REPORT OF COMMITTEE NO. 2 INORGANIC CHEMISTRY

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CONTENTS

INTRODUCTION

Any survey of pure and applied research and development in inorganic chemistry is faced with an initial hurdle which is, simply and straightforwardly, the question: "What is Inorganic Chemistry? How does one define it?" It becomes immediately apparent, when one attempts to answer these questions, that no two respondents will give the same answers. In order to prepare this report, it has been necessary to adopt a conventional, if somewhat elastic, definition of inorganic chemistry.

We feel that we cannot do better than quote from the introduction to a recent article entitled "Inorganic Research in Canada" which appeared in the June, 1967, issue of "Chemistry in Canada"* and of which the author of this portion of the present survey was a co-author.

"We have defined inorganic chemistry as that which is studied by those of us who call ourselves inorganic chemists; or that which might be regarded by an inorganic chemist as a legitimate research or development project for an inorganic chemist. By this definition, inorganic chemistry, like beauty, is in the eye of the beholder".

An alternate definition of modern inorganic chemistry was quoted by R.S. Nyholm in his article entitled "The Renaissance of Inorganic Chemistry", Journal of Chemical Education, Vol. 34, p. 166 (1957), and is as follows: "Inorganic chemistry today is the integrated

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* "Inorganic Research in Canada", by R. D. Heyding, J. B. Taylor and N. F. H. Bright, "Chemistry in Canada", Vol. 19, [6], pp. 22-27 (1967).

study of the formation, composition, structure and reactions of the chemical elements and their compounds, excepting most of those of carbon".

This definition, by its exclusion of most carbon compounds, draws attention to a particular problem: Is one to conclude that all work involving every other element than carbon is necessarily inorganic? Certainly not, nor is all the work involving carbon, organic; for example, that distinguished Canadian contribution to high-temperature technology, the manufacture of calcium carbide, is certainly not organic chemistry. The writer feels that while inorganic chemistry concerns itself with those compounds that are, in the main, not carbon-containing, nevertheless, many compounds of metals with organic ligands, a field which has achieved great prominence in recent years, should properly be considered as inorganic.

The definition of inorganic chemistry is more a matter of philosophy of outlook, purpose of investigation, and attitude of mind than of precise statement. For instance, inorganic compounds are frequently investigated by physico-chemical techniques, and a distinction may have to be drawn as to whether a given research is physical or inorganic chemistry. We have had to base this distinction on intent: where the investigation is principally concerned with the application of techniques or the physical principles behind them it may best be regarded as physical chemistry, but where specific properties of the working substance are of importance, and the study of these by some physico-chemical technique is merely the means of achieving a desired end, the work should be classified as inorganic chemistry.

Similarly, when one comes to work on a larger scale, the development of an inorganic process for industrial manufacture, in which, inevitably, engineering problems have to be overcome, then the kinetics and thermodynamics of the inorganic system involved, the chemistry of any corrosion problems that may have to be tackled, and so on, fall within the scope of inorganic chemistry, whereas the engineering methods that are devised to cope with these problems more properly lie within the domain of chemical engineering.

In the field of organometallic compounds, it is often not the organic ligands per se that are of interest, but their configuration about, and their influence upon, the electron envelope of the metallic central ion. This, we feel, is inorganic chemistry. Where, however, these types of compounds are used as intermediates in the preparation of more complex organic molecules (e.g., Grignard reagents), or where they are used to produce certain catalytic or other effects in organic systems (e.g., lead tetra-ethyl in gasoline), then the emphasis here is on organic chemistry, or possibly, when carried out on the manufacturing scale, on chemical engineering; these are not inorganic chemical studies.

Similarly, in the field of mineralogical and metallurgical chemistry, it is true that most, if not all, operations deal with inorganic chemical materials, often at high temperatures and/or pressures and, owing to the nature of the resources of our country, often on a grand scale. However, we have concerned ourselves in this section of the survey and in Section No. 3 merely with the chemical processes involved in these industries and with the chemical development work that led to their being set up. The physical metallurgy of the metallic products does not concern us, although the chemical factors controlling the structure and chemical nature of the alloys and inter-metallic compounds that may result from such operations, do. In mineralogy, the chemical factors, such as phase equilibria, controlling the stability of the various minerals in a natural assemblage do, we feel, lie within our purview. The texture of the mineral and the techniques of its beneficiation are the concern of the mineralogist or of the ore dressing engineer, not the inorganic chemist. There will, naturally, be some overlap between this section of the report in this area and the Section from Committee No. 3, dealing with Metallurgical Chemistry.

In what follows, we propose to give a brief account of the historical background of inorganic chemistry in Canada. We will then review the scope of the present work, not only as regards the personnel involved, but also in relation to the projects in progress and to the dollars and cents spent thereon. An assessment of the balance or imbalance of this work in the Canadian context, recommendations for any future modifications of the emphasis of effort, and a prediction of the scale of operations in the foreseeable future will also be given.

While we have, of necessity, leaned very heavily on the views expressed by our various respondents in the different fields of effort, we have not hesitated to state our own views, where, as a result of consideration of the information thus made available to us, we have felt that certain statements needed to be made for the good of the future health of basic inorganic chemistry in Canada.

HISTORY AND PROGRESS OF RESEARCH AND DEVELOPMENT IN INORGANIC CHEMISTRY IN CANADA

When one looks at the history of chemistry in Canada, it appears that the various areas of chemical specialization are so closely interwoven that it is difficult to separate inorganic chemistry from the other specialties. In the early years, many of the research or development programmes were undertaken because of the availability of certain Canadian resources such as raw materials or water power. Some grew out of the exigencies of war or out of other special situations in the history of the country. Many of the early research programmes were on a pilot scale or were even full-scale operations, perhaps because laboratory or bench-scale equipment was not available and laboratory techniques were not well developed.

Some historical landmarks in industrial inorganic chemistry include the following:

1. Discovery of the present commercial process for producing calcium carbide by T. L. Willson (1892), a Canadian in the U.S. The first Canadian carbide plant built by Willson at Merritton, Ont. (1896).

2. First cyanamid plant in North America built in 1909 at Niagara Falls, Ont. Production of cyanide from cyanamid in Canada 1916.

3. First surphuric acid plant in Canada (1867) built by Canadian Chemical Co., in London, Ont., by Bowman and Smallman. [Bowman's son extended this operation to the production of nitric and muriatic acids, phosphoric acid and various phosphates, sulphurous acid and bisulphites].

4. Manufacture of Portland cement (ca. 1830), extended to rapid-hardening aluminous cement (1931).

5. Development of refractory industry, Canadian Refractories Ltd., (1934) with technical assistance from N.R.C. and the Ceramics Section of the (then) Dept. of Mines and Resources.

6. Development of phosphorus industry (1896) in Buckingham, Quebec.

On the academic side, the teaching of chemistry began in several Canadian colleges before 1850, but little research appears to have been carried on there in the early years. At the University of Toronto in the 1890's, W. H. Pike instituted an Honours course in Chemistry and Mineralogy and introduced a research problem in the final year of that course, and, by 1897, the Ph.D. in Chemistry was established as a research degree.

However, owing to the prominence and popularity of physical chemistry and organic chemistry, inorganic chemistry languished in largely-deserved obscurity for many years. The subject itself was almost entirely factual and descriptive, and practical work in it was largely confined to qualitative and quantitative analysis. The fact is that, for several decades, there was lacking a generally acceptable theoretical basis for systematizing the study of inorganic chemistry; lacking such theoretical guidelines the subject did not appear to offer avenues for fruitful research, and, in North America at any rate, it fell largely into neglect. Only during and after World War II did inorganic chemistry become seriously reinstated in the undergraduate curriculum and develop into an area of a significant amount of research in the universities.

The resurgence of inorganic chemistry has been made possible by a much more widespread appreciation of the conclusions to be drawn from quantum mechanics concerning the states of electrons in atoms and molecules, the nature and spatial characteristics of chemical bonds, and so forth. Also, there has come to the chemist's disposal an array of optical, electrical, and magnetic techniques that permit him to investigate the structure of compounds in terms of physical properties predicted by or related to his theoretical models, and so enable the theoretical basis of his structures to be tested. Some concerns have been expressed, and possibly with some justification, that the new generation of chemists will be better versed in such theoretical considerations than they are acquainted with the facts of inorganic chemistry which the theory is intended to explain.

Research in inorganic chemistry in official institutions such as the National Research Council, the other technically-based Government Departments such as the Departments of Agriculture, Health and Welfare, and Energy, Mines and Resources, the Crown-Corporation type of organizations such as the Atomic Energy of Canada Ltd., Eldorado Mining and Refining Ltd. and the Polymer Corporation, and also the Provincial Research Councils or Research Foundations, where such exist, dates originally from about 50 years ago. It was the incidence of World War I that really precipitated the Federal and Provincial Governments into the prosecution of scientific research. Certain Governmental organizations such as, for example, the Geological Survey of Canada, are much older, but it was only the stress of war-time conditions that caused the spread of research in chemistry as a government-sponsored activity. World War II, in a similar way, spawned its crop of official research institutions, notably A.E.C.L. and Eldorado, both associated originally with Canada's effort in the atomic energy field. Inorganic chemical research and development are now being actively pursued in many of these establishments, particularly in those with a metallurgical bias such as Eldorado and the Mines Branch in Ottawa.

If one looks for parallelism of development of research activity and facilities in the academic, institutional and industrial sectors, one finds anomalies that are not entirely due to the type of organization that one is considering. Thus, one finds relatively little effort being exerted in industry that is of interest to the modern academic; the reverse is even more true. The effort in the official laboratories manages to pursue a middle course in blending pure and applied work and so tends to be of more general interest to the other two sectors.

These various trends will, we hope, be substantiated by the statistical data which follow in the later sections of this portion of the survey. Whether or not these trends can be regarded as healthy and desirable for the future of Canada's scientific effort will also be considered.

PERSONNEL, PROJECTS AND PENCE

A. Personnel

In this portion of the review and also in the succeeding portions, the comments will be sub-divided into three areas dealing, respectively, with the academic, institutional and industrial contexts.

I. The Academic Field

In the academic field, to ascertain the extent of the effort and the trends that are becoming apparent, one should consider the number of members of the university staffs engaged in teaching and in research in inorganic chemistry, the number of post-graduate students and post-doctorate fellows working in this area, and also the number of undergraduate students currently specializing in chemistry. It is, of course, the last-mentioned group that, by 1972, will be contributing towards the numbers in the second group. Also, the number of undergraduates controls, in large measure, the number of faculty members needed to instruct them. It is, however, not easy to predict the proportion of these undergraduate students that will choose to specialize in inorganic chemistry in their post-graduate and later studies. It is considered probable that there will not be much change from the present distribution of interests.

Less than a decade ago, there were fewer than 15 modern inorganic chemists in Canadian universities. True, there were, and still are, some older members of staff whose outlook has been almost entirely coloured by the "classical" inorganic and analytical chemistry of the nineteenth century. However, the traditional association of inorganic with analytical chemistry has now all but disappeared, and courses in "classical" descriptive inorganic chemistry have been heavily curtailed. In looking to the future, we feel that this trend will be maintained.

At the present time, there are about 80 professors in Canadian universities and similar institutions that offer two or three courses in undergraduate inorganic chemistry, together with laboratory instruction, as well as, in most departments also, graduate courses.

On the basis of at least tentative enrolment forecasts for the universities up to 1972, one can estimate with reasonable reliability that about 148 inorganic chemistry professors will be required in Canadian universities by that date.

According to the National Research Council Survey of Graduate Students in Science and Engineering, there were, during the academic session 1965-66, 58 graduate students working for the Master's degree and 79 doctorate students. The corresponding figures for the year 1966-67 were 63 and 106, respectively. When one considers that, since 1962, only 72 candidates have been awarded the Master's degree and only 84 have obtained Doctoral degrees in inorganic chemistry, it is apparent that a considerable growth in the corresponding figures for the next five years must be expected. One should also make an allowance for the contributions that the newer universities will make to these figures.

Based on estimates given by 22 universities who offered forecasts of their future expansion, the number of graduate students in inorganic chemistry, scaled up to include <u>all</u> Canadian universities, would, in 1972, be of the order of 530. However, a brief submitted by the Chemistry Department of the University of Western Ontario suggests that the expansion of the graduate student population will not be quite so dramatic over the next five years. Their forecast for inorganic post-graduate students in 1972 is of the order of 325-390. Nevertheless, even this more conservative figure does indicate a very considerable increase in the graduate student population, possibly by a factor of 2.0 to 2.5 by comparison with the present figure.

Again, based on a somewhat limited response, one is led to expect a rather rapid increase in the number of post-doctorate fellows working in inorganic chemistry in Canadian universities. The 1966-67 figure is about 25, whereas the projected 1972 figure could be as high as 110-120, i.e., a five-fold increase. Thus, there is an indication that, over the next five years, although the number of faculty members is likely to increase from 80 to about 148, a growth factor of 1.8, the number of graduate students might increase by a factor of 2.0 to 2.5, and the number of post-doctoral fellows by a factor that could be as high as 5.0. It would appear that, not only will the number of supervisors increase, but also that the number of students, graduate and post-doctoral, per supervisor will also increase. It may, therefore, well be a matter of some concern as to how well the supervisor will be able to discharge his teaching responsibilities to an increasing number of undergraduates, while, at the same time, directing the researches of an increasing number of graduates and fellows. It is perhaps appropriate to inject the comment that while university departments are prone to be optimistic in estimating their expansion, constraints that are beginning to make themselves felt in the financing of universities across Canada could impose limits appreciably below those given here.

II The Institutional Field

The types of institution included under this heading are Federal and Provincial Government Departments, Crown Corporations, which, in several instances, are operated much like private industrial operations, Provincial Research Councils and Foundations, where such exist, and the few co-operative or non-profit organizations operated collectively by groups of related industries, e.g., the Pulp and Paper Research Institute.

The number of people employed in inorganic chemistry in institutional laboratories in Canada in 1967 was of the order of 230, including both professional and technical personnel.* From the usual pattern of distribution of professional vis-à-vis technical personnel, it would be indicated that there are probably about 100 professional scientists employed in the inorganic chemical field in Canada at present in institutional laboratories.

Predictions for the future of inorganic chemistry in these laboratories generally point to a steady rather than a dramatic expansion. There is no indication of any "explosive" increase in activity. Organizations such as Atomic Energy of Canada Limited, Ontario Research Foundation, Polymer Corporation and the National Research Council's laboratories <u>outside</u> the Ottawa area, have definite plans for expansion which involve staff increases in inorganic chemical programmes of 30% to 50% over the next five years. This would mean a maximum increase of about 30 in the number of professional staff members employed in these laboratories. Federal Government Laboratories <u>in</u> the

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* "Chemistry in Canada", loc. cit., Vol. <u>19</u>, [6], pp. 22-27, (1967).

Ottawa area are usually less certain about their future growth and the estimates available were more conservative, being in the range of 15% to 25% so far as professional staff increases were concerned. It was felt that even these figures might be optimistic in the present economic climate.

In total, it is doubtful whether the institutional requirements for new professional inorganic chemists will exceed 50 spread over the next five years. About half of these requirements will be for graduates at the Ph.D. level. The requirements for technical support will probably be only slightly higher.

III The Industrial Field

The greatest difficulty in adducing reliable information in this area again arises from the various interpretations of the meaning of the term "inorganic chemistry" by the different recipients of questionnaires.

One good example of the difficulty of definition of inorganic chemistry in the industrial context occurs with many of the large metallurgical corporations in Canada, both ferrous and non-ferrous. Although, unquestionably, the materials that they deal with and produce are inorganic in nature, and the chemical reactions on which their operations are based are inorganic, yet those corporations choose to regard their operations as lying within the discipline of metallurgical engineering rather than that of inorganic chemistry. Consequently, much of the work, some of a very high scientific calibre, conducted by such corporations has not found its way into the material and statistics reported in this survey.

Many Canadian chemical industrial establishments, whose main concern is definitely in the inorganic area, claimed to do no research or development work at all and stated that they were manufacturing facilities only; the research work for their industries was done by their principals, generally either in the U.K. or in the U.S.A. There are a few notable exceptions to this state of affairs but, in general, it is true to say that, to a large extent, Canada's industrial inorganic chemical "know-how" is imported and not self-generated, particularly if one excludes the metallurgy-based industries.

Of approximately 70 questionnaires sent out by the author to Canadian chemical industrial establishments which might reasonably be expected to engage to a greater or less degree in inorganic chemical research and/or development, 38 were returned and, of these, 18 claimed not be be so engaged at all. Thus, only twenty organizations were left from which to draw conclusions. Only five of these twenty claimed to be conducting inorganic chemical research in sufficient extent to need the employment of ten or more professional chemists. Only one of these companies could be considered strictly "chemical"; the others were concerned either with some phase of chemical metallurgy or with ceramics and refractories. Out of a total professional chemical population of about 460 reported by these companies, 173 were stated to be engaged in inorganic chemistry. Of these, about 50 were "retreaded" inorganic chemists trained originally in other disciplines. Very few of those trained <u>originally</u> in inorganic chemistry had ceased to be so engaged.

Insofar as technical support is concerned, there appears to be about 1.25 support personnel per professional chemist, irrespective of his particular interests.

The predictions offered by the respondents as to their future requirements over the next five years for professional and support personnel indicated that an approximately 50% increase in professional inorganic chemists was expected to occur, with a slightly greater percentage increase in support personnel.

The surveys of research and development personnel in the industrial sector issued for the various years by the Dominion Bureau of Statistics are not categorized under suitable headings to allow information relating specifically to inorganic chemistry to be accurately or readily extracted. If one provisionally assumes that Canada's inorganic chemical population is employed solely for in one or other of the following divisions of the labour force: Mines, Primary Metals (ferrous), Primary Metals (non-ferrous), and Non-metallic Mineral Products, then, for the most recent year for which full data are available (1965), the figures of Table 1 can be quoted. It is realized that, in all these figures, there will be included a considerable proportion who are not inorganic chemists nor, indeed, chemists of any kind. However, the figures should serve to indicate upper limits, and are probably correct as to order of magnitude.

TABLE I

NUMBER OF PERSONS ENGAGED IN R & D, BY INDUSTRY AND TRAINING, 1965.

DBS 13-527 (1965) Table 25

Level \ Industry		Mines	Primary Metals (Ferrous)	Primary Metals (Non-ferrous)	Non-Metallic Mineral Products	Totals
Scientists and Engineers	Bachelors	174	85	143	46	
	Masters	40	14	36	7	
	Doctors	23	14	39	4	
SUB-TOTAL		237	113	218	57	625
Supporting Personnel	Technicians	202	70	283	73	
	Other	121	62	200	36	
SUB-TOTAL		323	132	483	109	1047
GRAND TOTAL		560	245	701	166	1672

The division of the professional scientists and engineers amongst the various classes of employment within these four industries is given in Table II. The figures represent full-time equivalents.

TABLE II

Scientists and Engineers engaged in R & D, by Industry and Scientific Discipline of Employment, 1965. D.B.S. 13-527 (1965) Table 27.

Discipline \ Industry		Mining	Primary Metals (Ferrous)	Primary Metals (non-ferrous)	Non-Metallic Mineral Products	Total
ENGINEERS AND TECHNOLOGISTS	Civil	-	10	-	3	
	Chemical & Food	35	14	58	14	
	Electrical & Electronic	3	11	7	1	
	Mechanical	7	3	20	3	
	Metallurgical	95	55	54	2	
	Mining	14	-	4	-	
	Other	1	-	-	3	
	Sub-Total	155	93	143	26	417
SCIENTISTS	Chemists	50	10	40	15	
	Earth Scientists	6	2	7	2	
	Mathematicians	6	-	1	-	
	Physicists	1	-	11	10	
	Administrators	19	8	12	4	
	Other	-	-	4	-	
	Sub-Total	82	20	75	31	208
	GRAND TOTAL	237	113	218	57	625

From our present point of view, the most relevant figures in these tables are the numbers of chemists employed in these industries, who total 115.

Undoubtedly, some who are included as chemical and metallurgical engineers could reasonably be regarded as inorganic chemists. It would thus appear that the figure of 173 obtained in the former, more limited survey, is certainly not in error by any order of magnitude. It would also appear to be true that the ratio of professional to support personnel lies generally in the range 1:1 to 1.5, again agreeing with the former survey. This being so, one is, therefore, led to hope that the prediction of a 50% increase for professionals and slightly more for support personnel is also not seriously in error.

It is of interest to see how the professionals in the four industry groups considered are distributed amongst basic research, applied research and development types of activities. This is shown in Table III.

TABLE III

Scientist and Engineers engaged in R & D, by Industry and Type of Activity, 1965 D.B.S. - 13-527 (1965) Table 28.

Industry / Activity	Mining	Primary Metals (Ferrous)	Primary Metals (Non-Ferrous)	Non-Metallic Mineral Products	Total
Basic Research	16	8	30	6	60
Applied Research	112	40	42	21	215
Development	109	65	146	30	350
TOTALS	237	113	218	57	625

This represents 9.6% employed on basic research, 34.4% on applied research and 56% on development. It will be of interest to compare these figures with the assessment by the reporting industries of the distribution of their projects amongst the three types of activity. (see page 28).

B. Projects

In surveying the types of project on which Canada's inorganic chemists in the three main sectors are engaged, it has been convenient to divide inorganic chemistry into twenty areas and to locate each project in the most nearly appropriate area. This list of twenty inorganic chemical topics is given as Appendix I. (see page 44). The various sectors were asked to designate their projects as being either (i) pure or basic research, (ii) applied or developmental work, or (iii) contractual studies. Again, we will consider the three sectors in succession.

I. The Academic Field

Current academic research programmes can be classified principally as pure or basic chemistry. Based upon the NRC Survey of Research in Canadian Universities for 1966-67 and upon replies obtained to questionnaires associated both with this present survey and with the "Chemistry in Canada" article*, it would appear that, of the close to 200 projects reported upon, only 7 were considered to be applied, and 2 were given as being contractual. If one weights the amount of time spent upon projects of various types, then the percentage of pure or basic research vis-à-vis applied research becomes over 98%. This is, of course, to be expected and is, indeed, as it should be. The university is, more than any other environment, the place where advances in fundamental knowledge should and, in fact, must be made. A university that does not contribute to the stock of fundamental knowledge is

* "Chemistry in Canada", loc. cit., Vol. 19, [6], pp. 22-27, (1967).

failing in half the purpose for which it is set up and does not provide the proper stimulus for either student or professor.

The range of subjects studied under the heading of inorganic chemistry in Canadian universities is as diversified as the subject itself. Indeed, one is tempted to speculate as to whether or not we are spreading ourselves too thinly. Possibly, we would do better to establish "centres of excellence" in a more limited variety of fields. However, the academician does not like to feel that he is restricted or fettered in any way in his choice of research area.

The assignment of any particular project into one or other of the twenty classifications referred to above was, to some extent, arbitrary, as many projects overlap two or more of the twenty areas; however, the general picture is probably clear and correct. The distribution of these projects amongst the various universities is shown in Table IV. Those universities not mentioned in the Table did not report any research activity in inorganic chemistry to any of the three sources used for the production of this information. The diversity of the work and the very great predominance of basic or "pure chemistry" projects are the two most obvious factors to be discerned from this Table. The most popular topics for research are obviously those associated with coordination compounds (Topic 4), with the structure, crystallography and spectroscopy of inorganic compounds (Topic 15), and with the non-metallic elements (Topic 13); in this last-mentioned category, fluorine occupies a prominent place. The transition elements (Topic 18), also claim a fairly large measure of attention. Those aspects of inorganic chemistry that could be considered as being more nearly related to the industrial context,

TABLE IV

University Research Projects in Inorganic Chemistry 1966-67

Committee Survey Data

(* - indicates Applied projects; ** - indicates Contractual projects)

University \ Project Type		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
British Columbia		2			1	1		1*	1					2	1*	7			1	1
Victoria			2		2					1				1						
Simon Fraser		1			3							1		1	1	2		1**	3	
Alberta (Edmonton)					2	3			1			1		2		2	1	2		
Calgary					1							1			1	1				
Saskatchewan (Saskatoon)											1*			2						
Saskatchewan (Regina)					1							1**				2				
Manitoba (Winnipeg)								1						1		1			1	
Lakehead															1					
Windsor					1															
Western Ontario					2				1					3	1	3			1	
Waterloo					3			1		1		1* 2		2	2	1	1*			1*
McMaster			1		3	2				3				7		6				2
Brock					1									1		1				
Toronto			1		1	1		1				1		2	1	2		1	2	
Queen's					2					1								4	1	2
Ottawa												1		2					1	
Carleton		1			1													1	2	
McGill			1		4	1					1	3		1		1		1		
Montreal					2										1					2
Laval																			3	
New Brunswick					1															
Mount Allison												1								
Dalhousie					1											1		1		
Nova Scotia Tech. College																1	1			1
St. Francis-Xavier												1				2				
Acadia			1		1															
Memorial		1			2									1		1			1	
Totals	189 7* 2**	5	6	-	35	8	-	3 1*	3	6	1 1*	12 1* 1**	-	28	8 1*	34	2 1*	9 1**	17	8 1*

although themselves coming under the heading of "pure chemistry", namely, topics 2, 6, 7, 8, 10 and 20, are obviously among the most neglected areas. One is tempted to wonder whether this is because it may be relatively easy to produce some sort of results that would be publishable while working with the multiplicity of coordination compounds, or with the sophisticated spectroscopic techniques that are available today, whereas to produce publishable work in a number of the other fields such as Nos. 7, 10, or 20, is more time-consuming, as well as being often more demanding experimentally and more difficult to interpret.

While Canada can quite legitimately claim to provide "centres of excellence" in the fields of transition elements, co-ordination compounds, fluorine chemistry and inorganic spectroscopy, it would be encouraging to see even <u>one</u> university emerge as an internationally-recognized centre in, say, high-temperature inorganic reactions or in phase-equilibrium and thermodynamic relationships. Perhaps our nearest approach to pre-eminence in this area is at the University of Manitoba, where for many years, the thermodynamics and phase relationships of aqueous salt solutions and halide melts have been under study. With the emergence of Canada as the world's leading potash producer, such work becomes of special significance.

In Canada at the present time, we have a group of very new, smaller universites. These, of course, will gradually be building up their research programmes. It is logical and, indeed, almost inevitable, that many of the faculty members of these newer universities should be younger men who have trained under the more senior professors of our older universities. This will lead in many cases, to a mushrooming of the effort expended in those research areas of interest to these senior professors. Consequently, those subjects on which considerable effort is already being placed will tend often to become still more widely studied, whereas those areas that have hitherto been neglected by comparison, are likely to remain so unless some effort is made by the older universities to bring in senior professors whose interest lie in the "neglected" areas. In time this would result in more wide-spread effort being directed towards these areas. One realizes that this could not easily be accomplished as senior professors probably would not be too willing to come to universities where, so far as their research interests are concerned, they would be compelled to work in intellectual isolation. Nevertheless, we feel that the effort would be worthwhile and that the Canadian inorganic chemical scene, both academic and industrial, would inevitably benefit therefrom.

II. The Institutional Field

Our information on the projects worked upon in the Canadian institutional laboratories rests very largely on the data gathered by Dr. J. B. Taylor*. This is summarized in Table V, the topics again being as listed in the Appendix I (page 44).

It will be seen that the effort is directed very largely along the lines that are associated in some way or other with Canadian inorganic materials resources, their processing, and their development. For example, there is considerable effort being placed on inorganic reaction mechanisms and kinetics, (Topic 11) presumably related to process development. Probably for a similar reason, the study of equilibrium and thermodynamic relationships in inorganic systems

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* "Chemistry in Canada", loc. cit., Vol. 19, [6], pp. 22-27, (1967).

TABLE V

Institute Inorganic Research Projects 1966-1967

(* indicates applied research projects) Committee Survey Data

itute \ Topic	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
CL Chalk River							3*				1*				2*			2*	
CL White Shell							1*								1*				
.C. Research Council											1								
ew Brunswick Res.&Prod.Council							1*								1*	1*			1*
ntario Research Foundation		5*					2*				3*					2*			2*
askatchewan Res. Council							2*				1*								
griculture, Research Branch		1*					1*												
nergy Mines and Resources. Geological Survey		1*	1*				1*												1*
Extraction Metallurgy				1*			1*				5*								
Mineral Sciences				1			2* 1			1*	1*				1*		1		
Fuels and Mining															1*	1*			
Mineral Processing							1*								1*				
ldorado Mining and Refining				1*			2*									1*			
olymer Corporation															1*	1*			
RC Building Research						1*					2*				1*				
RC Applied Chemistry						1	1* 1			1*	1				3	1			
RC Pure Chemistry		1	1			1	1				1			1	2				
RC Pure Physics										1							1		
RC Atlantic Reg.Lab.							1				1*				1				
Pure 23		1	1	1		2	4			1	3			1	6	1	2		
tals Applied 67*		8	1	2		1	18			2	14				9	6		2	4
All 90		9	2	3		3	22			3	17			1	15	7	2	2	4

(Topic 7), is fairly widely conducted in institutional laboratories, whereas there is little or no effort placed on the more theoretical or esoteric subjects such as co-ordination chemistry (Topic 4), and the halides, chalcogenides and pnictides. On the other hand, it must not be thought that the institutional laboratories are entirely oriented towards "practical" topics, since a significant number of theoretical inorganic chemical projects are under way in these establishments.

Dr. Taylor, in his comments on the results of his survey of institutional inorganic research in Canada makes the following comments:

"There is no doubt that much of the current activity is related to programmes started at least five to ten years ago, and an element of self-perpetuation is evident."

"Some pure research is done in most institutes but very few engage in "way out" research to any extent. At NRC, there is a more definite bias towards pure research and, at the same time, a noticeable sensitivity in some sectors to questions aimed at determining potential applications of the work. At several institutes, there is considerable emphasis on exploitation of particular Canadian resources and the work is, in many cases, good sound long-term applied research and not just development".

"In the field of inorganic chemistry, there is no foundation at all for any suggestion that insufficient applied work is being done in Federally-supported institutes. It would not be difficult to argue that there is, in fact, a distinct off-balance _away_ from pure research".

The author of this portion of the survey is compelled to say that he is not in full agreement with this last quotation from Dr. Taylor's comments.

Since institutional laboratories are mainly supported by public funds, it is quite proper that the activities in which they are engaged should be seen to have some relevance to the public interest. The author feels that, in general, there is a reasonable balance in the types of projects studied in institutional laboratories between pure research, applied research, and development. Their principal field of activity should be applied research and this is just where their predominant effort lies.

III. The Industrial Field

It has been rather more difficult to obtain reliable information concerning the distribution by topic of the inorganic chemical research currently being conducted by industry for several reasons. The gross amount of research that is done is rather limited; many companies do no research but are merely manufacturing facilities, with their research being done by principals in other countries; in addition, some of the companies who are engaged in research and development are somewhat reticent to reveal the detailed nature of the projects on which they are engaged. In the following table, details are given of the research being conducted by twenty industrial respondents to our questionnaires, with the topics again being assigned to one or other of the same twenty areas that were used in the case of academic and institutional research topics. No attempt has been made to distinguish between research and development, although the companies were asked to indicate whether their projects should be considered as falling under the headings of pure, applied or contractual research. The companies have been identified by number and province only.

TABLE VI

Industrial Inorganic Research Projects

Committee Research Data

Note: * - indicates pure research project; ** - indicates contractual project

Company No.	Province / Topic	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	Ontario/Quebec		1**											1**							
2	Ontario				1*																
3	Quebec											3									
4	Quebec																		2		
5	Manitoba											1			2						2
6	Quebec											2		1							1
7	Ontario										1										
8	Ontario			2										1							2
9	Quebec							1			1**	5			1				2 1**	2	2
10	Quebec						1					1 1*									2 1*
11	Ontario										1	1									1
12	Ontario										1**										1 1**
13	Alberta											1* 2		1	2		1 1**		3 1** 1	1	2
14	Alberta						1														
15	Ontario					1*															
16	Ontario		2	1			1		1**			1*				1 1*					1
17	Quebec													1							
18	Quebec/Ontario			1			2							1							2
19	Ontario				1*	1*								1							
20	Ontario			1								1		1							1
Totals	Pure 9	-	-	-	2	2	-	-	-	-	-	3	-	-	-	1	-	-	-	-	1
	Applied 73	-	2	5	-	-	5	1	-	-	2	16	-	7	5	1	1	-	8	3	17
	Contractual 9	-	1	-	-	-	-	-	1	-	2	1	-	1	-	-	1	-	2	-	1
Grand Total	91	-	3	5	2	2	5	1	1	-	4	19	-	8	5	2	2	-	10	3	19

It will be seen that 80% of the projects are considered to be applied; one would presume that a considerable proportion of these would actually fall under the heading of development rather than applied research, although no figures can be quoted. 10% of the projects were stated to be contractual; it is probable that most of these would be considered as applied research. The remaining 10% were considered to be pure or fundamental long-term research, without immediate hope of financial return being attached to them.

The 10% pure research figure accords well with the 9.6% basic research figure quoted earlier (page 18) for the number of people involved in certain inorganic-oriented industries. The figures of 80% of applied projects plus 10% of contractual projects are not in conflict with the figures of 34.4% of personnel engaged in applied research and 56% in development work.

The industrial research areas in which the greatest effort is being placed are in high-temperature studies (Topic 20), generally related to refractory products and processes, metallurgical processes, carbides, refractory metals, ceramic oxides and similar materials. Considerable effort is also put into studies of the mechanism and kinetics of inorganic reactions (Topic 11), obviously with the view of achieving a greater understanding of the inorganic processes involved in the manufactures. No other area of research is followed to anything like the same extent as these two.

Future Projects

Respondents from the academic, institutional and industrial contexts were all rather reticent in speaking of their intentions for future projects. In the academic area, the fields of study will, of course, be very largely dependent on the individuals who happen to be directing research at that time. However, it appears entirely likely that those areas where the greatest effort is currently being placed will continue and may become even more predominant, whereas, regretfully, the current "neglected" areas are likely to become even more so unless vigorous steps are taken to prevent this (see page 23).

In the institutional field the distribution of activity between the various topics will probably not change very much, partly because of the continuing interests of the persons involved, and also because of the specific purposes for which the institutes were set up and their commitments to the Canadian public.

In the industrial field, there at present appears to be little likelihood of revolutionary new programmes. Projects based on Canada's mineralogical wealth will continue to predominate. There is some intention to increase the amount of research on fertilizers. More sophisticated analytical procedures, applied to inorganic materials, are the objectives of several companies; the introduction of on-stream and automatic methods of analysis applied to inorganic and metallurgical processes will increase. There will, in all probability, be a noticeable increase in effort on the technology of the more exotic ceramic materials such as ferrites and piezoelectric materials, both for Defence purposes and in the private sector, also on semiconductors and nuclear fuels, the latter associated with the resurgent demands for uranium and nuclear power in the 1970's. Automation in the control of inorganic reactions on a large scale will be increased, particularly in the hydrometallurgical field. There will also probably be a significant increase in interest in the chemistry of phosphorus, sulphur and the halogens, the former associated with organometallic materials, the latter two with bleaching agents for the textile, pulp and paper industries.

C. Pence

The determination of the precise expenditure of funds on research and development in any area is fraught with difficulties and uncertainties. The greatest uncertainty, and one that is especially characteristic of universities and to some degree also of publicly-supported institutes, lies in assessing overhead costs chargeable to R & D in equitable proportion to those associated with other activities.

I. The Academic Field

The data from the collated results obtained from replies to questionnaires sent out in connection with the C.I.C. survey are given in Table VII.

TABLE VII

Intramural Chemistry R & D Expenditures (1966-67) C.I.C. Survey Table 37.
(In thousands of Dollars)

SUBJECT	Operating and Minor Equipment	Major Equipment ($5000 - $100,000)	Major Installation	Sub-Total
General Inorganic Chemistry	642	160	25	827
Physical Inorganic Chemistry	479	147	25	651
Theoretical Inorganic Chemistry	78	0	0	78
TOTAL	1199	307	50	1556

The total funds available to universities for all branches of chemistry (in thousands of dollars) for the same period are given as 18,049 for teaching, 10,178 for R and D, and 515 for other purposes, giving a total of $28,742,000 (C.I.C. Table 35). It would thus appear that less than one-sixth of the chemical R and D funds of the universities are spent on inorganic chemical work.

In the aforementioned article in "Chemistry in Canada",* Dr. R. D. Heyding quotes the following figures for the academic year 1966-67 and forecasts, as given by the university personnel themselves, of their figures for 1972. These figures do not include fellowships or demonstrationships awarded to students and are based on a rather limited number of replies, pro-rated to the total university inorganic faculty and student populations.

TABLE VIII

University Grants in Inorganic Chemistry (Heyding Data)

PARAMETER	1966/67	1972 Projected	Growth Factor
Operating and Equipment Grants per student	$4,000	$3,300	0.8
Student and PDF Support from grants, per student	1,400	2,000	1.4
Total Grants per student	5,400	5,300	0.9
% Industrial support	0.8	0.8	1.0
% U. S. Support	7	0.9	0.13
Total Grants per Member of Staff	11,000	20,000	1.8
TOTAL GRANTS	$\$0.9 \times 10^6$	$\$3.0 \times 10^6$	3.3

Dr. Heyding comments "In view of the expansion expected in staff and students, estimates of the cost of academic research by 1972 are remarkably conservative". A really accurate figure for a 1972 forecast is difficult, if not impossible, to achieve.

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* "Chemistry in Canada", loc. cit., Vol. 19, [6] pp. 22-27, (1967).

II. The Institutional Field

While quite comprehensive data are available concerning the expenditures involved over the whole of chemistry in government and other institutional laboratories engaged in R and D, it is difficult to extract from this information the figures that apply only to inorganic chemistry.

The C.I.C. Table II shows about one million dollars expenditures in government departments under committee 02 and about 3-1/4 million dollars under committee 03. Of the one million under 02, about 865 thousand had to be classified as "other", i.e., it was outside the numbered list of specialties which are similar to the committees 20 "Topics".

Dr. Taylor, in his studies, has stated that, if one includes salaries but not capital depreciation and support services costs, then the large spenders of research monies in this area in the Federal Government are N.R.C., A.E.C.L., Eldorado, and the Mines Branch of the Department of Energy, Mines and Resources. Each of these organizations spends between one quarter and one-half million dollars per annum on inorganic projects. Very few programs can be operated for less than $20,000 per annum per man, although the Mines Branch and NRC appear to spend less than this at times. It is possible that this may be the result of the use of the relatively cheap Post-doctorate Fellow as the operating scientist. On the other hand, some projects run as high as $50,000 per man.

III. The Industrial Field

Here again, and perhaps to an even greater extent, it is difficult to sort out the expenditures relevant to inorganic effort from those relating to chemistry as a whole. In gathering information from the respondents to the aforementioned "Chemistry in Canada" article, insufficient figures concerning expenditures were obtained, owing largely to the reticence of the respondents to divulge the information, to make meaningful summaries or predictions therefrom.

From the information published by the Dominion Bureau of Statistics in their 13-527 documents "Industrial Research and Development Expenditures in Canada", it is not possible accurately to extract the information relating to chemistry as a whole; much less inorganic chemistry as such. However, adopting the same arbitrary method as was used for the personnel figures, viz., selecting the four areas most likely to contain inorganic chemical effort, one arrives at the following figures for the year 1965, the most recent year for which full information is available.

TABLE IX

Current and Capital Intra-mural Expenditures by Industry. 1966
D.B.S. 13-527 (1965) Tables 182

Category	Mines	Primary Metals (Ferrous)	Primary Metals (Non-Ferrous)	Non-Metallic Mineral Products
Wages and Salaries	4,922	1,912	6,256	1,339
Other	3,895	2,104	4,092	765
TOTAL	8,817	4,016	10,348	2,104

CAPITAL EXPENDITURES (in thousands of dollars)

Industry / Expenditure	Mines	Primary Metals (Ferrous)	Primary Metals (Non-Ferrous)	Non-Metallic Mineral Products
Lands and Buildings	1,133	1,970	1,513	398
Equipment	1,156	1,020	2,325	425
TOTAL	2,289	2,990	3,838	823
TOTAL INTRA-MURAL EXPENDITURES	11,106	7,006	14,186	2,927

The proportion of these funds devoted to nuclear energy, space travel and defence requirements are listed in Table X for the year 1965 (in thousands of dollars).

TABLE X

Current Intra-mural R & D Expenditures, by General Field of Application and Industry 1965, D.B.S. 13-527 (1965) Table 13

Industry / Application	Mines	Primary Metals (Ferrous)	Primary Metals (Non-Ferrous)	Non-Metallic Mineral Products
Nuclear Energy	1,440	49	109	22
Space Travel and Communication	44	-	-	14
War and Defence	373	52	348	109
Other	6,547	5,502	9,214	1,639
TOTAL	8,404	5,603	9,671	1,784

This shows that defence and related areas form only quite a small fraction of the total expenditures in these fields.

The distribution of these funds between basic, and applied research, and developmental projects for 1965 are listed (in thousands of dollars) in Table XI.

TABLE XI

Current Intra-mural R & D Expenditures, by Type of Activity and Industry. 1965. D.B.S. 13-527 (1965) Table 14

Industry / Area	Sub-Total	Mining	Primary Metals (Ferrous)	Primary Metals (Non-Ferrous)	Non-Metallic Mineral Products
Basic Research	1,741	513	139	834	255
Applied Research	8,740	4,132	2,633	1,316	659
Development	14,981	3,759	2,831	7,521	870
TOTAL	25,462	8,404	5,603	9,671	1,784

This is in good qualitative agreement with the data given earlier (pages 26 and 27) on the types of inorganic R and D projects being undertaken in industry. Table XI shows that less than 10% of their expenditures go on basic research, while about 60% go on developmental projects, the remainder going on applied research work. From more recent information for the year 1966 available from data obtained in connection with the C.I.C. survey, the industrial expenditures on research and development in inorganic chemistry per se and on metallurgical chemistry are as follows: (Figures in thousands of dollars).

TABLE XII

by [illegible]

Intra-mural R and D Operating Expenditures for C.I.C. Areas and Character of R and D. 1966 C.I.C. Table 26

C.I.C. Area	Basic Research	Applied Research	Development	Sub-Totals
General Inorganic Chemistry	367.4	1,353.0 ~~1,226.0~~	931.2	2,6[illegible] ~~2,524.7~~
Physical Inorganic Chemistry	181.6	924.7	281.4	1,387.7
Theoretical Inorganic Chemistry	0	0	0	0
TOTALS	549.0	2,277.7 ~~2,150.7~~	1,212.6	4,03[illegible] 3,912.4
Metallurgical Chemistry	445.8	13,05[illegible] ~~12,923.3~~	5,079.9	18,[illegible] ~~18,449.1~~

These figures disclose the fact that, as might be expected, only a little over 10% of the effort goes into basic research in inorganic chemistry in the industrial scene, and only between 2 and 3% in metallurgical chemistry. It is rather surprising that both industrial inorganic and metallurgical chemists should consider that they devote over 50% of their expenditures on applied research and less than one-third on development. It is felt that, either applied research is substantially more expensive to conduct than an equivalent amount of development work or the assignment of many projects to the applied research field may be somewhat erroneous and they should, in fact, have been considered as development. This latter reason is, we feel, the more likely explanation of this apparent discrepancy.

In summary, the expenditures show that, in the three contexts, the universities are the heavy spenders in basic or pure research, the institutes spread their expenditures more evenly but tend to lean most heavily towards applied research, while industry spends its money largely on developmental work and, to a lesser degree, on applied research. This distribution is as expected and is probably the way it should be.

To forecast future expenditures with any degree of accuracy is even less reliable than the assessment that has been given of funds currently being devoted in the various sectors on R and D in inorganic chemistry.

Future estimates for academic expenses have already been given (see page 30). Insofar as institutional and industrial laboratories are concerned one can only assume the present fraction of support for inorganic chemistry will remain constant within the total expenditure forecast for chemistry R and D. Thus, of the following estimates for 1970 one may anticipate that about 15% will be devoted to inorganic work.

TABLE XIII

Comparison of Expenditures for Chemistry R & D. 1966 and 1970. C.I.C. Survey - Tables 2 and 24.

	1966 ($000)	1970 estimates ($000)
Federal Government		
Operating	24,523 ~~23,881~~	[illegible] 37,283
Capital	7,339 ~~7,269~~	[illegible] 10,445
Provincial Government		
Operating	211 ~~199~~	289
Capital	32	45
Industry		
Operating	[illegible] ~~90,800~~	[illegible] ~~120,000~~
Capital	[illegible] ~~33,500~~	17,737 ~~18,000~~

Of these figures those relating to capital outlay for government installations are the most difficult to predict because they are particularly susceptible to the influence of prevailing financial conditions.

These figures have, presumably, taken into account the effect of inflation on the value of the dollar, and, accordingly, must be interpreted to signify only a modest increase in investment in chemical R & D within the industrial sector. It is difficult to reconcile these estimates with a frequently stated national objective to increase the percentage of the G.N.P. devoted in Canada to scientific research and development. And there are no indications that inorganic chemistry is apt to fare relatively any better than other branches of the chemical field.

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

From the material presented in the foregoing chapters in this Section of the Survey, it will, we think, be apparent that inorganic chemistry in Canada is now a dynamic science in the academic sphere; it is extensively practised in certain governmental and other official laboratories; it is being ever more widely used in the industrial sector. In general, therefore, we report a healthy state of affairs. But there is yet far to go to achieve an optimum state, and there are many phases on which earnest effort is necessary to correct imbalances and neglects.

The most obvious area where such effort is necessary arises from the diverse nature of inorganic chemistry itself. So many phases of study can legitimately be considered as being inorganic chemistry, that it is not really surprising that it appears to emerge as two almost totally unrelated sciences when practised in the academic context or when practised in industry. On the one hand, we have more theoretical aspects of the subject, based upon the quantum theory, structural and bonding considerations, spectroscopic behaviour and related topics, that are, to an almost exclusive extent, studied in the universities. On the other hand, we have the more practical aspects of the subject, essentially resource-based and using the techniques of high-temperature chemistry, chemical metallurgy, electrochemistry, etc.; this area is found, to an almost equal degree of exclusion, in the industrial laboratories. Official or governmental laboratories attempt, not entirely successfully, to bridge the gap, but, necessarily, they lean more towards the practical or resource-based areas.

As one might expect, in university and industry alike, everybody wants more money --- money to employ more people, money to buy the ever-more-complicated and sophisticated equipment that is used in modern inorganic chemical research, money to travel to conferences for the purpose of communication with fellow scientists, money to cover the stipends of more post-graduate students and post-doctoral fellows, money to develop processes currently operated only on the bench or pilot-plant scale.

There is one aspect that the author feels may have been overlooked in these ubiquitous demands for more financial support. In the last analysis, there is only one real source for such funds, and that is the taxpayer's pocket. Surely, in some instances at least, it would be more economical and would by-pass the inevitable attenuation of available funds due to administrative costs, for the industry to plough a higher proportion of its own profits directly back into research and/or development effort and, hence, eliminate the necessity for Government hand-outs. The universities, of course, do not have this recourse available to them, but even they should be prepared to "soil their hands" with a proportion of contract research and thereby earn themselves some more funds which they could plough back into their more preferred academic avenues.

Although the following comment does not apply exclusively to inorganic chemistry, it is perhaps more relevant in the inorganic industries than elsewhere. A very real effort must be put forth to endeavour to take products to a more sophisticated and advanced stage of fabrication. Canada must not merely be a supplier of raw materials for other nations, but must, itself, aim at being the manufacturer of a wider range of technologically advanced products. There is more money to be made by advanced technology of the products than in merely supplying partly-processed raw materials.

The subjects coming under the heading of inorganic chemistry that appear to be neglected by comparison with other areas are as follows:

(i) The chemistry of glass and ceramics; this has been quoted by many different respondents as being a prime area where a major improvement is called for. There is a need for the setting up of courses at the Institute of Technology level, at the University level and at the post-graduate level to train technologists and professional scientists in the techniques and principles of high-temperature inorganic chemistry as they apply to the fields of glass and ceramics. The industrial scene also neglects these areas rather shamefully. The advice of the Canadian Ceramic Society could profitably be sought in this regard.

(ii) Solid-state chemistry; this could have many areas of application, e.g., mineralogy, crystallography, semi-conductor technology, electronic and magnetic ceramics, computer and space technology.

(iii) Inorganic electrochemistry.

(iv) Inorganic thermochemistry.

(v) Extreme high-temperature plasma studies.

There were several comments by respondents in all areas that emphasize the desirability of the following courses of action being followed:

(i) Provincial Research Councils and similar organizations should consider the purchase of the expensive and sophisticated items of research equipment needed for today's inorganic chemistry. These instruments could be made available on a time-rental basis to smaller companies which do not have the financial resources nor necessity for the full-time use of such equipment.

(ii) Industrial research laboratories, in many cases, would prefer to take the graduate at the Honours B.Sc. level and train him in the particular areas relevant to their own interest. However, a mechanism for allowing credit towards a higher degree is urged, based on the research work done in the industrial context. The university, of course, must remain the final arbiter of the technical competence of the work done and of its worth towards the granting of a research degree.

(iii) Industry could very profitably make much wider use of academic personnel as consultants, to the benefit of both parties.

(iv) The universities should treat inorganic chemistry on a par with the other branches of the science in terms of personnel and the allocation of funds, and should be prepared to make <u>senior</u> appointments in the field of

(iv) cont'd.

inorganic chemistry. These men should have wide interests and be able to stimulate the above-mentioned neglected areas.

(v) There appears to be wide-felt need for the National Research Council to become more heavily committed in the field of inorganic chemistry by setting up a range of research programmes in this area.

(vi) There is a tendency for university research to be spread rather too thinly over a wide variety of topics at any one location. The development of "centres of excellence" in specific fields would appear to be generally desirable. The appointment of the above-mentioned senior members of faculty should assist towards the attainment of this objective.

(vii) Insofar as is possible, university research programmes should be oriented towards the Canadian context and concerned with the resources in the country. A suitable choice of systems on which to work could often help in this regard, while not invalidating the academic integrity of the project.

(viii) Universities must disabuse their graduates of the impression that applied research conducted in an industrial environment is, in any way, intellectually inferior to the so-called "pure" research conducted in the academic environment. In some way also, they should endeavour to cease producing post-graduates for their own consumption only, and make them available to

(viii) cont'd.

the institutional and industrial fields. There has been a marked tendency for the universities to be inbred and "cannibalistic" in the production of research personnel.

(ix) There is a general high regard for the quality and training of the technologists turned out by the Institutes of Technology and the Community Colleges. More of them should, however, be encouraged to specialize in inorganic chemistry. Further, serious thought must be given to the problem of career development for such personnel; it is also necessary that they should be placed under the technical direction of professional scientists, rather than under personnel of their own level of training. In this way, their level of training and usefulness can be enhanced.

APPENDIX I

TOPICS CONSIDERED TO BE "INORGANIC CHEMISTRY"

1. Atomic structure.
2. Boron and silicon compounds; asbestos, clay, glass, etc.
3. Carbon, germanium, lead, tin; includes graphite, etc.
4. Coordination compounds.
5. "Electron deficient" compounds; boron hydrides, metal alkyls, etc.
6. Electropositive elements and their compounds (alkalies and alkaline earths, building products, etc.).
7. Equilibrium and thermodynamic relationships in inorganic systems.
8. Hydrogen and the hydrides; high energy fuels.
9. Inner transition elements.
10. Inorganic materials useful as solid state electronic devices, semiconductors, etc.
11. Mechanism of inorganic reactions; reaction kinetics.
12. Nomenclature and symbolism.
13. Nonmetals; halogen, oxygen, and nitrogen families, high energy oxidizers.
14. Solutions and solvent theory; nonbacteriological aspects of water chemistry.
15. Structure of inorganic compounds; crystallography, spectroscopy, etc.
16. Synthesis of inorganic materials.
17. Theoretical inorganic chemistry; ligand field theory, molecular orbital theory, ionic models, theory of metals, etc.
18. Transition elements.
19. Sulphur, selenium, tellurium.
20. High-Temperature Inorganic Reactions.