Response to Comments on Thermal Polypeptides
by P. A. Temussi et al.


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Summary. The above authors claim to have examined critically the thermal polycondensation of amino acids "as a possible prebiotic path of chemical evolution of life". Some of the flaws in their premises and interpretations are discussed here.

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In broad terms, the pathway of chemical (prebiotic molecular) evolution imputed to us by Temussi et al. (1976) is essentially correct; the details are not.

i) Amino acids need not be synthesized at temperatures imputed by Temussi et al. We regard the syntheses of amino acids that can be carried out in open systems in the laboratory below 120°C (and that begin with compounds found in abundance in nature) as the most plausible. For example, we have hydrolyzed the reaction product of formaldehyde and ammonia (constituents of interstellar matter; Herbig, 1974) at only the boiling point of an aqueous solution of the product with conc. HCl (Fox & Windsor, 1970). It has long been known that formaldehyde and ammonia give hexamethylenetetramine (Chemnitius, 1928) at temperatures <20°C. Wolman et al. (1971) have verified that hydrolysis of pure hexamethylenetetramine yields a set of amino acids.

ii) Biochemists recognize that temperatures convenient for laboratory use do not necessarily signify that those temperatures were required in the geophysical realm (Lehninger, 1975, p. 1036; Rohlfing, 1976). This is not to say, however, that temperatures up to 200°C have been rare on the Earth (Bullard, 1962). They have been abundant in volcanic zones (which do not necessarily include volcanoes; e.g. Yellowstone). Experiments, moreover, show that we do not require for polycondensation the 200°C claimed by Temussi et al., nor even 100°C. We have accom-
plished polycondensation below $70^\circ$ with polyphosphoric acid (Harada & Fox, 1965a); Osterberg & Orgel (1971) have demonstrated the formation of polyphosphates from acidic phosphates also below $100^\circ$ (cf. also Rabinowitz et al., 1968). The condensation of amino acids in the absence of phosphates is known to occur over sufficient time at temperatures below $100^\circ$ (Snyder & Fox, 1975; Rohlfing, 1976). With or without a phosphoric medium, temperature can be traded for time (Hennon et al., 1975).

Another reason for our not preferring the amino acid synthesis imputed by Temussi et al., is the use of a reducing atmosphere therein; the relevance of this has long been doubtful. Temussi's argument that yields of other syntheses are lower than in Miller's 1955 synthesis ignores the fact that those rather high yields are obtained in closed systems, which must be used in order to retain the gases. While Miller's yields are high for "simulation" experiments, the biogeochemist Florkin (1975) dismisses Miller's (1955) synthesis as geologically inadequate (see also Fox, 1973, 1974; Fox et al., 1976).

The statement of Temussi et al. that "thermal condensation can be performed only with mixtures containing large amounts of trifunctional amino acids to prevent extensive carbonization" is not true; small proportions can be used (Harada & Fox, 1965b; Rohlfing, 1967; Oshima, 1968; Fox & Waehneldt, 1968).

Temussi's premise that knowledge of the structure of the thermal polypeptides is crucial to assessing the significance of thermal polycondensation, and the intimation that those chemical structures must be identical to contemporary structures are antievolutionary concepts (Fox & Suzuki, 1976). Carried to its logical conclusion, Temussi's statement becomes an assertion that the contemporary must have evolved from the contemporary. In our overview, on the other hand, primordial structures permitted functions, and more evolved structures, to follow. Proteinoids are not proteins; in the theory that we have detailed, proteinoids preceded protein through supramolecular structures (such as protoribosomes) that intervened in evolution (Nakashima et al., 1970; Fox, 1972; Nakashima & Fox, 1972). Temussi should add steps beyond i-iii.

We agree with Temussi et al. that thermal polycondensations of amino acids yield high-molecular weight polymers by facile elimination of water. A fuller listing of advantages includes: simplicity, versatility, and controllability for the processes; and orderliness, enzymelike activities, and morphogenic qualities for the products (Fox & Dose, 1972).

Temussi's interpretation of his NMR-derived information is misleading because it imputes data on a very small fraction of a polymer to the entire product (Fox & Suzuki, 1976). It is also in disagreement with the polyaspartic acid studies of Kovacs et al. (1961), a paper not cited by Temussi et al.