hot water yielding 86%. The tyrosine derivative was too insoluble and was not recrystallized. This yield was 77%.

N-(β-Carboxyethyl)-valine was prepared by the fusion technique of Ford[3]: A mixture of N-(2-cyanoethyl)-DL-valine (10.64 g.) and 2.4 equivalents of barium hydroxide octahydrate was heated on a steam-bath for 30 minutes during which time the melt solidified. The solid was suspended in water and sulfuric acid added to remove barium. The product crystallized upon reducing the volume, the yield being 73%.

The monocyanoethyl derivatives of tyrosine and aspartic acid were also hydrolyzed by boiling 6 hours with 2 *N* sodium hydroxide. Four moles of sodium hydroxide was used for each mole of cyanoethyltyrosine while three moles of alkali was used with each mole of cyanoethylaspartic acid. Since the N-β-carboxyethyl derivatives were insoluble in cold water, the products were readily obtained by neutralizing the alkali with hydrochloric acid and washing free of chlorides. N-(β-Carboxyethyl)-aspartic acid was recrystallized from hot water for a yield of 60%. N-(β-Carboxyethyl)-tyrosine was quite insoluble (Table I) and was not recrystallized. Analysis indicated a pure product, yield 85%.

Dicyanoethyl derivatives of DL-alanine and DL-methionine were subjected to hydrolysis with barium hydroxide in the same manner as described above for the monocyanoethyl derivatives. The yield of N-(β-carboxyethyl)-alanine was 75% and of N-(β-carboxyethyl)-methionine was 56%. None of the dicarboxyethyl derivatives was found.

Hydrolysis of Reaction Mixtures.—Acrylonitrile reacted with amino acids as previously described.[2] The barium salts of glycine, DL-alanine, DL-valine and DL-aspartic acid were used and the sodium salts of DL-methionine and L-tyrosine were employed to effect the reaction with acrylonitrile. About 500 ml. of water was used with each mole of amino acid. After completion of the cyanoethylation reaction, an additional two equivalents of barium hydroxide was added to neutralize the new carboxyl group formed from the nitrile and to allow an excess of one equivalent. For example, with one mole of glycine, 0.5 mole of barium hydroxide was used for the cyanoethylation and an additional mole was added for the hydrolysis. The mixture was boiled 5 hours and the N-β-carboxyethyl derivatives isolated as described above for the hydrolysis of cyanoethyl derivatives with barium hydroxide. Yields of the N-β-carboxyethyl derivatives, based on the amino acid, were as follows: glycine 70%, alanine 80%, valine 50%, methionine 80%, tyrosine 85% and aspartic acid 50%.

N-(β-Carboxyethyl)-acetylmethionine.—Five grams (0.0226 mole) of N-(β-carboxyethyl)-methionine was dissolved in 100 ml. of hot water and 50 ml. (0.5 mole) of acetic anhydride added in two equal portions while stirring. After 30 minutes, the solution was evaporated to dryness under reduced pressure and 50 ml. of dioxane was added to the residue. Evaporation to dryness was repeated to remove residual acetic acid. The residue was taken up in 20 ml. of water and a precipitate of 0.7 g. of unacetylated material was discarded. Acetone (10 ml.) was added to the clear filtrate and the solution set at 4° for 3 hours. The crystals weighed 3.5 g. and contained 5.16% nitrogen (calcd. 5.29). Upon recrystallization from hot water, 3 g. of the crude crystals gave 1.15 g. of the product which melted at 146–148°.

Anal. Calcd. for $C_{10}H_{17}O_5NS$: C, 45.5; H, 6.87; N, 5.29; neut. equiv., 264.3. Found: C, 45.5; H, 6.39; N, 5.28; neut. equiv., 264.6.

Unsuccessful Attempts at Acylation.—Treatment of aqueous solutions of other N-β-carboxyethyl derivatives with acetic anhydride yielded the starting materials. Glacial acetic acid–acetic anhydride suspensions yielded a sirup on heating. Benzoylation by the Schotten–Baumann technique and benzenesulfonylation by the Hinsberg method also gave sirups from which we were unable to isolate the desired acylated derivative.

Condensation with Diamines.—Equimolar quantities of the N-β-carboxyethyl derivatives of glycine, alanine and leucine were heated under nitrogen with both ethylenediamines. The temperature was raised slowly over a period of 6 hours to 230° and then high vacuum applied for 2 hours while the temperature was raised to 250°. In each case browning occurred at 200–225°. As the temperature was increased above 230°, solubility in water was lost and the resin became infusible. The resins were dark brown, brittle solids.

PEORIA 5, ILLINOIS RECEIVED NOVEMBER 5, 1951

[CONTRIBUTION FROM THE CHEMISTRY LABORATORY, UNIVERSITY OF NOTRE DAME]

The Influence of Sulfide, Sulfoxide and Sulfone Groups on the Saponification of Ethyl Benzoate[1]

BY CHARLES C. PRICE AND JOSEPH J. HYDOCK[2]

The ethyl esters of *m*- and *p*-methylmercapto-, -methylsulfinyl- and -methylsulfonylbenzoic acids have been prepared and characterized. Their rates of saponification in 56% acetone and 95% *n*-butyl cellosolve and their ultraviolet absorption spectra have been measured and interpreted.

In order to obtain information concerning the influence of sulfide, sulfoxide and sulfone groups on aromatic systems, ethyl benzoate derivatives with these substituents in the *m*- and *p*-positions have been prepared and their rates of saponification measured. The influence of these groups on the ultraviolet spectra is also reported.

Experimental[3]

Phenyl methyl sulfide was prepared by the method of Bourgeois and Abraham.[4] The yield of purified product was 23 g.; b.p. 193.5–195.0° (737 mm.); $n^{25}D$ 1.5835 (lit. $n^{25}D$ 1.5832).

***m*- and *p*-Methylmercaptobenzoic Acids.**—Both of these acids were prepared by following, in part, the procedure of Allen and MacKay.[5] The diazotized aminobenzoic acids were treated with sodium disulfide to give the bis-carboxyphenyl disulfides.

The disulfide was reduced to the mercaptobenzoic acid by sodium sulfide and subsequently methylated with methyl sulfate by the method of Brand, Gabel and Rosenkranz.[6] The *m*- and *p*-methylmercaptobenzoic acids can be recrystallized from 50% methanol. Both are white crystalline solids. Based on the reactant aminobenzoic acid the yields averaged 45–55%.

Compound, acid	M.p., °C. Obsd.	Lit.	Ref.
m-Methylmercaptobenzoic	126.0–127.0	126	6
p-Methylmercaptobenzoic	191.5–192.0	190	7

Sulfones.—Phenyl methyl sulfone and *m*- and *p*-methylsulfonylbenzoic acids were prepared from the corresponding sulfides by the general method recommended by Gilman and

(1) Presented at the International Congress of Pure and Applied Chemistry, New York, September, 1951.

(2) The Coca-Cola Company Fellow, 1947–1949.

(3) Unless otherwise stated, all melting points are corrected. Microanalyses by Micro-Tech Laboratories, Skokie, Ill.

(4) E. Bourgeois and A. Abraham, *Rec. trav. chim.*, **30**, 413 (1911).

(5) C. F. H. Allen and D. D. MacKay, "Organic Syntheses," Coll. Vol. II, John Wiley and Sons, Inc., New York, N. Y., 1943, p. 580.

(6) K. Brand, W. Gabel and E. Rosenkranz, *Ber.*, **70**, 305 (1937).

(7) S. Smiles and D. C. Harrison, *J. Chem. Soc.*, **121**, 2025 (1922).

Beaber.[8] The sulfide was dissolved in sufficient glacial acetic acid to bring the mixture to a homogeneous phase. A 50% excess of 30% hydrogen peroxide was then added and the mixture refluxed for a period of four hours in the case of phenyl methyl sulfone and 20 hours in the case of *m*- and *p*-methylsulfonylbenzoic acids. After the reaction was complete the mixture was allowed to cool whereupon the *m*- and *p*-methylsulfonylbenzoic acids separated from solution. In the case of phenyl methyl sulfone the reaction mixture was thrown into water whereupon the sulfone separated. These sulfones were all white crystalline solids and were prepared in quantitative yields.

Compounds	M.p., obsd.	Lit.	Ref.
Phenyl methyl sulfone	87.0-87.5	88	9
p-Methylsulfonylbenzoic acid	264-265[a]	263-264	10
m-Methylsulfonylbenzoic acid	232-233.5[a]	230	11

[a] Uncorrected m.p.

The measured neutral equivalent for *m*-methylsulfonylbenzoic acid was 199.6, which agrees very well with the calculated value of 200.2.

Phenyl Methyl Sulfoxide.—To a mixture of 24.0 g. of phenyl methyl sulfide dissolved in 40 cc. of glacial acetic acid, 20 cc. of 30% hydrogen peroxide was slowly added. After addition was complete the mixture was refluxed gently for a period of seven hours. The mixture was then poured into water, extracted with ether and the ether extract washed twice with water after which it was dried over magnesium sulfate. The ether was removed on a water-bath and the product fractionated. A fraction boiling at 104–105° (0.7 mm.) was selected for ultraviolet absorption measurements. The sulfoxide was a white solid at room temperature melting at 29.5–30.0° (lit.,[12] b.p. 75° (0.01 mm.), m.p. 30.0–30.5°).

***p*-Methylsulfinylbenzoic acid** was prepared most satisfactorily by heating 53 g. of *p*-methylmercaptobenzoic acid and 530 cc. of 2 *N* nitric acid at 95° until no more nitrous fumes were evolved. This required almost 24 hours. Most of the solid was in solution. The solution was filtered hot and decolorized with Norit which discharged the yellow color. The crude product was recrystallized from water yielding 31 g. of white needle-like crystals, m.p. 232.5–233.0° (uncor.). A measured neutral equivalent of 183.3 agreed very well with the calculated value of 184.2.

Anal. Calcd. for $C_8H_8O_3S$: C, 52.16; H, 4.37; S, 17.40. Found: C, 51.84; H, 4.40; S, 17.50.

***m*-Methylsulfinylbenzoic Acid.**—Either the method described above or oxidation of the sulfide by means of a slight excess of 30% hydrogen peroxide in glacial acetic acid at 85° for 24 hours produced the sulfoxide in yields of 65–80%. Recrystallization was readily effected from water yielding soft white needles, m.p. 171.0–171.5° (lit.,[13] m.p. 170–172°).

Ethyl Esters.—All the ethyl esters described here were prepared by essentially the same procedure. The acid to be esterified was dissolved in approximately eight times its weight of absolute ethanol. The acid catalyst used was concentrated sulfuric acid and amounted to 2–3% based on the weight of the alcohol. The mixture was refluxed for 24 hours, after which time excess ethanol was removed by distillation and the remaining mixture was diluted with water. The liquid esters were extracted with ether and washed in the same manner after which they were dried over anhydrous magnesium sulfate. The solid esters were recrystallized until no change in the melting point was observed. The liquid esters were all distilled from a Claisen flask prior to fractionation. The yields in all cases were excellent. The liquid esters were fractionated through a Phillips-type column. Sizeable foreruns and residues were discarded and only a middle cut boiling in a narrow range was retained for measurements. Individual results are listed below as well as the elementary analyses for those esters not reported in the literature.

Ethyl *m*-methylmercaptobenzoate: b.p. 148.0–148.2° (6 mm.); $n^{20}D$ 1.5610. *Anal.* Calcd. for $C_{10}H_{12}O_2S$: C, 61.19; H, 6.16; S, 16.34. Found: C, 60.94; H, 6.26; S, 16.28.

Ethyl *m*-methylsulfinylbenzoate: b.p. 158.0–160.0° (0.08 mm.); $n^{20}D$ 1.5556. *Anal.* Calcd. for $C_{10}H_{12}O_3S$: C, 57.05; H, 5.75; S, 15.15. Found: C, 56.84; H, 5.94; S, 14.96.

Ethyl *p*-methylsulfinylbenzoate: m.p. 62.0–62.5°. *Anal.* Calcd. for $C_{10}H_{12}O_3S$: C, 57.05; H, 5.75; S, 15.15. Found: C, 56.84; H, 5.93; S, 15.32.

Ethyl *m*-methylsulfonylbenzoate: m.p. 74.0–74.6°. *Anal.* Calcd. for $C_{10}H_{12}O_4S$: C, 52.62; H, 5.30; S, 14.05. Found: C, 52.51; H, 5.42; S, 14.42.

Ethyl *p*-methylsulfonylbenzoate: m.p. 95.8–96.4°. *Anal.* Calcd. for $C_{10}H_{12}O_4S$: C, 52.62; H, 5.30; S, 14.05. Found: C, 52.62; H, 5.27; S, 14.25.

The following esters were previously reported in the literature: ethyl *p*-methylmercaptobenzoate, b.p. 170.0–170.5° (14 mm.), $n^{20}D$ 1.5784 (lit.[14] b.p. 168° (15 mm.)); ethyl *p*-nitrobenzoate, m.p. 56.4–56.8° (lit.[15] m.p. 57°); ethyl *p*-dimethylaminobenzoate, m.p. 63.5–64.0° (lit.[16] m.p. 63.0–63.5°). This ester was kindly provided by Dr. D. C. Lincoln. Ethyl benzoate was of commercial grade. A fraction boiling in the range 211.0–211.2° (751 mm.) was reserved for saponification rate measurements.

Ultraviolet absorption spectra were measured with a Beckman quartz spectrophotometer. Hexane was used as the solvent for the sulfides and sulfoxides, whereas 95% ethanol was required to dissolve the sulfones.

The data on maxima, minima and molar extinction coefficients are summarized in Table I.

TABLE I

ULTRAVIOLET ABSORPTION DATA FROM 240 TO 310 mμ

Compound	Max.	Log	Min.	Log
$C_6H_5SCH_3$	255	4.1		
	(280)[a]	3.3		
$C_6H_5SOCH_3$	250	3.6		
$C_6H_5SO_2CH_3$	266	2.9	270	2.7
	273	2.8		
$EtOOCC_6H_4$-	260	3.9	250	3.8
m-SCH_3	310	3.2	283	2.8
p-SCH_3	(280)[a]	4.3	250	3.7
	292	4.35		
m-$SOCH_3$	250	3.6		
	(285)[a]	3.0		
p-$SOCH_3$	272	4.0	248	3.3
m-SO_2CH_3	274	2.85	262	2.6
	281	2.8	279	2.7
p-SO_2CH_3	279	3.2	261	2.9
	(285)[a]	3.1		

[a] These values represent shoulders, not clear maxima.

Saponification Rate Measurements. A. In 56% Acetone.—The method used was essentially that described by Tommila and Hinshelwood,[17] as modified by Price and Lincoln.[18]

B. **In *n*-Butyl Cellosolve.**—It seemed desirable to select a solvent for saponification rate measurements with a higher boiling point than 56% acetone inasmuch as this would allow making rate measurements more conveniently at higher temperatures. The solvent selected was aqueous *n*-butyl cellosolve containing 95% of *n*-butyl cellosolve by volume.

The catalyst solution was prepared by diluting exactly 0.01 mole of carbonate-free sodium hydroxide solution from a catalyst stock solution of approximately 2.250 *N* with sufficient water to make 5 ml., these quantities being dispensed from micro-burets. To this was then added sufficient *n*-butyl cellosolve to make a total of 100 ml. in a volumetric flask. The ester solution was prepared by diluting

(8) H. Gilman and N. J. Beaber, THIS JOURNAL, **47**, 1450 (1925).
(9) R. Otto, *Ber.*, **18**, 156 (1885).
(10) R. L. Frank, *et al.*, *J. Polymer Sci.*, **3**, 59 (1948).
(11) P. W. B. Harrison, J. Kenyon and H. Phillips, *J. Chem. Soc.*, **129**, 2090 (1926).
(12) D. Barnard, J. M. Fabian and H. P. Koch, *ibid.*, 2444 (1949).
(13) Reference 11, p. 2088.
(14) K. Kindler, *Ann.*, **450**, 1 (1926); **452**, 90 (1927); **464**, 278 (1928).
(15) F. Meyer and K. Dahlem, *ibid.*, **326**, 335 (1903).
(16) F. H. Westheimer and R. P. Metcalf, THIS JOURNAL, **63**, 1339 (1941).
(17) E. Tommila and C. N. Hinshelwood, *J. Chem. Soc.*, 1801 (1938).
(18) C. C. Price and D. C. Lincoln, THIS JOURNAL, **73**, 5838 (1951).

exactly 0.01 mole of the ester with 5 ml. of water and enough *n*-butyl cellosolve to make 100 ml. in a volumetric flask. The solutions were thermostated at 0, 25 and 45°. The mixing of the solutions was accomplished as described in Method A.

The *n*-butyl cellosolve was Carbide and Carbon commercial grade and was fractionated twice over sodium hydroxide through a 900-mm. × 25-mm. column packed with glass helices. The distillate had a boiling point of 172.0–172.2° (745 mm.); $n^{20}D$ 1.4192 (lit.[19] b.p. 170.6° (743 mm.), $n^{20}D$ 1.4191). It could never be entirely freed of a component which slowly consumed alkali and for this reason the data in this solvent are probably not as reliable as those in 56% acetone.

Results and Calculations

The rate constants for the experiments in acetone were calculated from the bimolecular rate equation, simplified for equal initial concentrations.

For the *n*-butyl cellosolve experiments, it was not possible to use this simplified equation since blanks demonstrated that the solvent evidently contained a persistent impurity which reacted with some of the alkali, disturbing the equivalent concentrations of ester and alkali. For these experiments, the following equation was used

$$\frac{2.303}{a-b}\log\frac{b(a-x)}{a(b-x)} = kt$$

The values represented by the left-hand side of the above equation (in moles/l.) were plotted against time (in seconds) to give a straight line whose slope represents the value of the second order rate constant (Table III).

In the runs at temperatures other than 25°, corrections were necessary for the change in initial concentration due to the expansion of the solvent and also for the change in sample volume taken with a pipet near 25° from reaction mixtures at 0 and 40°. For the 56% acetone solution from the data of Tommila[20] and Lincoln[18] the initial concentration at 40° is given as 0.04922 molar instead of 0.05 molar and a 10-ml. pipet actually withdraws 0.4938 milliequivalent. At 0° the initial concentration is given as 0.05122 molar and a 10-ml. pipet delivers 0.5102 milliequivalent. These corrected figures were used in the calculations at 0 and 40°. For the 95% cellosolve solutions it was found that the initial concentration of ester at 0° was 0.05082 molar and at 45°, 0.04907 molar. Titration of blanks indicated that the concentration of alkali actually was 0.04902, 0.04875 and 0.04738 molar at 0, 25 and 45°, respectively, and that a 10-ml. pipet at room temperature actually withdrew 0.4887, 0.4875 and 0.4757 millimole of alkali from reaction mixtures at these three temperatures.

The results are presented in Table II for 56% acetone and Table III for 95% *n*-butyl cellosolve. The average deviation for the rate constants in 56% acetone was 2%, while in 95% cellosolve it was 5%. The σ constants were calculated from the rate measurements at 0 and 25° in accordance with the equation of Hammett.[21] For 56% acetone, the value of log $k°$ (−2.513) and of ρ(2.373) at 25° used were those given by Hammett.[20] The value −3.520 for log $k°$ at 0° was that given by Tommila and Hinshelwood.[17] Their values for a number of rate measurements of substituted ethyl benzoates at 0° were used to determine the value of ρ at 0°. This value was found graphically to be −2.614[22] by plotting log k against the σ-values of the substituents.

$$\log k - \log k° = \rho\sigma$$

TABLE II

RATES OF SAPONIFICATION OF SUBSTITUTED ETHYL BENZOATES IN 56% ACETONE AT 0, 25 AND 40°

Substituent	$k_0 \times 10^3$	$k_{25} \times 10^3$	$k_{40} \times 10^3$	σ
m-CH_3S	...	5.36	17.76	+0.10
p-CH_3S	...	2.046	7.086	− .07[a]
m-CH_3SO	7.01	...	....	+ .52
p-CH_3SO	7.69	...	....	+ .54
m-CH_3SO_2	15.2	...	....	+ .65
p-CH_3SO_2	28.6			+ .76

[a] Hammett[20] reports the value of σ for the *p*-CH_3S– group to be −0.047.

Duplicate measurements of the second-order rate constants for saponification of ethyl benzoate (6.22 and 6.67 × 10^{-4}), ethyl *p*-dimethylaminobenzoate (2.94 and 2.91 × 10^{-6}) and ethyl *p*-nitrobenzoate (6.92 and 6.91 × 10^{-2}) in 95% *n*-butyl cellosolve lead to a value of 2.4 ± 0.1 for the ρ constant at 25° for this solvent. This value was used in calculating the σ constants reported in Table III.

TABLE III

RATES OF SAPONIFICATION OF SUBSTITUTED ETHYL BENZOATES IN 95% *n*-BUTYL CELLOSOLVE AT 0, 25 AND 45°

Substituent	$k_0 \times 10^3$	$k_{25} \times 10^3$	$k_{45} \times 10^3$	σ
m-CH_3S	0.081	1.41	9.4	+0.14
p-CH_3S	..	0.53	4.25	− .03[a]
m-CH_3SO	0.75	9.5	..	+ .49
p-CH_3SO	.50	7.6	..	+ .45
m-CH_3SO_2	1.75	26.0	..	+ .67
p-CH_3SO_2	2.27	31.2	..	+ .71

[a] Hammett[21] reports the value for the σ constant for the *p*-CH_3S group to be −0.047.

Discussion

The over-all electrical effects of the sulfide, sulfoxide and sulfone groups are much as might be expected.

The values of σ for the methyl sulfide group (σ_p = −0.07 and σ_m = 0.10) are qualitatively similar to those for the methoxyl group (σ_p = − 0.268 and σ_m = 0.115).[21] The smaller negative σ_p for the sulfide may be an indication of a lesser resonance interaction donating electrons to the *o*-, *p*-positions since this must involve the less effective exchange between a 2p orbital on carbon and 3p on sulfur. Examination of the ultraviolet data (Table I) certainly indicates that there is, however, still a powerful conjugation between a *p*-sulfide group and the carbethoxyl function. The difference in σ-constants between the *p*- and *m*-positions is in accord with expectation from the calculated polarizing force of −0.65 × 10^{-4} dyne.[22]

The values of σ for the sulfoxide group (σ_p = 0.54 and σ_m = 0.52) are qualitatively as expected

(19) J. G. Davidson, *Ind. Eng. Chem.*, **18**, 670 (1926).

(20) E. Tommila, *Ann. Acad. Sci. Fennicae*, Ser. **A57**, No. 13, 3 (1941); *C. A.*, **38**, 6171.[10]

(21) L. P. Hammett, "Physical Organic Chemistry," McGraw-Hill Book Co., Inc., New York, N. Y., 1940.

(22) These values of ρ turn out to be quite accurately inversely proportional to the absolute temperature ($\rho_{25} \times 298 = 707$; $\rho_0 \times 273 = 713$), as predicted by C. C. Price, *Chem. Revs.*, **29**, 37 (1941).

since the semipolar bond to oxygen, putting a positive charge on the sulfur, would greatly increase its electron affinity, thereby causing an induced positive charge on the ring. The fact that this charge is essentially equal in the *m*- and *p*-positions (as indicated by the σ-constant) is in agreement with the very small estimated polarizing force for the sulfoxide group of -0.01×10^{-4} dyne.[22]

The ultraviolet absorption data in Table I indicate that the remaining unshared electron pair on the sulfoxide still retains strong conjugative properties, though definitely less than for the sulfide group.

The σ-constants for the sulfone group (σ_p = 0.76 and σ_m = 0.65) are more positive as expected because of a stronger inductive effect of the more positive sulfur atom in the sulfone. The difference in σ-constants is qualitatively in accord with expectation based on the calculated polarizing force of $+1.55 \times 10^{-4}$ dyne.[22]

The utilization in bonds with oxygen of both the electron pairs of the sulfur which were unshared in the sulfide has a marked effect in diminishing the conjugation properties of the sulfonyl group with the carbethoxyl group, especially evident in the marked increase in the absorption coefficient for the maxima around 280 mμ.

NOTRE DAME, INDIANA RECEIVED JULY 11, 1951

[CONTRIBUTION FROM THE CHILDREN'S CANCER RESEARCH FOUNDATION AND THE DIVISION OF LABORATORIES AND RESEARCH OF THE CHILDREN'S MEDICAL CENTER, AND THE DEPARTMENT OF PATHOLOGY, HARVARD MEDICAL SCHOOL AND FROM THE LABORATORIES OF THE POLAROID CORPORATION AND THE AMERICAN OPTICAL COMPANY]

Infrared Spectra and the Structure of Glycine and Leucine Peptides[1]

BY ELKAN R. BLOUT AND SEYMOUR G. LINSLEY

The infrared spectra of a series of glycine homopeptides and glycine–leucine heteropeptides have been measured in the solid state over the spectral range 650–4000 cm.$^{-1}$. The spectra of the glycine homopeptides show no evidence of unassociated amino groups, and in such peptides having varying molecular weights there is evidence of strong hydrogen bonding. There is a band in the spectra of these compounds at 1015 ± 10 cm.$^{-1}$ which appears to be characteristic of the diglycyl grouping. In some of the glycine–leucine heteropeptides there are apparently unassociated amino groups. In both the glycine peptides and the glycine–leucine peptides in the solid state there are both ionized and non-ionized carboxyl groups, as indicated by absorption bands at 1400 and 1680 cm.$^{-1}$, respectively. There is an unassigned absorption band about 700 cm.$^{-1}$ which appears in the spectra of all peptides and proteins examined.

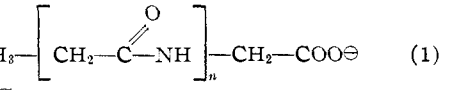
Recently several groups of workers have reported on some applications of infrared spectroscopy to the determination of the molecular structures of polypeptides and proteins.[2] In our laboratory we are investigating the effects of molecular weight and chemical constitution of polypeptides on their infrared spectra and the relationships that exist in the infrared spectra of amino acids, peptides, polypeptides and proteins. In this communication we report work with peptides and polypeptides of glycine and leucine.

The Glycine Peptides—In order to better interpret the infrared spectral data obtainable from high molecular weight polypeptides and proteins composed of many different amino acids, it was felt that it would be valuable to examine the spectra of a series of simple peptides. Consequently, we have determined the spectra of a homologous series of peptides of glycine, the most simple amino acid. Figure 1 shows the infrared spectra of glycine, diglycine, triglycine, tetraglycine, pentaglycine, hexaglycine and polyglycine[3] measured in the solid state over the spectral region 650 to 3600 cm.$^{-1}$ (approximately 2.75 to 15.3 microns).

Several observations may be made from an examination of these spectra: (1) As the molecular weight of the glycine peptide increases beyond triglycine, the spectra show fewer distinct absorption bands, and in the main outline the polyglycine spectrum approximates to that obtained with proteins such as histone and ribonuclease.[4]

(2) The strongest absorption bands in all the spectra are those associated with N–H stretching ($\sim$ 3300 cm.$^{-1}$), C=O stretching ($\sim$ 1650 cm.$^{-1}$) and amide N–H deformation ($\sim$ 1540 cm.$^{-1}$). Also there is a prominent, but not quite as strong band occurring around 1440 cm.$^{-1}$ which presumably is a CH_2 deformation mode.

(3) There is a very strong band at 1400 cm.$^{-1}$ in the spectra of glycine and di-, tri- and tetraglycine. This band becomes less intense in penta- and hexaglycine until in the polyglycine sample the band appears only as an inflection point. It may be assumed that this band is caused by ionized carboxyl groups from dipolar or zwitter ion forms such as I, especially since it would be expected that



(1)

(1) Presented in part at the Symposium on the Infrared Spectra of Large Molecules, 119th Meeting of the American Chemical Society, Boston, Massachusetts, April, 1951. This work was supported in part by U. S. Public Health Service Grant C-1522.

(2) See, for example, (a) W. T. Astbury, C. E. Dalgliesh, S. E. Darmon and G. B. B. M. Sutherland, *Nature*, **162**, 596 (1948); (b) E. J. Ambrose, A. Elliott and R. B. Temple, *ibid.*, **163**, 859 (1949); (c) I. M. Klotz, P. Griswold and D. M. Gruen, THIS JOURNAL, **71**, 1615 (1949); (d) S. E. Darmon and G. B. B. M. Sutherland, *Nature*, **164**, 440 (1949); (e) L. L. Uzman and E. R. Blout, *ibid.*, **166**, 862 (1950); (f) E. J. Ambrose and A. Elliott, *Proc. Roy. Soc.* (*London*), **A205**, 47 (1951).

(3) The spectrum of polyglycine from 700 to 1650 cm.$^{-1}$ reported previously by Sutherland, *et al.* (ref. 1a), and our results in this region are in substantial agreement. After this work was completed and while this manuscript was in preparation an article by H. W. Thompson, D. L. Nicholson and L. N. Short appeared in Spectroscopy and Molecular Structure, *Discussions of the Faraday Society*, **9**, 222 (1950). In this article there appeared some data over a more limited spectral range for a few of the compounds reported in this communication.

(4) E. R. Blout and R. C. Mellors, *Science*, **110**, 137 (1949).