proton. Kumler and Fohlen considered the structure (4) to be more favourable. Often the term ' zwitter-ions ' has been used to describe either of the structures (3) or (4). There is evidence both in favour of as well as against the ' zwitter-ion ' structure for urea. The high melting point, the short C–N distance of 1·37 (X-ray studies) and the high dielectric increment in water support a dipolar ion structure. On the other hand Cohn, Mc Meekin, Edsall and Blanchard[3] have, by their studies of solubility of urea in alcohol and water, concluded that it does not exist as a zwitter-ion. Kumler and Fohlen concluded from their studies of dipolemoment that urea and thio urea are resonance hybrids with 20 to 30 per cent. contribution of the forms with a separation of charge. Such a resonance structure





has also been suggested by Weizmann and Bergmann[2] who point out that the presence of the C–N bond as indicated by the Raman spectrum studies of urea (Kohlraush and co-workers) points to symmetrical formula. Wyman has suggested that it is more correct to interpret the behaviour of urea on the effect of resonance whereby the carbon may be regarded as bearing a negative charge and either one of the nitrogens a positive charge. On this basis the moment ought to be equal to C–N distance × electronic charge $= 1\cdot37 \times 4\cdot77 = 6\cdot53$ which agrees very well with the moment calculated by the new equation (6·5 in water and 7 in dioxane).

The moment of urea could be explained as being the vector (6·5 D) of the classical structure



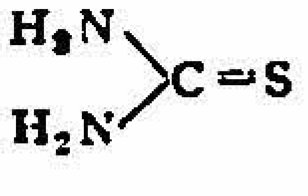
$O{=}C(NH_2)_2$

with C=O moment as 3·0 D, C–N moment as 1·1 D (1/6 × 1·37 (*d*) × 4·78 D (*e*) and N–H = 4·3 D.

(*b*) *Thiourea*

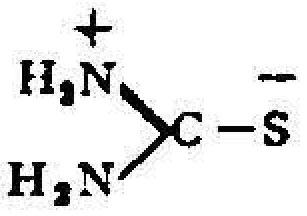
Devoto has studied the dielectric constants of aqueous solution of thiourea and reported a dielectric increment of 4. Kumler and Fohlen[20] and Bergmann and Weizmann[2] have studied the substance in very dilute solutions of dioxane. They have calculated the moment as 7·6 and 4·9 respectively. The moment of 7·2 obtained by the new equation from aqueous solution is in good agreement with that (6·3) obtained from dilute dioxane solution data of Bergmann and Weizmann.

Lecher[28] has emphasised that the high melting point of thiourea, its insolubility in a non-polar solvent, its behaviour towards acids and on alkylation seemed to point to a zwitter-ion structure and the same conclusion has been arrived at by Hynd and Mac Farlane[25] on the basis of reaction between urea and nitrous acid. Subsequently Lecher suggested a tautomeric equilibrium between the normal



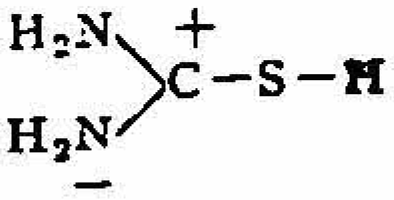
$(H_2N)_2C{=}S$ (1)

and the charged



$(H_2\overset{+}{N})(H_2N)C{-}\overset{-}{S}$ (2)

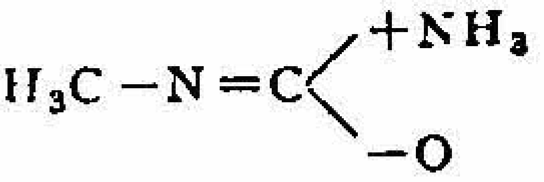
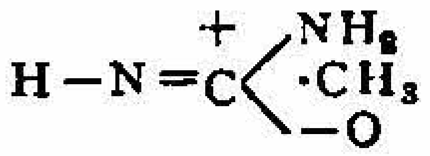
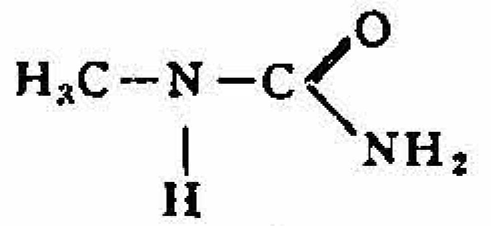
but finally abandoned the latter in favour of the former. Rivier and Borel[4] concluded from their ultra-violet absorption studies that thiourea itself does not contain C=S. This eliminates the possibility of structure (1). Clow[6] has advocated from his diamagnetic susceptibility studies a structure

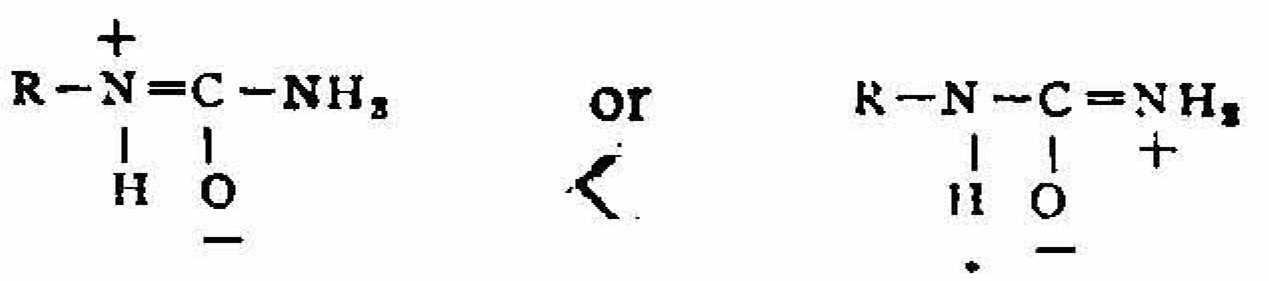


whereas Pauling suggested a true zwitterion structure. The structure given by Clow implies that the moment of the component ought to be C – N distance X electronic charge. Assuming the same C–N distance as in urea the moment = 6·5, comparing favourably with that obtained in dioxane (6·5) and in water (7·2) on the basis of the new equation.

(*c*) *Other Homologues of Urea*

Devoto studied the dielectric constants of methyl, ethyl, propyl and dimethyl ureas in aqueous solutions and found that they all gave a small positive dielectric increment. In addition he has also studied dimethyl urea and propyl urea in benzene and calculated the moments (D.C.M.) as 5·1 and 4·1 respectively. Hunter and Partington[24] have observed a moment of 4·8 for dimethyl urea. Moments have been calculated by applying the new relationship (Table VII).

It is interesting to point out that two alternative zwitter-ion structures (apart from resonance hybrids) are possible in the case of these homologues, *e.g.*, methyl urea could be given either the structure  or  depending on the fact as to which of the two protons of the hydrogen attached to the two nitrogens is shifted in the normal form  to form the two ionic structures. The rather low moments of the urea derivatives (dimethyl 5·1. propyl 4·1 in benzene) as compared with the parent substances urea and thiourea have been explained as being due to the fact that the increasing substitution of the urea or thiourea molecule prevents increasingly the electron transfer from nitrogen to oxygen. Kumler and Fohlen have postulated for the urea derivatives a general resonance hybrid structures as follows:



The moments calculated by the new equation for data on aqueous solution, on the other hand, indicates the same moment as for urea, for all the homologues. Thus the substitution of alkyl groups in the NH_2 groups of the parent substance urea does not seem to affect the dipolar nature of the molecule. If it is assumed, as suggested by Wyman, that owing to resonance it is the terminal carbon atom between the nitrogen atoms that bears the negative charge then the moment should be = C—N distance × 4·77 = 6·5 which agrees well with the observed values for the homologues and urea studied.

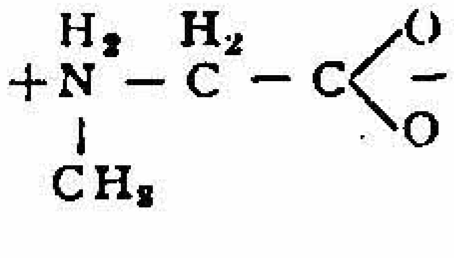
5. OTHER DIPOLAR IONS

These include a number of other peptides, betaines and related compounds some of which show a very large dielectric increment. Dipole-moments have been calculated by the new equation and the results tabulated as follows:

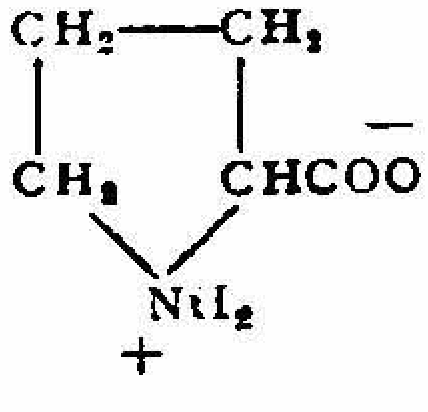
TABLE VIII

	$f_2 \times 10^4$	ϵ_{12}	$P_2 \times 10^{-2}$	μ
Lysylglutamic acid[9] ..	4·61	87·15	3621	44·1
ε,ε′ diaminodi (α-thio-*n* caproic acid[9]	7·71	83·71	1478	28·2
ε,ε′ diguanido di (α-thio-*n* caproic acid)[22]	1·81	..	1881	31·8
Sarcosine[13] ..	9·40	79·23	340·6	13·5
Proline[12] ..	7·77	78·82	321·6	13·1
Asparatic acid[12] ..	4·44	78·53	382·8	14·3
Glutamic acid[13] ..	1·47	79·31	384·2	14·3
l-Aparagine[22] ..	0·16	80·29	299·4	12·9
l-Glutamine[22] ..	0·18	80·63	323·6	13·2
Ornithine[15] ..	2·78	78·63	620·3	18·2
Creatine[22] ..	9·05	80·16	430·8	15·2
Glycocyamine[22] ..	1·80	78·87	444·0	15·3
d-Arginine[17] ..	6·06	79·92	759·0	20·1

(i) *Sarcosine*

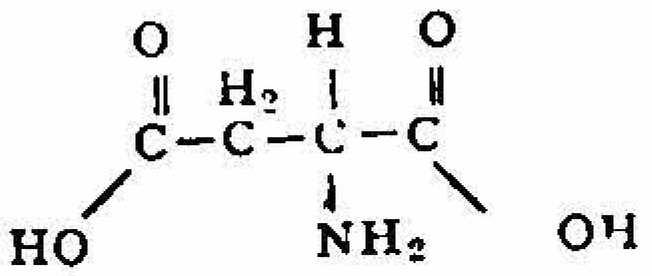


and (ii) *Proline*

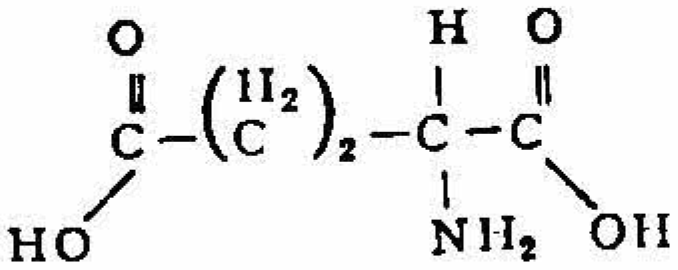


show nearly the same moment as an α amino-acid. This is due to the fact that the dipolar distances in the two cases are very nearly the same as in an α acid.

Asparatic

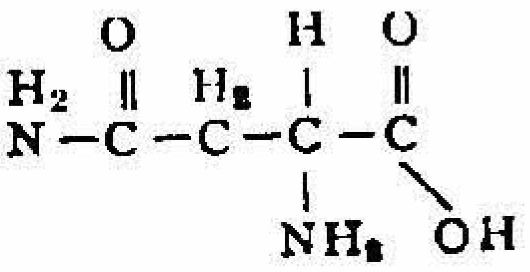


and glutamic

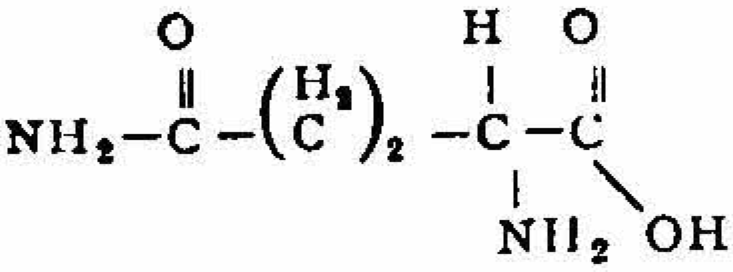


acids both possess the same moment and in view of this it is evident that the amino and carboxyl groups in the α position are charged. This is in accordance with expectations based on dissociation constants.

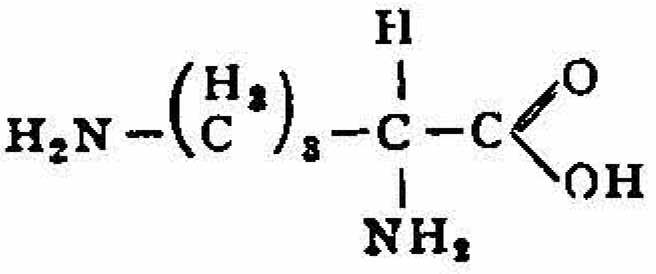
The two diamino acids asparagine



and glutamine

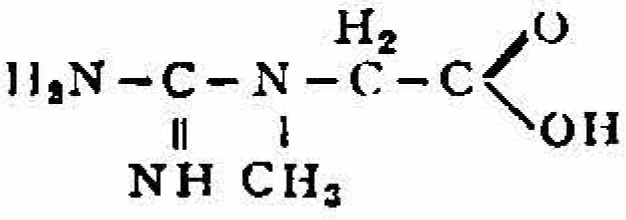


have the same moment while ornithine (also a diamino acid)

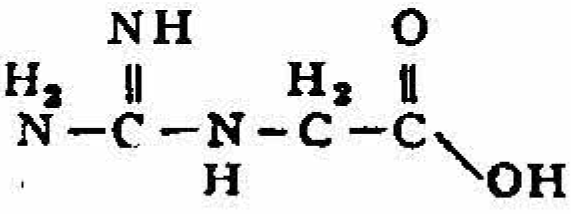


has a moment 18·2, from which it can be concluded that in the two former compounds it is the α amino groups and in the latter the more distant amino group that is charged.

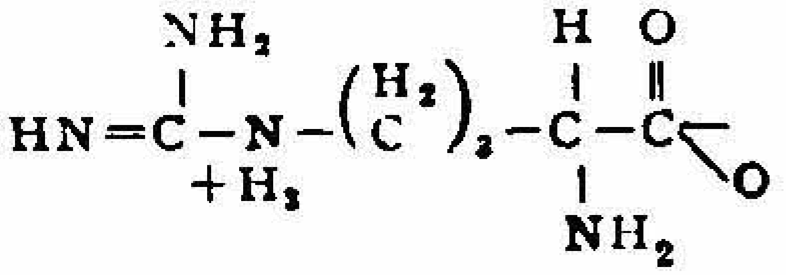
In the case of creatine



and glycocyamine



if, as suggested by Wyman, owing to resonance the positive charge is regarded to be located on the terminal carbon atom bearing the three nitrogens, then the dipole distance should correspond to that of a β amino-acid. The observed moments of these compounds are nearly the same as for β amino-acids. Arginine has a moment corresponding to a ε amino-acid and thus its structure could be written as



$$HN{=}\overset{NH_2}{\overset{|}{C}}-\underset{+H_3}{N}-\left(\overset{H_2}{C}\right)_3-\underset{\underset{NH_2}{|}}{\overset{\overset{H}{|}}{C}}-\overset{\overset{O}{\|}}{C}\overset{-}{\searrow}O$$

suggesting thereby that it is the NH group which is in 'δ' position with respect to the carboxyl group that is positively charged.

6. DISPERSION OF AMINO-ACIDS AND PEPTIDES

(*a*) *Introduction*

The first satisfactory investigation of the dispersion of dielectric constants of amino-acid solutions was made by Frick and Parts[21] at frequencies up to 66 megacycles. They obtained no change of dielectric increment with frequency in this range but observed considerable change in conductance from which they estimated the critical frequency by the relation

$$\lambda_m = 2\pi \times 3 \times 10^{10}\,\frac{(K_a^{\,d} - K_0^{\,d}) - K_0^{\,d} \times (\eta_1 - \eta_2)/\eta_0 + \rho K_0^{\,d}\ \eta_1/\eta_2}{[(\epsilon_a - \epsilon_0) + \rho\,(\epsilon_0 - n^2)]\ \omega^2} \times 36\pi \times 10^{-11}\ \text{cm.}$$

where K, η and ϵ denote the conductivity, viscosity and dielectric constants and the subscripts i and o refer to the solution and the solvent respectively. The authors pointed out that this equation closely follows a method of calculation used by Debye with the difference that $F = E$ instead of $E + \frac{4\pi I}{3}$.

Bateman and Potapenko[1] measured dielectric increments and absorption coefficients of aminoacids at 1176 megacycles (25·5 cm.) using Drude's I method. They calculated relaxation times (1) using Debye's theory with Wyman's modification, $\epsilon = a + bp$; (2) from molecular volume and viscosity applying Stokes law for the rotation of a sphere in a viscous medium. Marcy and Wyman[30] using a cathode-ray oscillograph conducted absorption and dispersion studies at 115 megacycles (2·61 meters) for lysylglutamic acid and glycinetripeptide. They calculated the critical frequency γ_c from the observed value of phase angle (ψ) by the equation

$$\frac{\epsilon''}{\epsilon'} = \tan\psi = \frac{(\epsilon_0 - \epsilon_\infty)\,x\gamma}{\epsilon_0 + \epsilon_\infty\,x^2\gamma^2},$$

where $\gamma_c = 1/\chi = \tau/2\pi$, τ being the relaxation time. τ has also been calculated from measurement of dispersion alone. The main conclusion of their work was that these dipolar ions orient as rigid bodies. It is worthwhile pointing out here that the authors found the relaxation times obtained from absorption to be widely different from those got from dispersion studies.

The latest available measurements of Conner and Smyth[11] using the first method of Drude at 375 to 750 megacycles, have been used to calculate the critical frequency by the equation

$$\frac{(\epsilon - \epsilon_\infty)}{(\epsilon_0 - \epsilon_\infty)} = \frac{1}{1 + \frac{\lambda_c^2}{\lambda^2}}$$

a/b, the ratio of major to minor axis has also been calculated from Perrin's equations.

In the present paper, the dispersion and absorption data have been utilized to evaluate the molecular radius a. According to Debye's idea of the rotation of a molecule amidst its surroundings as a sphere carrying a dipole rotating in a viscous medium, the relation between relaxation time and the radius a_s of the 'molecule rotor' has been derived, using Stokes law and on considerations of Brownian motion as

$$\tau = \frac{4\pi\eta a_s^3}{kT} \qquad (1)$$

η being the viscosity of the medium. τ has also been calculated from the observed critical frequency as $\tau = \frac{1}{2\pi\gamma_c}$. This latter relationship between τ and γ_c is a consequence of replacing the Clausius-Mossotti expression $\frac{(\epsilon - 1)}{(\epsilon + 2)}\frac{M}{d}$ by the new law of polarisation $(\epsilon - 1)\,M/d$. Values for a_s have been calculated from equation (1) for several amino-acids and peptides (Table IX).

The rotating long chain molecule like the amino acid scoops out a disc cavity rather than the ideal spherical cavity of Debye. a_D, the radius of such a cavity, can be easily derived as follows. Stokes[32] has calculated that the frictional torque ξ in a two dimensional rotation of a cylinder about its axis, is given by $4\pi\eta a_D^2 h$, a_D being the radius of the cylinder, h its height. For such a two-dimensional rotation Debye[11] in an earlier publication has evaluated ξ as τ/kT (as compared with $\tau/2kT$ for the rotating of a sphere) whence $\tau = \frac{4\pi\eta a_D^2 h}{kT}$. Applying this to the case of a rotation molecule it is clearly seen that h corresponds to the thickness of the molecular chains. Taking $h = 2$Å values for a_D have been calculated for a number of amino-acids and peptides. The results are given in the following tables:

TABLE IX

Substance	$\tau \times 10^{11}$	a_s (Å)	a_D(A)	$\mu/4{\cdot}77$
Glycine ..	4·9	2·36	2·57	2·52
Diglycine ..	11·4	3·33	4·31	4·33
Triglycine ..	18·1	3·89	5·43	5·44
Tetraglycine .	24·7	4·47	6·69	6·42
Pentaglycine	36·3	5·08	8·10	7·50
α-Alanine ..	6·4	2·57	2·90	2·58
α-Aminobutyric ..	6·2^{F}	2·40	2·66	2·62
γ Aminobutyric ..	7·9^{F}	2·60	2·97	3·70
ε-Amino caproic ..	12·9^{F}	3·00	3·86	4·47
Glycylalanine ..	20·[illegible]^{B}	4·04	5·75	4·43
Alanylglycine ..	21·[illegible]^{B}	4·11	5·87	4·43
Leucylglycine ..	18·0	3·91	5·48	4·40
Lysylglutamic acid ..	48·0^{W}	4·93	7·75	9·25
Alanyldiglycine ..	20·6	4·11	5·90	5·58
Leucyldiglycine ..	28·6	4·55	6·86	5·83
Alanylleucylglycine ..	27·8	4·49	6·74	5·80

F = Frick and Parts.[21]

B = Bateman and Potapenko.[1]

W = Wyman and Marcy.[30]

The rest from Conner and Smyth.[10]

(*b*) *Discussion*

In all these calculations it has been assumed that the rotating molecule is characterised by a single relaxation time. If the molecule is assumed to be an ellipsoid then according to Perrin it ought to be characterised by two or more relaxation times whose magnitude is a function of the dimensions of the axes of the ellipsoid. Perrin has given a method of calculation of these parameters so as to ultimately fit in experimental data. Marcy and Wyman[30] have found that it is impossible to obtain a satisfactory fit for the data for lysylglutamic acid and triglycine on the basis of Perrin's equation.

In the present work it has been possible to quantitatively interpret the dispersion and absorption on the basis of a single relaxation time.

The previous workers did not calculate the molecular radius but evaluated the relaxation time by substituting for η and V, the observed viscosity and molecular volume in the expression $\tau = \frac{3\eta V}{kT}$. Conner and Smyth[10] as well as Bateman and Potapenko[1] have observed that in the case of peptides relaxation times so calculated are lower than those calculated from dispersion and absorption. For the case of amino acids the results of these workers are at variance with each other. For glycine and alanine the lower observed value of relaxation time as compared with that calculated for a spherical model was attributed by Conner and Smythe to the probability that the " inner viscosity is of smaller magnitude than microscopic viscosity". The higher observed values of τ have been used to calculate axial ratios of an assumed molecular ellipsoid of revolution according to Perrin's equation.

Along with the values of a_s and a_D, the radii calculated on the basis of Stokes law for a sphere and a disc respectively, are also tabulated the values for dipole distance d given by μ/e where μ is the observed dipole moment and e = electronic charge. The values of μ are those obtained by applying the new equation $(\epsilon - n^2)\frac{M}{d} = 4\pi N\frac{\mu^2}{kT}$ for the aqueous solutions of these amino-acids and peptides. The table shows that the values of a_D correspond closely to the dipole distance d. The radii a_s calculated for a sphere are roughly of the same magnitude but definitely lower, the discrepancy being marked for the glycine peptides and lysylglutamic acid.

7. SUMMARY

The new equation $(\epsilon - n^2) M/d = 4\pi N\mu^2/kT$ has been applied to calculate moments from the dielectric constant data of aqueous solutions of a large number of amino acids, peptides, urea, betaines and other related compounds.

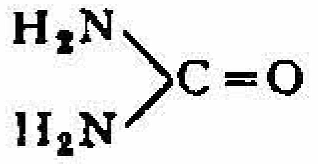
The studies on the amino-acids reveal (1) the moments of amino acids of the same type are the same ($\mu_\alpha = 12 \cdot 5$ D; $\mu_\beta = 14 \cdot 5$ D, $\mu_\gamma = 18$ D), (2) there is a gradual increase in moment from the α to the ϵ acids as the number of CH_2 groups separating the NH_3^+ and $CO\bar{O}$ group increases.

	α	β	γ	δ	ϵ	ξ
μ	12·5	14·5	18	20	21	23

For the glycine peptides the square of the moment (μ^2) varies linearly with molecular weight M, $\mu^2 = 5\,(M - 46)$, the relationship being very much akin to the statistical relationship of Eyring and others connecting molecular weights with the mean square distance between the ends of a long chain molecule. The eight dipeptides studied have all the same moment (21 D) and so also the four tripeptides (28 D). This is expected on the basis of a dipolar ion structure whence for the same class of compounds the dipole distance and hence the moment is the same.

The moments of glycine betaine (12·2 D) thio-betaine (12·6 D) and pyridine betaine (12·5 D) are the same as for glycine because the dipolar distance in the case of the former is the same as in glycine. The moment (14·3 D) of '*o*' benz betaine is equal to $e \times d$ the dipole distance (3·23 Å) calculated on the basis of a rigid model.

Urea, methyl, ethyl, propyl and dimethyl ureas have nearly the same moment (6·5-7 D). The moment of urea could be explained as the resultant vector according to the classical structure



The new dispersion equation has been used to calculate the molecular radii of α to ϵ amino-acids, glycine and other mixed peptides, using Stokes' formula for a rotating sphere and also for a disc. The radii of the disc cavity $\left(= \sqrt{\frac{\tau k T}{4\pi\eta h}},\ h = \text{thickness of cavity} = 2\ \text{Å}\right)$ corresponds to the dipole distance calculated as dipole moment/electronic charge. The assumption of a disc cavity is in conformity with the picture of a rotating long chain molecule.

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