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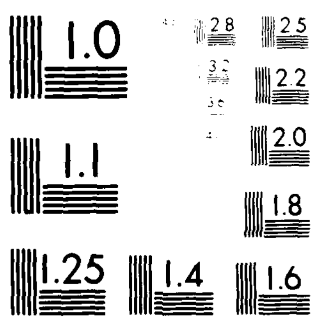

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POLYMER AND SURFACE SCIENCE IN EUROPE, ISRAEL, AND EGYPT: SOME OBSERVATIONS

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25 November 1981

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This report contains the author's observations relating to polymer and surface science research activities in European and Middle Eastern countries with emphasis on the quality and quantity of research and the directions research efforts are taking. The information was obtained in visits to university and industrial laboratories and government research organizations over a period of 21 months.

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POLYMER AND SURFACE SCIENCE IN EUROPE, ISRAEL, AND EGYPT: SOME OBSERVATIONS

Introduction

The title of this report is somewhat presumptive in that it would have been impossible to cover all of the research in polymer and surface science in Europe and the Middle East during the 21 months (Oct 78 - July 80) I spent at ONR London as a liaison scientist. Consequently, the report can only be a review of the laboratories visited, my impressions of the general quality and quantity of research, and trends in research directions. The report is divided into two parts: research in polymer science and research in surface science. The discussion of polymer research is more extensive primarily because the level of effort on polymers is much greater than that in surface physical chemistry or colloid science.

Polymer Science in the UK

There is "a lot of it about," to use a British expression. Virtually every university, polytechnic, and government laboratory is doing some work on polymers as part of its materials science research or in its engineering, chemistry or physics department. The work is well funded by government and industry. The Science Research Council (SRC) funds some of the basic research in polymer science. Indeed, the present chairman of the SRC is Prof. Sir Goeffrey Allen, who earned a well-deserved reputation for his work in polymer physics at the University of Manchester Institute of Science and Technology (UMIST). If nothing else, Allen's presence at SRC gives a high visibility to polymer science within this principal research-funding organization of the UK government. The Chemistry Committee of the SRC provides the support for fundamental studies on polymers. Research proposals are submitted to the committee and evaluated on the basis of their scientific merit and relevance. Once support is granted, the SRC exerts little influence on the course of the research and reviews progress only annually or, at most, semiannually. On the other hand, the Polymer Engineering Directorate (PED), which is part of the SRC, takes a different approach in selecting research topics, funding, and monitoring. The PED (*ESN* 33-5:189 [1979]), which until recently was headed by Dr. Anthony Challis, selects research topics very specifically. Problem areas in the British polymer industry are identified and universities are solicited to submit research proposals to address these problems. The subject areas in which the PED provides funding include the significance of impact testing, design parameters for glass-reinforced plastic (GRP) piping, compilation of engineering data for plastics, and the development of MS courses for polymer engineers. One result of the activity is that some highly competent polymer scientists are doing fundamental research that is immediately relevant to the needs of the plastics industry. Private industry is also a major source of funding for polymer research. This financial support comes in various ways: direct grants, which are usually for short-term applied research; joint funding by industry and government (mostly from the Department of Industry) for long-term applied research aimed at some specific recurring industrial problem; and financial assistance to students that may come as direct support or as participation in "sandwich" study programs. Under the sandwich system the student interrupts his studies after 1 to 2 yrs to spend 6 to 12 months in industry and then returns to the university or polytechnic to complete his course work. As an example of industry-government cooperative funding, there are consortiums concerned with GRP pipe and with polyvinyl chloride (PVC) pipe. In both instances a number of industries, which include chemical companies, fabricators, and piping users, have combined with government agencies to try to determine why there are unanticipated failures in the field and to develop better design standards to avoid failures. The consortiums are funding fundamental research on failure mechanisms and engineering studies to establish standards for design and production. (*ESN* 34-3:125, *ESN* 34-4:183, *ESN* 34-7:330, all 1980).

Compared to other government agencies and private industry, the Ministry of Defence (MOD) funds little polymer research in universities. In fact, MOD support of research is not nearly as pervasive as that of the DOD in the US. Much of the work is done in-house even to the production of specialty chemicals including some polymeric materials. I was much impressed with the in-house capability in polymer research and development I saw at the Propellants, Explosives, and Rocket Motor Establishment (PERME, Waltham Abbey, *ESN* 34-3:125 [1980], *ESN* 33-12:515 [1979]). There is some contract research, but usually it is a matter of a MOD scientist funding a university colleague to work jointly on some specific topic of mutual interest. The concept of a contract manager monitoring a large number of research programs has not taken hold in the UK to the extent it has in the US.

One of my friends at PERME, Dr. A. J. Kinloch, pointed out that he is fully involved in a project from the research stages through development to implementation in the field. He finds this very satisfying.

When I went to the UK, I had the preconceived notion that research was very academic and had little relevance to industrial practice. In actual fact, I found the situation to be quite the contrary. Most of the polymer science work I learned about was quite fundamental but was also deliberately application oriented. Two examples illustrate this point. Prof. Ian Ward (Univ. of Leeds, *ESN* 33-7:283 [1979]) is well known for his work in polymer physics, especially his studies of highly oriented polyethylene and other linear polyolefin polymers. After a preliminary discussion of the molecular details of ultra-oriented polyethylene, he showed me the power plant used by the Physics Department to produce sizable quantities of highly oriented polyethylene fiber. I have learned since that he is very active in finding commercial applications for polyethylene fiber and expects to license its production in the US. Another example is Prof. M. Bevis (Brunel Univ.) who developed a reputation for work on the microstructure of polymers at the University of Liverpool. At Brunel, Bevis is building a strong polymers research group devoted to studying the fundamentals of polymer processing. Although much work has been done on the engineering of injection, compression, and blow molding, Bevis is focusing his attention on the physics of these processes and is investigating the ways in which processing parameters (temperature, pressure, etc.) affect microstructure (See *ESN* 34-5:228 [1981]). It would appear that, as in the US, the shortage of funds for pure research without clear-cut, near-term application has forced many university research people "into the streets" to find practical problems and practical people who can use their skills. In a way, this is a return to the point where research in the UK began. Many of the universities of the Midlands—Manchester, Liverpool, Leeds—had their origins in the industrial revolution and were created to supply the technical competence needed by a rapidly growing industrial nation.

Polymer Science in Ireland

A short visit to the Regional Technical College (RTC) in Athlone (*ESN* 34-8:395 [1981]) to attend the conference on "The Role of Polymer Technology in Ireland" is hardly a sufficient basis for a fair appraisal of polymer science in Ireland. Nonetheless, I discerned a concerted effort to develop native engineers for the Irish plastics industry, much of which consists of multinational companies, but which also has an increasing need for locally trained professionals. The RTC at Athlone is devoted to training polymer engineers—mostly in synthesis and processing. With government and industrial funding, it is adding to its polymer processing equipment in order to provide more hands-on training. The native plastics industry is beginning to develop and because of favorable exchange rates is finding markets in Europe. Some of this growth has come about from government-sponsored, matching-funds projects for plant expansion and research to improve productivity.

Polymer Science on the Continent

Polymer research in Germany, France, Spain, and Italy is surprisingly diverse in both the level of activity and the quality of work. There is much evidence of the impact—both good and bad—of the social and political changes that have occurred since WWII. With its resurgence as a strong industrial nation, West Germany has had a parallel development in fundamental and applied polymer research. In France, the bulk of the research capability in all fields is contained in the laboratories of the Centre National de la Recherche Scientifique (CNRS), a government agency. I had the impression that CNRS, being within a governmental framework, did not experience the same pressures to make all research clearly relevant to practical problems as did the research organizations in most of the other countries I visited.

Polymer research in Spain, until very recently, was rather limited. Most of the industry in Spain was dominated by multinational corporations who did their research at central laboratories in other countries. In the last few years the Spanish government has been trying to encourage local industry and to develop the scientific-research base needed to support new industry. The situation in Italy is unfortunate. In the 1960s Italy was prominent in polymer research. Since then, government policies, which are now in the process of being reversed, resulted in the disbanding of research teams and the restructuring of universities, all of which has led to incompetent staffs and poorly-trained students.

As in the UK, a great part of the research on the continent is funded by governments. I have already mentioned the CNRS in France. In Italy, government funding comes from the Consiglio Nazionale delle Ricerche (CNR), which provides the bulk of the research money for both universities and CNR institutes. A similar arrangement exists in Spain, where funding is controlled by the Consejo Superior de Investigaciónes Cientificas (CISC: Council for Scientific Research). The situation in Germany has its own unique character. Government-controlled research is less pervasive, but it is there, nonetheless. For example, the Institute für Kunststoffverarbertung (IKV Aachen) is devoted to research and development for the plastics industry. IRV is a membership research organization which obtains some funding from the member industries situated not only in West Germany but throughout the western hemisphere. Research and development priorities and directions at IKV are determined by committees formed by representatives from the polymer industry and from the IKV staff. However, the bulk of the funding at IKV comes from the government, which has relatively little input as to how this funding is used.

Polymer Science in France

In Strasbourg I visited the Centre de Recherches sur les Macromolécules (CRM) headed until recently by Prof. H. Benoit, who is now at the Université Louis Pasteur (*ESN* 34-1:20 [1980]). I was impressed with the level of effort especially in polymer physics where they are studying the conformation of molecules in both dilute and concentrated solution and in the solid state. It was there that I gained the impression that there was no great concern about whether the work was of immediate practical significance. This is not to imply that a potential area of application could not be identified. However, such identification was not a major consideration in justifying the work.

At the 14th International Reinforced Plastic Conference held at the Centre de Documentation du Verre Textile et des Plastiques Renforcés, Paris, on 28 March 1979 (*ESN* 33-9:368 [1979] I had a glimpse of the level of industrial research on composite materials not only in France, but elsewhere in Europe. My general impression was that it was primarily application oriented and not especially sophisticated. However, industry-sponsored meetings can be deceiving; a visit to Prof. T. Vinh at the

Laboratoires de Electronique de Rhéologie et de Traiterieur des Matériaux et de la Construction Mécanique (Paris) revealed a sophisticated research program in continuous-fiber, organic-matrix composites. This was especially true of Vinh's work on the dynamic elastic properties of these materials (*ESN* 34-3:125 [1980]).

Polymer Science in Germany

West Germany is said to have the strongest economy in Europe and a visit to any of its research institutes or universities would seem to confirm this. As already mentioned, the IKV, although attached to the University of Aachen, is an independent research institute devoted to the plastics industry (*ESN* 34-8:395 [1980]). The emphasis at IKV is on computer control of polymer processing operations, specifically, injection molding and filament winding of composites.

The Deutsches Kunststoff Institut (DKI, Darmstadt), like IKV, was organized by an association of German chemical industries for the purpose of training engineers and scientists for the West German polymer industry (*ESN* 35-3:116 [1981]). Also like the IKV, the DKI is associated with a university—the Darmstadt University of Technology. However, the association is a loose one, although it seems to be a stronger connection than that between IKV and the University of Aachen. In the 28 years of its existence, the DKI has evolved beyond simply teaching to become a major research institute providing basic information for the polymer industry (membership in the governing organization now includes many companies from outside West Germany). I got the impression that the work at the DKI was somewhat more in the domain of science and less in engineering than that at IKV. One of the largest programs at DKI is on polyvinyl chloride (PVC). The work includes UV stabilization, processing, and polymerization chemistry. The documentation department at DKI was created in 1973 as part of the West German government's efforts to develop centers for the collection and collation of chemical information. DKI was designated as a center for plastics information.

I visited the BASF (Badische Anilin Und Soda Fabrik) Center Laboratories in Ludwigshafen, the polymer research groups in the department of General Physics of the University of Ulm (*ESN* 35-6:225 [1981]), and the Institut für Makromolekular Chemie at the University of Freiburg (*ESN* 35-6:225 [1981]). As might be expected, the work at BASF is for the most part applied, but there was nevertheless a good deal of highly focused fundamental research. I was very much interested in the elastomer-toughened plastics research, which has been an ongoing, highly regarded effort for over a decade. The research at Ulm and Freiburg was, of course, highly fundamental. The principal areas of investigation are polymer crystal structure and molecular conformation.

Polymer Science in Spain

As was mentioned earlier, polymer research effort in Spain is relatively modest (*ESN* 34-9:440 [1980]). Until recently, multinational companies dominated Spanish industry and provided their own research capability. However, in recent years a rapidly growing nationally based plastics industry has developed with an increasing need for local research support. This has prompted CISC to try to direct university research efforts towards more applied problems. For example, the Departmento de Química Macromolecular in the Escuela Técnica Superior de Ingenieros Industriales (Technical School for Industrial Engineers, Barcelona), which had been largely involved in the structure of biopolymers, has been directed to become more involved with synthetic polymers and so has begun a modest effort on the crystal strúcture of polyethylene and nylon.

Two centers of polymer science which were in the mainstream of research and development well before the revitalization of the plastics industry in Spain are the Instituto de Plásticos y Caucho (IPC, Institute for Plastics and Rubber, Madrid) and the Instituto de Estructura de la Materia (IEM, Institute of Material Structure, Madrid). At IPC about 30% of the effort is devoted to fundamental research, 40% to applied research, and the remainder to development. I was much impressed with the staff and the level of R&D effort. The director, Dr. J. Fontán, has worked extensively on the degradation of polyvinyl chloride and the development of thermally stable polymers. Dr. J. Royo heads the rubber group at IPC and is involved in fundamental work on inorganic fillers for elastomers, contract work for industry, and the development of standards in plastics and rubber for the Spanish government's department of standards. In fundamental polymer physical chemistry, Dr. J.G. Fatou is known internationally for his work on the thermodynamics of polymer crystallization and crystal conformation.

At IEM, polymer research is largely contained in the Macromolecular Physics Department headed by Dr. Baltá Callega, whose research is almost entirely in the microstructure of crystalline polymers and its relation to physical properties. The work is all fundamental and is definitely in the mainstream of polymer science research. The department is well equipped with sophisticated instrumentation for x-ray scattering, nmr, and ir spectroscopy. However, one of Baltá Callega's major contributions was accomplished by a relatively simple technique—microhardness measurements—to investigate the crystal structure of polyethylyene, including the highly oriented, ultrahigh modulus material.

Polymer Science in Italy

The influence of G. Nata on Italian polymer science during the 1960s is still in evidence. At the Milan Polytechnic I visited Prof. G. Zerbi, one of Nata's coworkers, who has done considerable research in the vibrational spectroscopy of polymers (*ESN* 35-2:70 [1981]). He is particularly interested in the structural defects in crystalline polymers that can be detected and characterized by infrared vibrational spectroscopy, Raman spectroscopy, and neutron scattering. Prof. L. Porri is also at the Milan Polytechnic, but his work is on the mechanisms of the stereo-specific polymerization using Nata-Ziegler catalysts.

Both Zerbi and Porri working are in the same research areas they were involved in when they were Nata's students and later his co-workers.

In Padua I visited Prof. M. Manni, who heads the CNR Biophysical Research Center at the University of Padua. I was much impressed with the enthusiasm of the staff at the center, the broad range of work they are doing in protein synthesis and structure-property relationships, enzymes from thermophilic bacteria, studies of model polypeptides, x-ray investigation of natural and synthetic biopolymers, and biomedical applications of enzymes.

Biopolymers are also emphasized in the Institute of Physical Chemistry at the University of Rome, where I met Prof. F. Conti. Conti is a spectroscopist who is using nmr and ir spectroscopy to study the structure of phosphorylases and their interaction with proteins, the structure of cell walls, the interaction of membranes with enzymes, and the structure of polybutadiene and acrylonitrile butadiene styrene. Prof. A.M. Liquori has done considerable work on the thermodynamics of protein structures. Currently, he is using irreversible thermodynamics to model membrane transport, and as an outgrowth of this work he has developed a generalized Onsanger theory. Prof. E. Giglio is an electron diffractionist who is studying the structure and conformation of biomaterials and synthetic polymers.

Polymer Science in Israel

Israel is an island of western science in the Middle East largely because the principal investigators have come from western Europe, the US, and, to a limited extent, from the Iron Curtain nations. Moreover, it has been the policy of the Israeli government to send scientists and engineers on sabbatical leaves to western countries on a regular basis. The policy has been largely curtailed because of inflation, but sabbaticals funded by the host institutions are encouraged. Such contacts have kept Israel in the mainstream and in many cases at the forefront of science. Without such contacts, scientists in Israel feel isolated.

Although various circumstances make it impossible to report on current efforts in polymer science in Israel, mention should be made of some of the people I met during my visit and the areas in which they are active. Dr. Y. Tirosh (Technion, Haifa) has worked extensively in experimental and theoretical fracture mechanics including work on organic matrix composites. Some of this work has been for the US Navy in collaboration with Dr. I. Wolock at the Naval Research Laboratory. Also at Technion is Dr. O. Ishai, who has studied the flow behavior of liquid suspensions of short fibers and the stress distributions in composites and in adhesive joints. Prof. D. Katz has done extensive work on the structure of polysiloxane films. At the Casalie Institute of the University of Jerusalem, Gad Maron heads a small group devoted to research on organic-matrix composites and adhesives. Despite the small staff and limited facilities, Maron has made notable contributions to many aspects of composite materials.

Polymer Science in Egypt

In contrast to the situation in Israel, scientific research in Egypt is quite limited and fraught with political and economic difficulties (*ESN* 34-9:437 [1980]). The funding available for research is extremely limited and the physical facilities and equipment are often primitive. Nonetheless I was able to contact a few groups that were doing very respectable research. The University of Alexandria Research Center (UNARC) was started with considerable financial help from UNESCO. The concept and formation of UNARC, however, are largely attributable to its present director, Prof. El-Sadr. Except for administrative personnel, the center has no permanent staff. It accepts scientists from Egypt (and to some extent from abroad) to conduct research for a few years in areas essentially of their own choosing. There is no requirement that the research be application oriented. However, during my visit I found that many of the projects were specifically directed to problems Egypt faces today. In Cairo I visited the National Research Center (NRC) and Cairo University. My general impression was that a few individual scientists are able to maintain viable research programs. At the NRC I visited Dr. N.A. Gahenem, who heads the chemical industry section. Gahenem's work is wide ranging and includes paints, coatings technology, cellulose chemistry, pesticides, and ceramics. He is best known within the US Navy for his work on antifouling paints.

Among the people at the University of Cairo I met was Dr. M.G. El-Sherbiny, a well-educated and extremely energetic young scientist. He had studied under Prof. D. Teer at the University of Salford (UK) on ion implantation and ion plating. Presently, he is setting up an ion plating facility at the University of Cairo. The main application of ion plating that El-Sherbiny plans to pursue is to develop corrosion-resistant coatings, specifically, coatings that reduce stress corrosion between titanium fasteners and aluminum skins on aircraft. He hopes to get some funding for his work from Europe or the US.

Some General Trends

The majority of the polymer research I learned about falls into three major categories; mechanical deformation, molecular conformation, and organic-matrix composites. The categories reflect my own personal interests, but nevertheless serve as a convenient framework for discussion.

As in the US there is considerable interest in polymer deformation, especially fracture (ONRL Report C-4-79). The reason for this is fairly obvious. Polymers are finding increasing use as structural materials, but field experiences reveal unexpected failures that in many instances appear to be due to brittle fracture even for such tough materials as high-density polyethylene. As a result, there are an increasing number of people attempting to characterize polymer fracture. Linear elastic fracture mechanics (LEFM) can reasonably handle the fracture of relatively brittle materials such as the epoxies or polyesters, but LEFM becomes highly suspect when dealing with such ductile materials as polyethylene. Not the least of the problems is to develop a specimen size or test technique that simulates the plane-strain conditions that exist in the field.

In the recent past, guessing at the molecular configuration of polymers, especially in a solid state or as melts, has been done from macroscopic examination, mostly rheological measurements. This situation is beginning to change as new techniques such as neutron scattering, photocorrelation spectroscopy, and advanced nmr and ir spectroscopies are being used increasingly to probe molecular configuration directly. I sense that the activity in Europe is greater than in the US. This is certainly true in the case of neutron scattering because of the neutron research facilities at the Institut Max von Laue Paul Langevin in Grenoble, France, which was built and is operated jointly by UK, West German and French scientists. Much of the theoretical development that occurred during the 1960s and 1970s, especially in network theory, is being given close scrutiny by means of these and other techniques (*ESN* 33-1:460 [1979]).

Polymer matrix composites unquestionably represent a major area of polymer research and development in Europe and Israel as they do in the US. The materials range from particulate filled polymers to continuous fiber glass and graphite-reinforced plastics. In addition to the role these composites play in the manufacture of GRP pipe, there is pressure from resin and fiber manufacturers to increase their use in automobiles, primarily because of the large market the automobile industry represents (*ESN* 33-5:186 [1979]). There is a certain amount of resistance in the automotive community to the use of composites because of the lack of data and experience and also because of a subjective antipathy to "plastic cars." The driving force to get composites into automobiles in order to reduce weight is not so strong in Europe as it is in the US, because most European cars are already small. However, the opportunity to replace energy-intensive metals with less energy-intensive polymers is compelling. Composite materials also represent a way of extending polymers that are expected to become more expensive as the price of oil increases.

<u>Surface Science</u>

There are far fewer research groups, in either academia or industry, devoted to research in surface science or colloids than are engaged in polymer science. There is one renowned group, however, at the Cavendish Laboratory, University of Cambridge, which was established by Prof. David Tabor and the late Prof. F.P. Bowden. Tabor is about to retire and it is likely that the work in surface physics will come to an end (*ESN* 33-6:231 [1979]). In the School of Chemistry, University of Bristol, Prof. R.H. Ottewill has developed a center of excellence for surface science built largely from a special grant from SRC. A similar center of excellence is being developed at the University of Strathclyde in

Glasgow. In France, the CNRS has a number of laboratories with groups devoted to various aspects of surface science and colloids. There is an effort to centralize some of the groups at the Centre de Recherches Sur La Physico-Chimie des Surfaces Solides in Mulhouse, southern France. The center is headed by Prof. J.D. Donnet and is very actively involved in both surface science and polymer research (*ESN* 35-6:228 [1981].

In the Department of Physics at the University of York there is a group involved in surface analysis by means of electron diffraction and electron scattering techniques, notably low-energy electron diffraction (LEED, [*ESN* 33-3:100 (1979)]). The work at York is closely coordinated with similar studies by Dr. J.D. Pendry at the Science Research Council laboratory in Daresbury. At the Loughborough University of Technology, Dr. J.M. Walls in the Department of Physics leads a sizable group that is involved in research and development on surface analysis by Auger analysis, electron and x-ray spectroscopy, and field emission microscopy. A large part of Wall's effort is an analytical service for industry; his clientele includes about 40 companies (*ESN* 33-7:283 [1979]). The research effort in Wall's group is primarily on instrument development and data analysis techniques. The microelectronics industry has come to depend on these surface analysis tools, and there is a group, headed by Dr. R. Heckingbottom, at the Post Office Research Center (PORC) devoted to surface analysis (*ESN* 34-6:286 [1980]). The group has an array of equipment for Auger analysis, x-ray analysis, transmission and scanning electron microscopy, and molecular beam epitaxy. Much of the work at PORC is routine analysis but, as Heckingbottom pointed out, he likes to have his people involved in fundamental surface studies and in instrument development. I found it interesting that at York, Loughborough, and PORC, most of the equipment is "homemade." This is so partly because it is cheaper to improvise what is required than to buy commercial instruments and partly because of needs for specialized instruments devoted to specific analytical problems.

Tribology is the study of the friction, lubrication, and wear of solids. The term originated in the UK where there has been a great deal of activity in the field, especially at Imperial College (Univ. of London) and at the Royal Aircraft Establishment (Farnborough) under Dr. J.K. Lancaster. I was also impressed with the extensive work by Dr. M. Godet at the Institut National des Sciences Appliqués in Lyon, France, and the work of the group at the Laboratoire de Tribologie at the Institut Supérieur des Materiaux et de la Construction Mécanique in Paris headed by Prof. J. Blouet. There is much communication between Lancaster, Godet, and Blouet (*ESN* 34-7:335 [1980]).

As might be expected, there is extensive research and development in surface physics and surface chemistry in European industry. Certainly, this is the case at the Research Center of the British Petroleum Company (Sunbury-on-Thames, [*ESN* 34-10:475 (1980)]) and at BASF (Badische Anilin und Soda Fabrik, Ludwigshafen, FRG [*ESN* 35-7:263 (1981)]). At the BP Research Center I was fascinated by the development of stable coal-oil dispersions and the efforts to use the dispersions to fire ship boilers. At BASF the primary surface studies are related to paint coatings. Both BP and BASF are engaged in catalysis R&D but it is all highly proprietary.

Adhesion science is sometimes considered a subdivision of surface science. In fact, the topic is so interdisciplinary it is almost meaningless to try to categorize it. Much of the research in the field is devoted to the mechanical properties of adhesive bonds, which are largely determined by the cohesive behavior of the adhesive. Rarely is it possible to measure the intrinsic work of adhesion between two solids. There are some exceptions, however, and I found a technique developed by Tabor at the Cavendish Laboratory especially intriguing. The experiment essentially involves a very smooth rubber hemisphere mounted on a balance; as the hemisphere is allowed to approach another solid, usually a flat surface, a weak but discerrable force of attraction can be measured. The force required to separate the hemisphere from a substrate is also measured. From these measurements the thermodynamic work of adhesion can be computed after the energy dissipated by the viscoelastic deformation of the elastomer has been discounted. Meaningful results require very careful attention to experimental detail but the rewards are worthwhile. By varying the substrate, the elastomer, and the surrounding environment it is possible to learn a great deal about the forces of attraction between solids. The work with this experiment at the Cavendish was terminated some time ago but experiments of this type and variations on the theme have been continued by Tabor's students Dr. A. Roberts and Dr. K.N.G. Fuller (Malaysian Rubber Producers Research Association, Welwyn Garden City, UK [*ESN* 33-8:321 (1979)]) and Dr. B. Brisco (Imperial College, Univ. of London). Prof. R.H. Ottewill (Univ. of Bristol) has used the technique to investigate the interaction of macromolecular layers adsorbed on the elastomer and substrate. Dr. D. Mausis (Laboratoire de Mécanique des Surfaces de CNRS, Meudon, France) has done an extensive theoretical study of the experiment.

Colloid science, that venerable subdivision of surface science, has waxed and waned in popularity over the past century. Colloids are those materials where the particle subdivision lies somewhere between the molecular range and macroscopic particles (submicron diameters). Recently there has been a revival of interest in colloid science, at least according to the people attending the Summer Conference at the Center for Marine Research of the Rudjer Boskovic Institute in Cavtat, Yugoslavia (*ESN* 33-12:491 [1979]). In the words of Dr. E. Matijević (Clarkson College of Technology, Potsdam, New York) "the importance of colloid phenomena in manufacturing processes, in biology and physiology, and in environmental pollution control is well recognized and this recognition is reflected in large increases in attendance at conferences on colloid and interface science especially by people from industry." Considering the pervasiveness and importance of colloidal phenomena, this author hopes that Matijević's optimism is justified.

Conclusion

It is difficult to make any meaningful, broad generalizations about research in Europe and the Middle East. The sampling is just too small. It can be safely said that research in polymer and surface science is alive and well and in some specific areas outstrips the corresponding activity in the US. Except perhaps for Germany, the level of funding is generally less than in the US. Consequently, there is less tendency to do "shotgun" experiments that attempt to cover all the possible variables. In my opinion, the British are especially adept at devising the incisive and decisive experiment to address a scientific question. As inflation and government policies reduce the funds available for scientific research in the US, we might do well to adopt this trait from our contemporaries in the United Kingdom.

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