

KURZE MITTEILUNGEN

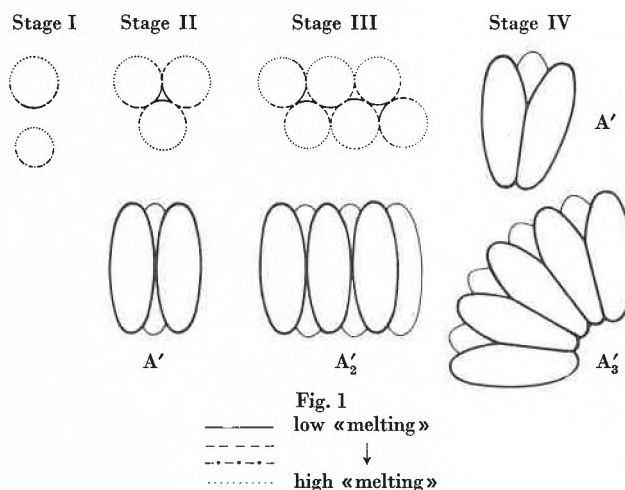
Bis am 20. des Monats bei der Redaktion eingehende Kurze Mitteilungen werden in der Regel am 15. des folgenden Monats veröffentlicht
Es werden auch Manuskripte aus dem Auslande angenommen

Endothermic Polymerization in Biological and Biochemical Processes: Polymerization of Tobacco Mosaic Virus Protein*

Tobacco mosaic virus (TMV) A protein is, in pH 6.5, 0.1 ionic strength phosphate buffer, a stable trimer of the chemical protein unit, with molecular weight of about 52,500.¹ Upon dilution to very low concentrations, it dissociates into the chemical units² with ΔF^0 at 3°C of about +4000 calories per mole of chemical unit.³ It polymerizes endothermically⁴ and reversibly following the kinetics derived by FLORY⁵ for condensation polymerization⁶ with ΔH^0 and ΔS^0 of +30,000 calories and +124 eu, at temperatures between 4° and 14°C¹ and of +190,000 calories and +678 eu at temperatures between 14° and 20°C⁷ per mole of A protein. Double discs consisting of thirty-two chemical units are a stable intermediate.⁸ Above 20°C, polymerization continues until rods resembling the virus are obtained,⁴ probably by the mechanism of stacking of double discs⁸ followed by slight rearrangement of the chemical units to form a helical structure like that of TMV. Polymerization is accompanied by a release of water molecules and an increase in volume.⁹

All of these properties of TMV A protein can be imitated accurately by a model composed of a slightly elastic ellipsoid of revolution, $24\frac{1}{2}$ Å in maximum diameter and 70 Å long, which is chemically totally inert except for ability to interact with or "bind" water. The model has four kinds of centers each with its own negative ΔH^0 and negative ΔS^0 for interaction with water. Each type of center has its own "melting temperature", defined by the equation, $\Delta F = \Delta H - T\Delta S = 0$. When the temperature is above the melting temperature for a type of center, ΔF for interaction with water will be positive and contact with water will be thermodynamically unfavorable; the center will be hydrophobic. When the temperature is below the melting temperature, ΔF for interaction with water by a center will be negative and water will be a favorable environ-

ment; the center will be hydrophilic. The centers are designated Type I through Type IV in the order of increasing «melting temperature».



The circles at the left margin of Figure 1 represent bands on the surface of the ellipsoid, the large circle near the maximum diameter and the small circle near the inside end. Centers are assumed to occupy 60° of arc on a band. Type I centers are at the bottom of the central band. Two Type II centers occupy positions on both sides of the Type I center. Three Type III centers are located on the entire bottom half of the band near the inside end. Six Type IV centers occupy the entire top half of both bands.

Below the melting temperatures of all centers, individual ellipsoids should be stable (Stage I, Fig. 1). Just above the melting temperature of Type I centers, a trimer, designated A', should be stable (Stage II). If the ellipsoids are essentially parallel, the now hydrophobic Type I centers will be in a non-aqueous environment and all other centers, all hydrophilic, will be exposed to water. In Stage III, just above the melting temperatures of both Type I and Type II centers, linear polymerization will take place. Figure 1 shows that six Type II centers are exposed to water on each A' and also on each polymer of A'. Thus, polymerization in Stage III involves the removal of six now hydrophobic Type II centers from water per "bond" formed. In terms of reactive surfaces, the polymer of A' is equivalent to A', a condition necessary for the application

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¹ K. BANERJEE and M. A. LAUFFER, *Biochemistry* 5 (1966), in press.

² A. T. ANSEVIN and M. A. LAUFFER, *Nature* 183 (1959) 1601.

³ M. A. LAUFFER, *Biochemistry* 5 (1966), in press.

⁴ M. A. LAUFFER, A. T. ANSEVIN, T. E. CARTWRIGHT and C. C. BRINTON jr., *Nature* 181 (1958) 1338.

⁵ P. J. FLORY, *J. Amer. Chem. Soc.* 58 (1936) 1877.

⁶ A. T. ANSEVIN and M. A. LAUFFER, *Biophysic. J.* 3 (1963) 239.

⁷ M. A. LAUFFER, in *Symposium on Foods: Proteins and Their Reactions*, Avi Publishing Co., Westport (Conn.) 1964, Chap. 5.

⁸ R. MARKHAM, S. FREY and G. J. HILLS, *Virology* 20 (1963) 88.

⁹ C. L. STEVENS and M. A. LAUFFER, *Biochemistry* 4 (1965) 31.

of FLORY kinetics. The free energy contributed by reduction of interaction with water during polymerization is thus minus six times the free energy for water interaction of Type II centers. Above the melting temperature of Type III centers, Stage IV takes place. Remaining A' particles assume the shape shown in the upper right of Figure 1 and subsequent polymerization involves removing six Type III centers plus six Type II centers from water. Polymers will now be curved, as illustrated in Figure 1, bottom right. The values of ΔH and ΔS for water interaction by Type III centers will be minus one-sixth of the difference between the corresponding values for polymerization at temperatures above and below the melting temperature of Type III centers. Stage IV polymerization will continue until double discs are formed. These should be highly stable because all hydrophobic Type I, Type II and Type III centers will be isolated from water and all hydrophilic Type IV centers will be in contact with water. When the temperature is raised above the melting point of Type IV centers, making them hydrophobic too, double discs will stack. Rotation of some ellipsoids about their long axis and slight rearrangement will transform a stack of double discs into a helical rod resembling TMV without exposing any hydrophobic centers to water.

KAUZMANN¹⁰ has applied the name "hydrophobic bond" to the consideration here described, but we prefer the name "entropic union". Interaction by a center with water can be by "iceberg" formation, by electrostriction, or by any other appropriate mechanism. Transfer of one carboxyl ion, one amino ion and four methane molecules from water to an organic medium involves enthalpy and unitary entropy increases of about 22,500 calories and 93 eu. These values are close to one-sixth of the differences between the values for polymerization of TMV A protein at temperatures above and below 14°C. Thus, a region with one carboxyl group, one amino group and four aliphatic chains exposed could resemble a Type III center.

Entropic unions play an important role in many biochemical and biological processes.^{7, 10}

By MAX A. LAUFFER

University of Pittsburgh*
and Max-Planck-Institut für Virusforschung, Tübingen

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¹⁰ W. KAUZMANN, *Advances in Protein Chemistry* 14 (1959) 1.