amino-acids in these hydrolysates, showing that there was chemical combination of polymer with the wool.

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Piezoelectric Resonances in Amino-acids

CRYSTALS of amino-acids may exhibit the property of piezoelectricity[1–4] and, like other crystals, may belong to one of the twenty-one so-called piezoelectric crystalline classes[5]. Our particular interest in investigating piezoelectric resonances in amino-acids was in connexion with our current study of nuclear quadrupole resonances (NQR). For this purpose, it is preferable to choose non-piezoelectric amino-acids so that there is no interference in the detection of the quadrupole spectra[6,7].

The results of our measurements on amino-acids[8–11] are given in Table 1. Experiments are performed on powders, using a superregenerative spectrograph[12] of NQR type[13] specially adapted for this work[14]. We have studied principally the L isomers of amino-acids, the only ones occurring in proteins.

Table 1 gives for each crystalline compound the spatial group and the corresponding crystalline class in the Hermann–Maugin notation as stated by Gurskaya[16], Derissen *et al.*[17], Harding and Long[18] and Albrecht *et al.*[19]. In the fourth column, a plus sign indicates a piezoelectric class; a minus, a non-piezoelectric one. The last column records our experimental results, a plus sign being assigned for the samples in which piezoelectricity has been identified. Glycine is a special case: it has three crystalline forms (Table 2). Piezoelectricity is detected in the powder[3,8,15], but not in single crystals, in agreement with Guibé's experiments (personal communication). Because the γ-form is the most stable at room temperature[16], it is reasonable to think that glycine powder is in the γ-form and single crystals are in the non-piezoelectric α-form.

Table 1. COMPARISON OF EXPERIMENTAL AND THEORETICAL PIEZOELECTRICITY FOR AMINO-ACIDS

Amino-acid	Spatial group	Crystalline class	Theoretical piezoelectricity[16–19]	Experimental piezoelectricity
L-Alanine	$P2_12_12_1$	222	+	+
D-Alanine				+
DL-Alanine	Pna	mm2	+	+
β-Alanine	Pbca	mmm	−	−
L-Arginine·2H_2O	$P2_12_12_1$	222	+	−
D-Arginine·HCl				+
L-Asparagine·H_2O	$P2_12_12_1$	222	+	+
L-Aspartic acid	$P2_1$	2	+	+
DL-Aspartic acid	I2/a	2/m	−	−
L-Cysteine	$P2_1$	2	+	+
L-Cystine	$P6_122$	622	+	+
DL-Cystine				+
L-Glutamine	$P2_12_12_1$	222	+	−
L-Glutamic acid	$P2_12_12_1$	222	+	−
D-Glutamic acid				−
Glycine	See Table 2			+
L-Histidine				+
DL-Histidine				−
L-Hydroxyproline	$P2_12_12_1$	222	+	+
L-Isoleucine				+
D-Isoleucine				+
L-Leucine				+
D-Leucine	$P2_12_12_1$	222	+	−
DL-Leucine	P1	1	+	−
L-Lysine·HCl·2H_2O	$P2_1$	2	+	+
L-Methionine				−
DL-Methionine	See Table 2			−
L-Phenylalanine				−
D-Phenylalanine				−
L-Proline	$P2_12_12_1$	222	+	+
DL-Proline				−
L-Serine				+
DL-Serine	$P2_1/a$	2/m	−	+
L-Threonine	$P2_12_12_1$	222	+	+
DL-Threonine		mm2	+	+
L-Tryptophan				−
DL-Tryptophan				−
L-Tyrosine				+
DL-Tyrosine				+
L-Valine	$P2_1$	2	+	−
D-Valine				+
DL-Valine	P1 or $P\bar{1}$	1 or $\bar{1}$	+ or −	−

Table 2. COMPARISON OF EXPERIMENTAL AND THEORETICAL PIEZOELECTRICITY FOR GLYCINE AND DL-METHIONINE

Amino-acid	Spatial group	Crystalline class	Theoretical piezoelectricity[16]	Experimental piezoelectricity
α-Glycine	$P2_1/n$	2/m	−	−
β-Glycine	$P2_1$	2	+	+ (β or γ)
γ-Glycine	$P3_1$ or $P3_2$	3	+	
α-DL-Methionine	$P2_1/a$	2/m	−	+ (α or β)
β-DL-Methionine	I2/a	2/m	−	

Our experimental results agree well with crystalline studies. In spite of the weakness of the piezoelectric resonances, it was generally possible to confirm this effect in those crystalline classes for which it would be expected. Recent crystallographic results[17,18] confirm our experiments. For DL-methionine, which crystallizes in two forms (Table 2), and DL-serine, experimental piezoelectricity is exhibited in contradiction with the findings on crystal structure. This discrepancy needs to be resolved. In about twenty cases—for lack of crystal data—it is impossible to make a comparison, but we believe our results will be of importance in the assignment of crystal structure. It is interesting to note that of the twenty L-amino-acids we have studied (glycine included), nineteen exhibit theoretical and/or experimental piezoelectricity.

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