COMMITTEE 07, POLYMERS ETC.

AREA 071, ELASTOMERS, PLASTICS AND RESINS

INTRODUCTION

Worldwide, the plastics industry is growing at the rate of about 10% per annum as compared with 3% per annum for the steel industry[1]. This is only one factor which contributes to making high polymers one of the fastest expanding fields of chemistry. It has been claimed[2] that 40% of the chemists and chemical engineers in the United States are employed in some aspect of the macromolecular industry either relating to natural polymers, such as cellulose, lignin, natural fibers, proteins or starch, or to synthetic polymers such as plastics, fibers and elastomers, or to the consuming industries such as the manufacture of adhesives, sealants, protective coatings, films, mouldings, extrusions, rigid and flexible foams, rubber goods, textiles, or paper. Another estimate[2] suggests that 70% of the graduates in chemistry and chemical engineering will begin employment in the macromolecular based divisions of the companies for which they are employed.

If one disregards natural and synthetic fibers and natural polymers such as cellulose and lignin which are more properly reviewed by other Committees, there still remains a very sizeable industry devoted to the synthesis and characterization, or utilization and conversion of synthetic elastomers, plastics and resins.

Some idea of the rate of growth of research in this field can be obtained from the proliferation of the literature[3]. Chemical Abstracts published just under 30,000 abstracts of original articles in 1946 and just over 180,000 in 1966, a sixfold increase. Over the same period the Journal of Polymer Science[4] and its various divisions grew from 600 pages in 1946 to nearly 9,000 pages in 1966, a growth rate more than double the average. This was accomplished in spite of competition arising from the formation and equally phenomenal growth of a number of other polymer journals, and an increase in the page size of the journal itself.

HISTORY OF HIGH POLYMER RESEARCH AND DEVELOPMENT IN CANADA

With such growth taking place one can wonder how Canadian participation fared over the same period. A recent review[5] showed without a doubt that many aspects of polymer science were being actively pursued across Canada. Nevertheless, there were many gaps and serious problems.

Industrial activity in the polymer industry goes back over 100 years[6,7]. As early as 1854 rubber footwear was manufactured by a company which was the forerunner of Uniroyal in Canada. Conversion of cellulose nitrate began as early as 1906 and production was undertaken during the following decade by Canadian Explosives Limited whose products found their way into such early synthetic based materials as paints, films, and coated fabrics (Fabricoid). However, the first truly synthetic high polymer was phenolformaldehyde resin produced in Canada in 1909 by a company owned by the pioneer Canadian scientists H.T. van der Linde and Dr. W.G. Cohoe. The most spectacular advance was made by Dr. F.W. Skirrow, G.O. Morrison and later Dr. K.G. Blaikie of Canadian Electro Products, (Shawinigan Chemicals Limited) who in the decade following 1917 discovered vinyl acetate, and the polyvinyl acetals which were to lead the way in the truly synthetic high polymer industry for some time.

In 1925 Courtaulds introduced rayon, in 1928 Canadian Cellanese produced cellulose acetate, and in 1931, Canadian Industries manufactured cellophane, all based on the natural high polymer, cellulose.

The pressure of wartime needs and activities encouraged new enterprises. In 1939, just before the war, the Naugatuck Division of Dominion Rubber started production of the first synthetic rubber in Canada, Thiokol, a polyalkylene polysulfide rubber of use in fuel resistant applications as in sealants, gaskets and tank liners. In 1941 Shawinigan Chemicals Limited branched out into polyvinyl chloride and its copolymers through Canadian Resins and Chemicals. However, the major growth and diversification was to come at Sarnia, Ontario, where Polymer Corporation Limited came into being in 1942.

The story of Polymer Corporation Limited may be found in numerous references(8). It is sufficient to record here that through the foresight of the late Honourable C.D. Howe, and a committee under Mr. J.R. Nicholson, a completely integrated complex of synthetic rubber producing facilities was financed by the Canadian Government according to a mater plan integrated with that of the United States. Subsequently this group of plants formed the nucleus of the present Polymer Corporation Limited operations. Soon other industries established synthetic polymer production facilities nearby, particularly Dow Chemical of Canada Limited,Du Pont of Canada Limited, and Imperial Oil Enterprises Limited.

The historical importance of the establishment of Polymer Corporation Limited, and the growing of the Sarnia petrochemical industry, is severalfold. Firstly,production began in Canada of the basic monomer units for many synthetic high polymers; butadiene, styrene, and isobutylene at first; later ethylene and propylene; and still more recently vinyl chloride and acrylonitrile, with potential for still further diversification. Secondly, the initial butadiene-styrene copolymers, butadiene-acrylonitrile copolymers and isobutylene-isoprene copolymers produced by Polymer Corporation Limited formed the basis of an extensive series of related elastomers, thermoplastics, and blends. Thirdly, Dow Chemical of Canada Limited, which was originally involved in the production of styrene at Polymer Corporation, set up its own styrene unit in the mid 1950's to supply its polystyrene unit which had utilized styrene from Polymer Corporation Limited since 1947. Dow subsequently started production of styrene copolymer latices and polyethylenes to be followed shortly by Du Pont of Canada in the latter field. The establishment of new units has continued, with Imperial Oil Limited still more recently starting production of polyvinyl chloride in Sarnia, based on purchased monomer.

Outside of Sarnia two centres have become active. Polyethylene was made first in Canada at Edmonton by Canadian Industries Limited who were later joined by Union Carbide in Montreal, bringing the producers of polyethylene in Canada to four. Since the second world war production of acrylic fibers (Orlon) and of polyamide fibers (Nylon) has started in the Montreal-Kingston area based on imported monomers. A beginning was made towards domestic courses of monomers for these fibers when acrylonitrile for acrylic fibers became available from Imperial Oil Limited at Sarnia.

While Canadian production of the basic, large volume synthetic elastomers, plastics and resins is an accomplished fact, there has not been continued growth into the new specialty fields. Indeed some older, well established products such as silicones, fluoroelastomers and fluororesins, the acrylate and methacrylate resins, polypropylene, as well as the whole generation of new plastics such as the polycarbonates, polyacetals, polyphenylenes, polyphenylene oxides and sulfides, polysulfones, polybenzimidazoles and related types, the polymeric carbons, the ladder and spiro polymers, and numerous others which have arisen predominantly during the space age research in the United States, are still neither being produced nor studied actively in Canada.

This encouraging but nevertheless incomplete industrial activity has had a comparable but less extensive counterpart in the field of academic research. Research started early, certainly under Dr. G.S. Whitby who was at McGill from 1920 to 1929 and at the National Research Council from 1929 to 1939. Indeed Dr. Whitby's early work on rubber and polystyrene represents truly pioneering research on the colloidal and macromolecular nature of these then novel structures. Dr. A.C. Cuthbertson of Mount Allison University studied polyvinyl acetate in the 1930's but otherwise little evidence of academic interest in the new field of high polymers was to be noted for sometime. Elsewhere in the world the science necessary for the impending rapid advance of the field was being developed by scientists of I.G. Farben in Germany, and to a lesser extent those of Standard Oil of New Jersey, Goodyear Tire and Rubber Company, Firestone Tire and Rubber Company, B.F. Goodrich Tire and Rubber Company, Dow Chemical Company, and E.I. DuPont de Nemours and Co. Inc., as well as by such well known names in the fields of high polymer research as Staudinger, Mark, Flory, Huggins, Melville, Treloar, Gee, Salomon and Medvedev to name only a few.

These early research efforts were to receive tremendous assistance from the massive synthetic rubber programme in the United States at which time such pioneers as Marvel, Kolthoff, Ferry, Maron, Kharasch, Debye, Philippoff, Tobolsky, Heller and many others started active research. This same impetus was given to Canadian research effort since, as part of the agreement whereby Polymer Corporation Limited was set up, there were agreements to establish in Canada both a basic research group and a development group to support this endeavour.

The basic research group was administered by the National Research Council and sponsored elastomer research at various universities under the guidance of scientists such as Winkler, Rinfret, Cragg, Sivertz, and Ivey. Although the support by the National Research Council has ceased to be separate from the normal research grant system, a number of those now receiving support for high polymer research belong to an Associate Committee on High Polymer Research which meets to discuss common problems and until recently, sponsored the highly successful Canadian High Polymer Forum. Several new research groups are being formed which will undoubtedly play significant roles in the future in the expansion of academic research.

The development side of the agreement was met by establishment at Polymer Corporation Limited of a broadly based and rapidly growing Research and Development Division, which undertook basic research, applied research, and development, and gave rise to a separate Technical Service laboratory. The large and modern laboratories in toto are able to synthesize new monomers, polymerize these by free radical, anionic, cationic or coordination complex catalysts to polymers, characterize these polymers as to molecular weight and structure, fabricate these polymers into test pieces and within limits, fabricate test items simulating consumer products.

Over the same period several other Canadian industrial laboratories[5] established sections devoted to the study of high polymers. While not on the scale of those at Polymer Corporation Limited, each in its field represents a sizeable and powerful force. Some of those with research groups which have significant research efforts on synthetic high polymers include Canadian Industries Limited, Du Pont of Canada, Shawinigan Chemicals, Domtar, Dunlop, Uniroyal, Dow, Imperial Oil, Reichhold and Glidden. One should not omit the fact that basic work is underway at the Division of Applied Chemistry of the National Research Council and applied research is active in the Division of Building Research of the National Research Council, the Ontario Hydro-Electric Power Commission Laboratories, and the Ontario Research Foundation.

Present Status

In dealing with research and development in a historical way the division of work between Universities and Industries is not brought out clearly. In fact, industrial work has been centered largely, and correctly, around the problems of synethesis of polymers and characterization of their properties with the view of extending their uses. Much of the University work has tended to centre around structure and the broader physico-chemical problems which do not enter into the sometimes restricted and confidential aspects of business operations. Regardless of the nature and purpose of the work, interest in macromolecular science has grown. Most of the university activity is centered in small groups of one man with his students and assistants. However, special mention must be made of the Division of Polymer Chemistry of the Department of Chemistry of McGill University. There a group of four scientists leads a team of over 25 working on all aspects of polymer science. This group works closely with the Pulp and Paper Research Institute of Canada on the same campus and allied to the Department of Chemistry although interested in natural polymers. The interaction is most beneficial since the resources of some 80 scientists including graduate students can be mustered.

Although various courses in polymer chemistry are available at Universities at both the undergraduate and graduate level there is not yet available a degree in polymer chemistry. Since degrees of this type are becoming more common elsewhere one can reasonably assume that polymer chemistry will take its place alongside radiochemistry, biochemistry and the other interdisciplinarial branches of chemistry as a major subject in both undergraduate and graduate courses. In the international scene this has long been noted through the formation of the Society for High Polymers in Japan, the Division of Polymer Chemistry of the American Chemical Society, and the more recent incorporation of a Division of Macromolecular Science in the International Union of Pure and Applied Chemistry. In Canada the formation within the Chemical Institute of Canada of a Division of Macromolecular Science should give Canadians strong representation in international macromolecular circles and stimulate interest in macromolecules.

In the absence of major schools of polymer science in the past, there has been no accumulation of experienced polymer scientists. Most of those who remained active classified themselves as physical or organic chemists interested in high polymers. More recently a considerable number of polymer scientists with long services in industry moved to McGill University, the University of Toronto and the University of Waterloo to establish "instant" high polymer activity. Nevertheless, much remains to be done to expand these groups and to establish others by attracting to Canada and to University life well trained and experienced individuals who can act as teachers and research directors for the graduates who are destined for careers in polymer chemistry. One of the opportunities for the Science Council is to establish chairs, departments or institutes of polymer science taking into account local interests and local strengths. Also funds might be used to bring prominent polymer scientists to Canada on sabbatical leaves or as visiting professors.

This immediately raises the problem of facilities and equipment. It is fortunate, perhaps, that high polymer chemistry does not require unusual facilities or equipment but rather modifications of known items. Unfortunately, the modifications are sometimes intricate and expensive so that instrumentation plays a major role. While the well established laboratories have many of nuclear magnetic resonance, electron spin resonance, microwave, light scattering, sedimentation, rheological, differential thermo-analysis, thermogravimetric analysis, infrared, x-ray, and other equipment, no single laboratory is completely equipped. Beyond the major centres of McGill University the University of Toronto and the University of Waterloo, the equipment is quite restricted in nature as yet. Almost completely absent are specific instruments such as high speed testing, torsional hysteresis, impact, rheological, and other equipment designed to characterize high polymers as distinct from small molecules. A major infusion of capital equipment into the existing and new centres will be required over the next decade at least.

The survey of research in progress indicates that most of the studies are on polymerization systems or polymers which have become well established commercially. There is comparatively little research work on the synthesis of new monomers or polymers upon which future industrial growth can be made. While work on improvements in the manufacture, use, and performance of existing types is commendable there remains the fact that Canadian science and technology is lagging behind that of many countries, particularly that of the United States. It is even noticeable that Canadian industry has not exploited available foreign technology, let alone developed advanced technology of its own.

The statistical data show very clearly how the research effort is distributed (Table 4.7-1, Table 4.7-2). Industrial laboratories appear to spend about 14% of the total research and development funds, on polymers. This expenditure is exceeded only by that on metallurgical research, and is just slightly greater than the percentage spent on chemical engineering. Greater than 60% of this effort is devoted to development, about 35% to applied research and about 5% to basic research. This distribution of effort is about right for industry although one might recommend more basic research. However, industrial performance far exceeds academic performance since the statistical data indicate less than one percent of university funds are expended on polymer research and less than three percent of university staff are assigned to organic polymer chemistry. Indeed industry appears to be spending three to four times as much as the universities on basic research.

This surprising anomaly has several explanations. Firstly, academic research has been mostly of a one man-one project type which indicates a breadth of interests but little real activity. Secondly, much of such activity has undoubtedly been absorbed into organic chemistry or physical chemistry in the Departmental budgets which may explain why polymer chemistry costs only one quarter the average. Thirdly, the major growth in polymer science in universities has taken place very recently and may not, indeed, be reflected in the statistics. Regardless of all the apologies, academic research on high polymers lags far behind industrial activity, and rates very low in the overall interests and activities of the University Community. Main growth and interest appears to be in the Departments of Chemical Engineering. The distribution of effort has been 80 - 90% basic research and the remainder applied research. Perhaps with Chemical Engineering Departments expanding their efforts, there may be more applied research in the future. A sixfold increase in academic research would be needed to balance industrial activity, however, and this growth is not immediately likely since it would involve changing the interest of present staff.

It is certainly true that the output of graduates trained in polymer science is in no way adequate for present needs or projected growth of the industry if the demand for skilled personnel reaches that existing in the United States.

Government laboratories are inactive in the general field of organic chemistry of high polymers although, as mentioned earlier, various laboratories have projects of interest to this field but which are classified elsewhere. This gap in government research has been noted as a significant one.

The Main Gaps

Two main gaps appear. One is work on new synthetic polymers and the other is study of polymer complexes of biological interest. The importance of synthetic polymers as materials from which to make substitute organs and parts of organs may be so vital to our health that research duplicating efforts elsewhere may be justified. There are several research groups in Canada whose efforts could form nuclei for greater effort in applying synthetic high polymers to human health and comfort.

The United States programmes in military research, space exploration, and atomic energy have encouraged an enormous amount of effort on new high performance materials, besides enabling other materials in the range of performance of engineering plastics to receive acceptance. Thus a whole generation of high performance plastics and composities useful for extrusions, mouldings, coatings, fibers, adhesives, and sealants has evolved and become commercial. Naturally the markets are very limited in Canada, the present materials are jealously guarded proprietary products of large foreign firms, and there is no background of experience here. Nevertheless, it seems reasonable that if Canada is to maintain a position in the production of advanced transportation and exploratory vehicles, some basic industry producing the improved materials must be encouraged and, if necessary, supported financially and by research and development effort.

This led the author in an earlier review[5], to suggest that a national objective was needed to form the nucleus for increased effort and that a possible objective was design and fabrication of living and working areas for the northland and transportation systems connecting them economically. Emphasis in the past has been on materials to withstand high temperatures in short-lived vehicles for air and space travel. In contrast there is also need for materials which will withstand low temperatures for long periods of time. A programme for study of structure and properties particularly in the search for such materials could be a national objective under the guidance of the National Research Council, the Defence Research Board or some other organization, with the assurance that if an adequate market developed there are industrial concerns able to undertake production of materials for which there is no conflict with the patents of others.

Future Patterns

Without a national objective, what is the pattern likely to be? What are Canada's needs? One can predict continued growth of academic research because of the interesting scientific problems which can be visualized. Several groups[5] are being formed or are growing, specifically at the universities of Simon Fraser, Calgary, Waterloo, Guelph, Toronto, McGill, McMaster and Montreal. In addition, as the graduates from these schools accept appointments at other universities it can be expected that new groups will form at these institutions in turn. The Division of Macromolecular Science and the Canadian High Polymer Forum,which is now part of the former, should form common meeting places for those with varied interests, and might even in the future be responsible for a journal of macromolecular science.

Perhaps under the stimulation of the discussions, some of the relatively unexplored fields might seem attractive to one or other of the academic groups. The subjects of addition and condensation polymerization have been active a long time. Certainly much good work can yet be done synthesizing and polymerizing new monomers and studying the properties and structures of the polymers. However, there is a place for centres of advanced study where new concepts can be explored in much the way that ideas such as replica polymerization, oxidative coupling, biochemical synthesis, or pyrolytic conversion have been studied intensively by institutes elsewhere. One of the major tasks of supporting bodies is to identify and support promising novel ideas at a time when these ideas are so nebulous that merely to define an objective is to lose the idea.

Over the next five years it is hoped that more emphasis will be given to the introduction of undergraduate and graduate courses in polymer science and more recognition of polymer science as a specialization at least comparable to nuclear chemistry or biochemistry in its breadth and importance in a university curriculum.

It is more difficult to visualize industrial trends. Undoubtedly existing laboratories will expand and new laboratories will be formed. However, the small size of the Canadian market suggests that industrial firms will not venture very far into new materials but will be content to produce and market, under licence if necessary, those materials which have attained some consumer acceptance in Canada. Somewhere along the line the specific needs of Canadians must be recognized either by government laboratories or agencies or by industrial research groups.

The appeal is often heard that those industrial concerns who market extensively in Canada should do some of their research in Canada. This may be a good suggestion but with the sophistication of modern research a splinter group may not be too effective unless very careful planning and coordination is practiced. Nevertheless, a splinter group under favourable conditions can be a happy solution to the problem.

Through such groups Canadians would contribute to the overall research effort of the industrial concerns from their homeland and their research would find worldwide use. In actual fact the chemical industry in Canada, and certainly those portions of it related to high polymers has been quite successful in this very philosophy. Several companies have made major contributions to the worldwide research and development effort from their Canadian Laboratories. Such items as the adhesives for Terylene tire cords by Canadian Industries Limited, the polyethylene process by Du Pont of Canada, the "beadlog"process* by Dow Chemical of Canada, the EPT process of Dunlop Research Centre, and the various "firsts" claimed by Polymer Corporation Limited in the fields of synthetic rubbers and thermoplastics are examples. The latter company introduced polyblends made by latex blending, soluble catalysts for the polymerization of cold rubber, oil extended Butyl and SBR rubbers, high gum tensile isoprene-acrylonitrile rubbers, and synthetic trans-polyisoprene, and more recently terminally reactive rubbers of a new type, all interesting new materials.

Other evidence of international cooperation is that of polyvinyl chloride in the ESSO organization. The technical aspects of all of the affiliated companies are handled from the Canadian organization. Not only is this obviously a matter of efficiency since other research and technical groups need not duplicate facilities and information available from Canada, but it clearly demonstrates that the Canadian research laboratories are on a par with the others. Other global companies should be able to use variations of this principle.

However, research in smaller companies is less easily justified and initiated. One of the major factors in introducing companies to research and its value has been the National Research Council Industrial Research Assistance Programme. This system whereby the expenditures on salaries are covered by grants,

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*large slabs of expanded polystyrene formed from expandable beads of polystyrene containing blowing agent.

providing the company supplies an approximately equal value of facilities and services, has been utilized by large companies such as Abitibi, Canada Packers, Canadian Industries Limited, Chemcell, Columbia Cellulose, Dow, Dunlop, Glidden, Imperial, MacMillan-Bloedel, Reichhold, Union Carbide and Uniroyal, as well as comparative newcomers to research, such as Abrex Specialty Coatings, Canada Glazed Papers, Canadian Technical Tape Limited, and Fiberglas Canada Limited. These companies have obtained support broadly in the field of high polymers. An assistance programme of the Defence Research Board supports mostly "hardware" projects, but some funds do assist projects in the high polymer field indirectly. However, there is no appreciable support for high polymers of the types used in space and supersonic vehicles or for use in unusual environmental conditions such as high energy radiation, high temperature, low temperature, ablative or abrasive atmospheres. The market for textiles, films and other products from the new materials are met by imported products.

While these assistance programmes have been very successful in initiating new research there has been a problem that a one-man/one-project type of study resulted. Perhaps a more flexible procedure of support will evolve so that industries may follow valuable leads more quickly, use experts to assist over limited periods of time, and change personnel and projects as the emphasis shifts.

In spite of the assistance programmes it is the feeling that Canadians are not yet utilizing fully the technology evolved outside of Canada. There may indeed be some tendency to try to duplicate or to circumvent existing technology rather than to licence a process and to expend funds thus saved on truly new and novel developments. The size of the Canadian market does not assure sales large enough to pay for extensive or expensive development programmes. Thus in making innovations in the development aspects of the chemical industry we must "think small" so that the product will be competitive economically.

Alternatively an aggressive export policy must be followed. However, basic raw materials costs are often so much more in Canada than elsewhere that only protection will allow a domestic industry to survive, and precludes export at a competitive price.

Another facet of development which is extremely expensive is evaluation, testing, and standardization. Equipment, particularly for such tests as environmental exposure is expensive and may not be required by any one company continuously. There would seem to be a place for an extensive and complete testing facility in Canada supported by contract testing from industry and government and, incidentally, available to university researchers on some appropriate basis. The funds released by elimination of duplication could be used for other aspects of research and development. Also this laboratory could expand the work of standardization and speed up comparisons and acceptances.

The cost of construction and operation of a comprehensive testing laboratory would depend greatly on the scope and the sophistication desired. A well-built laboratory of 10,000 to 15,000 square feet area costing about $500,000 would be ample for a beginning and could accommodate both heavy and light processing equipment, analytical equipment, files, storage, and office areas. Assuming a full time technical staff of four, one secretary and ten technicians an operating budget of $250,000 should be ample particularly if there are no additional overhead or depreciation charges. Such a nucleus could grow both in size and complexity as the demand for services increased.

An initial capital budget of as much as $250,000 might be desirable followed by an annual capital budget of perhaps $100,000 for a few years until the resources had become adequate for the service performed.

It would be important to locate this laboratory where the technical staff could have ready access to library facilities and also be near the rubber and plastics processing industry. This would suggest a location in Toronto or Montreal, perhaps in conjunction with some institution such as Ryerson in Toronto or École Polytechnique in Montreal, or one of the Universities.

The testing laboratory, or alternatively the National Research Council could act in another capacity. It is obvious that stimulation of research and development would result from the evolution of applications of high polymers that would benefit Canada. This requires collaboration between groups of companies engaged in synthesis, fabrication, and end use, and often the customer. For example, it seems improbable that casual coming together of the groups necessary to develop the northland will ever occur. Rather some leadership must come from an organization, probably governmental, which appreciates the problems and can gain the cooperation of the group devoted to mining and manufacturing, housing and transportation, and polymer synthesis and fabrication, as well as government or municipal officials so that an overall programme is possible. Arising from such cooperative development would be basic research projects of interest to university staff.

Finally some means must be found to encourage the highly speculative and costly development programmes which result from any successful research. A company should be expected to absorb some failures along with its successes but for many companies it appears that the chance of failure is in itself a great deterrent to action. Careful selection and evaluation of development projects may assist in reducing failures but this also greatly handicaps rapid advance in the face of worldwide competition. Unrestricted compensation for failures likewise is not a healthy approach. Some intermediate plan might be evolved whereby aid in the form of consultations can be given to assure success of reasonable projects, and "insurance" made available to cover costs of an intractable problem of importance to Canada which appeared reasonable on analysis but failed to make progress. Not to be neglected is a government supported idea exchange since one man's failure may well be of value to another under different circumstances. Perhaps Canadian Patents and Developments could list ideas and patents available which do not fit the objectives of the company which originated them.

References

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2. See various lectures by H.F. Mark and C.G. Overberger, specifically C.G. Overberger, C. and E. News, October 9, 1967, p. 88.
3. CAS today, ACS, 1967.
4. Interscience Publishers, Div. of John Wiley and Son.
5. Williams, Chem. in Canada, March 1967.
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Recommendations

1. The establishment of endowed chairs, complete departments or specialized institutes of polymer science should be encouraged, particularly where the opportunity of an institute of advanced study exists.

2. Highly trained personnel should be obtained on a permanent basis but as visiting Professors if necessary initially.

3. A massive infusion of new equipment, and perhaps construction of laboratories, is recommended with stress on equipment specifically for macromolecular research but not excluding equipment more usually associated with research on small molecules.

4. The establishment of undergraduate and graduate programmes in polymer science should be encouraged.

5. An outlet for the research expected should be made available in the form of a macromolecular journal.

6. Industries should be encouraged to broaden their production and research bases by utilizing new technology whether imported or self-developed.

7. Industries without previous research experience should be encouraged to establish research laboratories.

8. A plan for compensation for expensive developments of importance to Canada but which prove difficult or costly though worthwhile on analysis should be developed. Incentives for industry to accept a reasonable rate of failures to successes should be included in assistance programmes.

9. A broadly based testing laboratory specifically for Canadian conditions should be established with the necessary expensive equipment available to all.

10. An idea exchange whereby projects useful to other companies can be made available on a reasonable licencing basis should be established.

11. Governmental support should be used to encourage the development of new technology whether imported or self-generated which does not appeal to any Canadian manufacturer with the provision that, if successful, a Crown Corporation would be established to manufacture the product until the market could support competition.

12. A governmental body should be established or assigned the duty of determining national objectives and of coordinating the industrial and public group involved.

13. An effort should be made to expand or establish new institutes for contract research and development work, the services being available to all, but particularly to small industries.

Appendix

The data for this portion of the survey have been obtained over an extended period of time. Letters were written to many interested persons in universities, industry and government in 1966 requesting information which was summarized in a review published in Chemistry in Canada in March 1967. This was updated as seemed desirable by personal contact.

A circular letter was distributed to all members of the Division of Rubber Chemistry of the Chemical Institute of Canada, to most members of the Ontario Rubber Group and the Quebec Rubber and Plastics Group, and to all members in Canada of the Canadian High Polymer Forum. Recipients were invited to give their opinions and comments verbally at the time of the Canadian High Polymer Forum, the Division of Rubber Chemistry Meeting, or the Annual Conference of the Chemical Institute of Canada, or to send written comments later.

Some material from the ([illegible]),

A report by Dr. D.M. Wiles on the Physical Chemistry of High Polymers has been incorporated into this survey. The report was submitted in draft form to Dr. L.E. St. Pierre, Dr. J.E. Guillet, Dr. D.M. Wiles, Dr. S. Bywater, Dr. N.S. Grace, Dr. E.J. Buckler and Mr. G.L. Bata for comments and suggestions. A written comment was received from Dr. W.E. Cowie of the Defence Research Board.

It is hoped that all the comments were incorporated in the spirit in which the authors intended. The final report hopefully expresses the general concensus of opinions of the scientists engaged in the synthetic high polymer industry although the author must accept responsibility for last minute changes and additions.

COMMITTEE 07 - POLYMERS, ETC.

AREA 072 - ORGANOMETALLIC COMPOUNDS

INTRODUCTION

Astounding growth has taken place in recent years in the chemistry of inorganic compounds and particularly in the chemistry of compounds which lie between inorganic and organic. These fall into three broad classes. The first class would be illustrated by soaps and other metallic salts or partial esters. The second class would include coordination complex compounds such as ferrocene, o-phenanthroline complexes, and complexes, of copper and platinum with olefines. The third class is that encompassing compounds in which the carbon atom of the organic moiety is joined directly to the metal as in aluminium triethyl, tetramethyl lead, zinc diethyl, etc. This last series only is discussed in the report since the two other groups are more properly compared with the equivalent inorganic compounds; the organic portion usually exerting a modifying influence which can, of course, be quite marked.

History

While compounds of this type have been known for a long time they have not been studied or produced in Canada as a distinct class. No exact history of the use or organometallics in academic research was located but it is certain that such reagents as sodium alkyls, Grignards, lead tetra-ethyl, and others have been the subject of studies for many years. However, no major centre of organometallic research has emerged in Canada although several active centres exist as part of an inorganic research effort of a broader nature. Commercially the only production is believed to be that by Ethyl Corporation of lead tetramethyl and lead tetra-ethyl for anti-knock fluids and aluminium trialkyls and related aluminium alkyl halides as catalyst components in the production of plastics and elastomers.

Activity outside Canada

Organometallics have been the subject of very extensive research efforts in Germany, the United States and Japan. Several very successful industrial processes have emerged from their efforts. The first is the use of the organometallics as catalyst components in the manufacture of plastics and elastomers, specifically polyethylene, polypropylene, cis-polybutadiene and cis-polyisoprene, trans-polyisoprene, ethylene-propylene copolymers and terpolymers with other monomers, and polymers based on epichlorohydrin, ethylene oxide or propylene oxide. While the aluminium alkyls are available from Canadian sources the zinc alkyls, lithium alkyls, sodium alkyls, and potassium alkyls required for the complete range of reactions, are not.

The second series of materials is composed of a broad range of low molecular weight linear and cyclic olefines based on ethylene, propylene, isoprene and butadiene. For example, ethylene and butadiene can be combined to yield hexadiene-1,4. Butadiene can be cyclized to yield cyclo-octadiene and cyclo-dodecatriene and the corresponding methyl derivatives can be prepared from isoprene. Linear and branched olefines can be made from ethylene and propylene having terminal unsaturation so that normal alcohols and other derivatives can be made. Indeed this facet of organic chemistry is very active and promises to yield many novel and commercially attractive compounds. Propylene can be dimerized to 2-methyl-pentene-1 which in turn can be cracked to isoprene, a successful industrial process.

The review of industrial processes in use does not exhaust the possibilities for organometallics. It has been suggested that these might be used for mass transfer of metals such as is required in plating, purification, or separation of metals. Other reactions include alkylation or arylation and reduction.

Activity in Canada

Organometallic chemistry as defined for the purposes of this part of the survey cannot really be considered a significant activity in Canadian science. The expenditure in Universities is of the order of one-third to one-half of one percent of the total expenditures whether based on expenses or manpower. (Table 4.7-1, Table 4.7-2). The industrial activity claimed is about one-twentieth of one percent of the total. Surely this shows that this subject is in a very preliminary stage of development. It is of interest that both industry and universities claim that all expenditures are for basic research. Hopefully applied research and development will come. To balance the basic research under way, industry would have to increase its activity twenty-fold, one-third on applied research and two-thirds on development. If industry in addition matched academic research this would involve doubling its effort again, a massive forty-fold increase. Although this sounds enormous, the result would represent only two per cent of total industrial research and development activity, a not unreasonable figure for a new and promising field.

Future Trends

In spite of all the promising aspects of organometallic research there does not appear to be much interest in large scale production of most of the compounds. The market in Canada is small as yet for known materials, production costs are high and the export market uncertain. Nevertheless, it would seem desirable to encourage production at least of organometallics which are required for Canadian consumption, particularly any of specific interest to Canada.

To this end, academic research should be encouraged and expanded according to the interests of the scientists concerned and an increased flow of new products established. Appraisal of these developments and others arising elsewhere should be undertaken so that a broad base of development experience will be accumulated and production encouraged. A result of profitable production facilities would be the stimulation of a still more varied academic research programme. Development and production may have to be supported at first until such time that the industries can maintain a self-sustaining and economical production operation, supported by strong industry operated research and development organizations. Since organometallics lie between inorganic and organic compounds, one should include in any support projects from both those industries which are predominantly inorganic such as producers of the iron, aluminium, copper, nickel, zinc and lead and from the petrochemical companies whose interests have led them into utilizing ethylene, propylene, isobutylene, isoprene, butadiene or other simple hydrocarbons or their derivatives.

Recommendations

1. Academic research on organometallics should be encouraged in universities. Increased emphasis on organometallic chemistry should be part of undergraduate and graduate training.
2. Industries, government laboratories or contract research groups should follow actively new major uses for organometallic compounds and try to locate specific materials and uses for Canadians conditions.
3. Industrial research and development should be encouraged and supported and early production of organometallics required for Canadian consumption should be undertaken.
4. Means should be established whereby industries predominantly based on the

organic and inorganic branches of chemistry can be drawn together to cooperate in a programme of potential value to each.

APPENDIX

Data for this report were compiled from lists of active projects such as the National Research Council lists of supported research, the Engineering Research under way in Universities, the Biochemical Research under way in Universities, and the list of Economic Council of Ontario. No formal survey was made. The draft of the report was submitted to Dr. A.G. Brook, Dr. R.J. Gillespie, Dr. H.C. Clark, Mr. R.H. Shannon and Dr. J.D. McGilvery for comments. It is hoped that their ideas have been included as they wished to have them expressed. A brief in support of research on organometallic compounds was received from the Department of Chemistry, University of British Columbia.

220 - ORGANIC CHEMISTRY

COMMITTEE 07, POLYMERS, ETC.

AREA 073 - PART A

ORGANOFLUORINE COMPOUNDS

Replacement of hydrogen by fluorine in organic compounds can lead to a vast array of new materials with potentially interesting and useful properties. A list of research projects located in publications seems very short for such a large field. It must be recalled that titles might not mention fluorine even though a comparison of fluorine, hydrogen, deuterium or other elements substituted in equivalent positions may be involved. Most of the titles identified, on the other hand, indicated that the presence of the fluorine in the reactants was for purposes other than a study of the synthesis and properties of organofluorine compounds; kinetics or mechanisms, for instance.

Industrially, major emphasis on organofluorine compounds in other countries has been on fluorocarbons, including high polymers such as plastics and elastomers, and refrigerants. The last mentioned are made in Canada by Du Pont but no facilities to manufacture high polymers operate in Canada as yet. Those who manufacture fluoro-polymers elsewhere are supported by large research groups. Nevertheless, fluorides may be readily available as a by-product of the fertilizer industry as well as from natural sources. Thus, there may be strong economic reasons for establishing a fluorocarbon industry in Canada which ultimately would draw on the basic research of individual scientists to diversify and improve the product line. Scientists with worthwhile projects should be encouraged to develop new products and uses of interest to Canadians. Such organizations as Ontario Research Foundation, National Research Council and Defence Research Board should stimulate the establishment of a new organofluorine industry in Canada based on the new and novel compounds and uses arising from the academic research. One need is for a fluorocarbon elastomer or plastic with better low temperature properties than present materials, subsequently also other with better high temperature properties. A major need are organic materials with improved flame resistance for use in the construction and transportation industries. Initially production as well as research and development effort might need to be supported.

Recommendations

1. Academic research on organofluorine compounds should continue to receive support as worthwhile projects are submitted.
2. Commercial production of fluorocarbons used in Canada should be encouraged based on imported technology and supported by research and development.
3. New uses for fluorocarbons of specific value to Canada should be developed, possibly by a government organization or through contract research, whereby producers of fluorides, organofluorine compounds, and consumer items can be brought together to solve complex problems.

PART B - ORGANOPHOSPHORUS COMPOUNDS

The field of organophosphorus compounds is of such importance to biochemistry that it is not surprising that many of the studies found in lists studied are so oriented. Nevertheless, the number of studies of organophosphorus compounds appears small in relation to the total phosphorus industry. Organophosphorus synthesis industrially is probably limited to pharmaceuticals, antioxidants, and food additives. Other organophosphorus compounds such as insecticides, gasoline additives, plasticizers, pesticides, complexing agents, or flame retardants are imported.

In view of the lack of a strong organophosphorus industry with its own basic research, experimentation by individual scientists should be encouraged to fill its gap and to develop new products and uses. The phosphate industry, if not stimulated by this basic research alone, should be aided in broadening its own research activities and in bringing into production new or already established organophosphorus compounds for Canadian consumption. Under this stimulation further new organophosphorus compounds could be synthesized and studies leading to diversification of the products and uses undertaken until a self sustaining industry developed.

Some of the industrially important fields where organophosphorus compounts may be useful are in plastics and elastomers as plasticizers and antioxidants, in textiles and paper as flame retardants, and in pharmaceutical and food products as additives with biological activity. This interest in organophosphorus compounds should be aroused not only in those engaged in the phosphorus based industry, but also in fabrication and consuming industries, particularly those interested in organic materials of construction with flame resistant properties or flame retardant characteristics.

Recommendations

1. Academic research on organophosphorus compounds should continue to receive support as worthwhile projects are submitted.

2. Commercial production of organophosphorus compounds used in Canada should be encouraged based on imported technology and supported by research and development.

3. New uses for organophosphorus compounds of specific value to Canada should be developed, possibly by a government organization or through contract research whereby producers of phosphorus, organophosphorus compounds, and consumer items can be brought together to solve complex problems.

PART C - ORGANOSILICON COMPOUNDS

In contrast with the commercial importance of inorganic silicon compounds, organic silicon compounds appear to be receiving little attention in Canada. From a list of projects it is obvious that the field is confined to synthesis and studies of structures of a few novel silicon compounds.

Industrially there is no production of organosilicon compounds in Canada, although consideration has been given to the establishment of a silicone rubber plant a number of times. Major emphasis in other countries has been on the silicones which are extremely valuable resins and plastics with an uniquely broad service temperature range. However, silicones remain relatively expensive and are sold in small volume. The few major producers have large research organization in their own countries to support their production. No evidence of new large volume uses was found; just continued growth of the use of silicones as elastomers, resins and coatings. In the absence of the stimulation of a major producer in Canada with a development organization, basic or academic research will not find a receptive outlet. There will be no economic return from basic research until industrial activity is established.

Based on these considerations it is suggested that encouragement of basic research in organosilicon chemistry be supported and expanded as the interests of individual research directors dictate. Government laboratories, specifically the National Research Council, the Defence Research Board and other organizations, should develop new uses which may encourage both basic research and commercial production. Coming to mind immediately as an example is the project on aircraft windscreen rain repellants developed by the National

Research Council. Under the impetus of such new developments utilizing, hopefully, other new and novel silicones or organosilicon compounds, there would develop an organosilicon industry in Canada which would justify and support still more basic research, applied research and development.

Recommendations

1. Academic research on organosilicon compounds should continue to receive support as worthwhile projects are submitted.
2. Commercial production of organosilicon compounds used in Canada should be encouraged based on imported technology and supported by research and development.
3. New uses for organosilicon compounds of specific value to Canada should be developed possibly by a government organization or through contract research whereby producers of silicon and organosilicon compounds, and consumers can be brought together to solve complex problems.

PART D - ORGANIC SULFUR COMPOUNDS

Interest in sulfur and its compounds has been high, based largely on the commercial importance of inorganic compounds such as sulfuric acid, bisulfite and thiosulfate, as well as elemental sulfur itself. In more recent years research on organic sulfur compounds has expanded greatly. In Canada, this upsurge at first was largely a result of increasing scientific interest, but more recently has been spurred by economic and business aspects. Sulfur is a by-product of natural gas production in Saskatchewan and Alberta. Upgrading sulfur to its highest possible value is obviously to the economic advantage of the natural gas producers and consumers. On the other end of the scale, problems of disposal of hydrogen sulfide and sulfur dioxide wastes will prompt every increasing efforts toward solutions of air and water pollution problems.

Projects noted in various lists indicate a wide breadth of interests in Canada. Almost half of the academic research is in Alberta and Saskatchewan. At the University of Calgary, Dr. Hyne coordinates a broad programme sponsored by Alberta Sulfur Research Limited on fundamental problems associated with industry-wide objectives. Naturally most of the work is on elemental sulfur and inorganic sulfur compounds. However, interest is very much alive in the possibilities of upgrading sulfur and inorganic sulfur compounds to higher values materials such as polymers, pharmaceuticals and biochemicals, solvents, and chemical intermediates. As a by-product of the extensive studies by Dr. Gunning of the University of Alberta, many organo-sulfur compounds have been synthesized for the first time, vinyl mercaptan, thiacylopropene, cis and trans 2-fluorovinyl mercaptan, 2,2-difluorovinyl mercaptan, cis and trans 2-chlorovinyl mercaptan, 2,2-dichlorovinyl mercaptan, 1-fluoro, 1,2-difluoro and 1,1,2-trifluoro ethylene episulfides, cyclopropyl mercaptan, cyclobutyl mercaptan, vinyl ethylene episulfide, 1,2-perfluoro-dimethylthiophene, perfluorotetramethylthiophene, cyclopentene-1-thiol, and cyclohexene-1-thiol. A novel synthesis of a wide range of thiadiazoles has been developed. While most of the projects at the institutions appear to be dictated by the interests of the scientists, there are a few projects which could be related to commercial processes such as plastics and synthetic elastomers.

The synthesis of organosulfur compounds in Canada may be considered to have started about 1914 when sulfonates and sulfated oils were made by Mr. Yokum in London in a chemical plant which later became Yokum-Faust (now Nopco Chemical). More truly organosulfur compounds were produced by the Goodyear Tire and Rubber Company of Canada Limited, who made mercaptobenzo-thiazole in 1938. H.L. Blachford extended the line of rubber accelerators by making zinc and selenium diethyldithiocarbamate and tetramethylthiuramdisulfide. In 1939, Mallinckrodt Chemical (now a Monsanto Division) began the production of the pharmaceuticals, sulfapyridine and sulfathiazole. In the period 1942 to 1943, Naugatuck Chemical (now Uniroyal) began to make rubber, agricultural and fine chemicals and "Thiokol" polysulfide rubbers, the first synthetic elastomers to be made in Canada. The growth of Naugatuck has been such that it now dominates the rubber chemicals field making 2-mercaptobenzothiazole, 2,2-benzothiazole disulfide, dithiocarbamates, thiazoles, thiurams and xanthates among its many diverse products. In addition to rubber chemicals the compounds such as xanthates enter into flotation processes, conversion of cellulose, etc.

Growth of the industrial organosulfur compound industry since 1943 seems to have been largely diversification of the then current lines of interest.

Manufacture of Thiokol ceased but a new "Thiokol-like" polymer is actively under study by the Dunlop Research Centre. This is an episulfide rubber based on propylene episulfide or propylene and ethylene episulfides which may become valuable building blocks in many new polymers and chemicals. The same company has a programme of synthesis of novel organic sulfur compounds for olefines and polyolefines using sulfur monochloride, sulfur dichloride and sulfur polychloride. These compounds are not necessarily intended for polymerization. Some research interest in organic sulfur compounds has been expressed by other companies, particularly in phenylene sulfide, sulfone, sulfoxide or disulfide polymers, but no commercial activity in such sulfur containing polymers has been noted in Canada.

In recent years production of mercaptans has started at Imperial Oil's Sarnia refinery and carbon disulfide at Thio Pet-Chem Limited, Fort Saskatchewan and Cornwall Chemicals Limited, Cornwall. Canada Packers Limited produce N-acetylcysteine. There does not appear to be any one company dedicated to the production of organic sulfur compounds of a new type for as yet unexplored uses.

Since the organosulfur industry appears active there would seem to be a good basis for growth. Additional support for university research, particularly towards synthesis and properties of new sulfur compounds of potential commercial value would enable the development groups in industry to expand the various product lines, making available to the consuming industries (pharmaceutical, rubber, paper, textile, and others) new materials which may in turn improve their products or processes. Intensive support of those interested in synthesis of new compounds and their uses might be concentrated in Alberta. Concentrated support on problems relating to sulfur fumes in air and waste organic material in water might be concentrated in the areas most affected, the Windsor to Toronto area of Southwestern Ontario. It should be assumed that the economical production of the appropriate sulfur compounds in each area would attract manufacturers of sulfur containing polymers or organic sulfur derivatives to these Canadian locations.

The major gap of synthesis of new organic sulfur compounds of commercial interest may in part be responsible for lack of work on the fundamental properties and structure of organic sulfur compounds. Spectra of all types, bond lengths and angles, bond dissociation energies, hybridization and conjugation effects, and many other aspects of physical organic chemistry actively under study on the corresponding oxygen systems do not appear to be as actively pursued when sulfur replaces the oxygen. Data such as mass spectral, infrared, ultraviolet, nuclear magnetic, etc. usually have been obtained by the groups mentioned above when they synthesize new sulfur compounds, but the studies tend to be limited to those compounds synthesized.

The review of organic sulfur compounds brought forth two comments on the subject of communications and a suggestion to solve one of these. The first comment was that it was surprising to note so many scientists studying sulfur compounds. At the same time the objective of the research usually was not related to sulfur chemistry although the results certainly would be relevant. Thus there is a communication problem between scientists which needs to be solved by some medium which more than just lists titles of projects but also in some way lists fields of potential interest or areas of overlap.

The second problem of communication was between industries and the universities. This is partly due to the inability of industrial scientists to appreciate the value of academic research made available to them, and partly due to the inability of academic scientists to appreciate potential applications or uses of the results they obtain. The solution proposed was the development of specialized research institutes where the research results can be evaluated and developed to the point where concrete proposals of interest to industrial organizations can be made, perhaps even including plant design and operating data. Another solution mentioned earlier would be the sponsorship of fundamental research in universities by consortiums of industries such as is true in the case of Alberta Sulfur Research Limited and the Fundamental Research Group at the University of Calgary. In such closely associated group the industrial and academic points of view could be exchanged easily and time taken for all concerned to understand the purpose and value of the research undertaken.

Recommendations

1. Support of academic research on sulfur compounds should be maintained. There may be some advantages to concentrating synthetic work in Alberta and Saskatchewan and anti-pollution studies in the heavily industrialized Windsor to Toronto area.

2. Development of organosulfur compounds to the point where attractive proposals or designs can be submitted to industry should be undertaken by existing or new research institutes.

3. Industry should be encouraged to produce Canadian requirements of sulfur containing compounds, utilizing imported technology if necessary.

4. An objective to promote industry-university liaison would appear timely since the level of industrial activity is encouraging and the university interests broad. Exchanges of staff or the holding of joint meetings or discussions either independently of or associated with a research institute would be one suggestion.

PART E - STATISTICAL DATA

Statistical analysis of the field of the organo compounds of fluorine, phosphorus, silicon and sulfur indicated comparatively little activity. Approximately 1% of the University effort, whether measured in terms of funds or manpower, were devoted to these subjects, almost 95% being described as basic research. (Table 4.7-1, Table 4.7-2). Industrial activity reached only one-third of one percent of the total research and development budget, 75% of the activity being applied research, 15% basic research and something less than 10% development. Obviously none of these fields can be considered industrially active, nor tending in that direction. The volume of basic research is so small that no significant applied research or development need be expected.

If industry were to establish a distribution of basic, applied research and development considered average then annual expenditures could triple with all the increased effort going into development. If the basic research in industry were to be equal to the academic research the industrial effort would have to be quadrupled again. This would bring the effort to 4% of the present average industrial research and development effort which may not be unreasonable if it includes sulfur containing polymers and other major organic sulfur chemicals.

Appendix

The preliminary draft of the report on organo compounds of fluorine, phosphorus and silicon was submitted to Dr. H.C. Clark, Dr. A.G. Brook, Dr. R.J. Gillespie, Dr. J.D. McGilvery and Mr. R.H. Shannon for comments. The report on organo sulfur compounds was likewise submitted to Dr. J.B. Hyne, Dr. H.E. Gunning, Dr. A.R. Knight, Dr. P. Yates and Dr. R.T. Woodhams for comments and suggestions. It is hoped that all suggestions have been included and that the report is a fair assessment of the fields. A brief was received from the Department of Chemistry of the University of British Columbia in support of additional research on organic compounds of F, Si, P and S.

TABLE 4.7-1

OPERATING CHEMISTRY[1] R. AND D. INTRAMURAL

EXPENDITURES (1966 or 1966-1967)

(thousands of dollars)

CHARACTER	BASIC	APPLIED	DEVELOPMENT	TOTAL
PERFORMER	---	---	---	---
INDUSTRY				
071 Polymers, etc.	653	4,224	7,693	12,571
072 Organometallics	45	0	0	45
073 F,P,S i and S Organics	50	243	31	324
031 Metallurgy	446	~~12,923~~ 13,054	5,080	~~18,449~~
181 Chem. Engin.	459	3,128	~~8,435~~	~~12,022~~
Total Industry (all areas)	8,299	40,294	~~42,211~~	~~90,803~~
UNIVERSITIES (Inst.)				
071 Polymers, etc.	105	30	0	135
072 Organometallics	99	0	0	99
073 F,P,S i and S Organics	195	27	0	222
Total University (Inst.)	17,000	2,955	882	20,837
GOVERNMENTS				
071 (0250, 0265)				
Polymers, etc.	30	90	0	120
072 Organometallics	0	0	0	0
073 F,P,S i and S Organics	0	0	0	0
Total Governments (all areas)	~~7,892~~	~~9,9920~~	~~6,611~~	~~24,424~~

[1]Including chemical engineering and other related disciplines - Sources - Section 18 - Tables 26, 39 and 11a.
Note - Totals may not equal sums of individual items due to final rounding.

TABLE 4.7-1-2

MANPOWER EFFORT ON INTRAMURAL

CHEMISTRY[1] R. AND D.

University Departments (Or Institutes) 1966-1967

(Man-Years)[2]

	BASIC	APPLIED	DEVELOPMENT	TOTAL
ACADEMIC STAFF				
071 Polymers, etc.	27	2	0	29
072 Organometallics	4	0	0	4
073 F,P,S i and S Organics	14	0	0	14
Total Univ. (Inst.) (all areas)	854	153	34	1,041
TOTAL STAFF				
071 Polymers, etc.	110	5	0	115
072 Organometallics	18	0	0	18
073 F,P,S i and S Organics	42	2	0	44
Total Univ. (Inst.) (all areas)	3,506			

(FULL-TIME EQUIVALENTS)[2]

	ACADEMIC	P.D.F.'S	GRAD.STUD.	TECHN.	TOTAL
071 Polymers, etc.	19	5	47	8	78
072 Organometallics	2	4	6	0	11
073 F,P,Si and S Organics	6	5	10	5	26
Total Univ. (Inst.) (all areas)	~~541~~ 530	~~295~~ [illegible]	~~1,445~~ [illegible]	~~493~~ 474	~~2,774~~ [illegible]

1. Including chemical engineering and other related disciplines.
2. Man-years relates to employment; F.T.E. relates to work function, in this case R. and D., and expresses the effort in terms of personnel engaged full-time on R. and D.

Note - Totals may not equal sums of individual items due to rounding.
Sources - Section 18 - Tables 38, 40, 41 and 44.

TABLE 4.7-2 (con.)

MANPOWER EFFORT ON INTRAMURAL
CHEMISTRY[1] R. AND D.
INDUSTRY
(man-years[2])

Degree / C.I.C. Area	Dr.	Ma.	Ba.	Techn.	Total
071	87	51	230	417	785
072	1	1	1	1	4
073	3	3	4	8	18
Total	91	55	235	426	807

Source of data - Section 18, Table 27A.

1. Including chemical engineering and other related disciplines.
2. Assuming that, for each respondent, each category of manpower was distributed over the C.I.C. areas in the same proportions as were the expenditures.