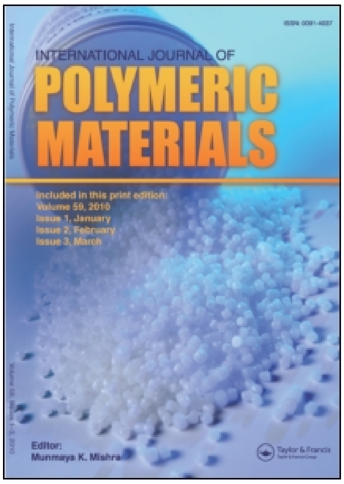

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The Challenge to Macromolecular Science

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The Challenge to Macromolecular Science

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Brief historical review of the development of macromolecular science and some of the challenges for present and future research.

The adaptation of polymeric materials for the artifacts of man originated in antiquity. Techniques for processing fibers, hides, wood, rubber and naturally occurring resins have precedents that predate recorded history. These are amongst the oldest technologies that have evolved over the centuries and up to the present. By contrast, the *science* of polymers, or macromolecules, made a late appearance—late, that is, relative to other branches of science. The modern science of molecules that we call chemistry had its beginnings around 1860. The foundations of quantum theory and quantum mechanics were established from 1900 to 1925, the theory of relativity from 1905 to about 1920. The basic concepts underlying macromolecular science were not put forward until after these epoch-making advances had determined the course and content of chemistry and physics for decades to come.

The motif of macromolecular architecture—the concatenation of atoms, or groups of atoms, to form covalently linked chains of great length—did not achieve widespread acceptance as the structural principle pervading virtually all polymeric substances until 1930 and doubts concerning its reality lingered for some years thereafter. Polymeric chemical structures had been suggested—even advocated—as much as 70 years earlier. However, for reasons difficult to grasp in retrospect, linear macromolecular structures were rejected in every instance. Instead, small cyclic structures were ascribed to substances

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now recognized as polymeric, in the molecular sense of this term. Thus, rings of three to twelve bonds were proposed for proteins, rubber, cellulose, starch, and various synthetically prepared polymers. The preoccupation of chemists in general with molecules representable by concise formulae conveniently expressed on the printed page, seems to have generated an overpowering conviction that all substances should be so constituted. The much larger chemical structures suggested from time to time for the most commonplace of substances, and the most important ones in the environment of man, were consistently cast aside, probably on this account.

Not until the late 1920's was it clearly established that cellulose and starch are high polymers consisting at the molecular level of long chains now known to be the universal theme amongst all polymeric structural materials, natural and synthetic. The epic of natural rubber is similar: determination of the chemical structure of the unit at the beginning of this century, appearance of a variety of cyclic formulae, and finally, in the late 1920's, the belated acceptance of the polymeric chain formula.

The polypeptide hypothesis regarding the chemical structure of proteins put forward by Hofmeister and by Fischer about 1902 did not gain widespread acceptance before 1930. As late as the mid 1920's, leading organic chemists of the period vied with one another in matches of ingenuity to invent esoteric cyclic structures for proteins, all seemingly in a vain effort to avert adoption of the polypeptide chain structure as the pattern for life-giving proteins, the abundance of chemical and physical evidence in support of the polypeptide structure notwithstanding. Evidently the vision of a polymeric structure for materials of such supreme importance was repugnant. Whether the polypeptide chain was regarded as inherently objectionable or merely something to be opposed because it departed from the structures that were in the mainstream of chemists' endeavors is a matter for conjecture. Bear in mind that Fischer had completed his *tour de force* in synthesizing a polypeptide of 30 units during the first decade of the century. Yet, even he clung to the belief that proteins consisted of chain molecules no longer than he had synthesized, a number of these being "colloidally" aggregated to form the protein "particle".

The saga of polynucleotides is even more striking. According to opinions that went essentially unchallenged until the mid 1940's, they were tetrameric. Only in the 1950's was it established that they consist of long chains of nucleotide units numbering as many as hundreds of thousands.

Evolution of ideas regarding synthetic polymers followed a similar course. Synthetic polymer chemistry developed rapidly once their molecular nature was understood and hence the skills of the chemist could be turned systematically to their preparation in ever increasing variety. The influence of the pioneering work of Staudinger and Corothers in this period cannot be overestimated. Their work placed the macromolecular hypothesis on a firm footing and at the same time elaborated methods of measurement and synthesis.

It is abundantly evident that long chain structure as the principle common to all substances we now know to be macromolecular was accepted with great reluctance. The aversion to polymeric formulae is well documented. Reasons for it are not. The best that can be ventured is that they were begotten of a combination of esthetics that place a premium on (apparent) simplicity, and accidents of history that directed interests and efforts in other directions.

It is important to observe that macromolecules are not clearly demarcated from their analogs of lower molecular weight. In every series of macromolecular homologs, species of intermediate chain length occur. The chemical bonds joining atoms in macromolecules are not discernibly different from those in small molecules; they are described by the same geometrical parameters. Any sharply drawn distinction between the domain of the molecules that are commonplace in the laboratory and the macromolecules that are commonplace everywhere else must necessarily be arbitrary. Hence, the science of macromolecules is fundamentally coextensive with the rest of chemistry, and with some of the ramifications of physics too. Not to be overlooked, however, is the inescapable fact that definite alterations in concept and theory are required for the understanding of macromolecules. Knowledge in the domain of giant molecules is not to be gained by simple deduction from concepts and rules gathered for small molecules. Modifications in viewpoint and method are required, and in some respects a different set of guidelines must be adopted.

The relatively late emergence of macromolecular science has had an important consequence that weighs heavily on present and future. The basic pattern of chemistry as a discipline, with its traditional subdivisions, became established prior to the appreciation of the molecular nature of polymers, and prior to the appearance of theories and generalizations describing their behavior. Macromolecules were therefore left out of the syllabus in its formative years. Only a few desultory remarks on colloids found a place in the textbooks, and these were generally misleading, if not wrong altogether. The subject has not gained entry since. Irrespective of one's views on the proper place for polymer chemistry and physics in the curriculum, its virtual absence therein at present is a fact to be reckoned with. It is a reality to be taken into account in charting the course of the Midland Macromolecular Institute.

The relevance of polymer science to industrial technology is self-evident, and, I think, widely recognized. I have already alluded to the close temporal correlation between the emergence of polymer science and the proliferation of synthetic polymeric materials. If the former did not in fact furnish the main impetus for the latter, at least it has played a major role in bringing into being what posterity may refer to as the age of polymers. Incidentally, I also believe it is a valid assertion that pure and applied polymer science continue to enjoy a mutually fruitful relationship.

The relevance of polymer science—the *same* science—to biology seems not as well appreciated. Custom, and perhaps prejudice rooted in the never-dying vitalistic view of things living, seem to sustain the impression that biopolymers are unrelated to the technological members of the polymer family. To be sure, biopolymers have acquired certain attributes in the course of their evolution that are not shared by their less refined relatives. But there are basic properties and behavioral patterns shared by all polymers: the thermodynamics of their solutions, rules governing their spatial configurations, manifestation of high elasticity under suitable conditions, crystallization, etc. The tendency to relegate biopolymers and technological polymers to different categories works to the detriment of the fuller understanding of both. Much stands to be gained from the broader view that embraces both of these artificially differentiated categories. If molecular biology is to rest on a sound *molecular* basis, then logic dictates that that basis be provided by the science of polymeric molecules. For this purpose a polymer science concerned with the fundamentals of macromolecular behavior in the broadest sense is required.

There is a further role for macromolecular science, and one for which it is especially well suited. I refer to the communication between science and the public. Most subjects at the forefront of science pertain to matters abstruse and quite remote from the interests and awareness of the nonspecialist. Chemistry is illustrative: its compounds, theories, and reactions offer relatively few opportunities for cultivation of interest on the part of the public at large. Polymeric materials, being exemplified in profusion in a multitude of articles of commerce, not to mention biopolymers too intimate to require mention, are ideally suited as subjects for communication of science to a wider audience. It is here that polymer science enjoys a special opportunity by virtue of its subject and purview.

The opening of the Midland Macromolecular Institute comes at a time of rich opportunities for contributions to science, to industrial technology, and to biology and medical science. I have tried to indicate some of these opportunities without, however, specifying particular directions of scientific inquiry in need of attention. To attempt the latter would be at the hazard of giving undue weight to the interests and prejudices of one person. Suffice it therefore to convey the conviction that macromolecular science still has a long way to go if it is to meet the challenges I have indicated. Much basic and creative science needs to be carried forward. Coherence of the subject through systematization of existing knowledge is of ever increasing importance as research spreads into new directions. At the same time, the importance of cultivating connections between macromolecular science and related fields should not be overlooked.

Finally, I would stress that genuine science is not an activity that can be directed by external control. Widespread opinions to the contrary notwithstanding, it is not an activity that is responsive to the needs of society—at least as society at large envisages its needs. I agree that original science—and invention too—have been influenced in every age by the contemporary scene and mood. But creative science and invention must innovate and initiate. In the highest expressions of their capacities, they do not function as agents for providing means to ends selected by an external body, whether it be a committee, directorate, or agency of government. It was not in response to a managerial decision, an Act of Congress, a referendum, a rally, or even the FCC that the telephone was invented. The same is true of the electric light bulb, the airplane, or the discovery of penicillin. Dalton and Laviosier did not undertake their researches under orders or in response to requests placed before them.

It is therefore important that the Midland Macromolecular Institute be self-directed. It should be accorded a wide freedom of choice in the direction of its investigations. But this is only one side of the coin; the admonition has its concomitant. The senior scientific staff must accept the responsibility to conceive researches in the vanguard of macromolecular science—researches that hopefully will prove to be of the foremost significance. The extent to which they succeed in meeting the challenge of this responsibility will be the measure of success of this Institute. We wish them well!