The Institute for the Study of Metals: The First 15 Years

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INTRODUCTION

On August 9, 1945 (Nagasaki Day), Chancellor Robert M. Hutchins of the University of Chicago announced, "Research which led to the invention of the atomic bomb will be continued at the University of Chicago through two new institutes devoted to the study of nuclear physics and metals." A third unit, the Institute of Radiobiology and Biophysics, was also created to focus on industrial health.

The new institutes, characterized by Hutchins as outgrowths of the university's major role in war research, were to bring a number of famous scientists to the university. Among the new members of the faculty of the Institute for Nuclear Studies were Enrico Fermi (Columbia University, Los Alamos), Harold C. Urey (Columbia University), Edward Teller (Los Alamos) and Joseph E. Mayer and his wife, Maria Goeppert Mayer (Columbia University). This institute was to be headed by Samuel K. Allison, professor of physics at the university, but temporarily on leave at Los Alamos.

As new members of the faculty of the Institute for the Study of Metals, Hutchins gave only two names: Cyril Stanley Smith (Los Alamos), was to be director of the Institute for the Study of Metals and professor of metallurgy at the university, and Clarence Zener (in war work at the Watertown Arsenal), who would be a professor of physics. With 15 years of research experience in the metallurgical industry, Smith was unique among the senior personnel at the new research institutes, and he proved extremely valuable to the university in its effort to obtain financial support from industry for the interdisciplinary institutes.

A VISION FOR THE METALS INSTITUTE

Four days after Hutchins' announcement, Smith submitted a plan for the organization of the new institute to Walter Bartky, the dean of the Division of Physical Sciences. With regard to the research program, Smith's vision of the institute was stated as follows:

> In accordance with the policy of the University as well as my own wishes, the Institute will concern itself primarily with research into the fundamental aspects of metallurgy and will not, except indirectly, develop its technology. In particular it is proposed to encourage those phases of metallurgy bordering on physics. The research staff of the Institute will be composed of metallurgists, physicists and chemists, selected because of their interest in various fundamental phases of metallurgical science and they will be given every encouragement to follow their studies without regard to commercial considerations. It is hoped at the outset to work in each of the following subjects in the fields of physical metallurgy: elasticity, plasticity, and fracture, including high velocity strains; structure of pure metal and alloy phases; ferromagnetism; nature and mechanism of allotropic transformation and precipitation; and the theory of the metallic state. In addition to these physical fields it seems highly desirable to cultivate work on the physical chemistry of corrosion and of metal reduction; the latter in particular has been neglected by scientific workers, and developments in the field for many years have been almost entirely of a practical industrial nature.
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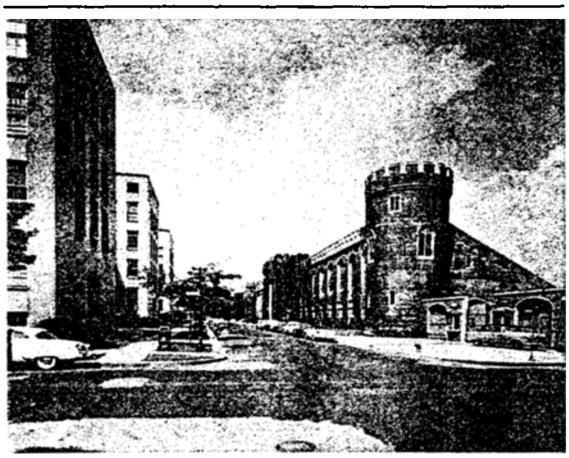
> To avoid the necessity of scientists becoming adept in the whole art of metallurgy, there will be a staff of professional metallurgists, graduate students, and technicians who (on approved request) will undertake the preparation of samples of any specified composition and treatment required by the scientific staff or designed to meet requirements specified by them. This "Metals Technology Section" will also institute its own studies of fabrication methods and will aim in particular at the development of methods of purification, reduction, and fabrication of those rare and little-known metals which cannot be satisfactorily procured commercially and of unusual combinations of common substances. The availability of metals and alloys selected for their suitability for the particular scientific studies in mind instead of for their commercial importance or availability should greatly aid the work of the fundamental research group. The new metals and methods should eventually be of great value to industry, but the primary aim of the staff of the Institute will be an increased understanding of metals, not immediately useful applications.



The Institute for the Study of Metals remained in its temporary quarters in the West Stands of Stagg Field (right) until 1951 when all three institutes moved into the new Research Institute building (left). However, the cryogenic facilities remained in the West Stands until 1957, when the low-temperature wing of the Research Institute building was completed. The Institute for the Study of Metals occupied the southern half of the West Stands. Immediately north of the metals institute is the squash-court area (ivy-covered section) where Chicago Pile No. 1 was built and went critical on December 2, 1942. The West Stands were torn down in the 1960s. This picture, taken about 1955, looks north along Ellis Avenue.

STAFFING THE INSTITUTE

With respect to the planned professional staff of the new institute, Smith wrote in the same plan:

> At the moment only two men are committed to the Institute. It is essential that we build up the staff as rapidly as possible. The men needed, divided into proper category and specific fields of interest are listed below together with some suggested names. In practically every case men listed know nothing whatever about the Institute or the fact that they are being considered. . . .
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> **Research Section:**
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> Metallurgist—interested in crystal structure, metallography
> Metallurgist—steel transformation, age hardening etc.
> Metallurgist—allotropy, transformation, solid, solution structure
> Physicist—elasticity, 'anelasticity,' plasticity and fracture
> Physicist—structure of intermetallic phases, solid state theory
> Physicist—structure of intermetallic phases
> Physicist—ferromagnetism
> Physicist—theory of metallic state
> Physicist—high velocity strains
> Physical Chemist—metal reduction
> Physical Chemist—corrosion
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> **Technology Section:**
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> Metallurgist—to direct work of section
> Chemist—preparation and purification of metallic compounds
> Metallurgist—reduction (thermal methods)
> Electrochemist—reduction (electrolytic methods)
> Metallurgist—vacuum casting (special techniques)
> Metallurgist—fabrication (rolling, drawing etc.)
> Metallurgist—powder metallurgy
> Metallurgist—mechanical testing (metallographer)
> Analytical Chemist: 3 needed
> Ceramist—experienced in "super" refractories

Apart from these appointments he visualized a large number of temporary research fellows with a Ph.D. background in the research section, as well as research assistants, technicians, and some graduate students in the technology section.

Smith remained at Los Alamos until the end of 1945. However, he pursued the problem of staffing the institute very intensely, and he scheduled the first meeting of its professional staff in Chicago on February 11–13, 1946. On April 11, 1946, Smith prepared the first detailed description of the new institute as it was taking shape. This memo was undoubtedly, in part, intended for publicity purposes. It provided a fairly detailed outline of the planned research and also provided the names of the scientists associated with the institute. The text is presented in the sidebar.

Eight years later, in a report dated December 17, 1954, Smith analyzed the personnel situation of the institute:

> It is believed that the environment for metallurgical research at the Institute is unique in the world and that it is particularly important to strengthen the Institute in this respect, not only for the sake of the research itself, but also for the great contribution that the University can make to the inspiration of higher scientific standards in metallurgical research laboratories generally.
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> The "metals" aspect of the Institute is in danger of disappearing. Currently (omitting the Director who mainly moves paper rather than metals), there is only one full-time tenure metallurgist in the Institute (Barrett) and one assistant professor. An imaginative physical metallurgist . . . is essential plus one younger man.
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> The work of the physics section of the Institute was seriously retarded by the resignation of Clarence Zener in 1951 and, to some extent, by the fact that the principal remaining physicist, A.W. Lawson, has perforce been partially preoccupied with problems of the Physics Department [of which he was then the chairman]. The section which should be the strongest in the Institute and provide the best bridge with solid state physics flourishing elsewhere has consequently somewhat suffered, and the highest priority appointment is that of a theoretical physicist of really top-notch quality. . . .
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> Closely behind this in order of importance is an experimental physicist of top rank.

On the other hand, Smith considered the chemistry section to be "in good shape. As long as a continued influx of good young men can be maintained, no additional top-level appointments are regarded as necessary." He also believed that although the low-temperature group was "excellently staffed, . . . the addition of one or more good experimental physicists to the group is highly desirable."

During the first 15 years of its existence, the institute made several attempts to bring new distinguished tenure-level metallurgists and physicists to the university. These efforts were not successful. However, the institute did bring a number of very distinguished visiting professors (e.g., N.F. Mott, G.V. Raynor, R. Kubo, and A.B. Pippard) to the campus for periods ranging from one month to one year. While the institute did not succeed in bringing in new tenure-level faculty from the outside, it had a great deal of success in attracting promising young scientists as research associates or as junior faculty members.

In his 1945 vision of the new institute, Smith did not fully anticipate that it would attract a very large number of graduate students from physics and chemistry. In fact, from 1949 to 1960, 31 students from the Department of Physics earned their Ph.D. degrees based on work carried out in the institute. Most of these students worked in the High Pressure Laboratory and did their Ph.D. research under the direction of A.W. Lawson. The corresponding number for the Department of Chemistry was 20; for the Department of Geology, it was two. Most of the chemistry Ph.D. students worked in the Low Temperature Laboratory under the direction of J.W. Stout or E.A. Long, or with N.H. Nachtrieb.

In 1955, Smith decided to take a yearlong sabbatical leave from the university in order to pursue his long-standing interest in the history of metallurgy. During his absence, the leader of the

C.S. SMITH'S 1946 DESCRIPTION OF THE INSTITUTE

The University of Chicago has recently announced the formation of an *Institute for the Study of Metals*. The purpose of the Institute is to bring metallurgists, physicists and physical chemists together to work upon the fundamental problems in metals, combining the varied backgrounds, techniques, and ways of thinking of these professions toward the common goal of understanding the behavior of metals, the relation of this behavior to their structure, and the mechanisms whereby the various types of structures are obtained. Though the director of the Institute is a Metallurgist and the main effort will be in the direction of the field indicated by its name, research will be aimed at the basic understanding of the solid state in general.

Advances in metallurgy in the past have in a large degree resulted from careful observation of large masses of data and inspired guessing by people familiar with the behavior of metals. Only in rare instances has theory clearly designated more than a general direction for improvement. It is believed that in this Institute rapid advances will be made both in a scientific understanding of metals, and in the relation of this scientific knowledge to practical problems. Here, under one roof, are collected the talents and viewpoints of all three professions. While the theoretical leadership will come mainly from physicists, metallurgists will bring their techniques (which will be used in preparing research materials for the whole Institute) and a knowledge of that vast reservoir of somewhat unassimulated data on structure and behavior of metals that constitutes modern metallurgy. The metallurgists will themselves undertake fields in which research on constitutionary structure, diffusion, phase transformations, grain growth, and similar fields in which a phenomenological approach must precede or accompany the strictly mathematical. Physical chemists will study reduction and reactions of metals with non-metals and the related thermodynamical sidelines; analytical chemists will not only provide service, but will develop new methods of analysis involving spectrochemistry, radiochemical techniques, and others.

An important initial field of research will be the deformation of metals, over the whole range from very small strains (anelasticity) to very large ones leading to fracture. Theories of resistance to deformation will be tested over a wide range of temperature on whatever metal will most sensitively show the effect desired—a marked advantage over the customary course which uses the material most available.

Semi-conductors and superconductors, ferromagnetism and antiferromagnetism are other fields selected by the staff for research at an early date. Problems of the structure of metallic phases (both of pure metals and of alloys), and the effect of deformation on structure will be studied by the x-ray laboratory. Particular attention will be paid to transition structures in all types of transformation.

A cryogenic laboratory is being built for the study of superconductivity as well as for spectroscopic, thermal, magnetic, structural, and mechanical studies over a wide range of temperatures. Liquid helium is planned for the immediate future, with extension to magnetic cooling in a few years.

Close relations will be maintained with the two other newly-formed research institutes at the University of Chicago, the Institute for Nuclear Studies and the Institute for Radiobiology and Biophysics. For example neutron scattering in relation to crystal structure is to be investigated in cooperation with the former. Cooperation with the research staff in industrial concerns will be established. In particular, it is hoped that industrial research men will work in the Institute as visiting research associates and will attend conferences on various aspects of metallurgy, to be held from time to time.

The Institute will maintain close connections with the instructional activities of the university, but it is not intended to establish a separate Department of Metallurgy, and consequently, no degrees in metallurgy will be awarded. Students may, however, elect to do a thesis under a member of the Institute staff, but must meet all academic requirements for degrees awarded by the physics or chemistry departments. A number of post-doctorate research associateships are available for metallurgists, physicists and others.

The laboratories of the Institute are at present housed in temporary quarters in the West Stands on Stagg Field—next to the spot made famous as the site of the first nuclear chain-reacting pile of 1942. A new research building is planned, immediately adjacent to the present campus, which will house not only the Institute for the Study of Metals, but also the Institute of Nuclear Studies and the Institute of Radiobiology.

A total staff, including both academic and service personnel, of about fifty is planned for the near future, and it is expected that a full force of about one hundred will be employed at the time the permanent building is occupied. At present, the academic staff includes the following: *J.E. Burke* (formerly associated with Cornell University; International Nickel Co.; and Los Alamos); *C.S. Barrett* (Carnegie Institute of Technology); *Simon Freed* (University of Chicago); *David Gurinsky* (New York University; Los Alamos); *Lester Guttman* (University of California; Los Alamos); *Harold Hirsch* (Stevens Institute; Los Alamos); *T'ing sui Ke* (Yenching University; University of California; Radiation Laboratory, M.I.T.); *Earl A. Long* (Ohio State University; University of California; University of Missouri; Los Alamos); *Norman Nachtrieb* (University of Chicago; Pittsburgh Plate Glass Company; Los Alamos); *Adam Skapski* (Jagiellonion University, Poland; Crakow Mining Academy); *Cyril Stanley Smith* (Massachusetts Institute of Technology; American Brass Company; Los Alamos); *John W. Stout* (University of California; Massachusetts Institute of Technology; Los Alamos); *Francis T. Worrell* (University of Pittsburgh; University of Tennessee; Radiation Laboratory, M.I.T.); *William H. Zachariasen* (University of Chicago); and *Clarence Zaner* (Washington State College; Watertown Arsenal).

Cryogenic Laboratory, E.A. Long, served as acting director. On Smith's return to Chicago, he resigned his directorship in 1957 in order to more fully pursue his historical interests. (In 1961, he left the university to assume a new position at the Massachusetts Institute of Technology as institute professor in metallurgy and the history of science.) Long succeeded Smith as director in 1957 and served in that position until the end of 1960, at which time he took an extended leave of absence to work in industry. Long resigned from the university as of July 1, 1962. In 1961, the chair of the Department of Physics, M.G. Inghram, served as acting director of the institute. On January 1, 1962, S.A. Rice assumed the directorship.

The first director of the Institute for the Study of Metals: Cyril Stanley Smith. Photographed around 1952, Smith is holding a small glass capsule full of soap bubbles that he used to illustrate how surface forces control the growth of grains in solid metals.

INDUSTRIAL SPONSORSHIP

Very soon after the formation of the three institutes, the University of Chicago initiated a major effort to gain industrial support for the new ventures through creation of the Industrial Sponsors Program, which invited numerous major industrial companies in the United States to become sponsors. As sponsors of the three institutes, the companies would contribute $50,000 per year to the university for a period of at least five years. The companies could also sponsor a single institute with a contribution of $20,000 per year.

The first sponsor of all three research institutes was the Standard Oil Development Company of New Jersey (now Exxon Corporation), the sponsorship of which started on January 15, 1946. Meanwhile, a number of metallurgical corporations elected to sponsor the Institute for the Study of Metals, and by August 1952 this institute had 17 sponsors. The total number of sponsoring companies of all three institutes peaked at 24 in 1950. By 1956–57, the number fell to 12.*

To maintain contact with the industrial sponsors, the institutes organized three annual two-day sponsors' meetings. At these meetings, current research at the institutes was highlighted. The first sponsors' meeting was organized in the fall of 1947. Usually, the fall meeting was hosted by the nuclear unit, the winter meeting by the radiobiology unit, and the spring meeting by the metals unit. Typically, the sponsors' meetings were attended by 50–80 industrial representatives; the metals institute meetings tended to attract the most visitors.

EARLY GOVERNMENT FUNDING

When the organization of the three institutes began, the system of organized governmental financial support for fundamental research had not yet been developed. Even so, the role later played by the National Science Foundation was, to some extent, initially played by the Office of Naval Research (ONR). The Institute for the Study of Metals got its first major contract from the ONR in 1946 in support of its research on the deformation of metals, which was organized by Zener and Smith. The modest first quarterly report on this program covered the period May 1–June 30, 1946. However, the second and third quarterly reports covering the periods August 1–October 31, 1946, and November 1, 1946–January 31, 1947, were quite voluminous, containing, essentially, the whole manuscript of Zener's new monograph *Elasticity and Anelasticity of Metals,* which was published by the University of Chicago Press in 1948.†

In May 1947, the metals institute received its second major contract from the ONR in support of its work on high-pressure research, directed by professor of physics A.W. Lawson. This important research project, which lasted until 1960, supported the development of extensive facilities for high-pressure research at the institute. These facilities provided the experimental base for a large number of graduate students, most of them from physics, but also a few from geology. The high-pressure facilities were also used by a number of other faculty members in the institute and by several faculty members from geology. The first Ph.D. thesis completed in the Institute for the Study of Metals originated in the high-pressure laboratory.‡

RESEARCH

The Institute for the Study of Metals was created as an interdisciplinary laboratory long before the pressure of modern research and large-scale government financing forced other laboratories of this type to be formed. Indeed, the institute undoubtedly served as a model for many of the interdisciplinary materials research laboratories subsequently created at other universities by the Advanced Research Project Agency of the Department of Defense.

A flexible organization, the institute began with a strong emphasis on the science of metallurgy, and it quickly achieved a position at the forefront of fundamental research laboratories dealing with metals. However, almost from the very beginning, the staff was equally concerned with research in physics, physical chemistry, and crystallography. Over the years, the emphasis on metallurgical research gradually decreased, and the focus on metal physics, solid-state physics, cryogenics, physical chemistry, and related areas steadily increased.

Key research programs during the institute's first 15 years include (in my opinion, of course) the following. It is largely these programs, rather than the total number of scientific papers published by that faculty, that gave the institute its name in research.

Defect Studies

Probably no series of studies carried out at the institute received more worldwide attention and stimulated more research elsewhere than the work on internal friction, which was initiated by Zener. These investigations were pursued by Zener with his coworkers—Kê, Dijkstra, Wert, and Nowick—and several graduate students. The work had a powerful impact on diffusion theory and experiments and has been widely referred to in the literature.

Surface Phenomena

Interest in surface phenomena goes back to the very beginning of the institute and continues to the present. The work of Smith in the field of surface tension, interfaces, and the origin of grain shapes and phase distributions had a tremendous impact on the science of metals and metallography. As A.H. Cottrell says in *Theoretical Structural Metallurgy,* "The modern interest in the shapes of grains is due largely to an

* From about 1960, the university attempted to modify the sponsors program so that it would cover all basic research in the Physical Sciences Division. By this time, however, the novelty of the sponsors program had been lost. Also, competing programs had been started at other leading institutions having a clearly defined engineering orientation. For example, the Massachusetts Institute of Technology initiated a somewhat similar sponsors program in 1948.

† This was the first volume in a series of monographs on metals originally planned by Smith. The second (and last) volume in this series was authored by Smith himself: *A History of Metallography.* Its first edition was published by the University of Chicago Press in 1960. By 1948–49, the quarterly reports to the ONR became the *Institute Quarterly Report.* These reports were issued to all industrial and government sponsors and provided preprints of all scientific manuscripts submitted for publication by members of the institute. In 1946, institute faculty members published four scientific papers, all in *Physical Review.* From 1950–60, the number of published papers averaged 40–60 per year.

‡ D. Lazarus, "The Variation of the Adiabatic Elastic Constants of KCl, NaCl, CuZn, Cu and Al with Pressure," *Phys. Rev.*, 76 (1949), p. 545.

outstanding paper by C.S. Smith." Smith's lecture on this subject, "Grains, Phases and Interphases: An Interpretation of Microstructure,"§ is the first of several papers of his in this field. They launched an avalanche of related research in a number of laboratories. By 1951, interest had grown to the point that the annual symposium of the American Society of Metals was devoted to it.

In 1950, R. Gomer joined the faculty of the institute and initiated a series of pioneering applications of field emission microscopy to adsorption and other surface studies. In the course of this work, cryogenic ultrahigh vacuum techniques were developed, which contributed to the study of adsorption on clean crystal surfaces of known orientation and perfection. Gomer also developed techniques for obtaining field emission from metal whiskers grown in-situ under high-vacuum conditions. In a collaboration with Inghram in 1954 and 1955, he also combined field emission with mass-spectrometry, allowing detailed studies of field ionization and desorption.

Diffraction Studies

As a result of Zener's prediction that body-centered-cubic metal structures may become unstable and transform to face-centered-cubic type structures at low temperatures, C.S. Barrett in 1947 initiated an x-ray investigation of lithium metal. He found that this metal undergoes a martensitic transformation to a face-centered-cubic form near −200°C; later, he found a similar transformation in sodium at even lower temperatures. While this transformation has not been found in the other alkali metals, somewhat related phase transformations occur in many body-centered-cubic intermetallic phases in Hume-Rothery type alloy systems. Extensive investigations in this general area were carried out by Barrett, J.S. Bowles, T.D. Massalski, H. Birnbaum, and others.

X-ray diffraction studies at the institute also provided valuable information regarding lattice dynamics. Thus, C.B. Walker's x-ray study of the lattice vibrations in aluminum, from which he obtained the dispersion curves for elastic waves and, for these, the general force constants necessary to describe the interactions between the atoms, is a classical study.

Transport Phenomena

Self-diffusion in solid and liquid metals was studied extensively by Nachtrieb and his students. In collaboration with Lawson, he also pioneered the use of high-pressure techniques for the study of diffusion. These investigations led to a realization of the importance of lattice relaxation about vacancies in solids and to the formulation of a principle of corresponding states. In other studies of defect motion, Lawson and coworkers extensively studied ionic conductivity, dielectric relaxation, self-diffusion, etc., in ionic crystals.

Low-Temperature Studies

More than any other part of the institute, the Low Temperature Laboratory in the early days was a meeting place for investigators from different traditional disciplines, and many fruitful collaborations were initiated there.

The first publication from the newly formed institute was a letter to the editor in the 1946 *Physical Review*. In this letter, physicist A.W. Lawson and physical chemist E.A. Long proposed the use of the thermal noise in an electrical resistor for low-temperature thermometry. However, since the effect depends on kT, it is actually much more suitable for thermometry at high temperatures. In due course, J.B. Garrison and Lawson described a resistance-noise thermometer intended for such applications.

J.K. Hulm and B.T. Matthias became interested in correlations between the occurrence of superconductivity and other physical properties. They initiated what was to become a systematic search for superconductivity in a large number of intermetallic phases. Originally, they were aided in this work by a graduate student from chemistry, G.F. Hardy. These investigations and their subsequent developments (carried on further by Matthias at Bell Telephone Laboratories and Hulm at Westinghouse) led to the development of alloys suitable for the construction of superconducting magnets that can produce very large magnetic fields without a dissipation of energy through electrical resistance.

Before 1950, Stout and his student M. Griffel investigated the magnetic properties of single crystal MnF_2 through measurement of the anisotropy of its magnetic susceptibility. Their experiments showed the development of a very large anisotropy in the susceptibility below the ordering temperature of 66.5 K. These investigations were later extended to other antiferromagnetic fluorides. A large number of other measurements were stimulated by the magnetic anisotropy measurements (e.g., the magnetic structure as determined by neutron diffraction, antiferromagnetic resonance as seen by microwave and infrared techniques, nuclear resonance of both fluorine and metal ion nuclei, and lattice changes associated with the antiferromagnetic ordering). In many cases, these other measurements were carried out elsewhere with single crystals grown at and loaned-out from the institute.

Another experiment of unusual importance was the measurement by Pippard, as a visiting scientist during 1955–56, of the anomalous skin resistance of single-crystal copper. He interpreted his results to yield the shape of the Fermi surface in copper. This was the beginning of experimental determinations of Fermi surfaces in metals.

R.J. Donnelly carried out an extensive program of experimental and theoretical investigations on hydrodynamic flow. His original interest was in the striking flow properties of superfluid helium. However, it soon became evident to him that much was not properly understood about the flow of normal liquids. With the theoretical stimulation of S. Chandrasekhar and the help of a number of collaborators, Donnelly performed a number of experiments that have shed light on the onset of turbulence in normal flowing fluids.

CONCLUSION

The research conducted at the Institute for the Study of Metals during its first decade was dominated by the faculty members who came to the institute during its first year. However, the loss of Zener in 1951, the resignation of Smith from the directorship in 1957, and, in particular, Smith's departure from the university in 1961, promoted a significant change in the character of the institute. Although Barrett, a metallurgist, remained on the faculty until his retirement in 1970, no young metallurgist served on the faculty after the departure of Birnbaum in 1961.

The research at the institute during its second decade was dominated by young faculty members who joined the institute during the 1950s, particularly those faculty members who remained at the institute in tenure positions for a significant period of time. The physicists in this group were M.H. Cohen, Walker, Donnelly, H. Fritzsche, and J.C. Phillips; among the physical chemists were Gomer, O.J. Kleppa, and Rice.

The reduced emphasis on the science of metallurgy and the increased commitment to new areas of chemical physics as well as to solid-state physics is reflected by 1967's change of the name for the institute to the James Franck Institute. James Franck, who won the Nobel Prize in physics in 1925, was a member of the Department of Chemistry at the University of Chicago from 1938 until his death in 1964.

ACKNOWLEDGEMENT

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§ AIME Technical Publication No. 2387, June 1948