Mines Branch Information Circular IC 192

THE MINERAL PHYSICS SECTION, MINERAL SCIENCES DIVISION, MINES BRANCH, 1963-1967.

by

J. D. Keys*

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ABSTRACT

The work of the Mineral Physics Section of the Mineral Sciences Division, Mines Branch, between 1963 and 1967 is reviewed. The transition which took place in the Section's activities during this period -- from instrumentation and radiotracer studies to the Section's undertaking a significant role in the Divisional sulphide program -- is discussed. An account of current research investigations is given, together with a detailed bibliography.

RÉSUMÉ

L'auteur passe en revue le travail accompli entre 1963 et 1967 par la Section de la physique minérale, de la Division des sciences minérales, Direction des mines. Il traite de la transition qui s'est produite dans les activités de la Section au cours de cette période: des études de traceurs radioactifs et d'instruments, au programme de travaux sur les sulfures de la Division, dans lequel elle joue un rôle important. Il traite de la recherche courante et donne une bibliographie détaillée.

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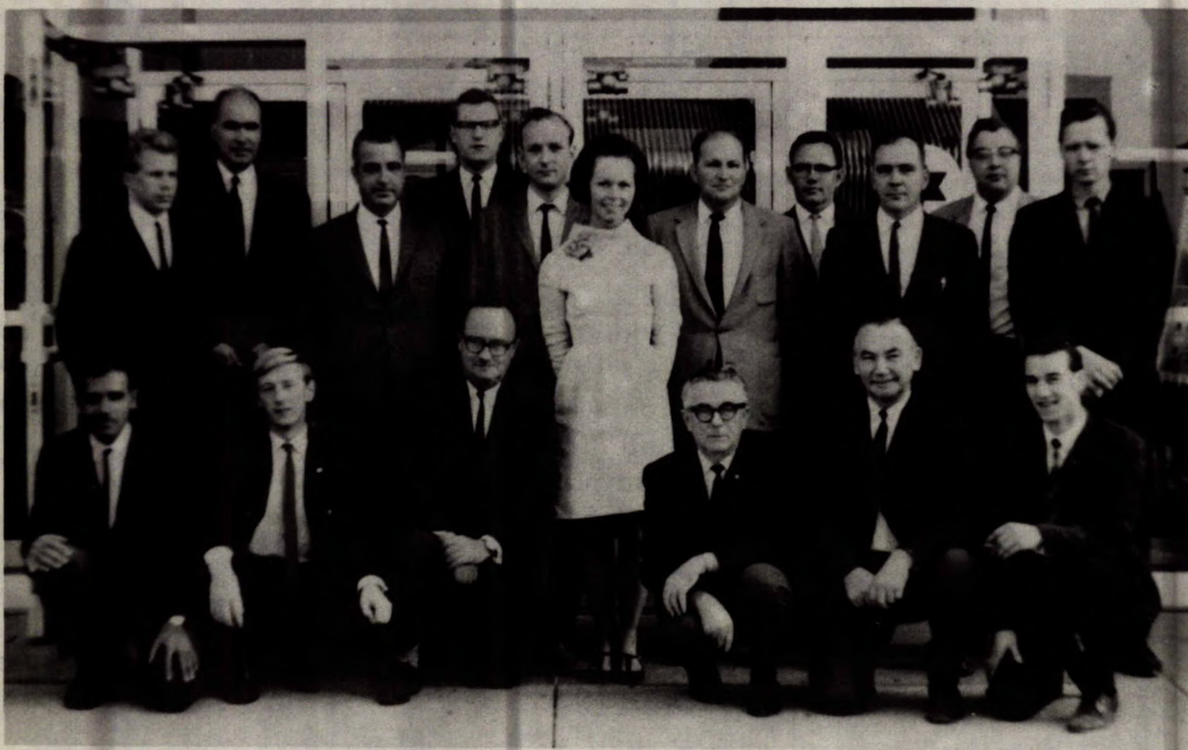

Staff of the Mineral Physics Section,
July 1967.

(Left to right)

1st row, standing:

Dr. D. Maksimov, C. A. Josling, Dr. H. P. Dibbs, Miss D. Hansen, T. M. Baleshta, G. E. Alexander, J. V. Krzyzewski

2nd row: Dr. J. D. Keys, K. Bartels, J. L. Horwood, Dr. R. H. Goodman

Kneeling: Dr. S. M. Ahmed, Dr. P. G. Manning, Dr. C. Lapointe, C. McMahon, A. H. Bettens, R. J. Tremblay

PREFACE

It has become traditional in the Mineral Physics Section to review periodically the activities of the Section and to record its achievements together with the changing character of its objectives. The history of the development of the Section from 1947 to 1963 has been given on two previous occasions. The first marked the dissolution of the Radioactivity Division and the birth of the Mineral Sciences Division; the second coincided with the resignation of G. G. Eichholz who had directed the work of the Section from 1951 to 1963. The departure of the present author provides an opportunity to continue the tradition.

The Mineral Physics Section came into being as the Physics and Electronics Section, Radioactivity Division, developed as the Physics and Radiotracer Subdivision of the Mineral Sciences Division, and has continued to expand as the Mineral Physics Section. The change in name, which functionally described the activities of the Section, was accompanied by a change of programs and objectives. Some of its previous activities have been retained and expanded; others have been curtailed, or abandoned, and new ones have been undertaken. The new name reflected the changed role of the Section and marked a complete integration of its projects with the programs of the Division. A similar break with the traditional "program per section" concept occurred within the other Sections. The result has been the formation of a number of Divisional programs which may involve members from all Sections.

The most satisfactory aspect of the achievements of the past four years is undoubtedly the flexibility shown by the members of the Section in leaving the familiar paths of the previous decade to embark on a program requiring a vastly different background. For many, this meant leaving fields of research to which they had contributed significantly and entering new areas where great effort was required in order to gain the necessary knowledge and where it was expected that their scientific contributions would decrease appreciably for some years. It is a credit to the individuals concerned that they applied themselves without hesitation to the new program and within a short time have been able to make significant contributions.

In this review, I shall trace the steps which led to the development of the new programs, and shall record the progress that has been made in pursuing them. The objectives are different, but they are as vital to the development of Canada's mineral industry as were the previous ones. The results of these programs, if properly exploited, will lay the foundation upon which future beneficiation processes will be based.

Ottawa, August 1967. J. D. Keys

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INTRODUCTION

The Mineral Physics Section was formed as the Physics and Electronics Section, Radioactivity Division in 1947. It was established to provide the leadership in these fields which was necessary to develop Canada's uranium industry. The Division was eminently successful and the contributions of the Section played a major role in developing and disseminating the knowledge upon which the industry thrived. The history of this period has been set forth in Information Circular IC113 (1).

Upon the close of the "uranium era", perhaps better described as the "initial uranium era", in 1959, the Section was incorporated into the new Mineral Sciences Division as the Physics and Radiotracer Subdivision. With the new name came a new aim, which, although different in objective, employed similar techniques. Prior to 1959 the emphasis had been placed upon detection and semi-quantitative analysis of uranium- and thorium-bearing ores, whereas the new program was aimed at demonstrating the usefulness of radiotracers in mining and metallurgical processes. The extension of the older activities to new and fruitful fields was both logical and successful.

In addition to the application of radiotracers to process evaluation, the Section expanded its instrumentation interests. It embarked on a number of ambitious projects, aimed at developing an automatic control capability, which would co-operate with other Divisions of the Mines Branch in serving industry. The achievements of the period 1959-1963, during which the new programs came to maturity, have been recorded in Information Circular IC150 (2).

With the departure of Dr. G. G. Eichholz in 1963, the objectives of the Section were examined in the light of the functions of the Mineral Sciences Division as a whole. Consideration was given to the capability in the private sector for performing industrial radiotracer tests and for developing control instrumentation. Account was also taken of the future requirements of the mineral industry. During the period 1959-1963, Commercial Products Division, Atomic Energy of Canada Limited established itself as a member of the industrial community, capable of undertaking industrial radiotracer tests. In keeping with the policy of not competing with a commercial organization, the Section withdrew from activities which might duplicate this aspect of AECL's operation. It was further noted that the projects arising from this form of investigation were independent of programs pursued within the other Sections of the Division.

The result of this appraisal of the Section's activities was a decision to develop new programs that would integrate with other mineral investigations, current or planned, in the Division. Furthermore, the requirement within the Division for electronic development appeared to be such that a concurrent external program would be impossible to maintain. The question of withdrawing from certain areas of endeavour and re-establishing the people in new and challenging programs was examined carefully before it was decided to assist in developing a Divisional program based on the investigation of the properties of sulphide minerals (3). It was anticipated that initially this Section and the Mineralogy Section would be the main contributors. In order to establish the new character of the Section, the name "Physics and Radiotracer Subdivision" was replaced by "Mineral Physics Section".

The new program was born from a desire to fulfill one clause of the mandate of the Department, namely, "aiding the mineral industries -- by the application of long-term research to improve the economics and utilization of the mineral resources of Canada." Within these terms of reference, it seemed natural to start with the sulphide minerals, with which a large fraction of Canada's mineral wealth is associated. The objectives of the program may be summarized by stating that the intention was to provide fundamental information on the bonding and structural properties of these minerals. It was hoped that the results of these investigations would provide knowledge useful in developing further the processes of comminution, beneficiation and extraction.

During the past three years, the program has been successfully launched, contributions have been made, and many unanswered questions have been asked. The most striking achievement so far has been the ability of the members of the Section to show once again their flexibility by undertaking research projects in completely new and almost foreign fields. In this age of specialization it is remarkable that mature scientists can transfer their energies and thoughts to an area where entirely new concepts are required. It has been stated previously, and should be recorded again, that without a well-trained, enthusiastic and co-operative staff the transition would not have been possible.

FACILITIES

The new programs have placed (and are still placing) a severe strain on the Section's budget. The purchase of scalers and counting equipment was discontinued and replaced with the acquisition of laboratory instruments required for investigating solid-state phenomena in minerals. The major items have now been, or are being, acquired and the Section's laboratories are quite well equipped to carry out the projects in progress.

SULPHIDE PROGRAM

One-half of the Section's effort is at present devoted to co-operative projects involving the sulphide minerals. Although the projects may appear to be of a basic nature, the results will be applicable to mineral processing and extraction metallurgy.

A study of the surface properties should be an important aspect of the program. Cleavage, as encountered in comminution, creates new and increased surfaces; extraction, through dissolution, removes atoms or molecules from the surface; and flotation is made possible through the attachment to the surface of flotation agents or depressants.

Before investigating the properties of surfaces, it is well to remember that minerals are semiconductors (or insulators). As such, the properties of the bulk, upon which the surface properties depend, can be influenced enormously by foreign atoms that reside within the lattice. Thus, it appears that prior to a characterization of a mineral surface it is necessary to characterize the data. As a consequence of this conclusion, most of the projects undertaken have been aimed at increasing the knowledge of the bulk properties of the minerals.

The choice of projects resulted from a compromise between staff background and information desired. One such project involves the application of the Mössbauer effect (A11) to the study of iron in sulphide minerals. This effect occurs in solids when Co^{57} decays to Fe^{57}, gamma radiation being emitted in the process. In normal circumstances, emission of the gamma ray would cause the nucleus to recoil - a consequence of the law of conservation of momentum. This results in a small but significant decrease in the energy of the emitted gamma ray. However, there is a finite probability that the lattice vibrations are in such a mode that when the gamma ray is emitted the recoil is taken up by the lattice as a whole. A moment's thought will show that when this takes place, the gamma ray is emitted with virtually the full energy available from the transition. Where can this phenomenon help us in a study of minerals?

It turns out, when one examines the situation in the Fe^{57}, that the levels involved in the gamma-ray transition are slightly influenced by electric (and magnetic) field gradients. These are caused by the electrons surrounding the nucleus. In particular, the s electrons, which are often the valence electrons, have by far the greatest effect. We can now conceive of an experiment involving a source containing Co^{57} and an absorber (target) containing iron, of which a small fraction is Fe^{57}. If the energy levels in the Fe^{57} in both source and absorber are the same, and if the conditions of lattice vibration are appropriate, the gamma ray emitted from the source will be resonantly absorbed in the absorber. On the other hand, if the electric field gradients surrounding the iron nucleus in the absorber are different from those in the source, resonant absorption cannot occur. This latter is usually the case, but fortunately, by using the Doppler effect and moving the source relative to the absorber, resonance can be achieved. An observation of the magnitude and character of the Mössbauer effect can be related immediately to the electrons surrounding the nucleus, which in many cases are the bonding electrons. We then apparently have a tool for investigating rather sophisticated phenomena associated with the structure of solids and, in this case, minerals.

This effect has been used to study the fields in the neighbourhood of iron nuclei in pyrite, chalcopyrite (Figure 1), arsenopyrite, and iron-containing zinc sulphide (F-71). Final conclusions regarding the properties of interest will have to wait until low-temperature experiments have been performed, but significant information has been obtained. Pyrite, as predicted, shows no sign of ferromagnetic coupling between iron atoms. Furthermore, the directions of the electric field gradients at the iron nuclei conform to bonding directions in the crystal. The existence of Fe^{2+} and Fe^{3+} in zinc sulphide has been confirmed, with the added information that substitutional Fe^{2+} is very ionic - significantly more so than that attributed to the zinc atoms. Based on this observation, an explanation has been advanced for the expansion of the ZnS lattice as a result of iron additions. The project is about to enter the low-temperature experimental phase, at which time some anomalies and ambiguities should be resolved.

Complementary information can be obtained by measurement of the magnetic susceptibility of minerals (Figure 2). This property is of particular (but not exclusive) interest in minerals where elements of the transition series are involved. For elements of the first transition series, Mössbauer studies are limited to minerals containing iron, whereas magnetic susceptibilities can be used to investigate the behaviour of all members.

Not unlike the Mössbauer effect in its origins, the magnetic susceptibility of a mineral depends upon the behaviour and interaction of the electrons - with themselves in this case rather than with the nucleus. For elements of the first transition series, FeS_2, $CuFeS_2$, Fe_5S_6, the magnetic properties of their sulphide mineral compounds vary from almost diamagnetic through antiferromagnetic to ferrimagnetic. In addition to the above minerals, many compounds and chemical complexes exhibit forms of magnetism whose characterization assists in determining valence states or bonding properties.

Iron-containing zinc sulphide provides an interesting example of the information to be gained from magnetic susceptibility measurements. For small additions (approximately 1%) of iron, the behaviour is paramagnetic, indicating little or no interaction between iron atoms. As the iron content is increased, antiferromagnetic coupling between iron atoms takes place

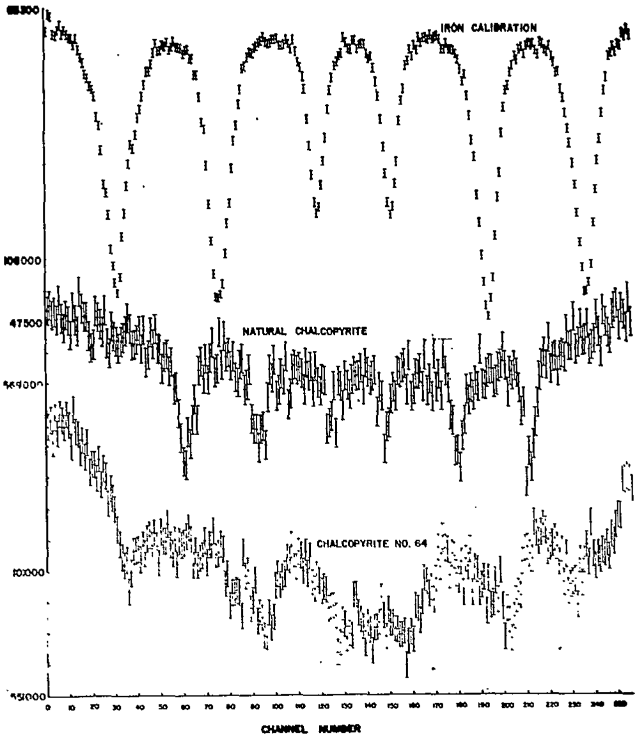

Figure 1. Mössbauer spectra of two chalcopyrites which were indistinguishable by X-ray methods. Although the structures appeared to be identical, the Mössbauer effect shows that there is a difference in the hyperfine interactions between electrons and iron nuclei in the two specimens.

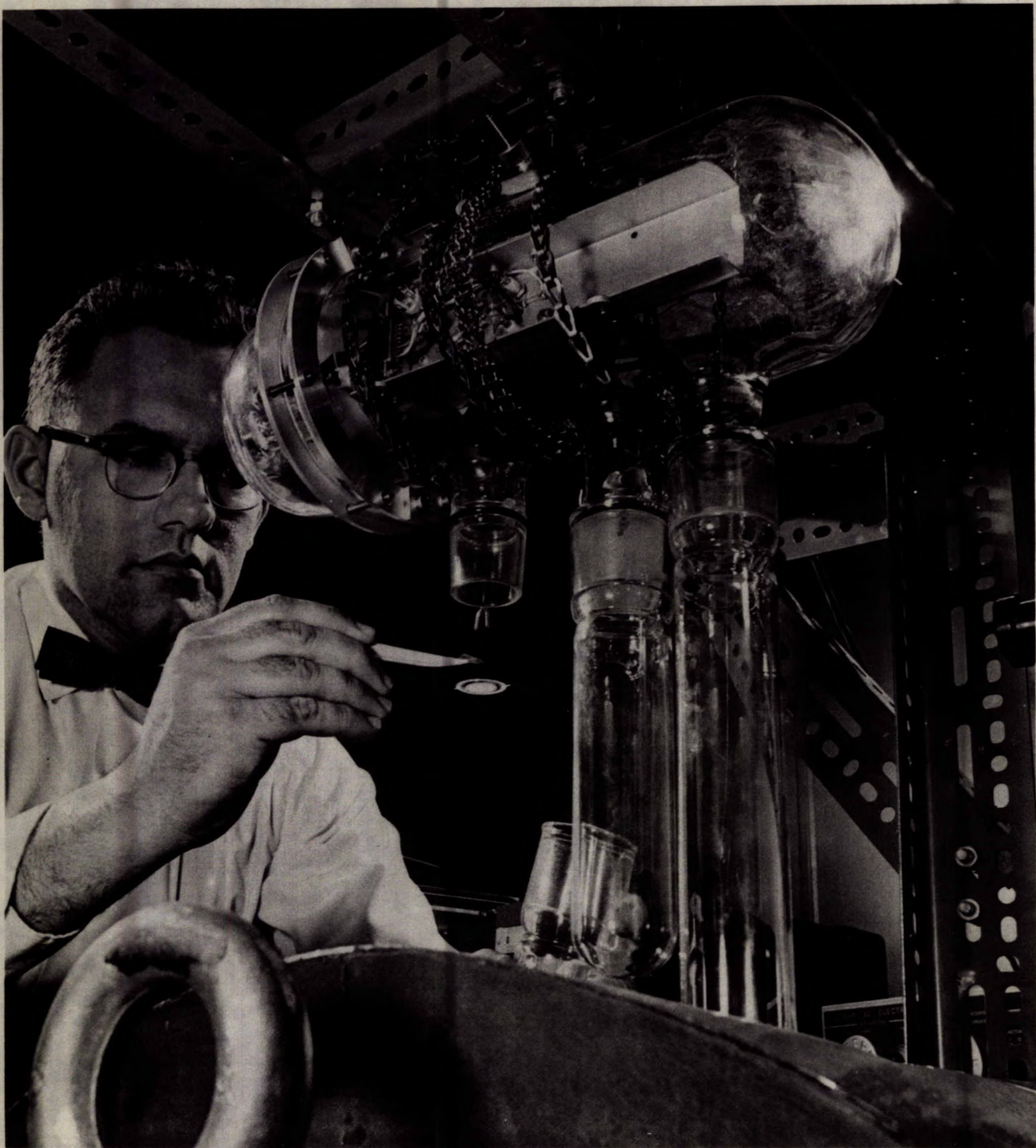

Figure 2. Adjustment of the tare weight on the electrobalance used in measuring the magnetic susceptibility of minerals.

which results in an apparent net decrease in the effective magnetic moment. This information, combined with the results of optical absorption studies and electrical measurements, allows one to form a coherent picture of the behaviour of iron in this mineral.

The first results to be obtained from studies of the properties of minerals in the sulphide program came from an investigation of the optical absorption spectra of iron-containing zinc sulphide (F72). Application of ligand field theory to the spectra yielded the information that iron was present as Fe^{2+} in substitutional (zinc) sites and as Fe^{3+} in interstitial octahedral sites. Although it was not possible to assign a definite value to the ratio, a figure of 10 for Fe^{2+}/Fe^{3+} did not seem unreasonable. In view of the large numbers of Fe^{3+} involved (perhaps 10^{20} cm^{-3}), and the consequent availability of large numbers of electrons, this work sparked a study of the electrical transport properties of iron-containing ZnS in order to confirm the existence of the supposedly free electrons. The results of this study are described later.

The success of the optical absorption studies in ZnS has led to a series of investigations ranging over a wide variety of silicates, garnets (Figure 3) and micas (F84, F95). The siting - octahedral or tetrahedral, distorted or otherwise - of a number of elements of the first transition series has been established. The contribution that this technique can make to the study of minerals has been clearly demonstrated and the ground work has been firmly laid for future advances in this field.

The measurement of the electrical properties of iron-containing ZnS provided some surprises. In spite of an iron content of approximately 14 atom %, of which perhaps 10% occurred as Fe^{3+}, the material was found to have a very high resistivity, approximately 10^8 ohm-cm; there was no measurable Hall effect, indicating a very low mobility, and the thermoelectric power was positive as a result of conduction via holes rather than via the expected electrons. Further studies, combined with a knowledge of some of the properties of ZnS (4), indicated that the electrons were strongly trapped in the crystal and that the conduction took place by the hopping of holes between d-levels of the iron atoms. This explanation appears to be consistent with the observation that iron occurs both substitutionally as Fe^{2+} and interstitially as Fe^{3+}, provided there is some electron interaction, i.e. exchange, between atoms in the two locations.

Electrical measurements have also been made on many of the more common sulphide minerals. In the majority of cases, the results will only be related to the characteristic properties of the compound when relatively pure synthetic specimens are prepared. For pyrite, however, it has been possible to derive a value for the effective mass of the charge carriers. This is one of the significant parameters to be used in characterizing the mineral.

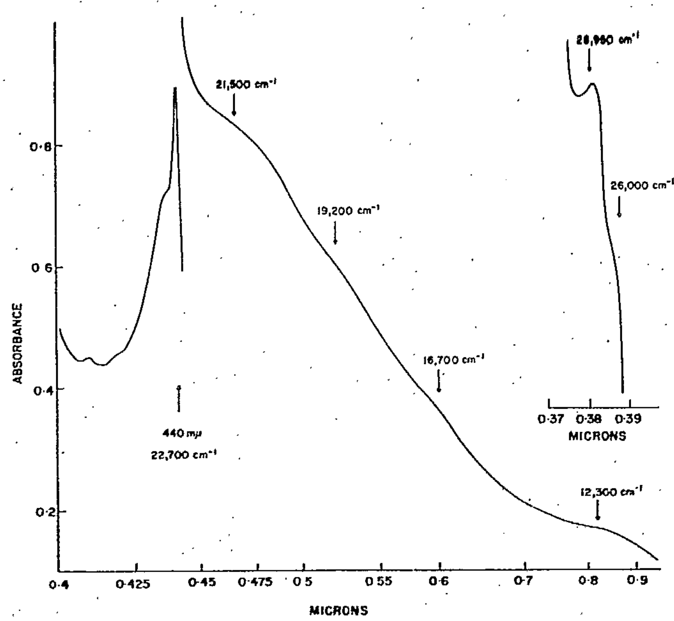

Figure 3. Optical absorption spectrum of octahedral Fe^{3+} in the garnet andradite. Arrows mark the absorptions characteristic of the electronic transitions between crystal field states of the iron atom.

Although it has been found impossible to completely characterize a mineral compound by measuring the properties of a natural specimen, nevertheless it is the natural mineral that is of ultimate concern. It is therefore important to make these measurements on natural minerals, in order that the properties of the pure synthetic laboratory specimens can be related to what occurs in nature. It follows, from the results obtained to date, that synthetic mineral compounds of known composition must be studied before a characterization of a mineral is possible. This phase of the sulphide program, together with the studies of the surface properties, has just begun.

SURFACE PROPERTIES OF MINERALS

Work has continued on the nature of the adsorption of oleic acid on hematite and magnetite, following along lines similar to those described previously. The study has also included an investigation of the flotation characteristics of cassiterite. The technique employed has made use of radioactive tracers and has enabled the effects of oleic acid concentration and pH to be determined. This study has added to the basic knowledge of the flotation of the above-mentioned minerals and is essentially completed.

The behaviour of the liquid double layer, and the extent to which specific ion adsorption occurs on oxide mineral surfaces, have been investigated extensively (A5). Measurements of the differential capacitance of the double layer, and of the charge density at the surface of the minerals, have been made. The results generally follow the same pattern, namely that at low pH, below the zero point of charge, there is little specific ion adsorption; but at higher pH, such adsorption does occur. This project is directly related to flotation characteristics of the various minerals studied and has provided valuable information on the nature of the interactions at the liquid-solid interface. A similar study of the liquid-solid interaction at sulphide mineral surfaces has just begun.

SEMICONDUCTOR RESEARCH

Studies of the phenomena encountered in the thermoelectric device material, Bi_2Te_3, have continued. The ion drift experiment referred to in a previous information circular has been completed and a remarkable result has been obtained (F91). For drift parallel to the cleavage planes, in the temperature range 300-400°C and at a current density of 250 amps/cm^2, copper, silver and gold migrate in a bipolar fashion, i.e. to both the anode and cathode simultaneously. It is believed that this type of drift has not been observed previously, and it is probably characteristic of a class of compounds with structural and bonding properties similar to those of Bi_2Te_3.

In the course of this investigation, data on diffusion of iodine have been obtained. The effects of a temperature gradient alone on diffusion of silver are being determined, and it is anticipated that on completion of this work the study of Bi_2Te_3 will come to an end.

This project was carried on largely as a result of the existence of a thermoelectric device industry in Canada. With the demise of that industry, further studies of the properties of the materials concerned do not seem appropriate.

PROPERTIES OF FERRITES

For some years, the Mines Branch has been under contract to the Electronic Components Research and Development Committee, Defence Research Board, to study the fabrication techniques associated with ceramic materials that have defence applications. In 1965 the terms of reference were extended to include a similar study of ferrites. The Mineral Physics Section had not been directly involved with the ceramic studies, but with the increased commitment in a field related to the interest of the Section, some members have actively joined the program.

The contributions from the Section have been largely in the field of evaluation, with some assistance in special phases of fabrication. Apparatus has been acquired through the contract, and methods and procedures for evaluating the products have been established. This work is carried out, not only in conjunction with the Branch commitment, but also has been used to assist industry in evaluating its own materials. The type of liaison associated with this project indicates a method whereby a government laboratory can give assistance to a Canadian industry and thereby benefit the economy.

NEUTRON ACTIVATION ANALYSIS

The development of a neutron activation analysis facility which was initiated previously has progressed to the point where there now exists a semi-quantitative analytical instrument (D1). It is possible to determine the presence of a number of elements on a routine basis, and the operation is gradually integrating with the Analytical Chemistry group within the Division. Although it is extensively used in determinations made in conjunction with Branch programs, some members of the private sector have found it a convenient, useful and rapid method for determining oxygen in a variety of matrices. As there is no similar facility operating in Canada, no conflict exists with private industry in performing these services.

INSTRUMENT DEVELOPMENT

For many years the Section has been involved in the development of instrumentation for use in Branch programs or of potential use in industry. The history of contributions to the beneficiation process dates from the Lapointe Picker Belt in the early days of the Radioactivity Division. The most recent project of this nature to be undertaken was the construction of a laboratory model of an ore-sorting system (Figure 4) based on the detection of characteristic X-rays emanating from ore bombarded with electrons from a radioactive strontium-90 source (A9).

A second project resulted in the development of a prototype instrument for automatically scanning konimeter slides used for dust-sampling in mines. Existing methods relied on manual counting by trained operators and it was anticipated that a useful contribution could be made by the introduction of an automatic system. Such a system was constructed under the auspices of the Mines Accident Prevention Association of Ontario and combined closed-circuit television techniques with pulse-height analysis. One version has been in field use for two years.

A considerable effort was expended on the design and construction of an X-ray and electron backscatter display system, for use in conjunction with an electron microprobe analyser. This was successfully completed and has made it possible to obtain visual and photographic displays of the surface of objects subjected to this type of investigation.

Perhaps the most ambitious undertaking has involved the installation of a PDP-8 computer, on line, operating in a time-shared mode with the Mössbauer effect experiment (A10) and an automated four-circle X-ray diffractometer. Although the instrumentation has been the responsibility of one member of this Section, the integration with the diffractometer has been a joint effort with the Mineralogy Section.

CONCLUSIONS

In this circular I have attempted to summarize the goals and progress of the Mineral Physics Section during the past four years. A comparison with similar summaries made previously will indicate the extent of changes in programs and direction that have taken place. No doubt the aims were ambitious, and perhaps not all that was hoped for has been accomplished. Nevertheless, a firm foundation in the study of the physics and chemistry of minerals has been established and members of the Section have attained a competence in their respective pursuits. The long-term prospects are bright, and the spirit of co-operation that cuts across Section lines augurs well for the future.

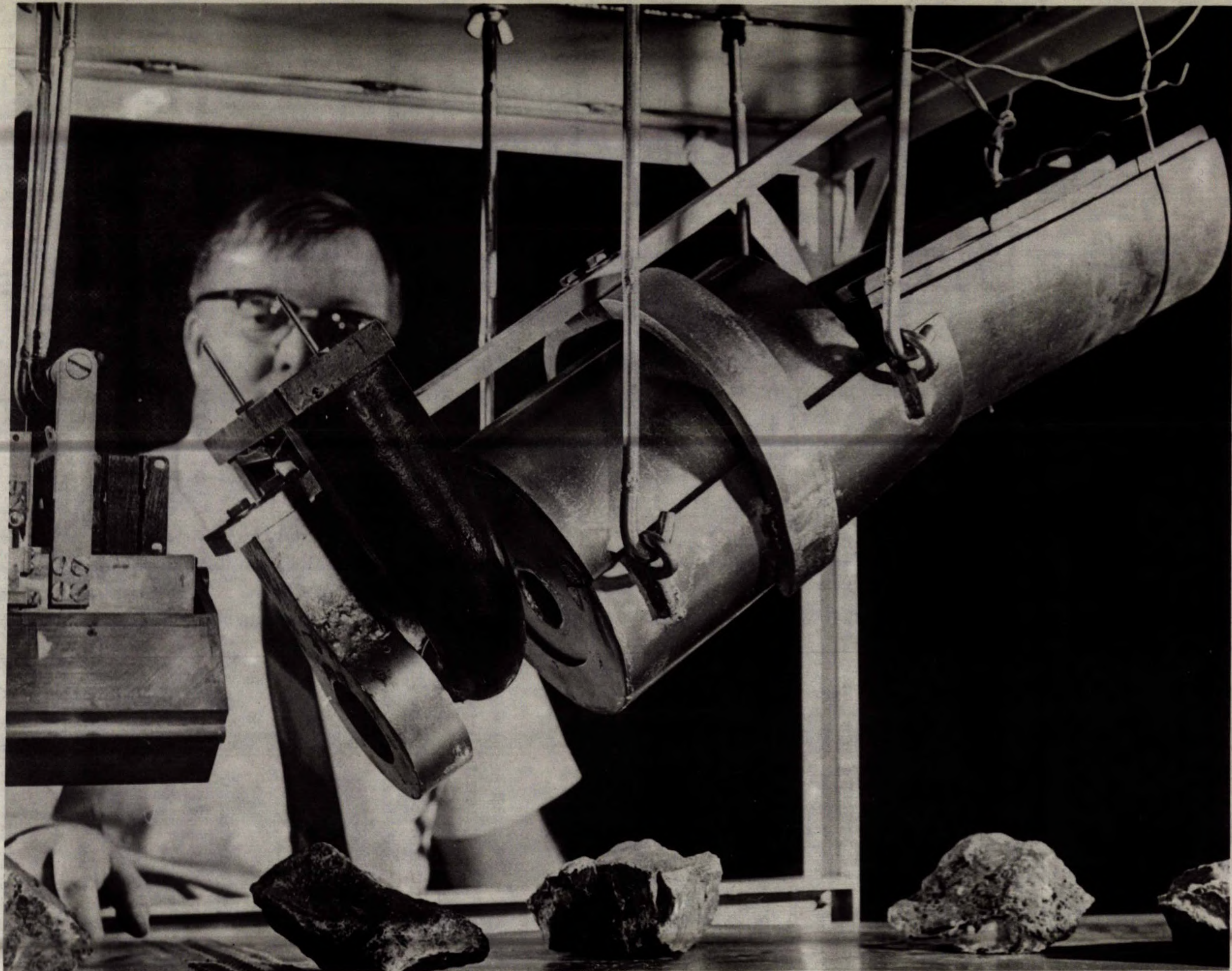

Figure 4. Laboratory prototype of fluorescent X-ray ore-sorter. The device on the left houses the radioactive strontium-90 source used for excitation. Characteristic X-rays are detected by the shielded counter suspended at the right of the picture.

ACKNOWLEDGEMENTS

Had there not been a competent and co-operative group to work with, this report would not exist. It records the progress of seventeen people, most of them having embarked on new projects in unfamiliar fields. I am grateful to them for their support of these programs that are sure to provide information upon which the future Canadian mineral industry will depend.

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APPENDIX A
STAFF OF THE MINERAL PHYSICS SECTION, 1963-1967

A. Scientific Staff

John D. Keys, B.Sc., Ph.D. (McGill)	1958-1967
Christian M. Lapointe, B.Sc., D.Sc. (Laval)	1946-
John L. Horwood, B.A. (Toronto)	1947-
Hugh P. Dibbs, B.Sc. (Manchester), Ph.D. (London)	1958-
Irvine I. Tingley, B.A., M.Sc. (Dalhousie)	1961-1964
Ronald H. Goodman, B.A. (Sask.), Ph.D. (McMaster)	1963-
Philip G. Manning, B.Sc., Ph.D. (Wales)	1964-
Syed M. Ahmed, B.Sc., M.Sc. (Mysore), Ph.D. (Saskatoon)	1966-
Theodore M. Baleshta, B.S.E.E. (Indiana)	1964-

B. Postdoctorate Fellows

Philip G. Manning, B.Sc., Ph.D. (Wales)	1961-1963
Syed M. Ahmed, B.Sc., M.Sc. (Mysore), Ph.D. (Saskatoon)	1963-1965

Visiting Scientist

D. Maksimov (Moscow)	1964-

C. Technical Staff

Charles McMahon	1946-
Arsene H. Bettens	1951-
Jean M. Lefebvre	1951-
Gordon E. Alexander	1953-
Allan F. Seeley	1953-1964
Joseph V. Krzyzewski	1954-
Clifford A. Josling	1955-
Donald W. Carson	1966-
Robert J. Tremblay	1966-
John Van Dalen	1965-1966
Klaus Bartels	1967-
Mrs. Barbara Owens (née Moore)	1960-1966
Miss Diane Hansen	1966-

D. Summer Assistants

David Fisher	1964
Lamont Baker	1964
David Hanes	1965, 1966
David Dutton	1966
Denis Demers	1964
V. Seshadri	1965
Peter Ducz	1967

***

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A11 R.H. Goodman, "The Mössbauer Effect", Chem. in Canada, 31-36 (April 1966).

A12 J.D. Keys and H.P. Dibbs, "On the Bonding in Bismuth Telluride", Phys. Stat. Sol., 19, K11-13 (1967).

A13 P.G. Manning, "Europium Oxalate Ion Association in Water", Can. J. Chem., 44, 3057-3062 (1966).

B. PAPERS PRESENTED

B1 R.H. Goodman, M.W. Johns and J. Kitching (McMaster University), "The Decay of Kr^{90}", Paper 11.5, presented at the Annual Meeting of the Canadian Association of Physicists, Quebec, June 6-8, 1963.

B2 P.G. Manning, "Complexing of Rare-Earth Ions by Tartaric Acids", presented at the 45th Annual Conference of the Chemical Institute of Canada, Toronto, June 6-8, 1963.

B3 H.P. Dibbs, "Industrial Applications of Neutron Activation with a Neutron Generator", presented at the Annual Meeting of the Canadian Nuclear Association, Montreal, May 27-29, 1963.

B4 H.P. Dibbs, "The Principles and Applications of Neutron Activation Analysis", presented at the Conference of Metallurgists, Montreal, September 9, 1964.

B5 H.P. Dibbs and J.L. Horwood, "A Radiotracer Test at the Noranda Smelter", presented at the Conference of Metallurgists, Montreal, September 9, 1964.

B6 H.P. Dibbs, "Determination of Oxygen by Fast Neutron Activation Analysis", presented at Annual Meeting of the American Institute of Metallurgical Engineers, Chicago, Illinois, February 1965.

B7 R.H. Goodman, "Mössbauer Study of Single Crystal Iron Sulphide (Pyrite)", presented to the meeting of the American Physical Society, Washington, D.C., April 26, 1965.

B8 S.M. Ahmed, "Dissociation of Oxide Surfaces at the Liquid-Solid Interface", presented at the Annual Conference of the Chemical Institute of Canada, Montreal, Quebec, April 30, 1965. (MS-65-85)

B9 R.H. Goodman and J.E. Richardson, "The Use of a PDP-5 Computer for the Collection of Mössbauer Experimental Data", presented at the Digital Equipment Users Society Meeting, Harvard University, Boston, Mass., May 20, 1965. (MS-65-43)

B10 S.M. Ahmed, "Double Layer Studies in Flotation", presented at the 4th Canadian Conference of Metallurgists, Ottawa, August 30, 1965.

B11 P.G. Manning, "The Gadolinium Break Effect", presented to the Annual Meeting of the Chemical Institute of Canada, Montreal, Quebec, May 30, 1965. (MS-65-44)

B12 D. Maksimov and C. Lapointe, "The Adsorption of Oleic Acid on Hematite as Influenced by pH-A Radiometric Study", presented to the 4th Canadian Conference of Metallurgists, Ottawa, August 30, 1965. (MS-65-88)

Papers Presented (cont'd)

B13 R. H. Goodman, "A Study of Iron-containing Minerals using the Mössbauer Effect", presented to the Symposium on Structural Inorganic Chemistry, sponsored by the Chemical Institute of Canada, Halifax, N.S., September 1, 1965.

B14 P. G. Manning, "The Ratios of Stepwise Stability Constants: The Rest Effect", presented at the Symposium on Structural and Inorganic Chemistry, sponsored by the Chemical Institute of Canada, Halifax, N.S., September 1, 1965. (MS-65-47)

B15 R. H. Goodman and C. A. Josling, "The Mössbauer Effect", presented to the Canadian Association of Applied Spectroscopy, Toronto, Ontario, February 15-16, 1966.

B16 P. G. Manning, "The Application of Statistical Analysis to the Interpretation of Stepwise Stability Constant Ratios", presented to the Department of Chemistry, University of Waterloo, April 12, 1966.

B17 P. G. Manning, "Some Complexes Present in Aqueous Ferric Chloride Solutions", presented at the C.I.C. Conference, Saskatoon, June 5-8, 1966.

B18 S. M. Ahmed, "Electrochemical Studies of Double Layer on Hematite and Magnetite", presented at the CIMM Conference in Toronto, August 29-31, 1966.

B19 R. H. Goodman, "Iron Impurity States in Zinc Sulphide", presented to the Canadian Association of Physicsts at Sherbrooke, Quebec, June 8-11, 1966.

B20 R. H. Goodman, "An Ore Sorting System Based on X-Ray Fluorescence", presented at the Operating Conference Meeting of the AIME in Philadelphia, December 5, 1966.

B21 R. H. Goodman, "A Mössbauer Spectrometer Based on a Small On-Line Computer", presented at the Third Mössbauer Methodology Symposium, New York, January 29, 1967.

B22 R. H. Goodman, "Certain Transducing Devices for Use in the Mineral Industry", presented to an Engineering Colloquium, University of Saskatchewan, February 14, 1967.

B23 R. H. Goodman, "The Small Computer as a Laboratory Instrument", presented to the Computer Science Group, University of Saskatchewan, February 20, 1967.

B24 R. H. Goodman, "The Mössbauer Spectra of Iron-Bearing Minerals", presented at the University of Manitoba, February 22, 1967.

B25 R. H. Goodman, "A Mössbauer Spectrometer Using On-Line Computer Techniques", presented at the Second Symposium on Low Energy X- and Gamma-Ray Sources and Applications, Austin, Texas, March 27-29, 1967.

Papers Presented (cont'd)

B26 C.M. Lapointe, "Radiometric Techniques in Flotation Research", presented at the Conference of Canadian Gold Metallurgists, Mines Branch, Ottawa, January 17, 1967.

C. MINES BRANCH TECHNICAL BULLETINS

C1 TB 52, "A Radiotracer Test at the Noranda Smelter, July 15, 1963", J.L. Horwood and H.P. Dibbs, January 1964.

C2 TB 55, "The Determination of Oxygen by Fast Neutron Activation Analysis", H.P. Dibbs, March 1964.

C3 TB 57, "A Slime Level Indicator", R.H. Goodman, October 1964.

C4 TB 60, "Procedure for the Fabrication of Printed Circuit Boards", A.H. Bettens, September 1964.

C5 TB 67, "An Ultra-Sonic Power Oscillator", by R.H. Goodman and A.H. Bettens, March 1965.

C6 TB 84, "Measurement of the Surface Areas of Powders by Krypton Gas Adsorption Method. Construction and Operation of the Apparatus", S.M. Ahmed, July 1966.

D. MINES BRANCH RESEARCH REPORTS

D1 R155, "Activation Analysis with a Neutron Generator", H.P. Dibbs, February 1965.

E. MINES BRANCH INVESTIGATION REPORTS

E1 IR 63-98, "Uranium Air Dust Monitoring at Atlas Steels Limited, Welland, Ontario, August, 9, 1963", C. McMahon, September 29, 1963.

E2 IR 63-101, "A Radiotracer Test at the Noranda Smelter, July 15-18, 1963", J.L. Horwood and H.P. Dibbs, October 7, 1963.

E3 IR 64-13, "Air Dust Monitoring at Atlas Steels Foundry, Welland, Ontario, December 19, 1963", C. McMahon, January 21, 1964.

E4 IR 64-43, "The Effect of Bulk Density in the Determination of Oxygen by Neutron Activation Analysis", C. McMahon, May 4, 1964.

E5 IR 64-82, "The Determination of Silica in Iron Ore Concentrates by Fast Neutron Activation Analysis", H.P. Dibbs and C.McMahon, September 9, 1964.

Mines Branch Investigation Reports (cont'd)

E6 IR 64-99, "Feasibility of a Proposed Radiotracer Test at Atlas Steel and Titanium Limited, Welland, Ontario", J.L. Horwood and H.P. Dibbs, December 10, 1964.

E7 IR 64-108, "Development of an Improved Temperature Controller for Phase Equilibrium Studies", G.E. Alexander, December 28, 1964.

E8 IR 65-68, "Tests on a Lithium-Drift Germanium Detector", G.E. Alexander, August 26, 1965.

F. INTERNAL REPORTS

F1 MS-63-46, "Attendance at the National Convention, IEEE, New York, March 25-28, 1963", J.L. Horwood, April 10, 1963.

F2 MS-63-49, "Tartrate Complexes of the Rare-Earth Elements. I: The d-, dl-, and meso-Tartrate Complexes of Tb and Eu", P.G. Manning, April 9, 1963.

F3 MS-63-53, "The Oak Ridge Radioisotope Conference, Catlinburg, Tenn., April 1-3, 1963", G.G. Eichholz, April 17, 1963.

F4 MS-63-54, "Discussion on Proposed Tracer Tests at the Noranda Smelter, April 26, 1963", G.G. Eichholz, May 2, 1963.

F5 MS-63-61, "Visit to Atomic Energy of Canada Limited, Chalk River, Ontario, May 14-15, 1963", R.H. Goodman and I.I. Tingley, June 16, 1963.

F6 MS-63-68, "Visit to Electronic Associates, Ramsey Engineering and Philips Electronics, Toronto, May 27-30, 1963", R.H. Goodman, July 8, 1963.

F7 MS-63-73, "The Extraction of Scandium by Mixtures of Oxine and Neutral Organophosphorous Reagents", P.G. Manning and Pranowo, July 26, 1963.

F8 MS-63-76, "The Extraction of Am^{241} from Sulphate, Thiosulphate and Tartrate Solutions by Thenoyltrifluoracetone", P.G. Manning, August 21, 1963.

F9 MS-63-81, "Field Trip to Noranda, Quebec, to Conduct a Radiotracer Test at the Noranda Smelter", J.L. Horwood and H.P. Dibbs, August 23, 1963.

F10 MS-63-90, "The Determination of Ionium in Uranium", Miss Sandra Adams, September 23, 1963.

F11 MS-63-93, "Visit to the Soviet Union, March 1 - July 31, 1963", J.D. Keys, November 8, 1963.

Internal Reports (cont'd)

F12 MS-63-97, "A Report on Visits to Several Research Laboratories Located in Western Europe, August 1 - September 23, 1963", J.D. Keys, February 7, 1964.

F13 MS-63-114, "A Slime Level Indicator", R.A. Klump, December 5, 1963.

F14 MS-63-115, "Report on the Annual Meeting of the Institute of Electrical and Electronic Engineers, Toronto, September 29 - October 2, 1963", R.H. Goodman and G.E. Alexander, October 10, 1963.

F15 MS-63-116, "Exchange of Silver Ions at Single Crystal-Solution Interfaces", I.I. Tingley, August 27, 1963.

F16 MS-63-117, "Second Progress Report on Konimeter Slide Counter Project", T.R. Flint, December 6, 1963.

F17 MS-64-12, "Field Trip to Nuclear Data Inc., Madison, Wisconsin, U.S.A.", G.E. Alexander, February 24, 1964.

F18 MS-64-16, "A Report on Some of the Mössbauer Effect Experiments at the Argonne National Laboratory, The University of Illinois, Westinghouse Research Center and the Bell Laboratories", R.H. Goodman, March 2, 1964.

F19 MS-64-30, "Discussion on Paper 'Radioisotopes as Industrial Tools in Canada' by L.J. O'Riley for Presentation at the Engineering Institute of Canada Conference, Banff, May 27-29, 1964", J.D. Keys, April 30, 1964.

F20 MS-64-34, "The Determination of Antimony in High-Purity Iron by Neutron Activation Analysis", H.P. Dibbs and C.H. McMaster, May 19, 1964.

F21 MS-64-35, "Impressions of Events Occurring at the Spring Meeting of the American Physical Society, Washington, D.C., April 27-30, 1964", R.H. Goodman, May 20, 1964.

F22 MS-64-38, "Konimeter Slide Counter-Scaler Control Circuit Description and Transistor Technology Reference", T.R. Flint, May 26, 1964.

F23 MS-64-46, "Attendance at Ninth Scintillation and Semiconductor Counter Symposium, and Visits to the United States Geological Survey, Washington, D.C., February 25-28, 1964", J.L. Horwood, June 17, 1964.

F-24 MS-64-54, "Attendance at 20th Annual Powder Metallurgy Technical Conference, April 27-29, 1964, at Chicago, Illinois", J.L. Horwood, July 2, 1964.

Internal Reports (cont'd)

F25 MS-64-82, "Exchange of Nickel Ions Between Single Crystal Nickel Surfaces and Nickel Chloride Solution", I.I. Tingley, September 28, 1964.

F26 MS-64-83, "The Ratios of Stepwise Stability Constants. 2: The Rare-Earth Acetates", P.G. Manning, September 30, 1964.

F27 MS-64-86, "The Ratios of Stepwise Stability Constants. 3: Rare-Earth β hydroxymonocarboxylates", P.G. Manning, October 7, 1964.

F28 MS-64-91, "Applications of Radioactive Isotopes in Canadian Industries", J.D. Keys, October 15, 1964.

F29 MS-64-92, "Interaction of Oleic Acid and Cassiterite in Flotation Studies", C.M. Lapointe and L. W. Pommier, October 16, 1964.

F30 MS-64-93, "Visit to Digital Equipment of Canada, Carleton Place, Ontario", R.H. Goodman, A.H. Bettens and C.A. Josling, October 16, 1964.

F31 MS-64-94, "The Ratios of Stepwise Stability Constants. 4: The Rare-Earth Tartrates", P.G. Manning, October 21, 1964.

F32 MS-64-98, "The Rare-Earth Chlorides", P.G. Manning, October 27, 1964.

F33 MS-64-99, "Structures of Rare-Earth Citrates", P.G. Manning, November 5, 1964.

F34 MS-64-117, "The Extraction of Am^{241} from Sulphate, Thiosulphate, and Tartrate Solutions by Thenoyltrifluoroacetone", P.G. Manning, December 9, 1964.

F35 MS-65-2, "The Sulphates of Some Trivalent Actinide and Lanthanide Ions", P.G. Manning, January 5, 1965.

F36 MS-65-3, "The Use of the IBM 7094 Computer at the University of Toronto", R.H. Goodman and C.A. Josling, January 7, 1965.

F37 MS-65-10, "The Use of an "ON LINE" Computer for Mössbauer Experiments", R.H. Goodman and J.E. Richardson, January 26, 1965.

F38 MS-65-29, "The Use of a PDP-5 Computer on Mössbauer Experiments at Digital Equipment of Canada Limited, Carleton Place, Ontario", R.H. Goodman, February 15, 1965.

F39 MS-65-30, "Contribution to the Development of Apparatus for Mössbauer Effect Studies", L. Baker, February 18, 1965.

F40 MS-65-32, "The Rare-Earth Dicarboxylates", P.G. Manning, March 1, 1965.

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F41 MS-65-33, "Modifications to Baird Atomic Model 530 Spectrometer for Operation in Conjunction with Nuclear Data ND 130", G.E. Alexander, March 19, 1965.

F42 MS-65-38, "Highlights of the Annual Meeting of the American Physical Society held in New York, January 27-30, 1965", R.H. Goodman, March 30, 1965.

F43 MS-65-40, "Attendance at IEEE Instrument Show at New York, 23-26 March, 1965", J.D. Keys and G.E. Alexander, April 14, 1965.

F44 MS-65-43, "The Use of a PDP-5 Computer in the Collection of Mössbauer Experimental Data", R.H. Goodman and J.E. Richardson, April 20, 1965.

F45 MS-65-44, "The Gadolinium Break Effect", P.G. Manning, May 10, 1965.

F46 MS-65-47, "Ratios of Stepwise Stability Constants. The Rest Effect", P.G. Manning, May 17, 1965.

F47 MS-65-49, "Calculated Sensitivities for Activation Analysis with a Neutron Generator", H.P. Dibbs, May 27, 1965.

F48 MS-65-51, "Report on 1965 International Conference on Modern Trends in Activation Analysis, College Station, Texas, and of a visit to the Department of Nuclear Engineering, Atlanta, Georgia, April 19-24, 1965", H.P. Dibbs, June 15, 1965.

F49 MS-65-56, "Chloride and Sulphate Ion Association with some Lanthanide and Actinide Ions", P.G. Manning, June 11, 1965.

F50 MS-65-58, "Attendance at the American Physical Society Meeting held at Washington, D.C., April 26-28, 1965", R.H. Goodman, June 21, 1965.

F51 MS-65-78, "An Illegal Character Detector for Use with a PDP Computer", C.A. Josling, July 22, 1965.

F52 MS-65-79, "The Spring DECUS Meeting Held at Harvard University and a Visit to Digital Equipment Corporation at Maynard, Mass.", R. H. Goodman, July 23, 1965.

F53 MS-65-85, "Studies of the Dissociation of Oxide Surfaces at the Liquid-Solid Interface", S.M. Ahmed, August 10, 1965.

F54 MS-65-86, "Linear Regression", V. Seshadri, August 20, 1965.

F55 MS-65-87, "Double Layer Studies in Flotation", S.M. Ahmed, August 24, 1965.

Internal Reports (cont'd)

F56 MS-65-88, "The Adsorption of Oleic Acid on Hematite as Influenced by pH-Radiometric Study", D. Maksimov and C. Lapointe, August 25, 1965.

F57 MS-65-89, "Experimental Designs and the Analysis of Variance", V. Seshadri, September 1, 1965.

F58 MS-65-107, "Rare-Earth Picolinate and Picolinate-N-Oxide Complexes", P.G. Manning, November 5, 1965.

F59 MS-65-110, "An Electronic Ore Sorter", R.H. Goodman, A.H. Bettens and C.A. Josling, November 24, 1965.

F60 MS-65-118, "A Correlation of Stepwise Stability Constant Ratios and Some Structural and Bonding Properties of Transition Metal and Zinc Complexes", P.G. Manning, December 3, 1965.

F61 MS-65-119, "Some Complexes Present in Aqueous Ferric Chloride Solutions", P.G. Manning, December 7, 1965.

F62 MS-65-120, "The Mössbauer Effect, High Resolution Probe of the Interior of Materials", R.H. Goodman, December 10, 1965.

F63 MS-65-126, "Europium Oxalate Ion Association in Water", P.G. Manning, November 9, 1965.

F64 MS-65-131, "Visit to Ferrox Iron of Canada Limited, Prescott, Ontario", J.L. Horwood, November 23, 1965.

F65 MS-65-132, "Report on a Visit to Syracuse University, New York", J.D. Keys, October 18, 1965.

F66 MS-66-1, "Cu (II) in Octahedral Sites in Sphalerite", P.G. Manning, January 14, 1966.

F67 MS-66-3, "The Use of On-Line Computers with Four Circle X-ray Crystal Diffractometers: A Visit to Several Laboratories Using this Technique", S.A. Forman and R.H. Goodman, February 22, 1966.

F68 MS-66-8, "A Correlation of Stepwise Stability Constant Ratios and Some Bonding Properties of Transition Metal and Zinc Complexes" P.G. Manning, March 15, 1966.

F69 MS-66-9, "A Single Electrometer Method of Measuring Transport Properties of High Resistivity Semiconductors", T.M. Baleshta and J.D. Keys, March 16, 1966.

F70 MS-66-11, "Resistivity and Hall Coefficient Measurements on Doped and Undoped Samples of Gallium Arsenide", D.P. Demers, March 22, 1966.

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F71 MS-66-22, "Iron Impurity States in Cubic Zinc Sulphide (Sphalerite)", R.H. Goodman, April 1, 1966.

F72 MS-66-24, "Absorption Spectra of Fe (III) in Octahedral Sites in Sphalerite", P.G. Manning, April 21, 1966.

F73 MS-66-26, "Electrochemical Studies of the Double Layer on Specular Hematite and Magnetite", S.M. Ahmed, April 28, 1966.

F74 MS-66-28, "A Study of the Bonding Properties of Sulphur in Bornite", P.G. Manning, May 2, 1966.

F75 MS-66-44, "The 1966 Spring Meeting of the American Physical Society, Washington, D.C., April 25-28, 1966", R.H. Goodman, June 22, 1966.

F76 MS-66-57, "The Stepwise Stability Constant Ratios for Ferric Fluoride Complexes", P.G. Manning, July 27, 1966.

F77 MS-66-65, "A Constant Acceleration Mössbauer Spectrometer Using an On-Line Computer" (Abstract only), R.H. Goodman, August 1966.

F78 MS-66-72, "Transition Metal Impurities in Sphalerite (ZnS)", D. Fisher, September 8, 1966.

F79 MS-66-73, "Europium Tartronate Ion Association in Water", P.G. Manning, September 12, 1966.

F80 MS-66-74, "A Comparison of the Geometric and Van der Pauw Techniques of Measuring Resistivities", D.H. Dutton, September 1, 1966.

F81 MS-66-75, "Symposium on Automatic Control, Laval University, August 29-31, 1966", R.H. Goodman, September 23, 1966.

F82 MS-66-78, "An Introduction to the PDP-8 Computer, Its Operation and Programming", C.A. Josling, September 30, 1966.

F83 MS-66-83, "Rare-Earth Hydroxymonocarboxylate Ion Association in Water", P.G. Manning, October 5, 1966

F84 MS-66-88, "The Near Ultraviolet to Near Infrared Absorption Spectra of Fe(III), Fe(II) and Ti (III) in Biotite and Clintonite", G.H. Faye and P.G. Manning, October 28, 1966.

F85 MS-66-93, "The Effect of Distance and Moderator Thickness on the Neutron Energy Distribution from a 14 MeV Neutron Generator", C. McMahon, November 14, 1966.

F86 MS-66-95, "An Ore Sorting System Based on X-ray Fluorescence", R.H. Goodman, C.A. Josling and A.H. Bettens, November 16, 1966.

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F87 MS-66-96, "The Application of On-Line Computer Techniques to Mössbauer Spectroscopy", R.H. Goodman, November 17, 1966.

F88 MS-66-100, "On the Bonding in Bismuth Telluride", J.D. Keys and H.P. Dibbs, November 21, 1966.

F89 MS-66-101, "Mössbauer Spectroscopy Using an On-Line Computer", R.H. Goodman, December 7, 1966.

F90 MS-66-102, "The Structures of Zinc Chloride and Bromide Complexes in Water", P.G. Manning, December 8, 1966.

F91 MS-66-107, "Electrotransport in Single-Crystal Bismuth Telluride", H.P. Dibbs and J.D. Keys, December 19, 1966.

F92 MS-66-109, "Europium Tartronate and Mandelate Ion Association in Water", P.G. Manning, December 21, 1966.

F93 MS-67-1, "Certain Transducing Devices for the Mining Industry", R.H. Goodman, January 3, 1967.

F94 MS-67-2, "The Small Computer in the Laboratory", R.H. Goodman, January 3, 1967.

F95 MS-67-3, "The Optical Absorption Spectra of the Garnets Almandine-Pyrope, Pyrope and Spessartine, and Some Structural Interpretations of Mineralogical Significance", P.G. Manning, January 4, 1967.

F96 MS-67-4, "Radiometric Techniques in Flotation Research", C.M. Lapointe, January 10, 1967.

F97 MS-67-5, "Absorption Spectra of Fe (III) in MgO", P.G. Manning, January 11, 1967.

F98 MS-67-10, "The Determination of Aluminum and Silicon in Bauxite", C. McMahon and H.P. Dibbs, January 31, 1967.

F99 MS-67-13, "Correlation of Absorption Spectra and Structure of Some Co(II) and Ni(II)-2, 2 Biquinoline Complexes", G.H. Faye and J.L. Horwood, February 8, 1967.

F100 MS-67-14, "Optical Absorption Studies of the Mixed-Ion (Cu and Al) Doping in Sphalerite", P.G. Manning, February 9, 1967.

F101 MS-67-19, "Studies of the Oxide Surfaces at the Liquid-Solid Interface. Part II: Fe-Oxides", S.M. Ahmed and D. Maksimov, February 21, 1967.

F102 MS-67-25, "Optical Absorption Spectra of a Manganese-bearing Silicate", P.G. Manning, March 2, 1967.

F103 MS-67-30, "Absorption Spectra of the Manganese-bearing Chain Silicates Pyroxmangite, Rhodonite, Bustamite and Serandite", P.G. Manning, March 14, 1967.

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