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Comments

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COMMENTS

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I am delighted to be here at this meeting in Stockholm on the occasion of Bengt Rånby's 75th birthday. The subtitle of this symposium, "Nature as a Model of Molecular Design of the Polymeric Materials of Tomorrow," is particularly appropriate to this occasion, and I want to thank the organizers for the invitation to say something about Rånby and his work.

Bengt and I have not spent a great deal of time together (we travel too much), but occasionally our paths cross in China, in Japan, or in the United States. Bengt, as you all know, is a kind gentleman in the real sense of the word. He is a dear colleague and friend, an international scholar, and a world leader in the field of polymer chemistry.

While I was going through his CV in preparation for this talk, I realized that he has been responsible for the publication of six books and more than 400 scientific papers (some of which are in Swedish). I also found that he and I seem to have a kind of mirror image relationship.

Bengt did his Ph.D. with Nobel Laureate Thé Svedberg, the inventor of the ultracentrifuge, one of the major tools in the early days of synthetic polymer chemistry. I did mine with R. G. W. Norrish, Nobel prize winner in photochemistry.

Bent found it necessary to leave his homeland and work in North America for seven years. I left North America to work in Europe in order to study for my Ph.D.

Bengt has always been interested in industrial research, and worked as an industrial chemist in the early days of the viscose rayon industry. I spent nearly 15 years working for Eastman Kodak who also made cellulose fibers. Eastman Kodak developed the entire process for making cigarette filters, and at one time produced 90% of the cellulose fibers for filters for cigarettes.

In 1961, Bengt left the United States and returned to Sweden to set up what is now the famous polymer laboratory here at the Royal Institute of Technology. In 1963, only two years later, I left the employ of Eastman Kodak to teach at the

University of Toronto and to develop a polymer program in the Chemistry Department, which up until that time had refused to have anything to do with molecules larger than simple organic compounds.

As I can gather from Bengt's CV, he made his first polymer studies on cellulose in 1944; I made my first polymer in 1947 while I was working as a summer student for Eastman Kodak.

Bengt has recently published a number of papers and patents on photografting. My thesis work dealt with how to make graft and block polymers using photochemical methods.

We have both, as you may gather, shared a deep interest in polymer photochemistry, and I would like to give you a brief history of the subject.

Many of us do not realize how recent is the subject of polymer chemistry. There were practically no man-made polymers prior to the turn of the century. Natural rubber was used, of course. Cellulose nitrate was the material from which Eastman made his movie film, and unfortunately caused a large number of fires in theatres because it was explosive. If the film stopped moving in the machine, it would catch fire. Later Eastman developed cellulose acetate, which is the basis for the famous "safety film."

The stiff collars that your great grandfather wore were made of cellulose nitrate plasticized with camphor. For all of the polymers I have mentioned thus far, the backbone was made by Nature. Chemists simply modified the side groups in order to obtain different properties, particularly solubility and moldability.

One of the most common misconceptions about plastics is that they are based on oil, and that since oil is going to run out some day, we have to find some substitute raw material for plastics. This statement was made in public by a director of the Chemical Institute of Canada, who should have known much better. But it has been picked up. And most people think that plastics will disappear when oil disappears.

However, historically, from 1900 to 1945, all plastics except for cellulose were based on coal. And through the acetylene route, which had been pioneered by German chemists, coal was used to make nylon, PVC, styrene, synthetic rubber, and the other major plastics of the first half of this century.

From 1945 to the present, however, plastics have been made from the cheapest carbon source. And the cheapest source of carbon is oil and/or natural gas. The reason for this was that the huge refineries built by all countries during the war to fuel their aircraft, tanks, ships, and other vehicles were no longer needed, causing the price of oil to drop by a factor of nearly ten. It is hard to remember that oil cost only $1.80 US a barrel as recently as 1948. That was the reason why the plastics industry chose to use oil rather than coal. However, the reserves of coal are so much larger than those of oil that there is no prospect of ever running out of the raw materials for plastics in the conceivable future.

The basic raw materials for plastics are carbon, hydrogen, oxygen, nitrogen, sulfur, and chlorine, which are among the most abundant elements on earth. However, it is worth noting that SASOL in South Africa and Eastman Kodak in the United States have gone back to using coal because its price does not vary with the political situation in the Middle East. This change makes both political and economic sense because with coal you can predict your raw material cost with relative certainty. You can buy enough coal right now for the next 30 years of production.

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You can buy it in the ground and know exactly the costs of getting it out, thus giving stability to a market which is rather volatile.

The use of natural polymers in the early days of the Plastics Age encouraged many people to suggest that we should go back to cellulose and other natural polymers as raw materials. About 20 years ago I published some calculations which make it seem unlikely that this will take place. I looked at the data on the production of natural fibers like cotton, wool, and linen, and also on the production of wood. To my surprise, I found that the maximum sustainable production of cellulose in a natural forest is about 500 pounds per annum per acre. Thus a subscriber to the New York Times needs an acre of Canadian forest to sustain his habit! To replace the entire United States production of plastics by wood (even if one could do so) would require all of the arable land of more than five states the size of Michigan.

The problem with using natural materials as the basis for resources is that it takes a lot of land to grow them. Cotton is an example. Without the use of fertilizer, the best yield one can expect is about 100 pounds of cotton per acre. With highly fertilized farms, one can expect about 500 pounds.

It is true that you can grow cellulose quite rapidly in tree farms, in particular in the southern United States. However, you are still going to be limited by the huge area of land that must be diverted to growing trees when there is starvation in many parts of the world. That situation is not going to improve much unless we gain control of the explosion of our population.

I would like now just to say a few words about another aspect of history. I believe it was Santayana who said that if you don't learn from the past, you're doomed to repeat it. And I think that probably applies to scientists as well as philosophers and military experts. You will recall that the ages of man have been named primarily for his most prominent material for making tools. Thus we have the Stone Age, which lasted for about 500,000 years. The Bronze Age which followed lasted about 5000 years; the Iron Age about 1500 years; the Steel Age about 600. And just about ten years ago plastics exceeded steel in volume of production. We are now in the Plastics Age. This change from steel to plastics has taken place within the lifetime of the people in this room.

When Bengt and I started to make plastics, they were considered cheap substitutes for something better. Now our most valuable products are built using plastics: spaceships and reentry vehicles, computers and telephones, heart valves and hip replacements, flexible tubing, tires, and so on. These materials are designed completely by chemists, starting with the most basic of raw materials. We are now in the Plastics Age and there is not much we can do about it except rejoice. The prospect of moving away from that age seems very remote.

One other part of this history is related to the fact that even molecules as we know them are new. In 1946 the chairman of my department, who was a physical chemist, told me, "you must not believe that molecules really exist because no one has ever seen one. We have to think of molecules as 'fictive constituents of matter' which are useful in explaining the way matter behaves, but may not exist at all." These ideas of the nature of large molecules were soon dispelled, particularly due to the work of Staudinger, Mark, and Carruthers. Modern chemists now take these ideas for granted.

It was, of course, a turning point in chemistry because polymers really are molecules and they behave like very big molecules. It is just that big molecules don't

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always behave like small molecules. I know Bengt and I both have had to fight very hard in our departments to get other chemists to recognize the importance of polymer chemistry.

In this Symposium you will hear a lot about what Bengt has done. However, I do want to mention the five major areas that he has been prominent in, and show how this fits the historical pattern that I have been talking about—going from a very limited understanding about polymers to now being able to synthesize just about any molecular structure we want.

Bengt started with cellulose chemistry. He was one of the first people to study "composite" materials. Cellulose is a composite that consists of crystalline microfibrils imbedded in a matrix of gamma-cellulose, which is noncrystalline. It was the conceptual beginning of the whole idea of synthetic composite materials.

Bengt also did some work on cellulose micelles, showing that you could suspend them in water and make useful products out of them. He then went on to polymer physics. The next problem, after one has made a new polymer, or discovered a polymer from natural sources, is to determine how its molecular properties affect the chemical and physical properties of the material. So he carried out a number of pioneering studies on polyolefins, PVC, and poly(4-methylpentene), which has the unique characteristic of having a lower density in the crystalline phase than it does in the amorphous phase, for reasons that Bengt was able to explain. He also studied blends where he did pioneering work using NMR studies.

To understand how to make polymers, you have to study the kinetics of polymerization. Bengt did some very early studies using ESR, since the early polymers were mostly made by free-radical catalysis. ESR was shown to be an elegant tool to study radical concentration and structure. He wrote a definitive book on the subject, and also published a large number of scientific papers in that area.

Bengt also recognized that graft and block polymers were going to be important in future technology. It took a long time, much longer than I expected, before block polymers actually did get into commercial production.

He did many studies on photodegradation and stabilization of polymers, and particularly noted the effect of singlet oxygen on polymers containing double bonds. These studies relate to ways of improving the stability of polymers to outdoor solar radiation.

His most recent work on photo-initiated, photocrosslinking of polymers is leading to some commercial processes in China, a country with which he has had a long-standing collaboration.

I would like to close my talk with a toast to Bengt Rånby. To paraphrase Isaac Walton, he is "The Compleat Macromolecular Chemist."

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