−10°. After further stirring at room temperature for 21 hr., the solids were removed by centrifugation and washed with pentane. Work-up of the liquid fraction afforded recovered starting material (11%), and, after treatment with dry HCl in ether at −20°, a low yield of phenylpyruvic acid (m.p. 147–150°, lit. m.p. 151–154°).[3] The infrared spectrum of this substance exhibited peaks corresponding to those recorded for phenylpyruvic acid.

The solids were dissolved in dilute hydrochloric acid and extracted with ether. Concentration afforded **4** as a crystalline precipitate (10%). Evaporation of the filtrate and sublimation afforded phenylpropiolic acid (m.p. 133–135°, lit. m.p. 133–135°; infrared, 3.4, 4.5, 5.9, 13.25, and 14.6 μ[4]; n.m.r., τ −2.2, multiplet at 2.6, area 1:5.2) in 11% yield.

Phenylhydroxycyclopropenone (C, 73.97; H, 3.96; neut. equiv. 147) was obtained as faint yellow needles, m.p. 244–245° dec. with gas evolution at 250°, by recrystallization from acetonitrile. Although the acid appeared to be an associate dimer in dioxane (osmometric mol. wt. 274, calcd. 292), its sodium salt in water was monomeric and dissociated (osmometric mol. wt. 80, calcd. for monomer 84, for dimer 112). The compound is slightly soluble in water and soluble in methanol, aqueous sodium bicarbonate, and 12 N hydrochloric acid. It decolorized bromine and permanganate, reduced silver nitrate, and gave a positive test with ferric chloride and periodic acid. The ultraviolet spectrum exhibited absorption at 248 mμ in strong acid and 256 mμ in strong base, with a pK value of approximately 1. The infrared spectrum (KBr pellet) was disturbingly amorphous, undulating from 3 to 11 μ with rounded peaks or shoulders at 4, 5.4, 6.2, and 7.2 μ and strong peaks at 13.0 and 14.5 μ. The n.m.r. spectrum in dimethyl sulfoxide exhibited a sharp singlet at τ −0.1 and a broadened singlet at τ 2.6 in area ratios of 1.1 to 5. The structure (**4**) seems to be the only reasonable isomer of phenylpropiolic acid consistent with all these facts.

The several rearranged products obtained in the reaction of olefin **3** with potassium *t*-butylate find an attractive explanation in the formation of a cyclopropene such as **2** (R_1, R_3, R_4 = Cl or $(CH_3)_3CO$, R_2 = C_6H_5) by α-elimination and ring closure, conveniently abstracted as the rearrangement **1** (R_1, R_3, R_4 = Cl or $(CH_3)_3CO$; R_2 = C_6H_5) to **2**. Ring openings of halogenated and alkoxylated cyclopropenes in the presence of alkoxide to give olefinic and acetylenic esters have been reported in the literature.[5,6] In fact, in a very closely related study, McElvain[6] observed the ring opening of cyclopropene **2** (R_1 = Cl, R_2 = C_6H_5, R_3 = R_4 = CH_3O) with alkoxides to give esters of phenylpropiolic acid and α-alkoxycinnamic acids. Apparently, their conditions of reaction and work-up were such that **4** was either not formed or not isolated.

The reactions of other polyhalopropenes with potassium *t*-butylate are under investigation. For example, 1,1,2,3,3-pentachloropropene (or tetrachloroallene) with excess potassium *t*-butylate in ether at −20° gives much the same mixture of olefinic *t*-butyl esters as obtained from the reaction of tetrachlorocyclopropene with potassium *t*-butylate (*cf.* ref. 5).

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(7) Fellow of the Alfred P. Sloan Foundation.

(8) Fellow of the Danforth Foundation.

The Helix Interruption Constant for Poly-L-glutamic Acid from the Pressure Dependence of Optical Rotation

Sir:

The cooperative nature of the helix–coil equilibrium in polypeptides leads one to expect the position of the equilibrium to be unusually sensitive to changes in conditions imposed on the system. No studies of the effects of applied pressure on the equilibrium have been reported, although the occurrence of volume changes[1,2] in the helix–coil transformation suggests that such effects should be observable. We wish to report the first results of such a study and to show that the effect yields new information about the nature of the equilibrium. Poly-L-glutamic acid (PGA) was chosen for this study because sufficient data exist to determine its helix interruption constant and other thermodynamic quantities.

Changes in helix content were followed by optical rotation measurements, using a Rudolph spectropolarimeter, Model 80AQ6, whose detection system was modified to give routine reproducibility to 0.001°. The solution was contained in a specially constructed, water-jacketed, stainless steel polarimeter tube of 1-dm. length. "Zero-stress-optical" glass[3] disks 8 mm. thick were used for windows. These windows exhibited no change in blank rotations under pressures up to 130 atm., which were supplied by a tank of compressed helium.

A 2% solution of PGA (Pilot Chemicals Lot G-34, degree of polymerization = 520, as determined from intrinsic viscosity) was prepared in 0.2 M NaCl. The pH was adjusted between 4.5 and 9.0 by addition of concentrated NaOH or HCl in order to vary the helix content or fraction of hydrogen bonds formed, f. The Moffitt parameter[4] b_0 was determined at atmospheric pressure from the rotatory dispersion between 400 and 600 mμ, and f was calculated as $-b_0/625$. The pressure derivative $(\partial f/\partial P)_T$ was obtained from the change in specific rotation with pressure, using the correlation of rotation with helix content.[4] For this purpose, rotations were measured at 546 and/or 436 mμ, the results for $(\partial f/\partial P)_T$ being the same within experimental error at both wave lengths. The calculation required a correction (amounting to about 6% near the center of the transition) for a pressure dependence of the rotation of the random coil, as determined on a solution at pH 9. No such correction was necessary for the helix rotation, as the latter was found to be independent of pressure in an experiment using dioxane–water (1:2 by volume)

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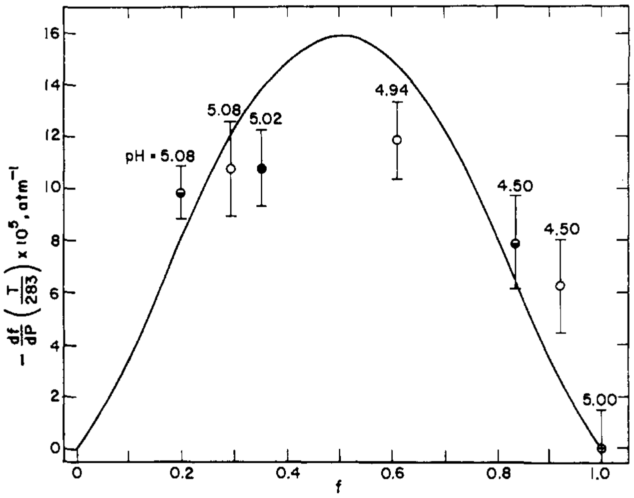

Fig. 1.—Pressure dependence of helix content f for poly-L-glutamic acid in 0.2 M NaCl: temperature (○) 10°, (◒) 20°, (●) 25°, (⊕) 20° in dioxane–water (1:2); indicated pH values were measured at room temperature; solid curve was calculated from eq. 1 and 2 with σ = 0.005, $\Delta\bar{V}$ = 1 cc./mole.

as solvent at pH 5, a condition in which f = 1 and in which the turbidity that complicates measurements in pure aqueous solution at low pH is absent.

As shown elsewhere,[5] f is related to the stability constant s and the helix interruption constant σ by the equation

$$f = \frac{1}{2} + \frac{s-1}{2[(1-s)^2 + 4\sigma s]^{1/2}} \qquad (1)$$

From eq. 1 we find

$$\left(\frac{\partial f}{\partial P}\right)_T = -\frac{\sigma s(1+s)\Delta\bar{V}}{RT[(1-s)^2 + 4\sigma s]^{3/2}}, \qquad (2)$$

where $\Delta\bar{V}$ is the change in partial molal volume of the residue on going from random coil to helix, and is equal to $-RT(\partial \ln s/\partial P)_T$. It is assumed here that σ is independent of pressure, *i.e.*, that no volume change occurs on formation of an interruption by a process that maintains a constant number of hydrogen bonds.[5]

The change in f over the 130-atm. range was 1–2% near the center of the transition, and $(\partial f/\partial P)_T$ was therefore essentially constant in this range for a given solution. On some solutions measurements were at both 10 and 20° in order to determine whether σ is sensitive to temperature. The experimental data are plotted in Fig. 1, with $(\partial f/\partial P)_T$ corrected, as shown, to 10° in order to remove any temperature dependence other than what may be contained in σ and $\Delta\bar{V}$.

A value of σ was obtained for each set of experimental conditions by simultaneous solution of eq. 1 and 2. An IBM 1620 computer aided in this calculation. $\Delta\bar{V}$ was taken as 1 cc./(residue mole) as found by Noguchi and Yang[2] for this system. The average value of σ thus obtained was $(5 \pm 2) \times 10^{-3}$. The theoretical curve of $(\partial f/\partial P)_T$ *vs.* f, using this value of σ, is seen in Fig. 1 to lie essentially within experimental error of all of the points. Assuming that $\Delta\bar{V}$ does not vary, we conclude that σ is insensitive to temperature, as previously expected.[5]

The above value for σ stands in contrast to the value 2×10^{-4} for poly-γ-benzyl-L-glutamate (PBLG) in a mixed organic solvent,[6] and does not support Zimm and Bragg's hypothesis[7] that this quantity should be independent of the side chain and solvent. While Zimm and Rice[8] interpreted titration data on PGA as giving support to the hypothesis, they recognized room for error in this interpretation. We conclude that the practice of using a single value for all polypeptides should be abandoned, since it is at best a very rough approximation.

The cooperativeness of the helix-coil transition can be visualized from the tendency for hydrogen bonds to group together in uninterrupted sequences. The average number of bonds in such a sequence has been shown[5] to be $1 + \sigma^{-1/2}$. This number is 15 for PGA, as compared with 72 for PBLG. The former is less cooperative than the latter, and this is one factor contributing to the gradualness observed for the thermal transition in PGA.[9,10]

Some of the data in Fig. 1 were taken on a single solution at two different temperatures. The decrease in f upon heating is similar in magnitude to that found by Fasman, *et al.*,[10] in a more extensive study of the temperature effect in the same system at pH 4.88. Their data, as well as ours, yield a value of −630 cal./(residue mole) for the enthalpy of helix formation, which is essentially constant from pH 4.88 to 5.08. This value is an order of magnitude larger than some previous estimates,[5] due in part to the larger value of σ found here. The entropy of helix formation is −2.0 cal./deg./(residue mole), and is likewise larger than previous estimates.

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The Solvolysis of 7-*anti*-Bromo-2-*exo*-benzenesulfonamidobicyclo[2.2.1]heptane. An Example of Solvolytic Ring Opening

Sir:

When 7-*anti*-bromo-2-*exo*-benzenesulfonamidobicyclo[2.2.1]heptane (I), the preparation of which is described elsewhere,[1] was refluxed for 25 hr. in an aqueous methanolic solution containing excess sodium carbonate, there was obtained 2-hydroxy-7-*syn*-benzenesulfonamidobicyclo[2.2.1]heptane (II) as the minor product and 3-cyclopentenylacetaldehyde (III) as the major product.

The formation of II can be visualized as occurring by backside displacement of the 7-*anti* bromine by the 2-*exo*-benzenesulfonamido group to give intermediate

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