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Tribute

Dedication of the virtual special issue of *Polymer* on nanocomposites in celebration of the 70th birthday of Professor Donald R. Paul

It is very fitting that this Virtual Special Issue of *Polymer* focusing on nanocomposites be dedicated to Professor Donald R. Paul of The University of Texas at Austin in celebration of his 70th birthday. Professor Paul is literally a legend in the field of polymer engineering and science, based not only on the quantity of contributions, but also for the profound quality and insight that he has brought to the field. Many of his key contributions have been reported in *Polymer*. In fact, on the occasion of the celebration of the first 50 years of *Polymer*, see http://www.polymer50.com/, Professor Paul was recognized as the most prolific and the most cited author over the history of the journal. According to my count, he has published 181 papers in *Polymer* and according to the Science Citation Index these papers have received 10,115 citations.

However, Professor Paul's impact on the field is even more profound than these statistics for *Polymer* indicate. He is, in fact, one of the most cited scientists in the world. His work in polymer engineering and science has been cited nearly 30,000 times according to the Science Citation Index. His h-index is greater than 80 and of these highly cited papers, 53 were published in *Polymer*. Many of the citations are to papers that are classics in their field. As a result of making some of the key discoveries in several areas of polymer science and technology, Professor Paul has received virtually every possible award and honor in the field of polymer science, including election to the National Academy of Engineering, receipt of the Herman F. Mark Polymer Chemistry Award, the Applied Polymer Science Award, and the E.V. Murphree Award from the American Chemical Society, receipt of the Alan S. Michaels Award for Innovation in Membrane Science and Technology from the North American Membrane Society, and receipt of the William H. Walker Award from the American Institute of Chemical Engineering. He has been elected as a Fellow of the American Institute of Chemical Engineers, the Society of Plastics Engineers, the Materials Research Society, and the American Chemical Society (plus the Divisions of Polymeric Materials; Science and Engineering and Polymer Chemistry). In addition to these highly prestigious awards, Professor Paul has won a number of other major awards for his teaching and research activities. In the paragraphs that follow, a few of the key research contributions that Professor Paul has made are outlined in more detail.

Today, it is well recognized that the mechanism by which small gas molecules migrate through polymer membranes is via the so-called solution-diffusion mechanism wherein gas molecules first dissolve into the high pressure face of a membrane, then diffuse down the concentration gradient, and finally desorb from the downstream face. This is also the mechanism by which liquids are transported through membranes such as reverse osmosis desalination membranes. In the early 1970s, there was great controversy in the field of membrane science about whether small molecule transport occurred through polymers as a result of solution-diffusion or via flow through unobservably small pores. Professor Paul undertook a series of elegant, fundamental studies that clearly demonstrated the correctness of the solution-diffusion approach. Practically single-handedly, he convinced an entire generation of scientists and engineers of the truth of his fundamental view regarding the transport mechanism of small molecules in polymers. It is difficult to describe in words the enormity of this contribution, or to adequately describe the profound impact it has had on literally thousands of researchers and ten of thousands of papers that have been written in this area since Professor Paul's pioneering studies.

The vast majority of gas separation polymers used today in applications such as air separation, hydrogen purification, and natural gas purification are rigid, glassy polymers. Professor Paul conducted critically important systematic studies in the 70s and 80s on the gas separation properties of polymers that later went on to be the basis for the membranes deployed commercially at Air Products and Dow Chemical's membrane division. Unlike

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rubbery polymers, the permeation properties of glassy polymers show a very distinct dependence on pressure, with permeability decreasing as pressure increases. Professor Paul formulated the most widely used model to describe the permeability decrease with increasing gas pressure in glassy polymers, the so-called "dual mode model". This model has become the de facto standard in the field of gas separation membranes and has been used by countless researchers the world over to describe and correlate their experimental permeability data. Like the contribution mentioned in the previous paragraph, it is difficult to imagine where the field would be today had it not been for Professor Paul's extraordinary contributions.

Professor Paul is also highly cited for his work in the area of thermodynamics of polymer blends. Many years ago, before Professor Paul's work, it was widely believed that almost any pair of polymers would be immiscible. It was further believed that it would be virtually impossible to prepare blends of polymers that would be miscible at a molecular scale. Although this dogma was widespread and almost universally adopted, Professor Paul questioned this conventional wisdom and did systematic experimental studies delineating the molecular basis for developing polymer blends that are miscible with one another at a molecular level. In addition to performing elegant experimental studies that unmistakably demonstrated the miscibility of appropriately selected polymers, Professor Paul developed a widely used theory describing miscibility of polymer blends. He edited several important books on this topic, and his work in this area has formed the basis for the industrial practice of using miscible polymer blends for wide variety of structural and other applications as well as the theoretical basis underpinning much of the modern literature in this area. Again, it is difficult to imagine where we would be today if Professor Paul had not made seminal contributions in this area many years ago. Many of these landmark papers were published in Polymer, including, for example, his paper, co-authored with Joel Barlow, entitled "A Binary Interaction Model for Miscibility of Copolymers in Blends," [*Polymer*, **25**(**4**), 487–494 (1984)] which has been cited 593 times, making it one of the most cited articles to ever appear in *Polymer*. In addition, he popularized the concept of "compatibilization" of multiphase blends using block and graft copolymers and made significant contributions to rubber toughening using "reactive compatibilization." He co-edited a two-volume book with S. Newman (in 1978) and another two-volume set with C. B. Bucknall (in 2000) that have become classics in the field of polymer blends with translations into Chinese and Russian.

In recent times, Professor Paul has made major contributions to the field of polymer nanocomposites, with many highly cited papers in this area published in *Polymer*. For example, his paper, co-authored with J.W. Cho, entitled "Nylon 6 Nanocomposites by Melt Compounding" [*Polymer*, **42**(**3**), 1083–1094 (2001)] has been cited 485 times. Papers in this area co-authored with his former graduate student, Dr. Timothy Fornes, have also received considerable recognition in the field. For example, his paper, co-authored by Dr. Fornes and others, entitled "Nylon 6 Nanocomposites: The Effect of Matrix Molecular Weight" [*Polymer*, **42**(**25**), 9929–9940 (2001)] has been cited 482 times. This paper demonstrated that essentially complete exfoliation of organoclays in polyamides could be achieved by melt processing and proposed a mechanism by which this occurs; this opened the door to a more versatile approach to nanocomposite formation than *in situ* polymerization.

In addition to making enormous contributions to fundamental and applied aspects of polymer science over a period of more than 40 years, Professor Paul remains highly active today in the field of glassy polymer physics, nanocomposite preparation and testing, and, more recently, water purification membranes. He is studying the relaxation of glassy polymers at nanometer length scales that are important, from a practical prospective, in the design and operation of gas separation membranes and, from a fundamental prospective, important for understanding the behavior of polymers in nanoconfined regions. His work in this area, directed towards understanding and describing physical aging in extremely thin glassy films, has utilized state of the art depth-resolved positron annihilation studies combined with other techniques to make the first measurements of physical aging, probed by gas permeability, in polymer films less than 20 nm thick [*Polymer*, **51**, 3784–3792 (2010); *Polymer*, **50**, 6149–6156 (2009); *Polymer*, **50**, 5565–5575 (2009)]. Thus, in addition to making groundbreaking and seminal contributions to the literature 20, 30, and 40 years ago, Professor Paul continues to push back the frontiers of knowledge in the materials science of polymers, and his work continues to be vital to the advancement of this field.

I have had the pleasure of being a collaborator and colleague of Professor Paul's since coming to The University of Texas at Austin approximately eight years ago. I have had no more satisfying interaction with a colleague in every sense than with Professor Don Paul. He is unassailably honest, straightforward, and easy to work with. At the same time, his incisive insight into technical problems allows our joint research projects to advance much faster than they could if I were working on them by myself. In addition to being an outstanding scientist, he is an extraordinary colleague and an excellent mentor for our students.

On behalf of the Editors at *Polymer* and your students and colleagues around the world, Happy Birthday, Don!

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