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Recollections

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Rheology is the science of flow, theology studies the flow of the wisdom of God to mankind on earth. Mailflow to departments of Rheology gets mixed up sometimes with mail to Theology Departments. In the words of the Greek philosopher, Heraklitus, παντα ρει, *everything flows*. And, in the words of the prophetess Deborah, ...*the mountains flowed before the Lord*... (Judges V.5). This led the Israeli pioneer rheologist, Reiner [1–3], to define the Deborah number for the units of flow of materials believed until recently to be solid such as asphalt, glass, rubber and many others. It is necessary at this stage to distinguish between two kinds of rheology. In the world of physics, rheology relates to the mechanics of continua, continuum mechanics. Phenomena of flow are observed on a macroscopic scale and the interiors of the objects in slow motion are not probed or considered. This, in some ways, recalls thermodynamics, the science of the flow of heat, which also does not provide detailed inside information on the nature of the materials presented in phenomenological fashion. Transition of rheology to molecular level investigation has been achieved in a number of appropriate instances by single molecule chemical investigation. Flory [4] has pioneered the calculation of the shape and size of synthetic polymeric macromolecules in dilute solutions in terms of rotation around chemical bonds and solvent and temperature dependent interactions. We have been able to show [5] that his analysis can be extended to biological macromolecules as well. Additional features have been introduced by poly α-amino α-helices and β-pleated sheets created by Pauling et al. [6,7], and the Watson–Crick DNA double helix structure [8]. The analysis can be extended to concentrated solutions and Flory and Hayashi have predicted and shown [9,10] that a polymer molecule in pure solid state maintains the conformation of a dilute macromolecule in the Flory T-state interaction balanced conformation. My discussion is dedicated to John D. Ferry, for his pioneering studies of macromolecular viscoelastic behavior in a wide variety of systems [11,12].

In 1958, I joined the Mellon Institute in Pittsburgh, directed by Paul Flory, for a 2-year stay, to study multi-component macromolecular polyelectrolyte systems. The Mellon Institute had served for many years since 1913 as providing advanced research for industrial companies. Eventually, these created their own research endeavors and the Mellon board decided to move into independent high-quality pure research. Paul Flory was assisted by Tom Fox, his well-known collaborator, and a group of outstanding young scientists joined the Flory Fox polymer group. I was privileged in my collaboration with Ed Casassa [13] leading to the development of the theoretical analysis of multi-component systems, of high value in the study of osmotic pressure, analytical ultracentrifugation, light, X-ray and neutron scattering, which have remained my main focus of research to the present day [14,15]. Further outstanding members of the polymer group were Bernard Coleman, Marshall Fixman, C.A.J. Hoeve, Hershel Markovitz, Guy Berry and Tom Orofino. Paul Lauterbur in the early stage NMR section of Aksel Bothner-By was nominated this year for the Nobel Prize for his creation of magnetic resonance imaging (MRI).

Don Plazek, a young post-doctoral scientist from J.D. Ferry's Madison Wisconsin laboratory, joined our group and set up equipment for the measurement of creep. We believed at that time that this was a wonderful experimental set-up because all you had to do was to come back briefly in long intervals of time to check the slow progress of creep, and all the time in between you could spend in other activities or at leisure. Don Plazek became in time a distinguished

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professor at Pittsburgh University and continued his activities in John Ferry inspired procedures of viscoelastic studies for many years. He wrote a beautiful ode honoring Ferry on the celebration of his 85th birthday in 1997 [16]. In 1995, Plazek was named the Bingham Medalist by the Society of Rheology for his research on the viscoelastic behavior of amorphous materials and the development of the stress controlled rheometer.

Hershel Markovitz was also active in rheology and I would like to mention a joint paper with Tom Fox and John Ferry on entanglement coupling spacings in linear polymers [17]. Bernard Coleman, in collaboration with Walter Noll from Carnegie University in Pittsburgh, was active in continuum mechanics [18]. I was invited to the continuum mechanics informal evening gatherings, attended inter alia by one of the great rheology masters, Clifford Truesdell from Johns Hopkins, at which vast amounts of dark German beer were consumed, *all beer and no molecules*, as the saying went in this group.

Mellon Institute was close to the Pittsburgh University Campus and right across the main road was the Biophysical Laboratory headed by Max Lauffer, where Gary Felsenfeld was working at that time, before returning to the NIH, the National Institutes of Health in Bethesda. I collaborated with Gary at the NIH for many years [19]. Also within walking distance of the Mellon Institute was located Henry Frank, a major expert in water structure, creator, with Marjorie Evans, of the now unlikely iceberg model of hydrophobic hydration. I returned to the Weizmann Institute in 1960 and Paul Flory moved to Stanford University in 1961, and the Mellon Institute eventually joined Carnegie University creating the Carnegie Mellon University.

I must mention that during our stay in Pittsburgh the Pittsburgh Pirates baseball club, whose stadium at that time was within hearing distance from Mellon Institute, beat the New York Yankees to win the World Series in 1960 and Roberto Clemente and Bill Mazerovsky were the great heroes to which our sons Shai (aged 11) and Danny (aged 10) gave their utmost dedication. This should be considered my baseball connection.

The Chemistry Department of Wisconsin University in Madison has been making unique contributions to synthetic and biological polyelectrolyte science over many years. Farrington Daniels joined the department in 1920 and his student John Warren (Jack) Williams received his PhD degree in 1925 [20], concerned with heat capacities of binary mixtures of organic liquids. Williams remained in the Department advancing to full professor in 1938. His independent research was devoted to measurements of the dielectric constant and dipole moments of liquid mixtures. Following a lecture visit of Peter Debye in Madison in 1927, Williams spent a year with Debye in Leipzig, including 2 months with J.N. Brönsted in Copenhagen. With his student, J. Lawrence Oncley, who later joined the Cohn/Edsall laboratory at Harvard Medical School [21], he achieved successful results in the study of dielectric frequency dispersion. While Williams was still a student, The Svedberg was a visiting professor in Madison and in 1923 he conceived the prototype of the analytical ultracentrifuge for the measurement of macromolecular molar mass, sedimentation and diffusion. In 1934–1935, Williams spent a year with Svedberg in Uppsala to study the technique and theory of ultracentrifugation. As a result, Williams created and installed the first analytical ultracentrifuge in Madison in 1936–1937, introducing this powerful technique into the USA. His studies concentrated on antibodies and the nature of the antigen–antibody reaction. In World War II, he collaborated with Edwin J. Cohn and John T. Edsall on the fractionation of proteins from human plasma, using the ultracentrifuge and electrophoresis. Among his students and collaborators were Robert Alberty and Louis Gosting and the theoretical scientist Richard Goldberg, student of John G. Kirkwood. The physico-chemical properties of the almost non-antigenic gelatin were studied for its possible use as a blood plasma extender for shock victims [22]. Extensive progress was achieved by Williams, Michael Wales, Hiroshi Fujita, Gerson Kegeles, Louis Gosting, Kensal van Holde and Robert (Buzz) Baldwin in the powerful use of the analytical ultracentrifuge [23].

John Douglass Ferry (1912–2002), born in the Yukon Territory of Canada, attended Stanford University, where he received his PhD degree in 1935. He went through a number of employments and during World War II he worked in Woods Hole Oceanographic Institute on antifouling paints for marine applications and at Harvard University Medical School in the Cohn/Edsall project on the fractionation of human plasma proteins for clinical use by the U.S. Armed Forces. He was coauthor of a paper [24] in the Cohn/Edsall bible [21]. His lifelong interests moved to fibrinogen, its conversion to fibrin, and the problem of blood coagulation. In 1946, John joined the faculty of the Department of Chemistry in Madison and in 1947 he was promoted to full professor. He was Department Chairman from 1959 to 1967 and became Farrington Daniels Research Professor in 1973. He was a founding member of the Rheology Research Center in Madison. His main achievements in the study of viscoelastic behavior are summarized in his classical book [25] and will be emphasized in related articles in the present publication. My personal activities in the study of viscous flow relate to establishing that polyelectrolyte molecules do not expand fully, construction of a Couette viscometer for the study of shear dependent DNA flow, and early reporting with Uriel Littauer of the essentially single strand nature of RNA structure [14,19].

Robert A. Alberty, student of John W. Williams obtained his PhD in 1947 and stayed in Madison for a number of years before moving to the MIT. His main activities are in biochemical thermodynamics [26]. He wrote the biographical memoirs of Farrington Daniels [27], outstanding leader and promoter of the Madison laboratory. Among Alberty's students in Madison we count Victor Bloomfield [28], one of whose first students in time was Phil Sharp, who won the Nobel prize for gene splicing. Bloomfield's activities [29] at the University of Minnesota are in physical biochemistry of nucleic acids, DNA condensation, dynamics in crowded macromolecular solutions, hydrodynamics, laser light scattering, optical tweezers and calorimetry.

An outstanding biophysical chemist now active in the Chemistry and Biochemistry Departments in Madison is M. Thomas Record [30] with whose research group we have many overlapping research interests in the study of macromolecular solute, cosolute and solvent interactions [15]. Tom obtained his PhD at the University of California, San Diego, and is now John D. Ferry Professor of Chemistry and Biochemistry in Madison.

Research in the Chemistry and Biochemistry Departments of the University of Wisconsin in Madison is staying on a continuing active quality level.

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