A Summary of ENGINEERING RESEARCH 1964

UNIVERSITY OF ILLINOIS ENGINEERING EXPERIMENT STATION
A Summary of ENGINEERING RESEARCH 1964

Compiled and edited by
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About the Summary

The Summary of Engineering Research 1964 is the seventh in an annual series. This edition presents the engineering research picture at the University of Illinois as of June 30, 1964. It is meant to be a general guide to the research program; space does not permit detailed description of individual research projects. Further information concerning a project may be obtained from the investigator in charge.

Each listing of a research project gives the project title, the names of the investigators (the name of the investigator in charge is designated by an asterisk), a brief description of the work being done, and a list of publications and theses that have resulted from the research during the past year. The letters in parentheses following the project title present the key letters of the sponsor. A key to sponsors appears on page 172.

Many of the projects have been under way for a longer time than the past year, but for the sake of brevity only the recent work and present status are reported here. Activities, publications, and theses for preceding years are listed in earlier editions of the Summary. Abstracts of departmental reports year by year through 1963 are available on request from the Engineering Publications Office.

The index on page 175 has been added as a new feature in this edition to facilitate the locating of specific subjects.

Additional copies of this and earlier editions of the Summary are available from Engineering Publications, 112 Civil Engineering Hall, University of Illinois, Urbana, Illinois 61803.
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University of Illinois Engineering Experiment Station
Urbana, Illinois, U.S.A.

William L. Everitt, Dean of the College of Engineering, Professor of Electrical Engineering
Ross J. Martin, Director of the Engineering Experiment Station, Professor of Mechanical Engineering
John J. Desmond, Assistant Director of the Engineering Experiment Station
Marvin E. Krasnow, Coordinator of Industrial Relations
Paul T. Bryant, Editor of Engineering Publications (to August 31, 1964)
R. Alan Kingery, Director of Engineering Publications (from September 1, 1964)
Daniel Alpert, Director of the Coordinated Science Laboratory, Research Professor of Physics
Jerry S. Dobrovolsky, Professor and Head of General Engineering
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Stanley H. Pierce, Associate Dean of the College of Engineering, Professor of General Engineering
Thomas A. Read, Professor and Head of Mining, Metallurgy, and Petroleum Engineering
Frederick Seitz, Professor and Head of Physics (to August 31, 1964)
Gerald M. Almy, Professor and Head of Physics (from September 1, 1964)
Henry S. Stillwell, Professor and Head of Aeronautical and Astronautical Engineering
J. W. Westwater, Professor and Head of Chemical Engineering
Industries and universities, while quite dissimilar in some ways, are alike in one respect: they share both the problems and the goals of technological progress. This means that they share the need to do research. Universities maintain active research programs to insure a vital, progressive teaching program and to make full use of the talents and qualifications of the faculty in fulfilling the university’s obligation as a center of intellectual endeavor. Universities and industry frequently cooperate in research efforts because such mutually beneficial programs encourage a combination of the rapid response time of industry with the breadth and depth of university talents and facilities.

The University of Illinois College of Engineering and its research programs are important to industry’s supply of engineers. Research provides positions for graduate students, helping them financially while giving them valuable research experience. This is particularly important in providing a source of young engineers capable of productive careers in research, important insurance for the future progress of engineering. At the same time, the opportunity to take part in a large and varied research program helps the teaching staff keep up with the latest developments in their special fields, allowing them to keep their teaching at the highest quality.

**ENGINEERING RESEARCH AT ILLINOIS**

Research activities are conducted in the departments and laboratories of the College of Engineering and are closely integrated with the graduate and undergraduate teaching programs of these academic units. Under the general supervision of the Dean, the research programs are administered by the Director of the Engineering Experiment Station, an Assistant Director, and an executive staff composed of the heads of the engineering departments. Annual expenditures for the research activities total more than $13,000,000 per year, principally provided by the sponsorship of projects by industry and government agencies and the research budget of the University.

The research staff consists of full-time faculty members who engage in both teaching and research, assisted by research engineers, graduate research assistants, and fellows. Excluding technicians and office personnel, more than 600 people are engaged in research within the academic departments.

In addition to activities along disciplinary lines in the academic departments, there is a strong trend toward greater cooperation across administrative boundaries throughout the University. As an example, the Materials Research Laboratory is an interdisciplinary group dedicated to research on the basic structure of materials. Research areas of principal concern to this Laboratory include the mechanical, electrical, magnetic, and optical properties of metals, insulators, and semiconductors. The effects on materials of high pressure, low temperature, and ionizing radiation are subjects of extensive investigations.

Two examples of all-University programs in which the College is participating are the Highway Traffic Safety Center and the Water Resources Center. The Traffic Safety Center represents the interests of people in the Colleges of Medicine, Law, Liberal Arts and Sciences, Engineering, and the Division of University Extension. The Water Resources Center conducts research programs in the Colleges of Law and Liberal Arts and Sciences, the Engineering and Agricultural Experiment Stations, and the Illinois State Water, Geological, and Natural History Surveys.

**RESEARCH WITH OTHER UNIVERSITIES**

The University and the College of Engineering are also participating in various programs of cooperation with other universities. In addition to its involvement in the common market approach to graduate education in the Committee on Institutional Cooperation with the other Big Ten schools and the University of Chicago, the U of I in 1964 joined the University of Colorado in instituting a cooperative program between the U of I and the U of C Colleges of Engi-
neering. The “Bi-University Institutional Liaison for Development” (Project BUILD) is designed to combine the areas of strength and great potential of the two schools for further development in teaching and research programs. This is being accomplished through visiting-exchange professorships at both institutions, cooperative research programs, graduate student exchanges, and joint conferences and seminars.

**RESEARCH FOR INDUSTRY**

The Midwest Electronics Research Center (MERC) is designed to assist electronics firms in handling the complex research required for military and space problems, new areas of civilian technology, and new product development. MERC is sponsoring a number of programs to accomplish its purpose: applications forums and seminars, cooperative research programs, consultanship arrangements, continuing educational and professional development programs, interpretive literature, joint industry-wide laboratories, and the Visiting Industrial Associates Program. The last program is permitting technical personnel from industry to participate in on-going electronics research programs on the Urbana campus. Among other things, such Associates serve a liaison function between their companies and the University through their direct contact with various phases of the more than six-million-dollars-a-year research program in electronics and related areas of solid state physics.

The Production Engineering Educational and Research Center (PEER) is concerned with machine tool engineering, metal processing, mechanization, automation and control engineering, tool and manufacturing engineering, and processing systems engineering. The activities of this Center include the development of a graduate educational program, the strengthening of current research areas, the opening of new areas of study, the evaluation of foreign developments, the development of an inclusive library, and the dissemination of its findings through short courses and symposia, lectures, conferences, and interpretive publications.

The Civil Engineering Systems Laboratory (CESL) was established in 1963 to aid the construction industry by making a computer and specially designed programs available for solving their problems. CESL, which is sponsored by two constructors’ organizations and a number of individual companies, has devised programs for its IBM 1620 computer to solve problems in job planning, business applications, productivity forecasts, and production analyses. Professor L. R. Shaffer of the Civil Engineering Department is Manager of CESL and Chairman of the Advisory Board.

**ADDITIONAL INFORMATION**

If you have questions concerning the work of the University of Illinois College of Engineering, or would like more specific information about the special research centers, or would like to discuss ways in which the College’s research program might benefit your company or industrial association, write or call Ross J. Martin, Director, Engineering Experiment Station, University of Illinois, Urbana, Illinois 61803.
The Department of Aeronautical and Astronautical Engineering does research in many technical areas which are important to the fields of aeronautical engineering and astronautics. Although the scope and emphasis of the research changes periodically, investigations are normally undertaken in each of the subdivisions of aerodynamics, propulsion, structures, and vehicle dynamics.

The research under way at the present time is concerned with supersonic and hypersonic aerodynamics, aerodynamic forces on an oscillating body, plasma generation, magnetogasdynamics, structural behavior at elevated temperatures, aeroinelasticity, viscoelasticity, stochastic structural dynamics, vehicle dynamics and propulsion. Plans are being made to expand the work in low-speed aerodynamics, ground effect vehicles, and in high-strength shock wave research, particularly with regard to investigating physical properties of shock fronts in ionized gases, interaction with electromagnetic waves, and thermal properties of shock waves including the transformation of electromagnetic energy into thermal energy in the shock front.

This is a compression chamber for the shock tube which is being used for undergraduate studies by the Department of Aeronautical and Astronautical Engineering.
Attenuation of Shock Waves in Combustion-
driven Double Diaphragm Shock Tube (ui)
H. O. BARTHEL*

The local Mach number as a function of distance along the test chamber was measured for a series of tests at a chamber pressure of 1 mm Hg. Maximum Mach number and fractional change of Mach number with dimensionless distance were found for shock waves with Mach numbers between 12 and 17.

Similar experiments will be conducted at a test chamber pressure of 1 mm Hg and Mach numbers up to 23.

Acceleration Effects in High-Speed Flow (dac)
A. I. ORMSBEE*

Theoretical investigations are being made of the effects of body acceleration on aerodynamic forces for the case of supersonic and hypersonic flow. A solution has been obtained for the pressure field on a wedge accelerated impulsively.

Method of Characteristics for Reacting Flows in Three Dimensions (ui)
A. I. ORMSBEE,* C. R. STROM

A method of characteristics procedure is being formulated for flow past three-dimensional bodies of a gas in chemical equilibrium.

Study of Rarefied Gas Flows (avco)
S. M. YEN*

The application of kinetic theory to flow field problems in the rarefied gas region is being studied. Since only certain physically significant quantities are of interest, it is essential only to determine some lower order moments of the velocity distribution function. Studies are being directed toward developing approximate methods of solving the Boltzmann equations with the aim of finding macroscopic flow properties in a flow field problem.


Study of the Moment Method of Finding the Approximate Solution of the Boltzmann Equation (ui)
S. M. YEN,* F. O. MARTIKAN

Under investigation is the use of the form of distribution proposed by Weizsäcker in solving Maxwell's transport equations for systems of appreciable deviation from equilibrium. Four collision integrals for the transport equations have been evaluated for both the case of hard spheres and Maxwellian molecules. These results have been used to find the moment equations for the shock wave problem with the assumption that the weighting function of the distribution consists of two delta functions so that six parameters must be evaluated. A numerical method will be used to solve the resulting three nonlinear first order differential equations for shock wave solutions.

Supersonic Flow Past Cones (ui)
S. M. YEN,* E. Y. CHANG

The difficulty of determining the inviscid supersonic flow field in the vicinity of a body requires the solution of quasi-linear partial differential equations subject to boundary conditions specified on an unknown boundary (shock wave). Thus, in general, the solution must rely on an iterative procedure whose convergence is not always guaranteed.

The objective of this study is to examine the problem of supersonic flow past cones on the basis of the complete Navier-Stokes equation. The technique of inner and outer expansions developed by Kaphun, Lagerstrom, Cole, and others is being investigated.

Three-dimensional Boundary Layer (ui)
S. M. YEN,* G. KELTNER, B. SINGH

A parameter showing the effect of boundary layer development along a cone generator has been found and used in the investigation of the boundary layer characteristics around a cone at large angle of attack in supersonic flow. A numerical method for solving the differential equations by using a digital computer has been developed. Complete boundary layer characteristics were obtained for a range of circumferential angles of 90 degrees.

The study of the three-dimensional laminar boundary layer characteristics is being extended to the case of hypersonic flow with high rates of heat transfer. The effect of dissociation is considered.


Study of Shock Wave Solutions (ui)
S. M. YEN,* H. J. SCHMIDT

This study is being performed with the cooperation of the Coordinated Science Laboratory and Professor B. L. Hicks in connection with his research on numerical studies of shock waves. The objective is to correlate Hicks' results on shock waves with those obtained by other methods and to study the possibility of using the Monte Carlo method of evaluating the collision integral and the numerical method of solving the Boltzmann difference equation in rarefied gas flow problems. Comparative study of physically significant macroscopic quantities has been made with respect to the following shock wave solutions: (1) Navier-Stokes, (2) Grad's Thirteen Moments, (3) Mott-Smith.

Two-dimensional Inlet Boundary Layer Study (gda)
H. S. STILLWELL*

A study was directed toward selecting methods of analyzing the boundary layer development in a two-dimensional supersonic inlet and the effect on drag coefficient and inlet pressure recovery of several arrangements for boundary layer removal. A method of analyzing the boundary layer development in the longitudinal direction along the inlet ramps was obtained by combining concepts previously described in papers by Reshotko and Tucker, and by Strood and Coleman. Variation of characteristics through the boundary layer was determined from an integration program prepared for a 1620 computer. Mean values of characteristics at any station along the flow were obtained from stream thrust averaging.

The analysis was applied to a specific inlet for a design condition of vehicle Mach number of 5.5 at an altitude of 75,000 feet. Cases were examined in which (1) the fuselage boundary layer was diverted at the inlet entrance and a part or all of the boundary layer built up in the inlet removed, and (2) the fuselage boundary layer was ingested, with subsequent removal of part of the boundary layer in the intake.


Aspects of Intense Long Spark Discharges (ui)
H. O. BARTHEL*

Detailed studies of the state and composition of four regions of an intense long spark discharge are being made. The four regions are (1) the current channel, (2) the luminous gas sheath around the current channel, (3) the nonluminous region behind the shock front, and (4) the electron region just ahead of the strong shock waves. Further, the possible suppression of the shock front due to the magnetohydrodynamic interaction of the magnetic field caused by the current with the shock front is under investigation.

Hypervelocity Wind Tunnel Nozzle Design and Calibration (ui)
J. L. LOTH*

A low-density, high-enthalpy, hypervelocity wind tunnel is now under construction as a joint operation of the departments of Aeronautical and Astronautical Engineering and Mechanical and Industrial Engineering.

The effects of boundary layer growth and convective heat transfer are being studied for the design optimization of axisymmetric hypervelocity nozzles which produce maximum diameter uniform velocity cores. An experimental technique has been developed to calibrate such nozzles by measuring simultaneously and directly the local values of velocity, density, and total enthalpy of hypervelocity flows in both the continuum and the molecular flow regimes. Preliminary tests have produced experimental results in

The shock tube at the Department of Aeronautical and Astronautical Engineering is used for studies of the initiation and structure of detonation waves in a hydrogen-oxygen system. Gases and pressure are selected on a vacuum manifold (above). Graduate student Andrew Crooker is setting the sensitivity of a pressure sensor preparatory to making an experimental run in the tube (below).
good agreement with the theoretically computed values. Because no assumptions have to be made about the state of thermal equilibrium of the flow, the test results can be used to compare the static temperature and the nonequilibrium level of dissociation of the flow.

Reflected Shock Wave Nonideality (ui)
R. A. STREHLOW,* H. B. DYNER

The reflected shock in a shock tube is used for many investigations of reaction kinetics and to determine other properties of gases at high temperatures. The properties behind a reflected shock are known to deviate from ideal behavior and this deviation is thought to be related to the nonideality observed in the incident shock behavior. In order to quantitatively study this relationship, measurements are being made of the incident shock velocity in a conventional shock tube as well as measurements of the reflected shock properties using an \((x,t)\) schlieren interferometer and a fast response pressure gauge. This project has already shown that mylar diaphragms send late random signals down the tube which are of sufficient amplitude to grossly affect the results of any investigation.

Rayleigh's Criteria for the Amplification of an Instability by Heat Addition (ui)
R. A. STREHLOW,* F. D. FERNANDES

This program is an attempt to mathematically formulate and verify Rayleigh's intuitive statements (Cf to, 1876) concerning the amplification of acoustic waves by periodic heat addition. Incidental to this work we have proved that plane acoustic waves traveling through an exothermically reacting mixture will always amplify if the chemical reaction has a locally positive activation energy. In addition, the analysis has shown that the majority of Rayleigh's intuitive statements are rigorously correct and that the only exceptions concern with a side effect, the frequency shift when added heat causes the wave amplitude to grow. We predict a frequency shift which he said was nonexistent.


Development of a Low-Density, High-Enthalpy, Hypervelocity Wind Tunnel for Undergraduate Instruction (nst; ul)
H. S. STILLWELL,* H. H. KORST,* L. R. DAVIS, E. F. HEBRAND, J. L. LOTH

The Department of Aeronautical and Astronautical Engineering and the Department of Mechanical and Industrial Engineering are engaged jointly in the design and construction of a low-density, high-enthalpy, hypervelocity wind tunnel for use in undergraduate laboratory instruction. The working gas will be heated by an arc-heater, and evacuation will be accomplished by a six-stage steam ejector. Continuous flow in the test chamber at Mach numbers up to 12 and pressures down to one micron of mercury will be provided.

The facility will be used in the development of advanced undergraduate laboratory instruction in the areas of gas dynamics, thermodynamics, and heat transfer. This is part of a program to give undergraduates laboratory experience with (1) the special physical aspects of crossing the border between continuum and molecular flow regimes, (2) the techniques and equipment used for measurements in these regimes, and (3) the operation of experimental facilities and evaluation of experimental results for low-density, high-enthalpy flows. It will also be possible to introduce students to correct and quantitative evaluation of phenomena associated with (1) high-enthalpy conditions and the resulting real gas effects, such as dissociation, (2) deviation from thermodynamic equilibrium conditions, and (3) high-density effects in both the continuum and the (nearly) free molecular regions, with emphasis on the transition between these regions. It is also expected that the facility will be useful to graduate students doing thesis research.

One-dimensional Detonation Stability (ui)
R. A. STREHLOW,* W. E. HARTUNG

This work is being undertaken to examine the stability of an overdriven detonation wave when a strong rarefaction fan approaches from behind the terminal isentrope. The analysis is performed by using a one-dimensional nonsteady method of characteristics analysis. It is expected that low-temperature sensitivity of the heat release function will yield stability. At the present time, the problem has been formulated and the FORTRAN code is being written for a 7094 digital computer.

Structure and Stability of Detonation Waves (brf)
R. A. STREHLOW,* A. J. CROOKER, R. E. CUSEY, R. B. GILBERT, R. LIAUGMINAS

Studies are being made of the initiation and structure of detonation waves in a hydrogen-oxygen system. This program currently has four main lines of investigation:

1. An investigation of transverse wave structure during initiation.

2. A theoretical investigation of reflected shock initiation using a heat release model to construct a nonsteady one-dimensional flow pattern for comparison with the experimental observations of initiation.

3. An experimental investigation of convergent channel initiation (this will be compared to a theoretical model).


These four programs are in various stages of development; however, none of them is complete. Soon it is expected to have a rather complete model for the process of reflected shock initiation, and there are indications that this model will agree quantitatively with the experimental observations. The convergent channel initiation work has just started, and it will be some time before experimental data will be obtained; similarly, the transverse wave structure studies have just started and will require some time to obtain the initial experimental data.
Turbulent Combustion Structure and Stability (nsf)
R. A. STREHLOW,* R. A. MAYS, A. PALM-LEIS

Studies are being made of the formation and properties of an equilibrium turbulent flame. This includes a study of the process of relaxation from an arbitrary flame shape and a study of the equilibrium flame which results from this relaxation process.

The measurements are being made in a turbulent combustion tunnel with a five-inch diameter using propane-air mixtures. Thus far the apparatus has been checked out to insure that the flow is as uniform as possible. Some rather high-quality schlieren and visible light photographs have been obtained for analysis. The interpretation of the data is being investigated at the present time.

Pulsing Combustion (ui)
R. W. McCLOY*

Nicola Tesla patented a pulsing combustion chamber using a "valvular conduit" in 1920. No test data are available on the combustion process or the valvular conduit. A pulsing combustion chamber with a variable volume and a variable exit area has been built and operated. Data regarding the variation of pressure with time, frequency, etc., are being obtained with a Fairchild Oscillo Record Camera.

Valveless Pulsejet (ui)
R. W. McCLOY*

A "valveless" pulsejet has been made which utilizes Nicola Tesla's "valvular conduit" as the aerodynamic valve for allowing air to enter, but which will not allow hot gases to exit. Frequency, pressure-time history, and thrust are being determined.

Ground Effect Machine (ui)
R. W. McCLOY,* H. W. CHEN

A two-dimensional peripheral jet is operated in conjunction with two cylinders which are equipped with blowing slots. The interaction between the air from the peripheral slots and the circulation created by the blowing slots should increase the base pressure under the GEM. In addition, the "Magnus" lift from the cylinders is expected to increase the lifting capacity of the GEM.

Elastic and Viscoelastic Analysis of Solid Propellant Grains (agc)
H. H. HILTON,* C. F. VAIL

This project consists of an analytical investigation of stresses, strains, and deformations in circular elastic or
viscoelastic finite length cylinders surrounded by a thin elastic shell. The linear elastic and viscoelastic problems have been considered, and large-deformation, nonlinear elastic cylinder problems are currently under investigation.

Fundamental studies in the linear theory of anisotropic, nonhomogeneous thermal viscoelasticity were also undertaken. Analytical procedures for the determination of linear viscoelastic stress-strain relations from uni- and multiaxial experimental creep and relaxation data were formulated. Experimental results have been analyzed, and numerical values for viscoelastic characterization of solid propellants have been generated.


**Fundamental Studies in Linear Viscoelasticity (ui)**

H. H. HILTON

This study has culminated in the preparation of a survey article on an introductory treatment of three-dimensional viscoelasticity. Generalized homogeneous, nonhomogeneous, isotropic, or anisotropic viscoelastic stress-strain relations have been constructed and analyzed in integral and differential forms. Separation of variable and integral transform elastic-viscoelastic analogies are discussed for quasistatic and dynamic linear problems. Illustrative examples, such as those of beams, thick-walled cylinders, wave propagation, vibrating reeds, indentation, and of thermal stresses by use of temperature shift functions, are presented with some detail. Special nonlinear viscoelastic laws, their associated elasto-viscoelastic analogy, and their application to creep rupture are also introduced.


**Approximate Solutions in Linear Viscoelasticity (agc; ui)**

H. H. HILTON, J. R. CLEMENTS

Approximate Laplace transform analogies are derived for linear viscoelastic media exposed to time- and space-dependent temperatures while obeying the thermomechanically simple and/or time-temperature superposition principles. The accuracy of these analogies as well as of the previously developed approximate analogies for viscoelastic differential stress-strain laws is evaluated by application to three specific problems. Exact and approximate solutions are obtained for uniaxial tension and simple bending of a material whose deviatoric and dilatational responses are represented by a temperature-dependent Maxwell body and elastic model respectively. The thermal loading of an infinite slab with thermomechanically simple properties is also analyzed.
The exact and approximate solutions for these particular problems are compared numerically, and the results obtained by using the approximate analogies are found to duplicate very accurately the exact solutions. The relative merits and complexities of these analogies and their applicability to viscoelastic thermal stress analyses are also discussed.


Dynamic Thermal Viscoelasticity (ui)
H. H. HILTON,* R. L. BROWN, W. H. DRYSDALE

This project consists of a fundamental analytical investigation of the response of linear viscoelastic bodies to transient temperatures. The influence of both dynamic conditions and time-dependent material nonhomogeneity is being considered. The analyses are based on simple viscoelastic model characterization and on thermorheologically simple responses.


Fundamental Studies in Nonlinear Viscoelasticity (agc; ui)
H. H. HILTON,* A. F. FRASER, C. F. VAIL

An analytical investigation is being conducted to formulate a number of relatively simple specific nonlinear viscoelastic constitutive equations and to apply these to the solution of problems with large deformations. Analytical formulations of a number of simple but meaningful experiments are being carried out in order to allow the determination of nonlinear viscoelastic material property functions.

Aeronelastic Effects Due to Aerodynamic Heating (ui)
H. H. HILTON,* H. M. JACKSON

An analytical study is being conducted to determine the effect of fuselage and/or lifting surface creep on lift distributions, control surface efficiency, torsional divergence, and stability derivatives of flight vehicles.

Buckling of Elastic and Viscoelastic Columns with Random Imperfections and Loads (ui)
Y. K. LIN,* H. H. HILTON,* T. J. McDaniel, W. Veljovic

Analytical studies have been continued on the buckling of elastic and viscoelastic columns which are either initially crooked or eccentrically loaded. The crookedness or load eccentricity is assumed to be random. Different boundary conditions are being considered.


Stationary Random Processes in Structural Dynamics (ui)
Y. K. LIN*

New techniques are being developed for the determination of stationary response of multiple degrees of freedom structures for which the classical normal mode approach is not suitable.


Nonstationary Random Processes in Structural Dynamics (ui)
Y. K. LIN*

Theoretical investigations are continued on the response of simple structures under nonstationary excitations. The response is treated as the projection of a multi-dimensional nonstationary Markoff process.


Acoustic Fatigue of Skin-Stringer Panels (afm1)

The first stage of the study is devoted to the theoretical determination of the natural frequencies and normal modes of vibration for skin panels with either uniformly or non-uniformly spaced reinforcing stringers. The recurrence type difference equations and the transfer matrices are used in this study. The second stage of the work to be commenced in June, 1964, will be devoted to the theoretical estimation of the fatigue damage of such panels under random noise excitation.


Thrust Magnitude Control of Rocket Engines (ui)
A. L. Ormsbee,* R. E. Gardner

An elementary theory for explaining the effect of fluid
injection at the throat of a rocket nozzle as a means of thrust magnitude control has been developed.


**Two-Year Research Program on an Experimental Test of Relativity† (nasa)**


The purpose of this work is to study the feasibility of, and to propose techniques for, using earth satellites to measure the Schiff effect, a general relativistic precession of a gyroscope in orbit described by Leonard Schiff in the *Proceedings of the National Academy of Sciences* (1960), p. 871.

Two approaches to the problem are being investigated:

1. The extension of electric vacuum gyroscope techniques to take advantage of the low acceleration environment of a satellite vehicle and thus to achieve the required three orders of magnitude improvement in accuracy over presently obtained terrestrial performance; and

2. The study of a low cost spinning satellite gyro with internal data acquisition equipment. In this case, the gyro is exposed directly to the space environment.

Both approaches require a comprehensive study of the effect on the gyro of stray electric, magnetic, gravitational, and acceleration fields as well as residual gas and electromagnetic radiation. The second approach also requires a study of the space environment and the effect of micro-meteorites on the accuracy and reliability of measurement. Both approaches require the development of techniques for accurate comparison of the gyro spin axis with fixed stars.

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**In Support of Rocket Studies of the Upper Atmosphere During the IQSY† (nasa)**

D. ALPERT,* H. KNOEBEL,* J. D. GOOCH, B. D. KIRKWOOD, H. V. KRONE, D. O. SKAPERDAS

The objective is to make rocket measurements during the International Quiet Sun Years of differential absorption and Faraday rotation in the D region of the ionosphere as part of a synoptic program of ionospheric measurements.

Opposite circularly polarized radio waves on slightly different frequencies will be transmitted from the ground and received by a plane polarized dipole in a Nike-Apache rocket. The audio beat and d.c. output of this receiver is telemetered to the ground. Measurements of the depth of modulation and phase of the modulation relative to the audio beat derived at the transmitters give, respectively, differential absorption and Faraday rotation data.

It is expected that two different ground stations will be set up at various locations throughout the world for seven tests including simultaneous firings from widely different latitudes during 1964.

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*This research was conducted jointly by the Department of Astronautical and Astronautical Engineering and the Coordinated Science Laboratory.

†This research was conducted jointly by the Department of Astronautical and Astronautical Engineering and the Coordinated Science Laboratory.
Research in the Department of Agricultural Engineering is pointed toward the solution of engineering problems in the agricultural industry. With the current trend toward substitution of capital for labor and greater resources per operational unit, opportunities for the engineer are many and challenging. As in other areas, the engineer working in the field of agriculture is confronted with the control of variables, and these in the field of agricultural production are especially difficult—soil, weather, energy forms, and animal and plant environments, to mention only a few.

Agricultural Engineering research is conducted and administered through the Agricultural Experiment Station. Financial support comes from four major sources: (1) Federal funds allocated directly to the station; (2) federal funds allocated on a regional basis and later assigned to individual stations; (3) state appropriations; and (4) trusts, gifts, and grants from non-governmental sources.

Without exception, those engaged in agricultural engineering research at the Illinois Station are graduate engineers, many having continued their formal education to the doctoral level in various areas of specialized engineering subject matter.

Today's agriculture presents fascinating yet complex engineering problems. Individuals who are well grounded in engineering fundamentals, who can work and communicate effectively with others, and who are dedicated to identifying and solving engineering problems in the industry can find in agricultural engineering research a rich, rewarding career.

An experimental remote-controlled mower has been developed for use on steep slopes. The mower is cable controlled, is small enough to permit transport in a pick-up truck, has a low center of gravity, and is instantly reversible. A one-cylinder gasoline engine powers the cutter and drives the mower through an electric drive.
ELECTRIC POWER AND PROCESSING

Research efforts in this area are directed to engineering system analysis for farmstead mechanization and quality control for processing agricultural products.

Major research efforts for the past year were devoted to developing facilities for evaluating the concept of housing, feeding, and milking dairy cattle (of equal production) in groups as compared to individual feeding and milking. Also a system of feeding individual cows (housed in groups) grain and concentrates in proportion to the water consumed by the animal is under study. Studies of the depth and rate of movement of the drying zone in grain are also being continued and refinements are being made in a system developed for removing and metering high moisture corn from sealed storage.

Removing and Metering High-Moisture Grain from Storage (iaes; usda)

D. R. DAUM,* H. B. PUCKETT,* H. H. BEATY, E. F. OLVER, G. C. SHOVE

Work is continuing on developing and testing systems that will simultaneously unload high-moisture grain (corn) from an airtight storage and provide a constant flow meter for the grain. Various systems and modifications have been tested. A satisfactory system was built and tested and overall performance was good. Metering accuracy was quite satisfactory with output being directly proportional to auger speed, but the power requirements were erratic and unpredictable due to variable flow characteristics of the material.

The unloading auger (metering device) was driven through a variable-pitch pulley belt speed reducer. Although this drive was satisfactory for the tests, it is unsatisfactory for farm applications due to the excessive maintenance that is required. Future research will be directed toward developing a low-cost, easily adjustable, variable-speed drive for the unloading auger.

All of the equipment is being developed for automatic operation. The testing facilities are located at the University beef farm and are part of a completely mechanized feeding system capable of automatic operation.


Development of Equipment and Controls for Mechanized Livestock and Poultry Feeding Systems (iaes; usda)

D. R. DAUM,* H. H. BEATY, E. F. OLVER, H. B. PUCKETT

Future work will involve testing a reed switch detector, comparing two-position control to three-position control and determining optimum correction rate. These tests will be conducted on a silo unloader handling corn silage in the automatic beef feeding system at the University.

The design of an auger feed injector for a medium-pressure pneumatic feed conveyor of 1-inch pipe was finalized after a series of tests were completed using various sizes, shapes, and auger speeds. Application for a patent has been made; two licenses have been granted and another is being processed. Work with pneumatic feed conveying will continue. Future tests will be concerned with a larger conveying pipe and larger injector. These are needed for systems requiring higher than one ton per hour conveying rates.


Equipment and Controls to Provide Optimum Growing Conditions for Confinement Rearing of Swine (iaes; usda)

H. B. PUCKETT,* A. H. JENSEN, E. F. OLVER, G. C. SHOVE

Two experiments designed to study the effects of floor temperature and air movement on the rate of gain and feed efficiency of swine in confinement were completed for both summer and winter conditions. Floor temperatures of 70, 85, and 100°F were maintained with low and also high air velocities in the sleeping areas. Ventilation rates of 50 cfm per lter were adequate for winter conditions. Considerably higher rates were required for summer condition and rates as high as 50 cfm per lter were used.

In the summer experiment, pigs at three weeks of age increased in average weight for low air velocities and as floor temperatures increased. With high air velocities weight decreased with an increase in floor temperature. After three weeks of age there was no significant difference in weights for any of the treatments. The winter experiment showed no significant difference in weights at any age.

Average daily gain of hogs was 1.47 pounds from 6 to 18 weeks of age and feed conversion was 2.53 pounds of feed per pound of gain.


Drying and Conditioning of Farm Grains (iaes; usda)

G. C. SHOVE,* H. H. BEATY, E. F. OLVER

Research is being conducted in drying and conditioning
farm grains with the view of improvement as well as the
development of new techniques for processing farm crops
to obtain high quality feed and market products.

Depth of the Drying Layer and Moisture Gradient in a Column of
Drying Grain

A reliable procedure for predicting the moisture gradient
in drying grain would be a valuable aid in the design of
drying equipment. Grain drying tests were conducted to
provide experimental data to aid in the development of a
relationship between the depth and moisture gradient of
the drying zone and the flow rate and condition of the
drying air. Air flow rates from 13 to 92 cfm per square
foot were used to dry shelled corn with a moisture content
of 28 percent, w.b. The air had a dew point temperature
of 51°F and a dry bulb temperature of 80°F. In these
tests the depth of the temperature gradient in the grain column
increased with an increase in air flow at the rate of 0.4 inch
per cfm per square foot.

A continuous record of the moisture content of grain in a
drying column would greatly increase the information
obtained. It appears that before a relationship can be de-
veloped between the thickness of the drying zone and the
drying air condition it will be necessary to follow closely
the moisture content of the grain throughout the drying
period. It is hoped that a procedure can be developed for
a continuous monitoring of the grain moisture as the grain
dries.

Intermittent Heat for Drying Shelled Corn

Some manufacturers of grain drying equipment are
claiming advantages for applying heat intermittently as
compared to continuous heat. A preliminary investigation
was made of the effect of intermittent heat on the moisture
gradient in a column of drying grain. The tests indicated
that intermittent heat reduces the moisture differential
across the drying zone by retarding the drying of the grain
first exposed to the drying air. It required a longer time
to dry a given quantity of grain with intermittent heat,
but when used intermittently the heat was required for
less total time.

of Corn Can Be Extended,” Illinois Research, 5:3 (Summer,
1963), p. 5.
G. C. Shove and W. V. Hukill, “Predicting Pressure Gradients
in Perforated Grain Ventilation Ducts,” Transactions ASAE,
of Drying Corn with Controlled Atmosphere,” Transactions

Automation in Feeding Dairy Cattle

E. F. OLVER,* K. E. HARBHBARGER, G. C. SHOVE

To effectively apply modern automatic equipment to
dairying, the concept of group handling of cattle must be
accepted. Cows must be handled in several production-
level groups for milking, feeding, and housing with a mini-
mum of individual attention. An automated dairy cow
feeding system is nearing completion on the University
dairy farm. It will handle 60 cows separated into three
production-level groups of 20 each. A complete ration will
be automatically metered to each group according to its
production level. The results of this combined research by
agricultural engineers and dairy scientists will provide
many answers to questions arising in the development of
mechanized feeding systems for dairy cows.

A new feeder for dairy cattle is being developed. It is
based on the principle of metering grain and feed to a cow
in direct proportion to the quantity of water consumed by
it. Feed intake, milk production, and water consumption
are all interrelated. Preliminary tests indicate that milk
production can be maintained by feeding concentrates to
cattle on the basis of their water consumption.

This automatic feeder is being used to feed concentrates
to two groups of 10 cows. The two groups will be alternated
between conventional feeding and the water-consumption-
controlled feeder to compare their feed intake and milk
production. Results so far indicate that this feeder has much
potential, and that it can be a simple, low-cost unit that
provides feed and water for a group of cattle, but still
meets the requirements of the individual cow.

K. E. Harshbarger and E. F. Olver, “A New Feeder for Dairy
E. F. Olver and K. E. Harshbarger, “Illinois Researchers
Relate Consumption of Cows’ Water and Feed,” The Feed

The Application of Electric Power to Farm
Operations (iaes; ifec)

H. H. BEATY,* D. R. DAUM, H. B. PUCKETT

Three studies are under way in this area:

Mating Feed to Livestock

A study was made to determine the possibility of using
rectangular holes cut in the bottom of a conveying auger
for metering feed (ground corn and fortified supplement)
to livestock. The holes spaced at 4-foot intervals were tested
at widths of 1 to 1 1/2 inches and lengths of 1/2 to 6 inches.
An analysis of five repetitive feed discharges for various
sizes of openings indicated a maximum coefficient of vari-
ation of 4 percent for discharges of feed at one-half the
theoretical capacity of the auger and 8 percent at full
capacity (at auger speeds of 36 rpm). The latter rate was
considered unsatisfactory.

Conveying Forages

Tests were conducted to obtain capacity and power
requirements for a 10-inch U-trough auger forage conveyor.
Power requirements for a 20-foot length of this conveyor
were .38 hp at no load regardless of angle of inclination
or speed. Power requirements varied from .4 hp at an
auger speed of 100 rpm with sludge conveying rate of 100
lbs/min. (moisture content 68 percent) and with conveyor
in horizontal position, to a power requirement of 1.85 hp
at a speed of 280 rpm with a conveying rate of 200 lbs/min.
and with the conveyor inclined at a 30-degree angle above
the horizontal position.

Grinding Feed

Tests to determine the power requirements and capacity
of small 5-hp roller mills are in progress.
FARM POWER AND MACHINERY

The research on farm tractors is aimed at providing information which will lead to more efficient and more economical power for the production of the food, feed, and fiber crops of Illinois. The information obtained from this work is sometimes usable directly by the farmers; more often it is passed on to manufacturers to aid in the production of better and safer equipment.

Research on machines has much the same aims and produces results in similar ways. The principal effort is placed on discovery of basic information on which the design and development of new or improved equipment may be based.

Dynamics of Tillage, Earthmoving, and Traction (iae; usda)

J. A. WEBER,* A. C. BAILEY, D. J. OLSON, J. C. SIEMENS, T. H. THORBURN, R. R. YOERGER

The aim of the work is to develop a theory that will relate soil properties and instantaneous tillage tool forces to the size and shape of soil failure break outs and particle acceleration patterns in front of the tool. Artificial soils are used in an indoor bin. Forces acting on flat tools as they moved through the soil compared fairly well with predictions based on retaining wall and free soil block theories. Studies of methods show that the various methods do not give the same result even in relatively uniform artificial soil. Work is in progress on the effect of speed on tool forces and break out patterns, and the measurement of soil properties that relate to change of force with change of speed.


Improvement of Farm Tractor Maintenance (iae; fss)

J. A. WEBER,* R. R. YOERGER, R. G. CARLSON, G. L. STAHL

The research on farm tractors is aimed at providing basic information that will facilitate maintenance and thereby improve performance. In connection with air cleaner study, the nature of the pressure waves in the air intake is being defined, and a wave simulator is under construction that will produce basic wave forms resulting from Fourier analysis. The simulator will then be used to identify basic wave characteristics that cause dust migration in cleaner elements.

Carburetion of a farm tractor has been redesigned with an additional jet which provides the fuel-air ratio for maximum horsepower and permits a lean mixture for part loads. The full load jet is activated by manifold pressure which also controls vacuum ignition advance. Field tests are planned to verify the 15 percent saving predicted by dynamometer testing.


Accelerated Drying of Farm Grains (iae; usda)

R. R. YOERGER,* L. W. COFER, D. R. HUNT, R. D. STROHMAN

The purpose of the investigation is to determine the relationship of the temperature, humidity, and air flow characteristics of the environment on the rate of moisture diffusion and final quality of the product for conditions of accelerated drying.

The theory that concurrent flow of grain and high temperature drying air is more satisfactory than counter-current flow for accelerated drying of corn has been verified. A loop drying system with control of the drying air temperature was used for drying approximately 100-gram samples of shelled corn suspended in a single layer. For tests ranging from 1 to 16 minutes the results indicated that visual kernel damage was related to the maximum kernel temperatures. Feeding trials with corn dried with high temperature air in a rotary drum drier being fed to two-week old pigs produced no significant differences in average daily gain or in feed conversion efficiency even with treatments showing visible physical damage to kernels.


Field Machinery Operations Analysis (iae; usda)


The objective of this project is to determine the optimum employment of farm machinery in field operations. Determination of the optimum implement size, optimum power level, and an economic replacement policy depends upon characteristic input data that are unknown at present.

Investigations into typical rate of repair costs are being initiated at three levels: (1) study of individual farm records
obtained from the Illinois Farm Business Records, (2) analysis of the shop records of a 10,000-acre farm, and (3) study of repair parts shipments from farm equipment manufacturing companies.

Parameters of field operations are to be obtained through instrumenting farm tractors. Hours of use, load factor, fuel consumption, work accomplished, and other typical operational data will be sought.

Improvement of Equipment for the Production, Harvesting, Handling, and Packaging of Fruits and Vegetables (iaes; usda)
D. R. HUNT,* D. L. HOAG, C. C. ZYCH

Work has continued toward the development of a stripping mechanism for a mechanical strawberry harvester. Using greenhouse grown plants, the geometrical effect of stripping finger shape, size, and spacing were checked for (1) effectiveness in removing the fruit, (2) damage to the fruit, and (3) amount of plant leaves removed. The data obtained are to be used in the design of an experimental machine for use on field crops.

A new program, initiated during the past year, is an investigation into methods for orienting onion bulbs for planting. The two approaches under consideration are suspension in an air stream and a gravity drop onto an inclined, V-shaped piece. Testing and evaluation are planned for 1964–65.

Equipment for the Establishment and Maintenance of Roadside Cover (iaes; idh)
R. R. YOERGER,* B. J. BUTLER, D. L. BOSWORTH, R. L. PERSHING

The development of equipment and techniques to reduce the cost, improve efficiency, and promote safety of work with roadside cover is the objective of this project.

An analysis of tractor chassis mechanics was begun to establish the relative importance of the various parameters in relation to the ability of vehicles to perform on grass-covered side slopes. Mathematical models have been developed to describe steady-state vehicle behavior, and the various modes of failure are being investigated with the aid of a digital computer.

A set of differential equations has been developed to describe the dynamics of flail mower knives under various operating conditions. Design parameters are being studied with the aid of the computer, and verification of the procedure is made with a laboratory test apparatus.

A mechanical baled-straw feeding table for use on a commercial machine for applying straw mulch and asphalt binder to newly seeded roadways was modified for another season’s use. Performance was highly satisfactory, and a manufacturer of commercial straw mulchers is building several units for testing in different areas of the country.

Several compounds were screened for their possible use as spray thickeners which present one means of reducing drift during application. Several promising materials were found.

Application of Energy to Soil Pulverization and Tillage (iae; usda)
H. P. BATEMAN, R. R. YOEGER
The investigation aims to develop a more efficient method of applying energy to pulverize soil. The energy requirements to pulverize soil were less for a slow, constant loading rate as compared to an impact loading rate obtained with a laboratory impact testing machine, similar to the Charpy impact testing machine used for steel. Both loading conditions indicated that more energy was required for the higher density soil and for the lower moisture condition used in the tests. The energy differences were more pronounced for the finer degrees of pulverization.

Field energy tests of tillage machines indicated that lower energy was required and the soil pulverized more completely during the plowing operation with the lower density soil resulting from reduced tillage the previous season. Energy requirements of tillage machines will be compared to the laboratory results to evaluate the energy efficiency of these machines and to determine ways to improve their efficiency.

The various soil physical conditions created by the tillage machines have continued to demonstrate that tillage systems which require less energy and produce sufficient pulverization in the row for seed germination will produce corn yields equal to those produced by the more costly methods. A number of the excessive soil compaction treatments have reduced yields especially for the Drummer silt loam soils.


FARM STRUCTURES
Work in the field of farm structures is concerned with all phases of farm building planning, analysis, design, and fabrication. The problems encountered in this field may be conveniently grouped into three areas—structural problems, environmental problems. Research in farm structures is pointed toward solving the present and anticipated problems in each of these areas.

Improved Analysis and Design of Farm Buildings (iae; usda)
J. O. CURTIS, E. L. HANSEN, D. B. BAULING, J. D. BRADLEY, J. P. LLOYD
The basic objectives of this project are (1) to develop more refined procedures of analysis and design for light building frames, (2) to develop and test new types and systems of framing and new construction techniques, (3) to study the suitability of new materials for use in farm building construction, and (4) to develop new building or component designs or modify existing designs for specific purposes.

Theoretical analyses and experimental investigations were made of a box-beam rigid frame with a discontinuous plywood web. The theoretical analysis was found to do an accurate enough job of predicting maximum stresses that it could be used for design purposes.

The stresses in plywood gusset plates of trusses were studied experimentally by use of brittle lacquer and strain gauge techniques. The normal and shearing stresses acting on cross sections taken through critical regions of the gusset plate were found to be quite different than those currently assumed in design.

Designs and preliminary plans have been prepared for three types of plastic covered greenhouses. The designs are being further evaluated by construction and use experience.

Work is in progress on the problem of developing lumber rigid frame designs for grain storages. An existing program for the digital computer has been modified to carry out the large amount of analytical work required.


Swine Housing Environment (iae; nrcc)
The objectives of this research are (1) to identify, characterize, and measure production of atmospheric contaminants (gases, odors, dust) in confinement swine buildings and (2) to determine the tolerance of swine to these contaminants.

Work this year has been concerned with objective (1). Air sampling was performed in buildings of two types of waste disposal methods: solid floors cleaned regularly, and self-cleaning, totally slotted floors with under-floor waste collection pits.

Ammonia was found in the solid floor building. The odors in this building, which were very strong and offensive, were collected along with feed and dust particles on filtering materials of special glass fiber paper and activated charcoal. The odoriferous components were separated from the filters by methods employing solvents, paper chromatography, and pyrolysis techniques. Infrared spectroscopy was used to aid in identifying the odoriferous components. The odor
could be dissipated by bubbling the barn air through certain chemicals and by heating.

Gases detected in the totally slotted floor building with under-floor pits were carbon dioxide, hydrogen sulfide, methane, and possibly ammonia. They were evidently produced by the biological activity in the ponded wastes in addition to respiratory gases. Some of the effects of hydrogen sulfide on the building and equipment were black deposits of copper sulfide on copper thermostats and electrical wiring, white deposits of zinc sulfide on galvanized steel, and black discolorations of lead-pigmented white paint. Quantitative analyses of the gases produced are in progress. Analyses of the odors in this building have not been made at this time.


SOIL AND WATER

In this area, emphasis is placed on basic research to determine design criteria for agricultural drainage, irrigation, and the hydraulics of erosion control structures. These studies require the application of the basic principles of soil physics and soil mechanics, hydrology, and the hydraulics of water.

Laboratory Studies of Conservation and Drainage Structures (laes; usda)


Three aspects of conservation and drainage structures studied in this project are the hydraulics of open channels and control structures, causes for the failure of conservation structures under flood conditions, and water flow patterns to subsurface drains. Current emphasis has been on studies of open channel flow and related phenomena.

An analytical and experimental investigation of the effects of channel sidewalls on laminar flow in open rectangular channels was completed in the past year. The objectives were to determine the effect of change in channel width to depth ratio on the velocity profile, and to develop a friction factor—Reynolds number relationship for laminar flow which would be independent of channel width to depth ratio.

Velocity profiles for laminar flow in channels with width to depth ratios from 1.0 to 60.0 were calculated through an iterative solution of a Poisson equation on the 7094 computer. The calculated profiles were then compared with those measured in a variable width laboratory channel.

The geometric series factor in the Boussinesq equation for laminar flow in rectangular conduits was used with the results of the laboratory tests to calculate values for friction factors and Reynolds numbers which, in theory, corresponded to those applicable to an infinitely wide channel, or a channel in which wall effects would be totally absent. The method was checked by comparing these values with

The stresses in plywood gusset plates of trusses were studied on this model by use of brittle lacquer and strain gauge techniques. The normal and shearing stresses acting on cross sections taken through critical regions of the gusset plate were found to be quite different than those currently assumed in design.

Graduate assistant D. L. Lebeda (right) and Professor D. L. Day are testing the production of atmospheric contaminants in confinement swine buildings.
those calculated from results obtained by other experimenters for various width to depth ratios. The close correspondence between friction factors at high Reynolds numbers regardless of width to depth ratio suggests this to be a suitable means for accounting for wall effects when other variables, such as channel roughness, are under investigation.

A study of tractive force distribution in circular channels with turbulent free surface flow was completed. Although erosion, sediment transport, and sediment deposition are all influenced by the distribution of tractive force along the wetted perimeter of a channel, existing means for describing and predicting the distribution have not been entirely adequate. A semi-analytical procedure was developed as the results of this study which appears promising for the determination of both velocity and tractive force distributions.

Assuming that the channel walls influence the velocity distribution primarily through boundary drag, or viscous effects, and secondarily through restriction of the turbulent fluctuations, the following functional relationship descriptive of the mean velocity $U$ at any point $y, z$ in the flow was proposed:

$$U_{y,z} = k_0 e (y,z) + k_1 u (y,z)$$

The functions $k_0$ and $k_1$ were evaluated as solutions to Poisson equations with unlike boundary conditions, using the 7094 computer. The factor $k_0$ was assumed to be unity, while $k_1$ was evaluated experimentally in partially full circular channels for two roughness conditions. Tractive force distributions could then be calculated on the basis of the described velocity profiles.

Tractive force distributions for trapezoidal channels, calculated with values of $k_0$ determined in the circular conduits, compared well with published results of measurements in trapezoidal channels. Additional investigation is required, however, to evaluate the applicability of these relationships over a range of channel shapes and roughnesses.

Also completed was a test of the hypothesis that hydraulic resistance in vegetated channels subject to intermittent discharge can be described through the use of parameters based on measured properties of the vegetative roughness and the flow. New equations were developed which, in some respects, were superior to relationships based on the Manning equation.

An investigation of numerical methods for solving the partial differential equations descriptive of steady flow in channels with spatially and temporally varied inflow has been initiated. The results of such a study should have significance in the design of diversion terraces and surface irrigation systems, as well as in the analysis of hydrologic phenomena.


R. N. Fenzi and J. R. Davis, "Hydraulic Resistance Relation-}


Runoff from Small Agricultural Areas in Illinois (iaes; usda)

B. A. JONES, Jr.,* R. L. McFALL

The objective of the project is to determine rates and amounts of surface runoff from agricultural watersheds of 25 to 1,000 acres. The major portion of the work is centered on four watersheds of 45, 63, 82, and 390 acres in Piatt County.

Rainfall, runoff, and cropping data were taken during the year to incorporate with other years' data to determine the effect of rainfall and cropping practices on runoff.

The precipitation for the water year October 1, 1962, through September 30, 1963, was 23.00 inches which is approximately 9 inches less than the 14-year average for these watersheds and 13 inches less than the 74-year average at Urbana, the nearest long-time record. Two rainstorms before May produced trace amounts of runoff but none of the summer thunderstorms produced runoff.

A computer program for the analysis of rainfall data was adapted to the IBM 7094 during the year. Some rainfall data were recorded on punch cards for analysis.

A Study of the Effect of Terrace Cross Sections and Terrace Grades on Surface Drainage and Soil Movement into and along Terrace Channels (iaes)

B. A. JONES, Jr.,* J. A. REPOGLE

The general objective is to determine the effect of terrace size, shape, spacing, and direction of field operation of machinery on terrace capacity.

This study is conducted on four terraced fields, two with parallel and two with conventional terraces, located on the Elwood Soil Conservation Research Station. In addition to the parallel versus nonparallel lines, one of the fields with parallel terraces has had the area between channels smoothed to remove miniature waterways and create conditions for more uniform flow toward the terrace channels. The general objective is to determine the effect of field operations on terrace capacity and grade for the different system designs.

All the profile and cross section data for field 1, 4½ years' data for field 3B, 2½ years' data for field 3A, and 1½ years' data for field C were plotted and planimetered as the first phase of analysis to determine change in cross sectional area and change in grade with time and direction of field operation. Reaches of the profiles will be analyzed for the effect of grade on change in channel dimension.
Irrigation of Farm Crops on Upland Soils of Southern Illinois (iaes)
B. A. JONES, Jr.,* L. E. GARD, G. E. McKIBBEN

Field corn was irrigated with a sprinkler system to determine the optimum time for application of water as related to stage of plant growth and the most economical return for the amount of water applied.

A random plot experiment was conducted on Grantsburg silt loam soil to study (1) irrigation and no irrigation; (2) four planting row widths, 20 inches, 26 inches, 32 inches, and 40 inches; and (3) atrazine spray with no cultivation and 2, 4-D spray with one cultivation. Variety P-G-Sx-29 was used with a uniform planting rate of 18,000 plants per acre.

Even though rainfall was above average—16.05 inches compared to 14.38 inches—and well distributed during the growing season, the addition of 3.75 inches of irrigation water increased yields by 16 bushels per acre as an average for all row widths. No significant differences in yield resulted from a difference in row spacing. The 48 cultivated plots averaged 5.5 bushels per acre more corn than the non-cultivated plots.

A Study of Rainfall Energy and Soil Erosion (iaes; ars; usda; isws)

The objectives are to photograph natural rainstorms, make computations of the amount of kinetic energy of the storm, and relate kinetic energy to soil and water loss and changes in certain physical properties of the soil.

Runoff data were obtained from 13 rainstorms, and soil loss data were obtained from 11 rainstorms. Raindrop photographs were also obtained from several rainstorms. The reduction of the photographic data to numerical form has been started and drop size data are being recorded on IBM cards for computer analysis.

A 16-mm motion picture camera was installed in the field to photograph the surface of one of the fallow plots during rainfall. A small amount of exposed footage was obtained. There is promise of obtaining useful qualitative information about soil surface changes and runoff behavior with this technique.

A vector-pluviometer (device for measuring the angle of incidence of rainfall) was designed, built, and installed at the field plot site. Only a few rainstorms of significant amount were received after this device was installed and only one of these was of the thunderstorm variety.


The Development of a Compendium of Information on Interrelated Highway and Agricultural Drainage Laws and Engineering Practices (iaes; idh; bpr)

A preliminary draft of a comprehensive research report was prepared on the practice and procedure phase of the project. The purpose of this report was to make a compilation and analysis of practices of the highway authorities and others in handling interrelated drainage problems. The information contained in the report was gathered from highway and consulting engineers, government agencies, and private individuals in Illinois and other states. The project advisory committee made a detailed review of the report, and with their recommendations a final draft is being prepared for submission to the sponsoring agencies. It is anticipated that the final draft of the report will be completed by the end of this fiscal year.


Water Infiltration into Soils (iaes; usda)
B. A. JONES, Jr.,* R. N. FENZL,* G. D. BUBENZER

This is an empirical investigation of infiltration rates with water applied by a portable sprinkling infiltrometer. The variation in the intake rate–time relationship with respect to changes in soil physical properties, vegetative cover, and antecedent moisture conditions has been measured on Gisn silt loam in two geographical locations in Illinois. During the current season measurements on Flanagan and Elliott soils will be performed.

The information obtained will be added to that for other important soils in the Midwest to provide basic values for the hydrologic analyses required for the design of culverts, dams, and waterways.
ARTHRUR L. FRIEDBERG, Head

The research program in ceramics and ceramic engineering reflects a broad diversity of interest in ceramic materials. Expanding interest in ceramic engineering is stimulated by the need for new materials for very high temperature use and to withstand other extreme conditions of service. Special properties of ceramic materials are being explored for use as semiconductors, nonmetallic magnets, and ferroelectrics. The demands for higher strength, higher temperature, lighter weight, or greater density in ceramic materials motivate intensified research in fiber glass, recrystallized glass, ceramic coatings, refractories, electrical ceramics, cements, and composites.

The Department of Ceramic Engineering maintains a close relationship with industry. Cooperative research programs and fellowships sponsored by industry and government form an important part of the department’s research effort.

Ferroelectric lead titanate crystals grown on the surface of a glass.
Structural Changes in Simple Glass Systems During Nucleation of Crystalline Phases†

C. G. BERGERON,* D. L. LIEDBERG, C. G. RUDERER, C. K. RUSSELL

This research involves the continuation of a study of structural changes which lead to the nucleation of crystalline phases in glass systems. The specific glass systems considered are the lead borate and lead silicate systems.

The initial studies of the growth of lead titanate from a silicate glass have indicated that growth is initiated by the formation of an apparently metastable phase which appears to have a degree of order intermediate between that of the parent glass and the crystalline phase. Subsequent growth of lead titanate crystals occurs at the expense of this initial phase.

It is proposed to continue these studies of the structural changes occurring in these systems prior to and during nucleation of the crystalline phase. The principal techniques being employed are low-angle scattering of X-rays, conventional X-ray diffraction analysis, electron microscopy, differential thermal analysis, and electrical conductivity.


†This research was conducted jointly by the Department of Ceramics Engineering and the Materials Research Laboratory.

Anelasticity in Some Group V and VI Uranium Compounds for Ceramic Fuel Elements (anl)

A. W. ALLEN,* R. FORLAND

Dynamic methods of determining Young's modulus, rigidity modulus, and internal friction in single crystals, bicrystals, and/or polycrystalline specimens will be used to characterize the deformation mechanism as related to structure, orientation, and microstructure. Materials will involve uranium oxide, carbide, or phosphide.

Fundamental Studies of Properties of Refractories as Related to Service in a Steel Pressure Casting Process (airl)

A. W. ALLEN,* T. A. WILLMORE,* R. J. BAKER, D. R. LANKARD

Phase equilibrium studies in the system MgO—Al₂O₃—ZrO₂ are being established to interpret the microstructure of aggregate prepared by fusion or sintering; the aggregate being subsequently used to prepare bonded refractory compositions for use in a steel pressure casting process. High-temperature strength studies of magnesium aluminate modified with zirconium oxide indicate a uniquely suitable material for this use. The phase equilibrium studies employ a high-temperature induction furnace (up to 2800°C) with special provisions for recording cooling curves and for quenching. High-temperature X-ray diffractometer cameras (to 1500°C), optical micrography studies of polished thin
sections, and quantitative X-ray diffraction of quenched samples complete the suite of analytical techniques being employed. A gas-air-oxygen automatically controlled sintering furnace capable of 2200°C in oxidizing atmosphere is being installed.


Thermal Properties of Ceramic — Metal Combinations (bc)
A. W. ALLEN,* D. R. LANKARD

Microstructural characterization of friction material composites prepared by deposition of flame-sprayed oxide-metal combinations on a metal substrate is the current objective of the program. The effect of different variables on the integrity of the composite and the degree of oxidation produced will be evaluated after microstructure has been characterized. Structural parameters which establish the utility of oxides or graphites for friction material use are also being studied.


The Effect of Grain Boundaries on the Electrical Conductivity of Cuprous Oxide (ui)
R. L. COOK,* J. F. BENZEL

The primary effort of this investigation was devoted to the development of a direct method of measuring the effect of grain boundaries on the electrical conductivity of nearly stoichiometric cuprous oxide at elevated temperatures. With the direct measurement of conductivity of the grain boundary, the effect of impurity concentration and oxygen pressure on grain boundary conductivity was determined.


Formation and Evaluation of Dibarium Silicate as a Hydraulic Cement (ui)
R. L. COOK,* K. M. HANNA

The hydration of barium silicate at various water to solid ratios at temperatures of 5°, 25°, and 50°C was studied with respect to stoichiometry and crystalline characteristics. The hydration mechanism of the dibarium silicate involved solution precipitation and subsequent crystallization. The degree of hydration of the dibarium silicate was determined by evaluating the uncombined barium hydroxide or the chemically combined water. The rate of hydration of dibarium silicate was found to be less than that of tricalcium aluminate but greater than that for tricalcium silicate and beta-dicalcium silicate. The dibarium silicate is completely hydrated in 30 days when mixed with a water to solid ratio of 0.8 or greater.


Thick Film Resistive Coatings (omc)
R. L. COOK,* R. S. HARMER

This work is concerned with the development of resistive coatings from semiconductor and insulating glasses in combination with non-noble metal powders. These coatings are to be applied to ceramic substrates and fired to form precision resistors. The resistance is to be controlled by composition and thickness over a range of 100 to 100,000 ohms per square per mil with a temperature coefficient of resistance less than ±200 parts per million.

Evaluation of Ferroelectric Barium Titanate (ccccc)
R. L. COOK,* F. E. RICHTER

A satisfactory ceramic capacitor grade of BaTiO₃ on a laboratory scale is being prepared to determine the reproducibility on this scale, using high-grade precipitated BaCO₃ and capacitor grade TiO₂. The investigation has dealt with the effect of varying the calcining and sintering conditions, barium titanate has been prepared for use in test compositions containing calcium, magnesium, strontium titanates, and zirconates. Also a study on variations in the BaO to TiO₂ ratio is being performed with respect to the effect on both physical and electrical properties.

Physical Properties of High Lead, Alumina-Silicate Glasses (hlp)
R. L. COOK,* R. J. SMID

This project has a two-fold objective. The first is the investigation of the possibility of obtaining glassy compositions in the range of 30–99 percent PbO, 0–10 percent Al₂O₃, and 0–40 percent SiO₂ at firing temperatures below 1200°C and firing times less than 60 minutes.

The remaining objective is the determination of such physical properties as solution rate, viscosity, expansion, solubility, and softening point of these glasses.

Effect of Metal Oxide Additions on the High-Temperature Electrical Conductivity of Polycrystalline Alumina (ui)
R. L. COOK,* R. A. VERNETTI

This work includes studies of the effects of 1, 2, and 4 mole percent of such metal oxides as CuO, NiO, Fe₂O₃, Cr₂O₃, MnO₂, and TiO₂ on the high-temperature electrical con-
ductivity of a 96 percent Al₂O₃ body. The range of temperatures for this study includes 500°C to 1500°C.

The structure and the mobility of the metal ion in the corundum crystal will be analyzed from the activation energy as determined by the resistivity temperature relationship. Several tests will be conducted to study the effect of the atmosphere (neutral, oxidizing, and reducing) on the electrical conductivity.


Conduction Mechanisms in Semiconducting Glasses† (asc)

A. L. FRIEDBERG,* W. D. COMPTON,* R. M. BROWN,* P. J. ROEDEM

The process of electrical conduction in the vanadium oxide glasses is being investigated. Electrical conductivity and Hall effect are being measured from about 300°C to about 80°C. The optical absorption spectrum and photoconductivity are also being investigated. An attempt is being made to correlate these effects with the properties of the single crystals of the same oxides. It is hoped that this correlation will give some indication of whether a conduction band exists in the glasses.

Glasses made in the system V₂O₅–P₂O₅ have thus far exhibited the same general type of resistivity–temperature relationship as those in the system V₂O₅–P₂O₅. Using absorption spectroscopy techniques, identification of the cationic species is being made to point up the differences in the valence state of the vanadium in the resulting glasses. The resultant information combined with measurements of resistivity, photoconductivity, thermoelectric power, and Hall effect should provide some insight into the mechanism of conduction in these glass systems.

Attempts to alter the valence state of the vanadium by preparing the glasses in a controlled environment has been carried out. This was done by varying the ambient oxygen pressure during melting.

J. A. NELSON,* R. E. FARRIS

Studies are being conducted in air and controlled atmospheres to determine the factors which lead to high-temperature reactions at the interface between metals and ceramic molds. The ceramic molds (ethyl silicate bonded refractory oxides) are used because of their ability to withstand thermal stresses which arise when molten metals are cast into them while at the same time they maintain precise dimensions on the cast object. Surface irregularities may develop, particularly with certain alloys, when reaction occurs at selected sites and leads to shallow pits on the metal. The objective of this investigation is to identify the reactions, to correlate the rate of reaction with time and temperature, and to establish conditions under which harmful reactions can be minimized.

Interfacial Reactions Occurring Between Metal and Ceramic Molds Used for a Precision Casting Process (asc)

J. A. NELSON,* P. J. MARCIALNDO

The utilization of ultrafine ceramic particles (below 100 millimicrons in size) by incorporating such finely divided materials into ceramic formulations of larger particle sizes is being investigated. In the initial phase of the program emphasis is given to obtain a better understanding of the role of the ultrafine particles in sintering and on the properties developed in fabricated specimens. As the work progresses it is anticipated that information will be obtained on the influence of extremely fine particles on the rheological properties of ceramic materials as they are prepared for forming operations.

Solid Solution, Color, and Thermal Stability in the System CdS-CdSe (ul)

A. L. FRIEDBERG,* A. J. EROLES

Solid solution crystalls in the system CdS-CdSe are important commercial red pigments. This program involved the study of the change in color, the thermal stability, and the change in crystal parameters as a function of selenium content in the CdS type crystal.


Sintering of Alumina with Minor Additions of Nickel, Chromium, and Aluminum Under Oxidizing Conditions (ul)

J. A. NELSON,* C. M. ASLAKSEN

The sintering characteristics of alumina were studied when small amounts of chromium, nickel, and aluminum were added in such a manner as to change the surface character of the individual alumina particles comprising the compacts. Thermal processing was carried out in an oxidizing atmosphere, and the sintering progress was evaluated in terms of the densification and microstructure.


Ultrathin Ceramic Particles (wrg)

J. A. NELSON,* P. J. MARCIALNDO

The utilization of ultrathin ceramic particles (below 100 millimicrons in size) by incorporating such finely divided materials into ceramic formulations of larger particle sizes is being investigated. In the initial phase of the program emphasis is given to obtain a better understanding of the role of the ultrafine particles in sintering and on the properties developed in fabricated specimens. As the work progresses it is anticipated that information will be obtained on the influence of extremely fine particles on the rheological properties of ceramic materials as they are prepared for forming operations.

The Thermal Expansion of Synthetic Beta-Spodumene as Affected by Additions of Iron, Potassium, and Sodium (pojc)

J. A. NELSON,* L. L. MARTIN

The thermal expansion of synthetic β-spodumene was measured when variable additions were made of iron,
potassium, and sodium in amounts up to three weight percent expressed as the oxide. The thermal expansion was found to vary significantly with respect to the compositions.


**Defect Structure Ferroelectrics (onr)**

**V. J. Tenny,** **R. M. BROWN**

This work concerns an investigation of the dielectric and structural properties of solid solutions formed in the system Na$_3$NbO$_6$—SrNb$_2$O$_6$—CdNb$_2$O$_6$ near the end member Na$_3$NbO$_6$. An investigation of the series Na$_{1-x}$Sr$_x$Cd$_{1/2}$Nb$_2$O$_6$ has revealed that the 365° transition in pure Na$_3$NbO$_6$ is lowered as the parameter $x$ is increased. The transition temperature is lowered approximately the same amount for a given substitution as it is when Sr$^{2+}$ alone is substituted into Na$_3$NbO$_6$. The relative dielectric constant is greatly increased due to the presence of the cadmium ions in the crystal. Maximum dielectric constants of 7000 have been observed at transition temperatures above 200°C. These solid solutions are presumably ferroelectric up to the temperature of the dielectric constant maximum. These ceramics must be sintered in an atmosphere of CdO vapor at temperatures in the vicinity of 1340°C. The dielectric properties are very sensitive to a gain or loss of CdO during the sintering heat treatment.

Work is in progress to determine the crystal symmetry of the various phases in the system by means of X-ray diffraction.

**Dielectric and Structural Investigation of Complex Compounds of the Perovskite Type ABO$_3$† (acc)**

**V. J. Tenny,** **D. Weirauch**

An investigation is being conducted of the formation of perovskite type phases of the type A$^{3+}$B$^{11+}$O$_{3+}$3. It has been established that BaZn$_{1/2}$Nb$_2$O$_3$ is a cubic perovskite with no ordering among the zinc and niobium ions. This crystal has a very low relative dielectric constant at 25°C. It forms solid solutions with BaTiO$_3$. A substitution of 5 mole percent of the BaZn$_{1/2}$Nb$_2$O$_3$ into BaTiO$_3$ nearly destroys the dielectric constant maximum associated with the tetragonal-cubic transition at 120°C in the titanate.

Thus far it has been experimentally impossible to form PbZn$_{1/2}$Nb$_2$O$_3$ into a perovskite phase. This mixture forms a cubic pyrochlore phase which is a solid solution of ZnO in PbNb$_2$O$_7$ plus PbO and ZnO.

It has been established that BaLi$_{1/4}$Nb$_2$O$_3$ can be formed into a perovskite phase at temperatures under 900°C, but subsequent high temperature heat treatment to promote sintering results in a decomposition of the perovskite phase into a complex and unknown mixture of compounds.

†This research was conducted jointly by the Department of Ceramic Engineering and the Materials Research Laboratory.
Relation of Composition to Young's Modulus of Elasticity of Glass (ui)
F. V. TOOLEY*

Constant factors for various ions represented in a wide range of glass compositions have been established for the purpose of computing Young's modulus from glass composition. Basic input glass composition data are being processed preparatory to the computation over a wide range of compositions. For each set of composition data employed, extent of correlation of actual and calculated modulus will be determined.

Modified Method for Determining Chemical Resistance of Glass (ui)
F. V. TOOLEY,* P. J. MARCHIANDO

One of the most commonly used methods of determining chemical resistance of glass consists in digestion of the glass in water under controlled conditions of time, temperature, and pressure. In such methods the concentration of attacking liquid is continually changing, i.e., increasing in concentration with respect to ionic species produced when the glass is attacked. A relatively small amount of work has been done under such conditions that the glass is continuously attacked by a liquid of constant composition. The current study seeks to develop a suitable method for studying the chemical resistance of glass to water attack, under conditions of continuous regeneration and recirculation of distilled water.

Effect of Some Minor Constituents on Melting Rate of a Typical Soda-Lime-Silica Glass Batch (ocfc)
F. V. TOOLEY,* J. A. MOSBARGER

The effect of additives and/or substitutions of Na₂SO₄, B₂O₃, CaF₂, and BaO on the melting rate of a typical Na₂O-CaO-SiO₂ glass batch is the subject of this investigation. The present work employs chemically pure or reagent grade materials of -200 mesh size; timed melts at 1400°C are examined after cooling for presence of unmelted relics. This work is basic to later investigations on the effect of grain size distribution of batch materials and impurities in commercial raw materials on rate of melting.

J. W. WESTWATER, Head

The research activities in the Division of Chemical Engineering of the Department of Chemistry and Chemical Engineering are primarily of a fundamental scientific nature dealing with a wide range of fields of modern interest. Principles of physics, mathematics, and chemistry are used as a basis for extending and interpreting the experimental results. This type of scientific approach gives the engineering aspects of the research a solid background of theoretical understanding. Fields of current research interest include solid state physics, heat transfer, mass transfer, fluid mechanics, kinetics, catalysis, high pressure studies, nucleation phenomena, electroorganic chemistry, interfacial phenomena, process dynamics, reactor design, and methods of applied mathematics.

The Division of Chemical Engineering is part of the Engineering Experiment Station and is in the Department of Chemistry and Chemical Engineering of the College of Liberal Arts and Sciences. In addition to the supplementary research facilities available through the Engineering Experiment Station, special research facilities available through the Department of Chemistry and Chemical Engineering include a microanalytical laboratory, a mass spectrometer laboratory, and a combined infrared and nuclear magnetic resonance laboratory.

This apparatus, developed by Professor H. G. Drickamer, permits X-ray measurements of lattice parameters of substances with simple structures to pressures as high as 500 kilobars.
THE EFFECT OF PRESSURE ON THE STRUCTURE OF SOLIDS

The purpose of the research program is to develop a deeper understanding of the structure of solids, and ultimately to permit the “design” of better solids for many particular uses. Apparatus has been developed which permits optical and spectroscopic studies to 170 kilobars. This allows direct observation of the effect of interatomic distance on electronic structure, which is directly related to many important and useful physical properties. A device has been developed which permits electrical measurements to 600 kilobars. Extensive studies are being undertaken on the approach to the metallic state in insulators and semiconductors, and on changes in the electronic structure of metals. Recently, the resistance apparatus has been modified to operate up to 720°C and down to liquid nitrogen temperature (−195°C). An apparatus has been developed which permits X-ray measurements of lattice parameters of substances with simple structures to pressures as high as 500 kilobars. An apparatus for Mössbauer studies to 250 kilobars is now in operation.

Research in this area is directed by Professor Harry G. Drickamer and is conducted in cooperation with the Materials Research Laboratory.

High Pressure NMR Studies (aecl)
H. S. GUTOWSKY, V. CLERON, C. COSTON

In collaboration with H. S. Gutowsky of the Physical Chemistry Division, the development of high pressure facilities for nuclear magnetic resonance is being undertaken. Initial studies will involve measurement of the Knight shift in metals. Ultimately, the hope is to study cesium near the electronic transition in 41 kilobars. Since this supposedly involves a large decrease in the character of the conduction electrons, there should be a catastrophic change in the Knight shift.

The Approach to the Metallic State at High Pressure (aecl)
B. M. RIGGLEMAN, R. B. AUST

Current studies on the approach to the metallic state involve iodine, selenium, and fused ring aromatic compounds.

In iodine and selenium it has been shown that the energy gap between the conduction and valence bands, measured optically, is indeed twice the activation energy for electrical conduction, indicating that these are intrinsic semiconductors. Studies on single crystal iodine show that metallic conduction is obtained at 160 kilobars in the direction perpendicular to the molecular planes, and at 230 kilobars in the plane of the molecules. Selenium becomes metallic at 130 kilobars.

The work on organic semiconductors has concentrated on pentacene. Efforts are under way to synthesize hexacene and possibly higher homologues. Studies are made both at 296°C and 77°C. At 77°C, pentacene exhibits a small positive temperature coefficient of resistance by 250 kilobars. At room temperature and pressures above 200 kilobars molecules of pentacene dimerize, giving rise to an increased resistance and changes in the optical absorption spectra. Very analogous behavior has been observed in single crystal graphite.

Anomalous Electrical Behavior of Metals at High Pressure (aecl)
R. A. STAGER, R. LYNCH

Electrical resistance measurements are being made on alkali, alkaline earth, and rare earth metals to help develop a better understanding of the relationship between interatomic distance and electronic structure. A wide variety of effects have been observed; only a few of the more intriguing ones will be noted here.

In potassium two phase transitions are obtained, at 380 kilobars and 360 kilobars. The latter is accompanied by a very sharp rise in resistance and occurs only below 260°C. The evidence is that it is a martensitic transition. Rubidium exhibits a very sharp rise in resistance at 190-200 kilobars and a maximum at 425 kilobars. These effects seem to be associated with an electronic rearrangement involving the promotion of a 5s electron to the empty 4d shell.

Calcium has a transition at about 150 kilobars to a semiconducting state, and a second transition back to a metal at pressures somewhat over 300 kilobars. Barium exhibits very unusual phase behavior in that above 15 kilobars its melting point decreases with increasing pressure. At 296°C above 500 kilobars and 170°C above 900 kilobars, it is a liquid at 190 kilobars and 170°C, the lowest melting point of any known material. At 77°K and 240°K, there is a solid-solid transition involving a large volume change, which is apparently due to an electronic collapse.

Ytterbium metal becomes a semiconductor at 20 kilobars and undergoes a sharp phase transition to another metallic structure at 40 kilobars. A number of other unusual effects appear in other rare earth metals.

It is planned to extend these measurements to solid solutions and alloys.

Electrical Conductivity of Organic Complexes (aecl)
W. H. BENTLEY, R. B. AUST

Aromatic hydrocarbon molecules form complexes with a variety of inorganic and organic molecules (e.g., iodine, bromine, chloranil, quinones). These complexes have optical and chemical properties, markedly different from either of the pure components. In particular, they are frequently considerably better electrical conductors than the components. Present theory is that these charged properties are concerned with electron transfer between molecules. This is very sensitive to intermolecular distance. A program has been initiated to study the resistance of such complexes as a function of applied pressure, to help elucidate the mechanism of electron transfer.
The Electronic Structure of Hexagonal Metals and Alloys at High Pressure (aec)
E. A. PEREZ-ALBUERNE, R. L. CLENDENEN, R. W. LYNCH

Measurements of the relative compressibility of the a and c axes of hexagonal crystals, combined with electrical resistance measurements at high pressure can yield important information about the position of the Fermi surface vis-à-vis the Brillouin zone boundaries.

Current studies include measurements on magnesium, cadmium, zinc, and on hexagonal alloys of silver and magnesium. As the Fermi surface approaches the Brillouin zone wall there is a very strong attractive interaction between them which inhibits expansion of the Brillouin zone in this direction, and therefore reduces the compressibility of the crystal along the corresponding axis. Our studies show that the interaction is very sensitive to the electron atom ratio and to the size of the energy gap at the boundary. As the Brillouin zone boundary finally does enclose the particular area of Fermi surface, the number of free electrons is reduced and a distinct increase in resistivity is noted.

Compressibility of Cubic Materials (aec)
E. A. PEREZ-ALBUERNE, A. R. CHAMPION

The compressibility of a number of salts having cubic structure have been measured to 400 kilobars. These include NaCl, KCl, CsCl, MgO, CaO, CdO, and CsS (high pressure phase). These results are being interpreted in terms of changes in the repulsive energy at small interatomic distances.

The measurements are being extended to a number of carbides including VC, TiC, NbC, and ZrC.

The Effect of Pressure on the Compressibility of Indium and Its Alloys (aec)
R. W. VAUGHAN

Indium crystallizes in a tetragonal structure with a c/a ratio of 1.075. With pressure the c/a ratio increases to about 1.10 at 200 kilobars and then decreases with further increase of pressure. Alloys of indium with tin, lead, and thallium have been prepared and will be studied. The results will be interpreted in terms of the electronic structure of indium in a manner quite similar to that applied to the hexagonal crystals mentioned above.

Mössbauer Studies at High Pressure (aec)
H. FRAUENFELDER, R. INGALLS, D. N. PIPKORN, C. K. EDGE

An apparatus has been developed which permits measurements of Mössbauer resonances to 250 kilobars. In collaboration with Dr. H. Frauenfelder's group in physics detailed studies have been made on the Mössbauer effect in iron. In the (ferromagnetic) bcc phase there is a decrease in the intensity of the local field with pressure and an increased electron density at the nucleus which scales approximately with the bulk density. At the 130 kilobar transition there is a large increase in electron density at the nucleus. The high pressure phase, which has the hcp structure, is not ferromagnetic.

Mössbauer studies are being extended to other transition metals, and work on a variety of alloys is planned.

Design Parameters for Supported Taper Pistons (aec)
K. F. FORSGREN

During the past several years supported taper pistons have been used in this laboratory for optical absorption, electrical resistance, X-ray diffraction, and Mössbauer studies to the highest static pressures ever obtained. Each type of apparatus has been designed in rather an ad hoc manner. A thorough study of the design parameters, stress gradients, effect of size and scale up, and variation of the pressure transmitting materials is being undertaken to get a clear idea of the ultimate possibilities and limitations of the method.

FLUID MECHANICS
(nsf; prf; afosr)

Studies of the interaction between a turbulent air stream and water are being conducted in order to obtain a better understanding of engineering applications, such as film-cooled rocket motors, wetted-wall columns, and pipe transport of two-phase fluid. Some of the questions being asked are as follows: (1) What are the reasons for the different types of wave structures observed? (2) How can these wave structures be described? (3) What effect do the waves have on the rate of heat, mass, and momentum transport through the liquid? (4) How can the increased interfacial stress be related to the wave structure?

The rate of heat, mass, and momentum transport between a turbulent fluid and a wall is controlled to great extent by the flow in a region very close to the pipe wall (the viscous sub-layer). Although the assumption of a rectilinear laminar motion in this region explains some phenomena, this model is incorrect and proves inadequate. An electrochemical technique has been developed to study the unsteady nature of the flow in the viscous sub-layer. It measures the average and the fluctuations in the velocity gradient at the wall. The technique is to be used to obtain an understanding of the structure of turbulent flow close to a wall and of the mechanism of turbulent exchange with a wall.

The understanding of the performance of catalytic reactors, pebble heaters, and absorbers depends upon our understanding of physical processes which are governed by the flow through a packed bed. Yet very little is known about the details of the flow field in a packed bed. Most studies have involved average measurements over a large number of particles. An experimental program which differs from previous work in that the scale of the measurements is smaller than a particle diameter has been initiated to study the flow field in a bed of spheres.

Natural convection can have a marked effect on heat transfer rates for flows at low Reynolds numbers. An understanding of this effect is being obtained by studying the distortions in the flow field caused by density variations.

Effect of Waves on Interfacial Shear Stress and on Transport of Heat, Mass, and Momentum

L. S. COHEN

Five types of interfacial structures for the co-current flow of turbulent air and a liquid film have been identified as smooth, two-dimensional waves, three-dimensional waves, roll waves, and dispersed flow. Experiments have been completed which define the conditions under which these different regimes exist. Theories have been developed to explain the appearance of roll waves and of two-dimensional waves.

Work is continuing to explain the other transitions and to explain the effect of the wave structure on the inter-
facial shear stress and on the rate of transfer of heat, mass, and momentum through the liquid film.

Atomization in the Co-Current Flow of Air and a Liquid
D. E. WOODMANSEE
At high enough relative velocities between air and a liquid in parallel flow droplets are torn from the interface. The mechanism of this atomization process is being studied using photographic techniques. A theory has been developed to predict the minimum relative velocity at which atomization will occur.

Measurement of the Average and the Fluctuations in the Wall Shear Stress
J. E. MITCHELL
The fluctuations in the rate of mass transfer from small sources on the wall of a pipe through which water is flowing turbulently are being measured. The source is a polarized electrode which is mounted flush to the tube wall. These measurements yield information on the unsteady nature of the flow in the immediate vicinity of the wall and therefore yield a better understanding of the wall transfer process. A model of the structure of wall turbulence is being developed.

Flow Field in a Packed Bed
K. R. JOLLS
Measurements are being made of the details of the flow pattern around a single sphere in a bed of packed spheres and of the variation with location on the surface of the sphere of the mass transfer rate between the fluid and the packing. Two techniques are being used: (1) the average on the fluctuating current to a polarized electrode embedded in the surface of one of the spheres is being measured, and (2) a colored filament is formed at the surface of one of the spheres. By using a glass column, glass spheres, and a fluid with the same refractive index as glass, it is possible to see through the column and the packing to view the motion of the colored filament.

Flow Around a Cylinder
J. S. SON
A technique has been developed to measure local values of the wall shear stress. This consists of measuring the average current to a small polarized electrode embedded in a solid wall. This technique will be used to obtain a better understanding of a number of boundary layer flows. A water tunnel has been designed to carry out these experiments. Initial work will consist of a study of the flow around a cylinder. Particular attention will be given to the wake region.

Effect of Natural Convection on Heat Transfer
D. P. SIEGWARTH
Density variations in water flow with a low Reynolds number through a horizontal heated pipe cause a spiral secondary flow to be superimposed on the primary flow. This secondary flow can be quite large at moderate temperature differences. On the basis of visual studies, it has been suggested that at large enough temperature differences the rate of heat transfer is controlled by the secondary flow and that the secondary flow may be described by a boundary layer analysis. This differs from the usual boundary layer analysis in that the properties of the field exterior to the boundary layer are not known. Measurements of the temperature field are being made at the end of a long section of electrically heated pipe so that a fully developed field having no change in the direction of flow may be studied. A constant temperature is maintained on the inside wall by using a thick-walled aluminum pipe.


HEAT TRANSFER AND PHASE CHANGES

Research in heat transfer, particularly as applied to instances involving nucleation and phase change, is continuing. The overall goal is an understanding of phase transitions. The present study includes boiling, condensation, bubble growth, drop growth, fouling deposition, and melting and freezing. Motion picture photography is a powerful tool used for this research, especially when a high-speed camera or time-lapse camera is coupled to a microscope.

Professor James W. Westwater directs research in heat transfer and phase changes.

Bubble Growth in Boiling Binary Mixtures (nsf)
J. M. YATABE
The rate of growth of bubbles in mixtures of two liquids is determined photographically. Bubbles in mixtures are influenced by heat conduction and mass diffusion simultaneously. The growth has been predicted theoretically for glycol-water. This plus a series of other mixtures are being tested.

Growth of Bubbles During Electrolysis (nsf)
J. P. GLAS
Bubbles of hydrogen, oxygen, and CO2 are formed on platinum, nickel, and copper electrodes in dilute solutions. Photography provides data of diameter versus time. The theoretical expression of Scriven for diffusion-controlled,
Isothermal bubble growth is being investigated under conditions of constant current density.

**Dropwise Condensation of Organic Vapors (nsf)**

A. C. Peterson

A photographic technique is used to measure the population of drops, the merging of drops, and the growth of drops of condensate on vertical copper surfaces. The effect of the temperature-difference driving force is being studied.

**Microscopic Motion at a Solid-Liquid Interface (nsf)**

D. V. Boger

Instability may develop at the interface between a solid and its melt, even at so-called steady conditions. The interfaces between ice and water are being examined by cine-microphotography.

**Boiling on a Fin (nsf)**

K. W. Haley

A horizontal cylindrical fin is immersed in a boiling liquid. One end of the fin is kept hot enough to cause film boiling, whereas nucleate boiling occurs at the other end. The experimental data are being used to test a proposed mathematical model.

**Nucleation Sites for Dropwise Condensation (nsf)**

J. L. McCormick

Water vapor is condensed slowly in the dropwise manner on a horizontal plate. The identification of the nucleation sites for drop formation is determined by photography through a microscope. Types of possible sites being tested include microscopic pits, scratches, and specks of various organic and inorganic solids.

**Film Boiling on a Horizontal Plate (nsf)**

D. E. Kautzky

No data exist for film boiling of binary mixtures on horizontal plates. Tests are being run using a gas-heated aluminum slab, 8 x 8 x 4 inches, as the hot surface and mixtures of chlorinated liquids as the test fluids.

**Photographic Study of Fouling (nsf)**

J. W. Palen

Continuous visual records of the process of fouling on a metal surface used to heat a contacting liquid are being obtained. Heat fluxes and temperature difference driving forces are recorded simultaneously. It is hoped to gain a new insight into the mechanism of fouling.


APPLIED MATHEMATICS IN HEAT AND MASS TRANSFER

Heat and mass transfer in a solid and in the boundary layer of a fluid flowing past this solid is being investigated.

Professor J. L. Hudson directs research in this area.

Solid-Liquid Heat Transfer (ul)

M. SELL

Heat transfer between a solid and a liquid is usually treated analytically by assuming that either the temperature or the heat flux is known at the solid surface. In some cases, it is not possible to predict these quantities a priori, and the problem must be investigated by considering heat flow in the solid and in the liquid simultaneously. Both analytical and numerical methods are being attempted. The work will be extended to include mass transfer with chemical reaction in the solid.

The Effects of Heat and Mass Transfer on Chemical Reaction (ul)

G. LEHMKUHL

The effects of heat and mass transfer on heterogeneous or fast homogeneous chemical reactions on or near the stagnation point of a cylinder are being considered. It is planned to verify the analysis experimentally.

PROCESS DYNAMICS

The analysis and design of chemical reactors has conventionally been based on a steady-state point of view. Recently, with the widespread application of automatic control, the need for time-dependent descriptions has arisen. It is the focus of this research to study the dynamics of chemical systems with the object of relating the results to classical kinetics, to linear or first order approximations, and to system characterization for stability and control.

Professor Daniel D. Perlmutter directs research in this area.

Dynamics of a Reversible Chemical Reaction System (nsf)

T. Z. FAHIDY

This research project is directed toward a study of relatively rapid chemical system fluctuations. The platinum-catalyzed oxidation of sulfur dioxide is well suited to this purpose; it is reversible at moderate temperatures (about 500°C) and shows no appreciable side reactions. This characteristic makes it possible to study this reaction in a nonflow system. In a constant volume apparatus the reaction may be followed by pressure and temperature measurements; changes in both these variables can be detected in time intervals of less than 0.1 second.

Chemical Reactor Stability by Liapunov’s Direct Method (nsf)

J. S. BERGER

Stability criteria are being developed for a well-stirred flow reactor with chemical kinetics as an arbitrary function of temperature and concentration. By the use of Liapunov’s Direct Method sufficient conditions are found to guarantee a region of asymptotic stability, as well as local stability of a given steady state. A specific solution has been found for N°th-order kinetics with Arrhenius temperature dependence, and the effect of reaction order on the stability criteria is being studied. The early results are being generalized by using a result of Krasovskii’s to explore the nature of several Liapunov functions. The region of proved stability can be greatly extended in this manner.

The Stability of Nonlinear Systems in the Region of Linear Dominance (nsf)

I. GURA

This investigation is attempting to bridge the gap between strict nonlinear analysis and the approximations of linearization. Typical analytic nonlinearities that occur in chemical engineering systems show pseudo-linear behavior in some region of phase space about the steady state. In this region it is possible to establish asymptotic stability which is not limited to the steady state alone. A number of systems of chemical engineering interest are being studied for automatic control implications.
Optimum Control of a Chemical Reactor (nsf)
W. O. PARADIS

Various computational techniques based on steepest ascent and classical calculus of variations present straightforward optimization procedures which are, however, very time-consuming. In some cases of systems with saturating elements, a much simpler procedure appears promising. This study is comparing the two approaches to a chemical reactor problem to find the limitations, if any, on the simpler procedure.

CHEMICAL REACTOR DESIGN

Advantages in experimental measurement and subsequent data interpretation can be realized by carrying out kinetic measurements in somewhat unconventional equipment. If surface-catalyzed reactions are studied in stirred-vessel reactors, better temperature and pressure regulation is attainable than in the usual packed bed, and it is possible to investigate flow and agitation as unconnected variables. Further, the data do not suffer the loss of accuracy that is associated with more conventional data interpretation by differentiation.

Research in this area is directed by Professor Daniel D. Perlmuter.

Heterogeneous Catalysis in a Stirred Reactor (prf)
R. TOLEDO

A continuous-flow stirred-vessel reactor is being used to study the kinetics of a metal-catalyzed alcohol dehydration reaction. Since all side reactions can be suppressed, it will be possible to investigate this reaction over a wide range of concentration, flow, and temperature conditions. The accuracy of analysis and constancy of conditions are notably better than the previously published data on this system. The apparatus will permit investigations at elevated pressure.

The Effect of a Porous Catalyst in a Stirred Reactor (prf)
D. L. RELYEA

Many chemical reactions (especially those of commercial interest) are carried out over porous catalysts. While it does make possible the consideration of a broader range of chemical systems, the inclusion of catalyst porosity as a variable also increases the system complexity by adding mass transfer resistance. In this research, a reactor is being developed for study of porous catalyst systems.

A Study of Gas-Phase Mixing (prf)
F. WANG

Information about the mixing pattern in a stirred reactor is needed for several practical reasons and to assess the range of validity of assumptions commonly made in interpreting kinetic and dynamic data. This study of mixing in a gas seeks to relate internal happenings to external (input-output) measurements.


FLUID STABILITY

This study has just been initiated. It is concerned with linear and nonlinear mathematical problems of fluid stability in fields having a driving force. Both the analytical and experimental aspects are to be investigated. The study is being sponsored by the Division of Chemical Engineering, University of Illinois.

Professor R. L. Sani directs research in this area.

TRANSPORT PHENOMENA WITH CHEMICAL REACTION

A knowledge of (1) heat and mass transfer rates with chemical reaction, (2) the effect of non-ideal flow conditions on chemical conversion, and (3) the transient behavior, particularly stability and control problems, of chemical reacting systems is important in a large number of engineering applications, such as the heat protection of high-speed vehicles in reacting atmospheres, the design of chemical rocket motors and other high-performance combustion equipment, and the design of industrial chemical reactors. This research program is concerned with an investigation of these phenomena principally by digital or analog computer studies of the governing transport equations.

Research in this area is directed by Professor Roger A. Schmitz.

Stability of Plug-Flow Tubular Reactors (ui)
M. J. RELLY

An analytical study of the stability, transient behavior, and control of some non-isothermal, plug-flow tubular reactor models with mechanisms of thermal feedback is in progress. The objectives of this work are to determine the criteria for stability of steady state operation and to investigate the overall transient picture, in particular, the occurrence of sustained oscillatory operation.
Heat Transfer with Finite-Rate Chemical Reaction (use)
R. G. LADD
This study employs the diffusion layer concept of heat and mass transfer to investigate, analytically and experimentally, the effect of a homogeneous exothermic reaction of the Arrhenius type on the rate of heat transfer to a solid surface.

The Effect of Secondary Flow in Curved Tubes on Chemical Conversion (ui)
H. J. GREZLAK
When a fluid flows through a tube whose axis is curved, a secondary flow develops, and the axial velocity profile is flattened. In this study the helical coil is suggested as a useful device for kinetic studies since the secondary flow may be avoided under certain conditions to permit the assumption to plug flow, thus eliminating the uncertain effects of component diffusion. The objective is to study the effect of the various parameters analytically and experimentally and to determine the conditions under which the assumption of plug flow results in negligible error.

Dynamics of Reaction-Rate-Controlled Combustion (ui)
M. P. GROSBOY
This investigation is concerned with extinction, ignition, and oscillatory behavior in reaction-rate-controlled systems. Some simple combustion chamber models and the spherical combustor, often employed in flame kinetics studies, are being studied analytically.

A Study of Non-Adiabatic Laminar Diffusion Flames (ui)
L. L. KIRKBY
The effect of heat losses on the extinction and the general transient behavior of laminar diffusion flames is being studied. Homogeneous and heterogeneous kinetics are being employed in the analytical study.


SURFACE PHENOMENA, DIFFUSION, AND CELLULAR CONVECTION
An understanding of interfacial phenomena is basic to the interpretation of most interphase transfer operations, including transport in biological systems. This research program is concerned with an investigation of interfacial properties, especially the physical-chemical and hydrodynamic factors which influence the rate of mass transfer through an interface.
Studies are currently being carried out in the following areas: (1) transient diffusion through the liquid-liquid interface, (2) diffusion or migration in a fluid interface, (3) interfacial instability and cellular convection in thin liquid films, (4) monolayer permeability.

Research in this area is directed by Professor J. A. Quinn

Diffusion and Flow in a Radially Moving Film (phs)
R. L. MERSON
Diffusion through a planar liquid-liquid interface has been studied using several binary systems. A thin film of water flowing radially outward from a central source was contacted with a variety of pure organic liquids and also with carbon dioxide. Several phenomena frequently encountered in phase contacting operations, e.g., stagnation of the interface due to trace quantities of surface-active agents, were explored. Measured rates of mass transfer were predicted exactly using the true surface age in the standard diffusion calculations.

Diffusion Through the Liquid-Liquid Interface (phs)
W. J. WARD
Diffusion measurements in three component systems are considerably more complex than binary systems. In this study, two concentric laminar jets are used to measure the diffusion of a mutually soluble component between two immiscible phases. The two jets are formed from concentric nozzles, with the outer phase traveling at a thin (approximately 20 microns) skin of fluid on the inner cylindrical jet. A radioactive solute is used to measure transfer between chemically equilibrated phases.

Mass Transfer at the Gas-Liquid Surface (phs)
R. E. PLEVAN
This project is concerned with absorption of a pure soluble gas into a stagnant liquid in the presence of surface-
active agents. The absorption chamber consists of a cell of constant total volume containing the absorbing liquid and saturated gas. Absorption rate is measured by following the decay of a step function in gas pressure with a sensitive strain-gauge pressure transducer. The effect of natural convection on the mass transfer rate is also being investigated.

Cellular Convection (phs)
W. T. MITCHELL, D. S. PRENSNER

The purpose of this research is to investigate interfacial instability as it applies to motion in thin liquid films. Of particular interest are the surface-tension-driven flows and criteria distinguishing surface-tension-driven from buoyancy-driven flows. Several interesting phenomena have been observed including oscillatory flow within a film heated uniformly from below.

Interfacial Resistance: Diffusion into a Laminar Liquid-Liquid Jet (phs)
L. C. LONG, Jr.

A technique has been developed for measuring transient rates of diffusion through a liquid-liquid interface using a laminar jet. Studies on several liquid pairs indicate a measurable interfacial resistance. The interpretation of the mass transfer results is influenced significantly by the hydrodynamics of the jet. Current work is concerned with the flow field in a laminar jet.

Diffusion in a Monolayer (phs)
R. O. MASS

Very little is known of molecular transport phenomena in two-dimensional systems such as adsorbed films. In particular few experiments have been performed on diffusion in monolayers formed on a liquid substrate. This project is concerned with the surface diffusion, in the absence of surface flow, of tagged surface-active molecules spread on water. In the current work stearic, palmitic, and oleic acids are being used as the tagged surface-active agents.


ELECTROCHEMICAL STUDIES

A literature search in the field of electro-organic chemistry is being conducted. A bibliography of material found in Chemical Abstracts, 55 (1961) has been prepared and is published in Electrochemical Technology, 7 (1963), pp. 308-311. A bibliography of material in Chemical Abstracts, 56 (1962) is being prepared.

In conducting the search of the literature, material of interest to members of the staff of Chemical Engineering and to those in theoretical electrochemistry is being collected.

Professor Sherlock Swann, Jr., conducts research in this area.
Research in the Department of Civil Engineering is being pursued currently in structures and structural mechanics; soil mechanics and foundation engineering; highway and traffic engineering; hydraulics, fluid mechanics, and water resources; sanitary engineering; photogrammetry and geodetic engineering; construction engineering; and computer applications in civil engineering. Although ostensibly separated by these various research interests, the staff members participate in a free and regular interchange of ideas.

The most important aspect of the research program is the active participation by graduate students. The graduate student educational program is coordinated with research on the theory that participation in creative effort and in the investigation of basic problems enables one to go beyond the limitations of present practices and contribute to the progress of the profession. Integration of the research and educational functions serves the research program by making available the services of high-caliber graduate students with fresh ideas, besides training these personnel as research engineers.

Furthermore, the department’s emphasis on graduate research programs has resulted in significant contributions to civil engineering progress and has been a decisive factor in attaining its high standing. A well-known premise is that excellence in instruction and in research are interrelated. These are underlying reasons for the steady growth of the research program which has attracted many competent new staff members and highly qualified students.

The new Civil Engineering Building is currently under construction, and the first phase as shown in this scale model will be occupied in November, 1965. Additional portions of the building are scheduled for completion in the following years. More than 200,000 net square feet of space will provide the most modern facilities for research and advanced study.
STRUCTURES AND STRUCTURAL MECHANICS

In addition to training graduate students, the structural research program is directed toward obtaining useful information of a theoretical and experimental nature concerning the behavior of structures and structural components, and applying this information for greater economy and efficiency in structural design. Subjects investigated are related primarily to the strength and behavior of structural components under static, fatigue, or dynamic loading. The structures studied range from models through full-scale members.

The structural laboratory is one of the most versatile and complete facilities of its kind. Standard universal testing machines varying in capacity from a few thousand pounds to 3,000,000 pounds, fatigue machines of 200,000-pound capacity, loading frames for the testing of beams and other structural elements or members, and a variety of special testing devices are provided in the main testing bay. In adjacent areas, additional fatigue machines of 50,000-pound capacity, small capacity testing machines, and various dynamic loading devices are provided. This extensive dynamic testing equipment, most of which was designed and built in the laboratory, permits the study of the complex problems associated with the response of materials and structures to transient loads.

Support facilities include new electronic tape-recording equipment, high-speed digital computers, analog computers, and other computational and data-reduction equipment which permit the study of such complex problems as the theoretical determination of the response of members, materials, and structures to various types of loadings.

Analysis and Design of Domes, Arches, and Shells (afswc)

N. M. NEWMARK,* A. R. ROBINSON,* R. L. JENNINGS, R. H. LEICESTER, C. Y. YANG

This program aims to develop analytical procedures for the computation of the dynamic response of arches, domes, and shells to loads resulting from blast of nuclear weapons; to apply these methods to specific problems, usually with the aid of high-speed digital computers; and to simplify procedures for the rapid determination of the structural response and for estimation of critical levels of blast intensity.

During the past year, work has consisted chiefly of completing a report on a method of analyzing interaction of structures buried in soil and the surrounding soil. Also, experiments are in progress to study the adequacy of this theory, as is work on the determination of the dynamic response of above-ground domes. A final report is being prepared.


Computation of Underground Structural Response (dasu)


The response of an underground structure to dynamic pressures is a relatively new field of investigation, brought about by the necessity of utilizing deep earth coverings to resist the effects of nuclear blasts. For this problem, certain questions are immediately apparent: the forces exerted on an underground structure at a given depth when a nuclear blast of specified yield is released; the behavior of a structure when it moves, with the surrounding earth mass also in motion; the interaction of the structure and the soil in which it is placed; and the effects of the properties of soil and rock on the propagation of stress waves and on the response of a given structure.

To answer or find analytical means of obtaining answers to these questions, the program has been divided into several phases:

(1) To obtain basic knowledge requisite to a better understanding of the wave propagation phenomena in a solid mass, as well as in a mass with discontinuities.

(2) To develop means of obtaining approximate numerical solutions to free-field phenomena; as well as structural-soil interaction phenomena.

(3) To evaluate and improve the present state of knowledge concerning the properties and their influence on the overall response of a given structure.

Mathematical formulations of stress wave propagation in nonlinear solids have been effected, and certain analytical solutions for one-dimensional locking-type media have been obtained. Shock stability in solids has also been studied.

Numerical methods for predicting ground motions under blast loadings have been developed. This involves direct computer simulation of a continuous medium; for this purpose, discrete models that are mathematically consistent with the classical theory of solid continua have been conceived and developed, and a number of hitherto unsolved problems have been successfully attacked. The method is presently being extended to handle nonlinear problems involving contained plastic fluid under dynamic conditions. Before the method can be applied to real earth materials, fundamental properties of soils and rocks under multidirectional stress conditions are required.


G. N. Harper, "A Numerical Procedure for the Analysis of

Discrete Models of Nonlinear Continua (nsf)
A. H.-S. ANG, M. AMIN, F. BARTON, R. BUNTING, R. CARARIE, L. GREEN

The objective of the program is the development of basic mathematical approaches for the analysis of a wide class of solid continua possessing linear and general nonlinear behavioral characteristics. The study has emphasized two- and three-dimensional solids with nonlinear behavioral properties, including solids that are defined by the constitutive equations of the classical theory of plasticity.

In order to be able to treat a wide class of nonlinear continuum problems of solids, a digital approach to these problems has been proposed. This involves the development of a number of mathematically consistent discrete models; a given solid continuum is then simulated by one of these models in terms that are suitable for direct digital calculations of high-speed computers. The behavioral characteristics of the models follow exactly those of the corresponding continuous solids.

With this approach, a number of hitherto unsolved problems of linear and nonlinear solids have been successfully resolved; these include the propagation of complex stress waves from higher dimensional solids possessing elastic or elastic-perfectly plastic stress-strain equations, and the progressive strain of plastic flow under contained conditions. Other problems under study include the flexural analysis of rectangular plates with elastic-perfectly plastic moment-curvature relationships.


Free-Field Ground Motions by Model Simulation (asfc)

A basic numerical approach for the analysis of motions and stresses in a half-space solid subjected to simulated blast loadings is being developed. The immediate application is in the prediction of free-field ground motions resulting from high explosive and nuclear detonations. Analyses of wave motions in solids are mathematically extremely complex; the prediction of earth motions is further complicated by heterogeneous earth media possessing nonlinear properties that are not well defined, particularly under dynamic and complex stress conditions.

In attempting to predict ground motions under these circumstances, the earth medium has been idealized to be a regionally homogeneous solid continuum with elastic-perfectly plastic behavioral characteristics as given in the classical theory of plasticity. The method of solution is essentially a digital simulation technique in which a continuum is replaced by a mathematically consistent model. Computer programs are coded to perform all calculations on the basis of a given model.

Preliminary calculations have been performed for problems of a half-space subjected to a directly transmitted pressure pulse or an expanding air blast pressure under axially symmetric conditions. The half-space has been assumed to be a linearly elastic solid until a limiting state of stress is reached. Beyond this limiting stress state, the material undergoes non-recoverable plastic deformations.


Numerical and Approximate Methods of Stress Analysis (onr; ndea)

The objectives of this project are to develop efficient numerical and approximate procedures for structural analysis and to apply these methods to the solution of problems of stress analysis, wave propagation, and stability in order to broaden the engineer’s understanding of these areas.

Two classes of analytical methods are considered. The first concerns procedures which are rapid and suitable for use in preliminary studies or initial design. The second class comprises methods which can be effectively used with high-speed digital computing machinery.

Topics under consideration in the past year have been numerical methods for stress and stability analyses of shells, a probabilistic approach to rational seismic design, wave propagation in nonlinear media, diffraction of elastic waves, dynamics of shells, numerical methods for beams, and a physical analog model for shell structures.


Influence Surfaces of Plate-Beam Systems (ndea)
A. H.-S. ANG, D. M. BROWN

Influence surfaces for moments at specified locations in a beam-slab floor have been presented before on the assumption that the beams have no resistance to torsion; that is, the beams have flexural stiffness but no torsional stiffness. Since reinforced concrete beam-slab bridge floors are not uncommon in practice, it is of interest to determine the effects of the torsional stiffness of the beams on such plate-beam systems.

The investigation was restricted to a plate-beam system consisting of five beams, three of which are interior beams
and the other two are exterior beams. The beams are spaced equally, and all beams are assumed to have equal flexural and torsional stiffnesses. Five different values of the torsional stiffness were used in the calculations.

Influence coefficients for important locations in the plate as well as for the beams have been calculated with the use of high-speed computers. The results have been presented in the form of contours representing influence surfaces for the system.


**Frequency Analysis of Plates and Grids (ui)**

D. V. REDDY*

The work forms part of a study of the dynamic behavior of interconnected beam systems and consists of a theoretical and experimental investigation of the frequency analysis of certain plates and grids.

The theoretical investigation has been broadly divided into two parts: (1) Generalized analysis based on the elastic equivalence of an orthotropic plate and a grid framework including the application of "affine transformation." (2) Numerical procedure assuming the distributed mass system to be replaced by an equivalent system of discrete "lumped" masses of inertia.

Experiments were carried out on a plate and a rectangular grid, both of trapezoidal shape and clamped along the boundaries. The fundamental and several higher frequency values were obtained by driving with an electromagnet, and the ratio of the plate and driver frequencies were monitored electronically. The nodal patterns obtained by the "sand pattern method" were also checked by oscilloscope techniques. The grid test was confined to frequency measurements only.

It is proposed to extend the program to include tests on a diagrid and a stiffened plate and to study errors produced by lumped mass approximations.

**Numerical Analysis of Thin Shell and Space Frame Structures (ui)**

W. C. SCHNOBRICH,* J. W. MELIN*

This study has as its objective the development of a general model composed of rigid prismatic members connected by deformable elements. These elements are arranged in a grid-like structure whose shape is chosen to approximate the shape of the original shell structure. By defining the stiffness of the deformable elements in the proper manner, the model becomes a means of obtaining approximate solutions to a variety of shell structure problems. Cross-sectional area and surface area properties of the shell are concentrated at the deformable elements.

One model has been developed for shells with positive and zero Gaussian curvature and studied in the elastic range. The results for the cylindrical shell are very promising. With a modest number of deformable elements, good correlation was found with the results of existing continuum solutions. The model has also been applied to shallow elliptical paraboloids and again good correlation was found. A revised model is being developed to treat all shell types including those of negative Gaussian curvature.

A digital computer program has been written which generates, in the computer, the governing set of linear simultaneous algebraic equations. The computer output gives the complete set of forces and displacements of the model.


**Inelastic Behavior of Multistory Steel Frames (ui)**

E. H. GAYLORD,* E. W. WRIGHT

At the present time, plastic design is not recommended for frames more than two stories high unless lateral forces (and displacements) are resisted by cross walls, partitions, special bracing, and/or the like. The proposed investigation consists of three parts:

1. The development of a mathematical model permitting a detailed digital computer study of the inelastic behavior of multi-story rigid frame subject to sideways. Column stability, residual stresses, and load history will be taken into account. Out-of-plane bending and twist will not be considered.

2. Analysis of results to suggest practical rules and procedures for plastic design of multi-story rigid frame buildings.

3. The use of probabilistic concepts to suggest realistic live load and wind load combinations for the design of multi-story buildings.

**Inelastic Lateral Torsional Buckling of Beam Columns (ui; nsf)**

E. H. GAYLORD,* C. R. NOWACKI

The purpose of this investigation is to determine the lateral-torsional buckling strength of as-rolled beams subjected to axial compression and various patterns of transverse loads in the plane of the web.

The governing differential equations will be solved by finite differences to determine bifurcation of equilibrium.

**Elasto-plastic Analysis of Orthogonal Grids (ui; nsf)**

E. H. GAYLORD,* L. G. PETRO

The elastic analysis of grid structures has been treated extensively, but little has been reported on their inelastic behavior. It is the object of this investigation to study the orthogonal grid, taking into account both bending and torsion of its members, and with various load patterns and boundary conditions. Three types of boundary are considered: (1) edge beam supported only at the corners of the grid, (2) edge beam supported intermittently at each node, (3) fully restrained against deflection, bending, and twist. The grid is loaded only at the nodes. The behavior of the grid is traced from the appearance of the first hinge to the development of the mechanism. Estimates of the amount
of hinge rotation needed to develop the mechanism are made.


Critical Loads of Elasto-plastic Space Frame (ui)
E. H. GAYLORD,* W. W. McVINNIE

The elastic stability of simple rectangular space frames has been the subject of recent investigations. However, most frames of practical proportions reach their critical loads after inelastic action has developed. Some work has been done on the elasto-plastic stability of plane, rectangular frames.

This study will investigate a steel space structure, rectangular in plan, consisting of four columns and four beams. Equilibrium configurations at increasing intensities of load will be determined and the critical load identified by giving the frame independently a small lateral displacement in each principal direction and a small torsional displacement. Because of the presence of primary bending moments owing to the loaded beams, the critical load can be expected to develop under elasto-plastic conditions.

Low-Cycle Fatigue (bs)
W. H. MUNSE,* J. P. CANNON, J. F. KIEFNER, P. G. LITTLE

The purpose of the low-cycle fatigue program is to investigate and evaluate the behavior of ship steels under low-cycle high-stress conditions and to study the relationship of this behavior of the initiation of brittle fractures.

During the past year, efforts have been directed toward an evaluation of the manner in which repeated loadings or stress history will affect the susceptibility of a notched and welded specimen to fracture in a brittle manner.


Fatigue of HY-80 (bs)

This investigation is concerned with the behavior of welds in high-strength quenched and tempered structural grade steels that are used for the construction of large Naval structures. Studies under way are as follows:

1. The effects of internal defects on the fatigue behavior of butt welds in HY-80 steel.
2. The initiation and propagation of fatigue cracks in welds and joints of HY-80 steel.

3. An evaluation of the fatigue behavior of welded joints in HY-100 steel.
4. An examination of the contribution of sulfide stringers to the hot-cracking in welded HY-80.
5. The effect of variations in welding procedure on the hot-cracking and fatigue behavior of welds in HY-80.


N-A-Xtra Joints (nsc)
J. E. STALLMEYER,* W. H. MUNSE,* W. M. DERBY, K. A. SELBY

This is a critical study of the effect of parameters introduced by the welding process on the fatigue behavior of butt-welded joints. These parameters include the weld toe geometry, residual stresses, and metallurgical structure in the heat-affected zone. Mechanical treatment in the nature of compressive deformation at the toe of the weld was used to alter the residual stress field as well as the geometry in this region. Machining was used to change the geometry only. Other treatments or changes in welding procedure have been used to provide a variety of different effects for study.

Experimental studies of the stress concentration effect using photostress techniques have been included. Analytical studies of the stress-concentration effect and the effect of weld geometry have also been carried out.

Fatigue of Stud Welds (gi)
J. E. STALLMEYER,* W. H. MUNSE*

Information on fatigue behavior of flat plate and beam specimens provided with stud shear connectors and subjected to different stress cycles and different loading conditions has been analyzed. All of the data have been compiled and presented in a paper at the 43rd Annual Meeting of the Highway Research Board.

No further work is anticipated, and with the publication of the paper by the Highway Research Board the project will be completed.


Flexural Fatigue Strength of Welded Beams and Girders (bpr)
J. E. STALLMEYER,* L. R. HALL, J. MATT, D. R. SHERMAN

Primary emphasis during the past year has been on the behavior of all welded beams with extremely thin webs. Pure moment, pure shear, and combined shear and moment have been used as variables in loading conditions. Physical parameters of the flange and stiffeners have been used as the primary variable for beams subjected to loading con-
ditions in which the critical buckling load for the panels under study has been exceeded during the maximum loading of the fatigue cycle.

A more thorough study of the influence of details and geometrical conditions at the ends of cover plates has been undertaken. A part of this study was carried out during the past year, and this year the program has been extended to include additional fatigue tests as well as studies of the stress concentration effects. This latter study will include phototrace tests to evaluate the effect of details.


Fatigue Data Summary (wrc; ui)
W. H. MUNSE*  
This study was initiated to assemble and analyze the available data on the fatigue strength of welded structural members and connections. In addition to the tabulation and analysis of laboratory data, a general discussion of structural fatigue and the factors which affect fatigue has been included and is now ready for publication by the Welding Research Council.

Fatigue Strength of Alloy Steels (wrc)
J. E. STALLMEYER,* W. H. MUNSE*  
This is a continuing program on which all of the experimental work has been completed. However, the continuing effort has been directed toward an evaluation of the fatigue properties of the alloys and their combinations and the development of guidelines for their use and application. It is expected that the continuation of this part of the work will be supported by the University of Illinois.

Welding Procedures (wrc; byd)
W. J. HALL,* W. H. MUNSE,* A. R. CHAMBERLAIN  
The notch toughness performance of carbon steel welds at various temperatures is being assessed by means of a series of tension tests of notched and welded wide-plate specimens. The effects of various welding procedures in minimizing the likelihood of brittle fracture at low ambient temperatures and nominal loads being evaluated. The studies have involved measurements of strength and ductility for as-welded, preheated, postheated, and mechanically stress-relieved specimens of various thicknesses.

Along with the large-scale plate tests, a program of fundamental studies, involving material properties, residual stress systems, and fracture mechanics approaches, has been undertaken to aid in the evaluation of the results.


Fracture Concepts (bs)
W. J. HALL,* R. N. WRIGHT,* G. R. ERHARD, S. W. TERRY, M. W. C. EMERSON, W. J. NORDELL  
Available information on the fracture behavior of mild steel is being evaluated to provide additional guides for the evaluation of the fracture toughness of fabricated structures. Selected parameters that have received study include the rate-temperature dependence of the yield point, notch acuity, residual stresses, effects of preheat, postheat, and mechanical stress relief, toughness as measured by fracture mechanics approaches, and rate effects associated with fracture propagation in wide plates. A limited experimental study was made of rate-temperature effects of metal adjacent to welds.

Behavior of Light-Weight Metals (ndea; ui)
W. H. MUNSE,* J. RADZIMINSKI  
Current work is concerned with the evaluation of the low-cycle, high-stress fatigue behavior of high-strength steels and titanium and the development of a theoretical relationship between the total strain conditions and the fatigue life of the material. Lives in the range of 1 cycle to 10,000 cycles are being considered.

Riveted and Bolted Structural Joints (idh; bpr; rcbjs)
The investigation is concerned with the behavior of riveted and bolted structural joints subjected to static and fatigue loads. A number of individual studies have been initiated, and these currently under way and the major results of some of these studies are as follows:

(1) A study of the effect of bearing pressure on fatigue strengths of riveted joints has led to recommendations for changes in design specifications for joints subject to repeated loads. (Project No. 1)

(2) The results of extensive tests on the effects of tensile pattern on the strength of structural connections are being summarized in a comprehensive report and have led to specification changes. (Project No. 2)

(3) An investigation of the behavior of several grades of bolts subjected to different combinations of tension and shear has been completed and a manuscript has been prepared for publication. (Project No. 3)

(4) Moment-rotation characteristics for flexible connections have been studied and an analysis has been developed by which the behavior of any such connection can be predicted. (Project No. 5)

(5) The analysis of data from a field study of a bolted railway bridge has been completed. The study shows that no joint slip has occurred during several years of service. (Project No. 6)

(6) As a result of a study on the calibration of ASTM A490 bolts, the use of A490 bolts is now permitted by the specifications of the Research Council on Riveted and Bolted Structural Joints. (Project No. 10)

(7) An investigation has been started on the elastic behavior and design of gusset plates. (Project No. 16)
Behavior of Welded Highway Structures
(idh; bpr)
W. H. MUNSE,* W. W. SANDERS, Jr.,* A. T. DERECHO,
R. HIGASHINNA, H. E. RUTENSCHROER

The study of welding and welded highway structures is to open more economical ways of construction for highway structures and more efficient methods of welding. The investigation consists of the following three topics:

(1) Welding of steel reinforcement for reinforced concrete; concerned primarily with the determination of the fatigue behavior of reinforced concrete beams with welded reinforcement.

(2) Effect of geometrical conditions on the fatigue behavior of welded joints; conducted to determine the effect of various geometrical conditions on the fatigue behavior of butt-welded joints in different structural steels.

(3) Inspection methods and quality control for welded highway structures; an extensive review of available inspection methods and their use in related fields (now completed).

A survey of the state highway departments to determine the present inspection practices of these departments for welded highway structures was also completed and a final report has been prepared.


The Chicago Bridge and Iron Assistantship (cbf)
A. R. ROBINSON,* W. H. MUNSE,* D. S. KORISTA

This work has consisted of a study of bending and buckling of longitudinally stiffened tubes. The buckling behavior of longitudinally stiffened straight tubes under end thrust has been investigated both analytically and experimentally.

The results of the analysis and associated experiments will be of aid in improving the understanding of structural action of certain types of penstocks and tanks.

A Programming System for the Analysis and Design of Structures (ons)
S. J. FENVES*

A problem-oriented computer programming language and system for the analysis and design of structures has been further developed. Three basic areas are being investigated: (1) the development of a sufficiently general and flexible control system to permit easy modification of the system capabilities, (2) the development of additional system capabilities for more comprehensive analytical modeling of structural problems, and (3) the study of the use of the system as part of an on-line, man-machine communication system.

Beam Configurations for Improved Lateral Load Distribution (aisi)
R. N. WRIGHT*

The objective of the program is to explore the advantages, in terms of weight, cost, and ultimate strength, of employing closed section members as stringers for bridge decks. Analytical procedures in combination with limitations on deflections and stresses will be used to determine optimum arrangement of stringer and slab. Geometrical and behavioral constraints correspond generally to American Association of State Highway Officials specifications. Optimum proportions are being determined by the method of steepest descent considering both material and fabrication costs.

Optimum Design of Framed Structures (ui)
W. J. HALL,* S. J. FENVES,* J. G. CROSE

An attempt is being made to find optimum design techniques as applied to framed structures. In the normal design process for framed structures, the parameters describing a structural configuration are assigned arbitrary values and, through the repetitive process of proportioning and analysis, a final configuration is selected. The procedures being investigated involve an attempt to design a frame directly with respect to one or more adopted criteria, such as minimum weight, geometry constraints, etc. This area of study has important practical implications and, with the advent of electronic computers, solutions to problems of this type appear to be attainable.

Minimum Weight of Plastically Designed Steel Frames (ui; nsf)
E. H. GAYLORD,* R. H. BIGELOW

This study discusses the application of the simplex method of linear programming to the determination of optimum (minimum) weight of steel frames designed according to plastic theories of behavior. The theoretical optimum solution is based on a best-fit linear relation between unit weight of member and plastic moment capacity for a range of moment capacities compatible with the structure geometry and load pattern. The method takes into account the interaction of axial force and moment in the columns, and the approximate, interim procedure for considering sideways instability proposed in ASCE Manual No. 41 on plastic design. The question of optimization for two or more prescribed systems of load is also considered.

A computer program generates the various combined mechanisms from the input elementary mechanisms. The resulting array of inequalities becomes input for the optimization program. Since the storage capacity of the computer limits the size of the structure which can be investigated if all mechanism inequalities are considered,
procedures based on a reduced array are demonstrated. With this modification, the program can accommodate most building frames for which present practice admits plastic design.


**The Inelastic Stability of Rectangular Steel Frames (ui)**

E. H. GAYLORD,* D. H. SAPP

Although the inelastic behavior of the isolated compression member is well established, the inelastic behavior of frames containing such members is not so well understood. In particular, the load at which the symmetrical deflected configuration of the symmetrical rectangular bent becomes unstable after the structure has become partially inelastic has only recently begun to be investigated. Chwalla (1938) showed that so long as the frame remains elastic, the critical load for lateral (sideways) instability is affected only slightly by the pattern of load on the beam of such a frame. Bleich has observed that this is not likely to hold where the frame remains stable into the inelastic range.

The purpose of this study is to investigate the stability of the (laterally) unbraced rectangular frame composed of 1-sections for a reasonable range of aspect ratio and of the position of a pair of symmetrically placed concentrated loads.


**Strength of Metal Columns Under Biaxial Bending (ui; aid)**

E. H. GAYLORD,* S. S. SHARMA

The purpose of this investigation is to find an improved approximate method of evaluating the ultimate strength of I-shaped steel columns under biaxially eccentric end load. The problem is of practical importance, since columns in building frames are usually loaded in this manner.

The proposed study aims at (1) developing interaction curves, (2) comparing results with existing (approximate) interaction curves, and (3) comparing results with a number of recently published test results.

A strain distribution at midlength will be assumed, taking into account warping strain as well as bending and axial strains. Assuming sinusoidal variation of displacements $u$, $v$, and $h$, the corresponding axial load at specified eccentricities can then be determined. The ultimate load will be determined from the condition $dP/du = dP/dv = dP/dh = 0$. Although the assumed sinusoidal deformation is not exact, the nature of the problem is such that such errors do not affect the results substantially.

**Design of Steel Structures for Minimum Cost of Material and Connections (ui)**

R. N. WRIGHT,* R. A. RITHA

Usual approaches to the optimum design of structures have been concerned with minimizing the weight of material. In this study the feasibility of including connection costs and material costs in the objective function was explored. Connection costs were expressed as a linear function of the moment capacity of the member connected. Using linear programming, it was shown that connection cost could determine the type of framing, simple or rigid, more economical for a particular structure.

**Influence of Superimposed Vibrations on the Flow Stress of Steel (nfs)**

R. N. WRIGHT,* D. L. RICH

The program is a survey of present knowledge of the influence of sonic and ultrasonic vibrations on the flow stress in steel. A limited experimental program is being carried out to identify the significant parameters and throw some light on the mechanism responsible for the reduction in flow stress usually observed.

**Highway Bridge Impact (lclh)**

W. H. WALKER,* C. P. SIERS,* A. S. VELETOS,* R. LUTHE, J. A. NIETO-ARAMIREZ

The effect of the various factors that influence the dynamic response of highway bridges has been under investigation. Information thus obtained may serve as a guide in the selection of appropriate impact factors in highway bridge design. The investigation is primarily analytical. However, small-scale laboratory tests have also been used to check and guide theoretical developments. Work during the past year included:

1. A study of simple-span highway bridges was continued with a view of developing a simplified method for estimating the effects produced by moving vehicles. Results have been summarized in a technical report by Walker and Veletos.

2. A study of the dynamic response of three-span continuous bridges was continued. The results of these and previous studies are summarized in a technical report by Nieto-Ramirez and Veletos.

3. The development of an analysis and computer program for simply supported beams to study the effect of inelastic action on the dynamic response of the bridge was initiated.


Investigation of Prestressed Reinforced Concrete for Highway Bridges (idh; bpr)
C. P. Siess,* M. A. Sozen,* G. F. Anderson, R. J. Lenschow, S. E. Olsen

The objective of this project is to obtain fundamental information for the optimum utilization of prestressed concrete by the structural engineer. Although the investigation is concerned primarily with prestressed concrete for use in highway bridges, the information obtained is applicable to other types of prestressed concrete and also to reinforced concrete construction.

The activities on the program involve analytical studies of the strength and performance characteristics of prestressed concrete beams complemented by comprehensive series of tests. During the past year, the studies included: (1) shear strength of beams with web reinforcement, (2) relaxation characteristics of prestressing reinforcement, (3) short- and long-time effects of transverse reinforcement in the anchorage zones of prestressed concrete beams, and (4) anchorage and flexural bond characteristics of prestressing reinforcement.


Multiple-Panel Reinforced Concrete Floor Slabs (ui)
M. A. Sozen,* C. P. Siess,* W. L. Gamble

This investigation is being conducted to compare, through a coordinated series of tests and related studies, the strength and behavior of various types of reinforced concrete floor slabs for the development of a consistent and economical design procedure. The work plan included tests and analyses of quarter-scale models of 9-panel floor systems, each model measuring 15 feet by 15 feet in plan. The following types of structures were tested: (1) Typical flat plate, (2) typical flat slab, (3) typical two-way slab, (4) two-way slab with beams of low flexural stiffness, and (5) flat slab reinforced with welded wire fabric.

The experimental program is complete. The current phase of the program involves comparisons of the test results with the predictions of various theories applicable to the elastic and inelastic stages of loading.


M. A. Sozen and C. P. Siess, "Investigation of Multiple-Panel Reinforced Concrete Floor Slabs: Design Methods—Their Evaluation and Comparison," Proceedings, Journal of American Concrete Institute, 60 (August, 1963), pp. 999-1028.


Lapped Splices of Reinforcement in Reinforced Concrete Members Subjected to Flexure (ul)

C. P. SIESS,* J. P. COLACO, M. NANES

The investigation is concerned with lapped splices of reinforcement in reinforced concrete members such as the columns in a multi-story building frame. Members containing such splices are being tested under conditions simulating shear loads and shearing forces produced in a column of a frame subjected to large lateral forces from wind or earthquake movements. No axial load is present. Variables include splice length and location and amount and spacing of transverse reinforcement in the form of closed ties.

Analytical Study of Composite Beams with Inelastic Shear Connection (ul)

C. P. SIESS,* P. K. H. DAI

The object is to compute the load-deformation characteristics and ultimate load-carrying capacity of composite steel and concrete beams of the type used in highway bridges, taking into account the inelastic behavior of the shear-connection as well as the materials of the beams.

Use has been made of a digital computer and solutions have been obtained for typical cases with emphasis on predicting the behavior of members which have been tested.


Behavior and Design of Deep Restrained Reinforced Concrete Beams (afswc)

C. P. SIESS,* A. F. DILL

This investigation aimed to determine the influence of end restraint on the strength and behavior of reinforced concrete deep members subjected to slowly applied loads as a basis for the development of minimum design requirements. The end restraint was applied in such a manner as to simulate the restraint that would be developed in continuous beams or frames.

Static tests were made on fifteen beams, five of which were simply supported and ten were restrained.

The investigation was concentrated on the crushing stage as the last stage for which meaningful concrete strains were available. It was shown that deep beams do have a capacity beyond crushing in terms of deflections and, sometimes, of moments. This reserve capacity is not now predictable in the same manner as the procedure developed in the report to predict the capacity at crushing.


Reinforced Concrete Models (ul; nsf)

M. A. SOZEN,* M. XANTHAKIS, W. D. SNIDER

This study utilizes small-scale reinforced concrete models to determine the behavior of complex reinforced concrete structures at all ranges of loading.

One phase involves an exhaustive study of the characteristics of the small-scale concrete used in the investigation. The second and major phase involves testing a 2-panel model of a reinforced concrete flat slab to establish the effect of strain deviations from the distribution of flexural reinforcement based on elastic analysis.


Study of Moments and Joint Forces in Multi-Beam Bridges (ul)

N. KHACHATURIAN,* A. S. ARYA, R. B. POOL

This project was undertaken to study the lateral distribution of concentrated loads on multi-beam highway bridges and to establish a design criterion. The study is developing a method of analysis based upon an idealized structure which closely approximates the actual structure. Included is a study of variation of joint forces and moments for a large variety of sections used in practice.

The first part of the work, completed in May 1961, was primarily a study of variations in moments and development of design rules for many types of cross sections. The second part of the study, completed in August 1963, was concerned with a study of the forces in the joints between the beams.


Analytical Study of the Behavior of Reinforced Concrete Beams Under Combined Shear and Bending Moment (ui)

N. KHACHATURIAN,* N. W. KRAHL

The work is based on a study of stability of crack in reinforced concrete beams. The study is carried out ana-
lytically relating depth of crack to the load acting on a beam, both in the region of pure flexure and in the region of combined stresses. The study helps to understand the behavior of the beam in the region of combined stresses by distinguishing between tension and compression failures. So far the work has been limited to simply supported beams with no web reinforcement.

**Tests and Analysis of Lined Tunnels (dasa)**

J. L. MERRITT,* N. M. NEWMARK,* W. P. DAWKINS, M. A. PLAMONDON

A comprehensive test program is underway to study the behavior of lined tunnels in rock subjected to the effects of very high-intensity stress waves. The program is divided into approximately 30 projects with many laboratories and agencies participating.

As part of this contract, one member of the project staff has been designated technical director of the entire comprehensive test program. During the earlier phases of the program, now under way, studies were being made to aid in making technical decisions and to form a framework for the subsequent analysis. After the test program is completed, the University will correlate and interpret the data obtained preparing a detailed analysis of the behavior of lined tunnels.

**Tunnel Analysis (afswc)**

S. L. PAUL,* A. R. ROBINSON,* M. ALI-AKBARIAN

The purpose of this study is to investigate the interaction of a plane stress wave in an infinite elastic medium with a cylindrical cavity having a thick elastic lining of uniform thickness. The wave is traveling in a direction perpendicular to the axis of the cavity. Stress, velocity, and displacement will be computed at various points within the lining. This information will be plotted with respect to time and to the angle around the opening.


**Design and Fabrication of Dynamic Load Generator (afswc; dasa)**

G. K. SINNAMON,* V. J. MCDONALD, W. P. DAWKINS, J. J. HEALY, J. D. PRENDERGAST

A dynamic soil testing machine is being designed and fabricated which will be capable of loading the top surface of a 4-foot-diameter specimen with transient gas pressure pulses which will approximate the loading from nuclear explosions.

Theoretical studies and experience with available machines were used as the basis for a preliminary design of this machine on a prior contract. A pilot model of part of the machine was then built and tested to confirm the design assumptions. Fabrication of the testing machine started on 1 July 1963 and will be completed on approximately 31 December 1964.

**Foundations Subjected to Dynamic Loading (ndea)**

W. J. HALL,* N. E. FUNSTON

The investigation is concerned with the time-dependent response of foundations on various types and combinations of soil subgrade conditions. Several types of mass spring models are being studied for possible representation of the system. The goal is to arrive at methods for estimating the frequency and amplitude at resonance, as well as the response at other frequencies.

**Hardened Lunar Structures (ui)**

J. P. MURTHA,* N. M. NEWMARK,* S. JOHNSON

This is a study of problems associated with the design and construction of lunar structures with the purpose of developing suitable engineering criteria. During the past year information relative to the lunar environment was compiled and evaluated to identify factors which may influence the structural design of lunar structures. Subsequent investigations considered the effect of lunar gravity forces or structure and foundations, and an excavation by cratering on the lunar surface.

**SOIL MECHANICS, ROCK MECHANICS, AND FOUNDATION ENGINEERING**

Research in these fields includes theoretical and experimental studies of the static and dynamic behavior of soils and soil masses in the laboratory and in the field; studies of the applicability of pedology and airphoto interpretation to engineering problems associated with surficial soils; investigations of engineering geology, properties of weathered and unweathered rock masses, and rock mechanics; and soil-structure interaction problems. The research is coordinated with work in structural and hydraulic engineering in the Department of Civil Engineering and research in the departments of agronomy and geology.

**Engineering Properties of Kaolinite (nsf)**

R. E. OLSON,* M. KIEFER, C. MIRZA

Consolidated-undrained and fully drained triaxial compression tests have been performed on sediments of sodium and calcium kaolinite at various pore water electrolyte concentrations and at various values of pH. Electron microscopic and X-ray diffraction techniques are being used to study the geometric arrangement of particles within the soil.

**Rheological Study of Concentrated Suspensions of Pure Clay Minerals (nsf)**

R. E. OLSON,* R. E. BUCKNAM

The viscous and thixotropic properties of slurries of kaolinite at water contents near the liquid limit are being studied using a specially designed rotating cup viscometer.
in which the pore water pressure in the slurry can be measured. An attempt is being made to apply the principle of effective stress to explain the viscous properties of concentrated suspensions and thus to correlate the results of theoretical studies of suspensions with engineering studies of similar clays at slightly lower water contents.

Illite and Illitic Soils (nsf)

R. E. Olson, J. Hardin

A broad investigation is in progress concerning the influence of physico-chemical variables on the shear strength and consolidation characteristics of the clay mineral illite. The goal is a basic understanding of the nature of cohesion, internal friction, sheeting sensitivity, and compressibility. Consolidated-undrained triaxial compression tests have been performed using both sodium and calcium illite and with various pore water electrolyte concentrations and values of pH. Both one-dimensional and ambient stress consolidation tests are being used to study the consolidation characteristics. The tests have demonstrated that double layer interactions exert an important influence on the properties of illite saturated with monovalent cations, but that they have shown very little influence when the illite is saturated with polyvalent cations. The pH exerts less influence on the properties of illite within the range of water content encountered in engineering work than might be expected from published studies of illite suspensions.


Engineering Properties of Montmorillonite (nsf)

R. E. Olson, L. Campbell, R. Mesri

Severe foundation engineering problems have been encountered with soils containing montmorillonite. Experimental difficulties encountered in performing effective stress studies of montmorillonite are so severe that few useful experimental data are available. Using improved experimental apparatus, consolidated-undrained triaxial tests are being performed on both sodium and calcium montmorillonite at confining pressures up to 120 psi and tests to 1,000 psi are planned. Attempts are being made to develop physico-chemical explanations for the engineering properties of this clay.

Properties of Unsaturated Soils (nsf)

R. E. Olson, L. J. Langfelder

The nature and method of defining effective stress in unsaturated soils is being studied using measurements of both volume change and shear strength. New apparatus is being developed to study soils with large negative pore water pressures. Negative pore water pressures down to -250 psi have been measured. The knowledge gained has been used to develop a theory of soil compaction in terms of effective stress.


Compaction Characteristics of Tropically Weathered Soils (ui)

D. U. Deere, P. Jimenez Quinones

The primary objective of this research was to correlate the laboratory compaction characteristics of some tropically weathered soils from Hawaii, Puerto Rico, and Liberia, West Africa, with the results actually obtained in the field during construction. Variables investigated include clay mineralogy, rainfall, placement moisture contents, and the soil index properties. Statistical methods were used in determining the degree of uniformity of the soils and in correlating the laboratory and field moisture-density relationship. Recommendations were made for a new type of field compaction specification to be applied to tropical soils which occur with natural moisture contents wet of optimum.

This research work is completed.


Effect of Colloidal Organic Material Upon the Engineering Properties of Soil (ui; nsf)

T. K. Liu, T. H. Thornburn, N. O. Schmidt

It is generally believed that a small fraction of colloidal organic material by weight will exert a radical change on the physical and engineering properties of the inorganic soil. Although agricultural research has provided some knowledge of the chemistry of this organic matter, very little is known about its influence on the physical properties of soils. A basic investigation has been initiated to isolate soil organic content as a variable by comparing the engineering properties of two soils that differ only in colloidal organic content. Several possible approaches will be investigated for the creation of soils with identical clay and non-clay mineralogy and adsorbed ions, yet differing in organic content of a given chemical composition. Finally, the soil compressibility and shear strength parameters will be related to the organic content.

Reproducibility of Atterberg Limits (ui)

T. K. Liu, T. H. Thornburn

A statistically controlled experiment was performed to investigate the effects of operator experience on the reproducibility of Atterberg Limits of a sandy silt soil, a silt soil, and a silty clay soil. Using standard procedures and a single piece of equipment the variations were found to be relatively small. Thus, it can be regarded as reproducible from the engineering standpoint. An experienced operator was found to have smaller variations in his results than the inexperienced operator. Generally, the plasticity index values were found to be the most variable and the liquid limit values the least variable, with the plastic limit variations occupying
an intermediate position. The results of the statistical analysis were presented by T. K. Liu at the 43rd Annual Meeting of the Highway Research Board.


Soil Exploration and Mapping (idh; bpr)

T. H. THORNBURN,* T. K. LIU, A. S. FEINBERG

Data on the engineering properties of the soils of Illinois are being collected and correlated with geologic and pedologic map units in order to provide a basis for the prediction of the engineering behavior of soils in any given location. The data are obtained by random sampling of representative soils in selected Illinois counties, and by the summarization of soil boring and test results secured by Illinois Division of Highways personnel.

Detailed studies have been completed on DeWitt, Livingston, and Will counties and final reports are in preparation. Studies of a group of depressional soils in several counties have been completed and publication is in process. A novel feature of these studies is the treatment of the data by statistical methods.

A master's thesis study of airphoto stereograms and mosaics of typical Illinois landforms resulted in the addition of fourteen stereograms representative of soil patterns of Illinois to the series available from the University Committee on Aerial Photography (Nos. 416–429).

Miscellaneous reports are being prepared covering a statistical comparison of clay contents as determined from hydrometer and pipette methods, the relationship between organic matter content and Atterberg Limits, and a comparison of airphoto and field methods of soil mapping.


Railroad Roadbed Stabilization (aar)

R. B. PECK,* D. U. DEERE, J. D. SCOTT

The purpose is to investigate the causes and cures of roadbed instability and to study methods of improving stability of natural and artificial slopes. The principal methods involve field observations and correlations with geological studies. In the current year attention has been concentrated on slides in Pliocene deposits in southwest Iowa. The project is completed.

Use of Admixtures for Chemical (and Physicochemical) Stabilization of Natural Soils for Road Building (idh)

T. H. THORNBURN,* C. H. HURLEY

A preliminary survey of available information is being conducted on chemicals which might economically be used in the field of stabilization of soils for highway purposes. A report was published in Highway Research Notes, No. 3. An annotated bibliography on the use of sodium silicate as a soil stabilizing agent has been prepared and a report on this material is in the final stages of preparation for publication.


Behavior of Soil Deposits as Determined from Case Histories (ui)

R. B. PECK,* M. T. DAVISSON, D. U. DEERE, H. O. IRELAND, Y. LACROIX

The objective of the project is to digest the results of field observations regarding the behavior of various structures established in earth or constructed of earth, and to deduce therefrom information concerning the fundamental physical properties of the earth materials. During the present year attention has been concentrated on the behavior of the grouted cutoff at Mission Dam, on earth pressures against open cuts, on settlements of large structures, and on the stability of slopes.


Geologic Factors in Engineering Projects (ui)


The influence of geologic factors on design and construction of engineering projects is being determined in this research program.

Boring logs, site inspections, test results, and construction experience are being correlated to obtain the necessary information. A doctorate thesis dealing with the suburban Chicago area has been completed. Another thesis is being prepared on the subsurface condition of the Omaha metropolitan area.


The Bearing Capacity and Settlement Characteristics of Footings in Loess (ui)

D. U. DEERE,* J. V. BENAK, S. J. SPIGOLON

The behavior of building foundations (spread footings) when founded on loessial soil is being studied. The settle-
ment characteristics as well as the factor of safety with respect to bearing capacity failures will be correlated with each other and with various sizes of footings. The study is being carried out by testing the failure in field-simulated circular footings ranging in diameter from 5 inches to 5 feet. Variations in the properties of the loess—density, water content, clay content, and depth of weathering—will also be correlated with the field test results and with the shear strength and compressibility as determined in the laboratory.


**Development of Index Properties for Intact Rock (afswc)**

D. U. Deere, R. P. Miller, E. J. Cording

For evaluation of prospective construction sites, a classification system for intact rock specimens, based upon index properties which will correlate with the engineering behavior of the rock, is being developed. The initial effort is directed toward the study of pertinent publications with particular reference to rock classification systems in general: drillability, grinding and crushing characteristics of rock; testing equipment, methods and theory; and the physical and mechanical properties of rock. Laboratory tests are to be performed on NX-core specimens (L/D = 2) for at least 12 rock types, including limestone, sandstone, basalt, dolomite, granite, gneiss, marble, quartzite, rock salt, siltstone, schist, and diabase. Cores are obtained from actual field exploration for engineering projects or from block quarry samples which are cored in the laboratory. Approximately three sources for each of the 12 rock types are being studied. A system of index properties is to be developed from data obtained from the intact core specimens which will be correlate with the more important physical properties of the rock, such as Young's modulus and compressive strength. From the results of this investigation, a simple instrument is to be devised for use in the field in order to evaluate the desired indices at the exploration site.

**Resistance Encountered in the Movement of Rock Masses Along Existing Discontinuities (ui; afswc)**

D. U. Deere, J. H. Withers

The purpose of the investigation is to determine the parameters, and the relationship between them, which play a role in determining the resistance offered to relative movement in rock masses. Both analytic and experimental approaches are used. Application of results to field situations is discussed.


**Stability of Ore-retaining Structures (ui)**

R. B. Peck, D. U. Deere, T. Raamot

The behavior of large natural clay masses under heavy loading is being studied. Ore storage structures in Chicago, Gary, Detroit, Cleveland, Buffalo, and Sparrows Point have been observed and their deformations correlated with the properties of the clay subsoil, the superimposed load, and the type of structure.


**Small Dams Engineering Research (fws)**

Y. Lacroix, D. Casagrande

Much progress has been made during the last ten years in the design and construction of dams; however, attention has been concentrated on large rather than small dams. This situation is partly a consequence of the relatively small sums that can be justified for exploration and research with respect to small structures, whereas the same percentage of expenditure provides ample funds for large projects.

The dams constructed and operated by the Illinois Department of Conservation belong to the category of small earth dams. Because of the great number of existing dams and several in the design stage, large sums have been and are being spent by the Department of Conservation for the design, construction, and maintenance of small dams. Therefore, it seems justified that the Department of Conservation sponsor, through a cooperative agreement with the University of Illinois, a research project on the subject of small dams. The project consists of applying newly available methods toward improvement of the selection procedures, the construction practices, and the performance of small dams.

The objective of the project is the assembling and evaluation of the significant data concerning design, construction, and performance of a selected number of dams under the jurisdiction of the Department of Conservation, State of Illinois.

**Buckling and Lateral Stability of Piles (ui)**

M. T. Davison, K. E. Robinson

A method of predicting buckling loads and lateral resistance of partially embedded piles has been determined for any variation soil support. The study is being extended to include the effects of nonuniform pile properties. Field load-deflection tests, soil tests, and theoretical analyses are being used to determine the pertinent soil properties and the behavior of the soil-pile system.


**Behavior of Soil and Rock Subjected to High Stress Levels (at)**

H. Kane, E. W. Brooker, B. Mohraz, G. Sakamoto

This project is a continuation of an earlier study of the behavior of soil and rock subjected to high stress levels under a condition of one-dimensional strain. The influence
of stress history on the coefficient of earth pressure at rest and the secondary structure of remolded cohesive soils has been studied experimentally in a specially developed one-dimensional compression test cell. In addition, the influence of small lateral strains on the coefficient of earth pressure is being investigated for two of the sands used in the earlier studies.

The results of these studies will provide information on the fundamental properties of soils under high pressures which are required for the solution of problems involving soil-structure interaction and soil arching.


Measurement of Pore Pressure in Soils Under Dynamic Loading (ui)
D. U. DEERE,* J. D. PETERS

The purpose of this research (now completed) was to develop a small pore pressure gauge capable of measuring pore water pressures in saturated clay soils loaded with short rise-time dynamic loads. The gauge as finally developed is 1/2 inch by 1/2 inch by 1 inch in size and uses as the sensing element a semiconductor strain gauge cut from a quartz crystal. The principle of this gauge is the ability to measure one component of the volumetric strain of a small deformable aluminum element. Pore water pressures can be measured under static conditions and under dynamic loads with rise-time as small as 0.001 millisecond.


Dynamic Soil-Structure Interaction Characteristics (afswc)
H. KANE,* M. T. DAVISSON, V. J. MACDONALD, R. E. OLSON, G. K. SINGNAMON, D. J. LEARY, J. L. SMITH

The behavior of soil under dynamic loading is an important factor in the soil-structure interaction problem. To study this behavior, special testing devices were developed and a series of dynamic, high-pressure triaxial and one-dimensional compression tests were conducted. The test results were evaluated to determine the influence of the rate of loading and pressure level on compressive strength, ratio of lateral to axial pressures, stress-strain relations, residual strains, and creep under constant load.


HIGHWAY AND TRAFFIC ENGINEERING

Highway engineering and traffic engineering research programs have been sponsored since 1951 by the Illinois Cooperative Highway Research Program, formed by contractual agreement between the Illinois Division of Highways and the University. The Bureau of Public Roads of the U.S. Department of Commerce contributes indirectly to the programs with federal grants-in-aid.

Cooperative program projects in highway and traffic engineering include management, materials and pavements, design, planning, and traffic regulation. Other highway studies are made in such civil engineering research sections as structures and structural mechanics, soil mechanics and foundations, and hydraulic engineering. Although much of the work under the program is in civil engineering, other University departments are participating.

The American Association of State Highway Officials established in 1962 the National Cooperative Highway Research Program to be administered by the Highway Research Board. The Program is to encourage an extended and coordinated highway research program at the national level. The University of Illinois has been awarded two contracts under this Program which were started in 1963.

The extensive national program of highway improvements now underway and the increasing volume of traffic on all parts of the highway system are stimulating demands for more research in every aspect of highway and traffic engineering. Additional projects in the highway and traffic engineering programs are sponsored by other public agencies and by private firms.

Highway Problems (idh; bpr)
E. DANNER*

This is a general type project set up to provide over-all program supervision for highway research and facilities for exploratory studies of miscellaneous highway technical and administrative problems and to conduct studies which are not extensive enough to justify separate projects.

As new projects are developed they may be separated from "Highway Problems" and established as independent investigations.

Highway Problems — Highway Research Program Supervision (idh; bpr)
E. DANNER*

Twenty-two projects were active in the Illinois Cooperative Highway Research Program between July 1, 1963, and June 30, 1964. In accordance with the Basic Agreement between the University of Illinois and the Illinois Division of Highways establishing the Illinois Cooperative Highway Research Program, the University is responsible for the general administration, supervision, and direction of the program. This includes coordination of the work of the project supervisors and project investigators and the handling of all contracts between the University and the Division of Highways.
Highway Problems — Highway Personnel Management (ich)
E. DANNER*

The objective is the development of effective personnel management policies, procedures, and practices for the Division of Highways to assure high morale, a capable engineering staff, efficient performance, and high professional standards.

The objective is being accomplished through a Personnel Advisory Committee of the Division of Highways appointed by the Chief Highway Engineer and a Committee of the Highway Research Board on Education and Training of Highway Engineering Personnel (Ellis Danner, chairman of both). Specific studies are made as problems arise to improve personnel management.

A study of the correlation of aptitude scores, grades in training programs, and performance ratings on the job for engineering technician trainees was initiated to aid future programs in the selection of trainees and in deciding whether trainees doing poor work in the program should be retained.

Studies are continuing as new questions arise.

Lime-Pozzolan Mixtures (various sponsors)
E. J. BARENBERG*

The purpose of the work was to evaluate lime-pozzolan mixtures as paving materials. More specifically, the objective of the program was to develop structural design procedures for pozzolanic pavements and to collect data on the comparative performance of lime-pozzolan aggregate mixtures and crushed stone under repeated wheell loads.

The laboratory work for this project has been completed and a final report written. The report includes a complete discussion of lime-pozzolan mixtures, its reaction mechanism, the factors influencing the physical properties of the mixture, and test procedures for evaluating the material. Results from the test program on the behavior of lime-pozzolan mixtures under static and repeated loads and comparative results from tests on crushed stone and pozzolanic bases are presented. The design of pozzolanic pavements is discussed and design procedures for pozzolanic base pavements recommended.

Development of Appropriate Methods for Evaluating the Effectiveness of Stabilizing Agents (nas)
E. J. BARENBERG,* A. ALBERGA, R. A. BEAZLEY, V. YACKOVLEV

Work is being carried out on both viscous (asphalt) and nonviscous (cement, lime) stabilizing agents. It is divided into a laboratory phase and a pavement-testing and evaluation phase. The laboratory work is directed toward the measurement of significant engineering properties of the stabilized materials. In the pavement-testing phase, pavements are being evaluated under both static and dynamic wheel loads using the University of Illinois pavement test track.
The durability of the materials is being evaluated in the laboratory by the standard durability tests, and by measuring changes in the engineering properties of the material after a number of freeze-thaw and wetting and drying cycles.

Correlation of the U of I Pavement Test Track with the AASHO Road Test (idh)
E. J. BARENBERG*

Detailed studies of the parameters to be considered in the correlation studies between U of I pavement test track and the American Association of State Highway Officials (AASHO) Road Test are being carried out. A careful analysis of the parameters which influenced the performance of the test pavements in the AASHO Road Test are being made so that the effect of any variation in these properties between the test road and test track can be anticipated. Model studies are being made to establish the appropriate relationship between the test track model and the AASHO Road Test prototype. In addition to the comparison and correlation of the test track and AASHO Test Road, fundamental studies of pavement behavior are being carried out to fulfill the secondary objective of this research program. The performance, behavior, modes of failure, and causes of failure of the test pavements under static and moving loads are being made.

Basic Properties of Seal Coats and Surface Treatments (idh)
M. HERRIN,* C. R. MAREK, J. L. SANER

This investigation is primarily concerned with the influence of consistency, type, and thickness of bituminous film on the performance of seal coats and surface treatments. Essentially the research was divided into two phases. One phase was related to the factors influencing the design and selection of materials for surface treatments. Since the amount of asphalt needed is primarily determined by the volume of voids between the aggregates, a comprehensive investigation was conducted to determine the relationship between the voids and such aggregate characteristics as shape, size, gradation, etc. In addition, a related study was begun to provide means of determining the appropriate type and grade of bituminous materials to be used for surface treatments.

The other major division of the research dealt with the viscoelastic properties and failure mechanisms of the bituminous binder. The behavior of the binder in tension and shear was studied especially as influenced by consistency and temperature. A special emphasis was placed on determining the applicability of the absolute rate theory for explaining the behavior of this type of material. This theory appears to have great promise and could be of great value to the engineer.


Lime Stabilization of Soils for Highway Purposes (idh)
M. R. THOMPSON,* R. WHITNEY

The problem of whether lime can be effectively and economically used in highway pavement construction in Illinois was investigated.

A large number of representative Illinois soils were sampled throughout the state and their reactions with various types and amounts of lime determined. The results indicate that lime-reactivity is greatly influenced by such natural soil properties as pH, Ca-Mg ratio, exchangeable sodium, natural soil drainage, organic matter, and soil horizon.

Studies of the fundamental engineering properties of lime-soil mixtures show that the tensile strength, shear strength, and durability characteristics of many soils are substantially improved by lime treatment. Additional studies are now being conducted to evaluate the durability and fatigue behavior of lime-soil mixtures.


Soil-Aggregate Mixtures for Highway Pavement (idh; bpr)
W. G. WESTALL*

This investigation aims to determine the variables of influence and their effect on the service behavior of soil-aggregate mixtures for use in highway pavements. In pursuit of this objective both field and laboratory studies have been performed.

The major portion of the work undertaken during the past year has been in conjunction with the investigation of the in-place shear strength of soil-aggregate surface courses by means of the Burgrass shear apparatus. The objective of this study is to provide data necessary for establishing usable relationships between the in-place strength of soil-aggregate mixtures and the properties of the materials.

The findings of that phase which is concerned with establishing relationships between the results of laboratory and field strength tests have been summarized in a report which was presented at the 43rd Annual Meeting of the Highway Research Board. The laboratory and field tests are completed.


Widths and Cross Sections for Medians of Divided Highways (idh; bpr)
J. W. HUTCHINSON,* T. W. KENNEDY, L. T. CERNY

The general objective of this study is to determine the desirable widths and cross sections of highway medians in
relation to safety, service to traffic, and economy. The investigation includes field studies of the service behavior of existing facilities, accident analyses, and experimental installations.

Current work includes an analysis of data concerning the frequency, nature, and causes of vehicle encroachments on the medians of Federal Aid Interstate routes 57 and 74 in Illinois for evaluation of median performance.


Tolerable Levels of Headlight Glare as Related to Median Performance (idh; bpr)

J. W. HUTCHINSON,* R. A. LONGFIELD, J. S. MCINTYRE

The objective of this study is to determine the levels of headlight glare that are acceptable in connection with the driving conditions (or tasks) encountered on modern divided highways. This work includes the preparation of an annotated bibliography of pertinent literature and a report on the current status of knowledge concerning levels of headlight glare that are tolerable in the functioning of the driver-vehicle-highway complex. Previous research related to this area of study will be identified, summarized, and interpreted for the purpose of developing an analysis of the factors (engineering, physiological, psychological, etc.) involved. Laboratory and/or field tests to verify or adapt existing information and obtain the additional information needed for accomplishment of the objective will also be included.

Vehicular Speed Regulation (idh; bpr)

J. E. BAERWALD,* W. T. GRUEN, G. BEZKOROVAINY, J. C. GLENNON, C. C. KU, L. WEBSTER

This investigation aims to determine the factors involved in regulating vehicular speeds, to evaluate these factors, to establish warrants for the regulation of speeds, to develop procedures for the application of these warrants, and to develop methods and devices for obtaining maximum compliance with the speed regulations. Field and laboratory investigations are conducted by members of the project staff and by employees of the Illinois Division of Highways.

During the past year work has been conducted on the following items: (1) a determination of drivers' attitudes toward, and compliance with, posted advisory speed limits on horizontal curves; (2) an investigation into various statistical procedures in order to determine the most reliable method to utilize in developing equations to predict mean spot speed; (3) an analysis of current procedures used in determining area-wide and speed zone limits; and (4) an investigation to determine drivers' attitudes on speed and speed limits (through the use of roadside driver interviews) in an attempt to gain insight into factors causing drivers to choose certain rates of travel.


GENERAL TRANSPORTATION AND RAILWAY ENGINEERING

Research in General Transportation and Railway Engineering utilizes a systems approach to study operational and engineering problems. With the aid of computers, the mechanisms and dynamics of railway structures and equipment are analyzed.

Optimization of Transportation Systems (ui)

W. W. HAY,* R. W. DRUCKER

This is a systems investigation into the various modes of transportation to determine the optimum techno-economic conditions for each mode as well as a comparison of the advantages peculiar to each facility.

Initially, research was begun into the payload-deadhead ratios of various capacity railroad freight cars. Using this criterion, the tractive effort per ton of payload and per ton of empty car weight, number of cars required for a given tonnage, and the parameters which affected these relationships, mainly speed and gradient, were studied and their effects determined for each type of car. Also, the rail stress caused by empty weight for various payload-deadhead ratios has been determined. In addition, a mathematical relationship has been derived for determining the payload-deadhead ratio of a car that will make that car equivalent in these respects to any other given car. This relationship has been programmed for use on the Civil Engineering Systems Laboratory IBM 1620 computer.

Similar research has begun into the payload-deadhead ratio of highway trailers, and the required thickness of pavement per ton of payload has been developed along with the required thickness of pavement required to support the empty weight of the trailer. Work is now continuing to the point where tractive effort per ton of dead load and per ton of payload and number of vehicles required to move a given tonnage under various payload-deadhead ratios may be determined.

Research in the railroad field is being expanded to the point where the determination of an optimum length of train for given motive power conditions will be mathematically determined. Future studies will be made to determine the cost factors of manpower, fuel, rolling stock, etc., in order to optimize operations.

B. E. S. Imai, "Behavior of Continuous Beams on Elastic Foundations Under Different Conditions of Loading," Ph.D.
HYDRAULICS, FLUID MECHANICS, HYDROLOGY, AND WATER RESOURCES

Research programs in hydraulics, fluid mechanics, hydrology, and water resources are concerned with both basic and applied problems in four major areas, namely: hydrology, water resources, hydromechanics, and hydraulic structures.

In hydrologic research, major theoretical studies are being developed for unit hydrograph theories and stochastic hydrology. Analytical studies, supplemented with field data, are being carried out for storm runoff from small watersheds, and for the determination of rainfall and runoff relationships for the design of water resources projects. Experimental studies are being conducted on watershed models and overland flow.

In the area of water resources, basic studies are being made on the use of mathematical models and operations research techniques in the planning and design of water resources systems.

In hydraulic research, major theoretical studies are being developed for the stochastic, hydrodynamic analysis of ocean waves on moored structures and of flow in water distribution systems.

Experimental research on hydraulic structures is carried out in the Hydraulic Research Laboratory, including model studies of sluice gates, culvert outlets, and wave forces on breakwaters; and study of tractive force in sewers and drains.

Basic Investigation on Watershed Hydraulics (nsf)

V. T. CHOW,* T. E. HARBAUGH, D. B. WARNER

This research is to investigate the basic laws governing the flow of surface water over drainage basins by controlled experiments on geometric basins. By controlling the various factors involved in the mechanics of flow, the experimental data so obtained can be more amenable to theoretical analyses for the determination of the basic laws. In addition to the shape of the geometric basin, other characteristics including slope, size, surface roughness, channel storage, channel density, etc., will be studied. The input rainfall excess is to be simulated by electronically controlled sprinkling systems composed of a large number of modules so that different patterns of rainfall supply and even the effect of the movement of rain-making clouds can be produced artificially. The output discharge from the basin is to be measured by electronic sensing devices which can automatically be digitized for the computer to construct the hydrographs of outflow.

During the year, effort has been made to design the rainfall simulator system which is composed of 100 modules. Each module is a box of 4 feet by 4 feet in size with numerous holes on the bottom. By controlling the discharge into the box, artificial raindrops are produced. The whole system is supported by a metal frame covering an area of 40 feet by 40 feet in size.

Stochastic Analysis of Rainfall—Runoff Relationship (ui)

V. T. CHOW,* R. RAMASESHAN

Under consideration are the inflow into a basin as a stochastic input, the basin as a linear system, and the outflow as the response of the basin to the input. The stochastic behavior of the system by sequential generation and simulation techniques is being investigated. The 28-year records of annual storm and flood flow from the French Broad River at Bent Creek, North Carolina, covering a drainage area of 676 square miles are mainly used in the analysis. First, statistical Markov models using shifting technique for the precipitation process in the annual storms are formulated and tested, and their parameters are evaluated. Using Monte Carlo method, 1,000 years of sequentially generated storms are produced. The effective storm rainfalls are routed through a conceptual mathematical model consisting of a series of linear reservoirs. By considering the rainfall abstractions to consist of a deterministic component and a random component, a good agreement is obtained between the historical flood frequencies and the sequentially generated flood frequencies. Finally, stochastic flood duration curves are developed and recommended for water resources design purposes.


Systems Analysis of Rainfall—Runoff Relationship (ui)

V. T. CHOW,* V. C. KULANDAI SWAMY

In this study the drainage basin is taken as a lumped hydrologic system. Assuming a general nonlinear equation for the basin storage and combining it with the equation of continuity, a differential equation for the system is formulated. The equation is quasi-linearized by assuming that the coefficients are functions of the average inflow and outflow of the system. Solution of the resulting equation produces four possible conceptual system models depending on the nature of the roots of the equations. Storms and the corresponding outflow hydrographs over six natural drainage basins varying from 7.16 to 1,141 square miles are analyzed by the proposed equation and theory. From the results of the analysis it is seen that three coefficients of the proposed equation vary with the outflow, thus indicating nonlinearity, while the remaining two coefficients do not change much and can be assumed constant. A study of the variation of the three coefficients seems to indicate that they decrease exponentially with the peak runoff. The storage equation derived in this study is shown for use in flood routing and it is proposed also for use in infiltration analysis.
Study of Nonlinearity of Hydrograph Theory by Laplace Transformation (ui)

V. T. CHOW,* M. H. DISKIN

The nonlinearity of the hydrograph theory is investigated by studying the properties of the kernel function in the Duhamel convolution integral via the properties of its Laplace transform. The Laplace transform of the kernel function is the transfer function of the drainage basin system. To facilitate the comparison of transfer functions and to accentuate the differences between transfer functions obtained from various storms and basins, a special form of transfer function is developed, which is dimensionless and eliminates the location of the centroid of the kernel function. By means of this complex mathematical transformation, various conceptual models for rainfall and runoff process in drainage basins can be easily compared, and the nonlinearity of the actual basin process can be evaluated.

The method developed from the proposed theory is tested with 31 storm records of rainfall and runoff for 14 drainage basins with areas ranging from 30 to 1,420 square miles. The result indicates that the instantaneous unit hydrograph varies systematically but nonlinearly with the storms, but there is also a random component superimposing on the process.


Hydrologic Study of Radiotelescope Site (ui)

V. T. CHOW,* J. P. MURTHA

The hydrologic characteristics of a small drainage basin at the University's radio telescope site near Danville, Illinois, are being studied. The radio telescope project is developed by the Department of Astronomy and the Department of Electrical Engineering and sponsored by the Office of Naval Research and the National Science Foundation. The reflector of the telescope forms a parabolic cylindrical surface, 600 feet long and 400 feet wide, on the stream bottom at the downstream side of the basin under consideration. A study has been made on the rainfall and flood problems on the upstream basin of about 173 acres in size, and an automatic rain gauge was installed for rainfall measurement. A hydrologic analysis has also been made to check the design of three dams that were built on the basin for flood control. At present, rainfall observation is continued to produce data for future analysis.

Water Resources System Analysis (ui)

V. T. CHOW*

This study uses the operations research techniques to optimize water resources system for the planning and development of water projects by utilizing mathematical models and simulation. Optimization is made by deterministic and stochastic linear programming and dynamic programming, considering various types of constraints including economic efficiency and budget limitations. For mathematical simulation, both random sampling and systematic sampling are considered, and additional hydrologic data are generated sequentially by means of Monte Carlo methods and Markov chain models. Study of the reservoir design is also made by using queing theory through the use of the sequentially generated stochastic input flow information.

Criteria for Analysis of Water Distribution Systems (nfh)

M. B. McPHERSON,* R. PRASAD, R. A. WISEMAN

Exploitation of previously developed generalized relations describing network head losses in a concise analytical form makes possible comprehensive system analyses, balancing pump–network–storage characteristics for optimization of a composite system design.

The feasibility and comparative cost of various operating options have been determined. Using a computer, system parameter combinations for given demand schedules have been studied, and results have been succinctly defined in simple representations. Simple analogous demand schedules, such as sine distributions, are being studied so that results can be completely generalized.

More complex hydraulic cases will also be investigated. Mathematical proofs and practical limitations of basic network and system parameters are being developed. Using statistical techniques, the possibility of simulating future demand schedules for general use in analysis, design, and operation will be studied.


Overland Flow Relationships for Non-Uniform Rainfall Excess (ui)

M. B. McPHERSON,* D. B. WARNER

The dimensionless overland flow hydrograph given by Izzard, including recession characteristics, has been investigated for uniform rainfall excess intensities. The suitability of Izzard’s procedures for estimating hydrographs for non-uniform intensities has been studied, as well as other numerical procedures. Data were obtained from laboratory measurements, using both a smooth and uniformly rough surface.


Scour Protection for Culvert Outlets (nsf; ui)

M. B. McPHERSON,* D. D. MEREDITH

Analysis of all classes of energy dissipators which may be suitable for culverts, and development of new devices for optimum over-all hydraulic performance are the ultimate goals of this study.

An analysis and experimental investigation of the U.S. Bureau of Reclamation Basin VI energy dissipator used in
conjunction with a box culvert has been completed. Criteria for classification and evaluation of energy dissipators for culverts have been established.


Variation of Tractive Force in Sewers and Drains (ui)

V. T. CHOW,* J. A. REPLOGLE

Tractive-force distributions over the wetted perimeter of an open channel was investigated both analytically and experimentally.

The solution of the problem is based on the assumption that a turbulent flow in the channel has a uniform velocity distribution modified by boundary effects and turbulent mixing. The boundary effects are further considered to consist of two additive components, namely, viscous effects and the secondary effects caused by the restraint of the turbulent fluctuations at the walls and the surface. The velocity of flow normal to the channel cross section is therefore expressed as the weighted sum of two functions of the Poisson equation type. The relative influence of the two functions on the total flow is defined experimentally for the relationship of the weighted coefficient to channel geometry and roughness.

The experimental determination of the coefficient is accomplished by using a smooth copper pipe and a rough steel pipe. The tractive force distribution is determined by a “law-of-the-wall” method and with the Preston technique using Pilot tubes calibrated in place. The equations are solved by the finite-differences method using the digital computer to evaluate the weight coefficient in the Poisson equations for both smooth and rough pipes.

The relations developed from this investigation compare favorably with some published velocity distributions including those obtained by Bazin.


Stochastic Hydrodynamic Analysis of Ocean Wave Actions on Moored Platform for Underwater Missile Launching (necel)

V. T. CHOW,* B. J. MUGA

The motions and forces induced by irregular waves on a construction type platform as moored in the open Pacific Ocean are to be analyzed. Prototype and model tests are conducted on the platform, named “Fishhook,” which is of the catamaran design, having a displacement of 850 tons. It is spread-moored by four 2½-inch stud link chains in 165 feet of water. Water level fluctuations, ship rotations and accelerations, mooring forces, and wind speed and directions are measured. Both prototype and model tests

Research assistant T. E. Harbaugh is conducting an experiment for studying the phenomena of watershed hydraulics dealing with overland and channel flow by using an artificial rainfall producer. (For description of project, see page 61.)

Studies of wave force action on structures are being conducted by use of a small wave-making machine. In an adjoining laboratory a large wave-making machine is under construction for use by graduate and research personnel.
data are analyzed in the form of amplitude response operations by the spectrum and cross-correlation analyses of the complex time series histories. The results are compared with the linear theory of ship’s motion. Equations of motion of the system for sinusoidal waves are formulated on the basis of the slender body theory for 6 degrees of freedom, taking into account both hydrostatic and hydrodynamic effects. The excitation functions and the various coefficients in the equations are obtained for sarges, sewages, pitches, swells, rolls, and yaws. Solutions are also given to the forces in the mooring cables and the horizontal force components and the yawing moment induced by the mooring system on the platform.

**Wave Forces on Breakwaters (ui)**

V. T. CHOW, J. P. MURTHA, W. J. GARCIA

Investigated were various aspects of wave forces on breakwaters concerning both the clapots and breaking waves impinging on vertical wall, sloping wall, and composite breakwaters. During the year five different wave conditions were investigated. The wave characteristics and pressure distribution on the face of the model wall for each of the wave conditions were measured. With the cooperation of the U.S. Army Engineers, the experimental work is being conducted at the U.S. Army Waterways Experiment Station.

**Water Wave—Structure Interaction (ui)**

J. P. MURTHA, C. C. PETRAUSKAS

The purpose of this investigation is to study the time variation of forces produced by gravity waves on coastal and offshore structures and to evaluate the subsequent structural motion. The effort involves laboratory studies of wave-structure interaction as well as analytical investigations. During the past year, laboratory equipment for small-scale investigations has been constructed, and experimental data relating to type of disturbance and subsequent wave characteristics have been obtained.

**PHOTOGRAVIMETRY AND GEODETIC ENGINEERING**

Research in photogrammetry at the University of Illinois was initiated in 1958 and has been sponsored by the University Research Board and the National Science Foundation. The various programs in this area are concerned with basic and applied problems in several facets of photogrammetry. Special emphasis is given to: error propagation, spatial aerotriangulation, analytical photogrammetry, close-range photogrammetry, and microphotogrammetry. Based on theoretical studies about the character of errors in spatial aerotriangulation, definite design criteria for the various parameters in aerotriangulation projects are being developed.

The Department of Civil Engineering also has been active in experimental photogrammetric research. A major portion of this research has been conducted as integral parts of international experimental research programs organized by the International Society of Photogrammetry (ISP) and the European Organization for Experimental Research in Photogrammetry (OEPEE). In much of the experimental work, the University has used the facilities of other institutions and agencies. The research laboratories of The Ohio State University; Cornell University; Geodesy, Intelligence and Mapping Research and Development Agency (G.I.M.R.A.D.A.) of the U.S. Army Corps of Engineers, and the National Research Council of Canada have been available to our staff.

The research capabilities of our photogrammetric laboratory will be materially enhanced in the immediate future by the installation of a Wild STK-1 Precision Stereocomparator.

**Studies in Spatial Aerotriangulation (nsf)**

H. M. KARARA, G. GRACIE, R. K. BREWER, A. A. ELASSAL

The main objective of this project is to attain a better understanding about the character of errors in spatial aerotriangulation in both its analytical and practical approaches. The following four basic studies are under way: (1) design criteria for aerotriangulation projects, (2) fundamental characteristics of random errors in spatial aerotriangulation, (3) a solution to the general case of relative orientation in analytical photogrammetry, (4) adjustment of photographic strips in analog aerotriangulation. Based on these studies, definite design criteria for the various parameters of aerotriangulation projects are being developed, thus eliminating the necessity of heavily relying on luck and/or long experience in designing such projects.

A major portion of the experimental phases of this project was conducted as an integral part of a world-wide experimental research program organized by the International Society of Photogrammetry (Commission III). The main goal of the international experimental research program is to give the practitioner a definite idea about the capabilities and limitations of spatial aerotriangulation.


Studies in Close-Range Photogrammetry (ui)
H. M. KARARA,* J. B. VOORHEES

This project entails a study of the fundamentals and a survey of the status of close-range photogrammetry as applied to the different fields of engineering and science. Special emphasis was placed on establishing design criteria for precise close-range photogrammetric systems. Experimental work was undertaken in connection with the measurements of cracks in concrete beams. The study reaffirmed the potentiality of photogrammetry as a method for indirect accurate measurements.

Errors Research in Geodetic Direction Determination (ui)
W. H. ELDRIDGE*

This study involves the characteristics and propagation of errors associated with celestial azimuth observations, both in classical procedures and in those less conventional. From the investigations already conducted, analysis has been made and correlation tests have begun.

The purpose of this study is to learn what errors are the most significant under the various combinations of conditions, how these errors propagate, and what possible correlations exist between them and the variables.

Much of the study has been founded upon library research and mathematical investigation, although a large number of field observations have been made under controlled conditions.

Already, the results of this research have led to new methods of meridian determinations that are more efficient and produce higher accuracies.

Sanitary Engineering

Since sanitary engineering problems can best be approached through better knowledge of the basic principles associated with the processes used in the field, emphasis is placed on research of a basic nature. Present fundamental research includes investigations of water purification, treatment of sewage and industrial wastes, and other studies covering the use of hydraulic, chemical, biological, and radioactive tracer principles and techniques.

Most research is conducted in the Sanitary Engineering Laboratory. A wide variety of precision instruments is available for the physical, biological, radiological, chemical, and biochemical investigations of water, sewage and industrial wastes. Facilities are also available for pilot plant studies on sanitary engineering processes of water and waste treatment.

Fundamental Factors in Treatment of Iron-bearing Waters (wspc)
R. S. ENGELBRECHT,* G. E. MARGRAVE, J. T. O'CONNOR, M. M. GHOSH, S. R. GOSWAMI

The factors which contribute to the widely observed difficulties in iron removal from ground waters have been

A stereogram contains two photographs of the same area, but taken from two different locations in space. The white vertical line at B-3 is the division between the two photographs. As part of a research project on engineering properties of soils, stereograms were developed, and their patterns are examined stereoscopically with respect to color, vegetation, and topography to evaluate the type of soil.

Using a mirror stereoscope and parallax bar, a research assistant determines preliminary elevation measurements prior to compilation of a topographic map.
identified as being related to: (1) the kinetics of iron oxidation (often the rate of oxidation of ferrous iron to ferric iron is too low); (2) precipitating of precipitated ferric oxides by organics to form a stable colloid which are small enough to pass through conventional sand filters; and (3) reduction of entrained ferric iron to soluble ferrous iron by biological growths in the filter sand.

A pilot plant has been built to observe these phenomena. It has been designed so that measurements of the difficulties described can be made as the filter "ripen." Also the plant can be used to test remedial methods for accelerating iron oxidation, promoting coagulation, and maintaining oxidizing conditions throughout the filter sand.


Factors Influencing Free-living Nematodes in Water Supplies (wspc)


The results of a one-year survey have shown that a raw sewage continuously supplied nematodes to a waste treatment plant and that considerable reproduction occurred within the plant. Primary and secondary clarifiers as well as primary and secondary digesters assisted in removing nematodes from the waste. Nematodes were unable to survive in anaerobic processes. Both activated sludge and trickling filter processes were breeding sites for nematodes, trickling filter beds being the most suited.

To obtain basic data regarding the factors governing the survival and growth of nematodes in these environments, closely controlled laboratory studies were conducted with two pure cultures of nematodes, Diplodasteroides sp., and Diplodaster nudaepatus. The genus Diplodasteroides predominates in aerobic waste treatment plants, while Diplodaster nudaepatus represented a genus that was commonly found in plants as well as in surface waters.

In agitated cultures Diplodaster nudaepatus reproduced at a higher rate whereas the growth rate of Diplodasteroides sp. was slightly reduced. Diplodaster nudaepatus was observed to be more resistant to temperature changes, whereas Diplodasteroides sp. was found to be more resistant to pH variations. Both species failed to reproduce at temperatures of 10°C and 35°C; temperatures in the vicinity of 20°C to 25°C were most suited for reproduction. A range of pH values between 5 and 9 showed no deleterious effect on the rate of reproduction of Diplodasteroides sp.; the corresponding pH range for Diplodaster nudaepatus was between 5 and 8.


The Fate of Radioactive Iron and Zinc in Natural Surface Waters (wspc)

J.T. O'CONNOR,* M. SONNEN, R. WATSON

The study is specifically concerned with the behavior of the radioactive forms of iron and zinc which may come from fallout or from reactor operations. These isotopes may be found in rivers and streams, on muds and slits, or in the organisms that live in river beds. When discharged to rivers, these metals leave the water rapidly, precipitating into or being adsorbed on the bottom muds. There they may be taken up by the benthic organisms. A knowledge of the mechanisms of transport and the distribution patterns must be obtained for control and monitoring purposes.

The work in progress entails several steps: the development of analytical techniques for monitoring natural waters for radioisotopes; a study of the precipitation or adsorption of these metals on river slits; a study of the effect of organic materials in releasing these metals from the bottom muds to the river water; a study of the uptake and concentration of the metals by underwater life; and a survey of the extent to which these radioisotopes already exist in environmental samples of river water and mud taken near nuclear installations in the United States.

Controlling Factors in Methane Fermentation (wspc)

R. E. SPEECE,* R. S. ENGELBRECHT, J. A. KEM, V. KOTHANDARAMAN

Presently the rate at which anaerobic digesters can be loaded with organic material is limited by the rate at which the methane bacteria can convert the resulting volatile fatty acids to methane. An unknown stimulatory material has been shown to be present in the supernatant of a well-operating anaerobic sludge digester, which markedly increases the ability of methane bacteria to produce methane.

The study to establish the optimum ionic concentration for maximum efficiency of methane production indicated the following: 0.02 M for the monovalent ions, sodium, potassium, and ammonium; and 0.01 M for the divalent ions, calcium and magnesium.

Coagulation by Employing Ammonium Chloride and Other Aerosols (oh)

L. HAYAKAWA,* J. W. SCHMIDT, M. L. DAVIS

An aerosol of ammonium chloride was prepared by a chemical reaction (NH₄Cl + HCl) and measured with an ultramicroscope. The particle size distribution was 1:2:4:8. Smoluchowski's theory for the coagulation of an aerosol is not in accord with this result in that no preferential particle volume should be expected. Smoluchowski's theory depends on the assumption that the ratios should be whole integral
numbers (1, 2, 3, 4, 5, 6, 7, 8) in ascending order. These may have random differences between them because any selection rule of number is not included in the equation for coagulation occurring in an aerosol.

Immediately after the formation of a titanium tetra-chloride aerosol, which was created with titanium tetra-chloride using a Wells-type atomizer, the size of an individual particle did not increase with an increase in the relative humidity, but the number of particles did increase. A few minutes later the coagulation of the aerosol increased with an increase in the relative humidity.


Contact Removal of Organic Matter by Microorganisms (wspc)
R. S. ENGELBRECHT,* R. E. SPEECE, R. H. SIDDIQI, R. STEPHENSON

The contact stabilization modification of the activated sludge process has shown promise of being the most efficient method for waste water purification. The process is based upon the rapid removal of the organic pollutant when initially mixed with the microorganisms. The mechanism whereby this initial rapid uptake of organic material by microorganisms is accomplished is under study.

With soluble substrates, permeases—enzymes which transport the substrate through the cell wall—have been shown to control the rate at which removal of an organic substrate is possible. This role of permeases in the initial rapid removal of organic pollutants in the contact stabilization process is the approach being taken to establish the mechanism. The effect of the ratio of substrate to microorganisms is being noted as well as the necessary time interval required by the organisms to utilize the substrate transferred into the cell.

Liquefaction of Insoluble Organic Compounds in Anaerobic Digestion (ndea)
R. S. ENGELBRECHT,* L. W. LEFEKE, R. E. SPEECE

The anaerobic digester of a secondary sewage treatment plant is charged with the destruction or conversion to innocuous products of 60 to 70 percent of the plant influent organic load. Almost all previous research on digestion has been concerned with the methane forming stage. The objectives of this study are to determine the basic controlling factors of liquefaction of insoluble organic matter. With further basic knowledge of liquefaction it is anticipated that the digester design may be placed on a more rational basis and that practical results of economic importance may result. The stimulation of liquefaction is of allied interest.

For this research the original seed will be well-digested sewage sludge. Stock digesters will be maintained on three insoluble substrates: carbohydrate, protein, and fat. The stock digesters will provide a reservoir for smaller digesters upon which the influence of variables may be determined.
The primary purpose of this study is to define the basic factors and conditions of the liquefaction stage of more resistant insoluble compounds in digestion. An ancillary aim is the attempt to stimulate this phase of digestion.

Fate of Substrate Carbon During Assimilation by an Activated Sludge Floc (wspc)
R. S. ENGBRECHT,* R. E. SPEECE, F. WALTERS

When an organism takes food into the cell, a number of energy producing and biosynthetic activities are simultaneously set in motion. Of importance to the sanitary engineer is the amount of substrate carbon that is used for the purpose of energy storage, cell synthesis, extracellular polysaccharide synthesis, and oxidation. It is the purpose of this investigation to dynamically observe the dispersal of carbon into these four metabolic pathways through the use of a uniformly labeled glucose substrate.

After acclimation of an activated sludge, radioactive glucose will be fed and the unit then sampled periodically to determine the quantity of carbon that has gone into each of these four areas. Sampling is to be continued long after the substrate has been removed from solution so as to observe the ultimate fate of intracellular carbon during endogenous respiration.

Growth Requirements for High Rate Methane Fermentation (wspc)
R. S. ENGBRECHT,* T. H. PATTON, Jr., R. E. SPEECE

It has been observed that the rate of methane fermentation in anaerobic digesters, using either domestic sewage sludge, many industrial organic wastes, or acetic acid as substrate, can be greatly increased by the addition of supernatant solids from a domestic digester. These supernatant solids are obtained by evaporating the filtrate liquor from a domestic anaerobic digester.

It is the purpose of this work to isolate and identify the compounds contained in these supernatant solids which are responsible for the rate increase that have been observed.

The Effects of pH on the Performance of Contact Stabilization Processes Under Shock Conditions (wspc; ff)
R. S. ENGBRECHT,* E. R. PERSHE, R. E. SPEECE

The effects of pH on the performance of biological units, including the contact stabilization process in the treatment of organic waste water, will be observed by subjecting stabilized activated sludges to pH changes which are related to the isoelectric point of the substrate. Various types of substrates will be studied to see if sorption of the substrate is influenced by changes in the electrical charge on the substrate. An attempt will be made to correlate the mobility and zeta potential of sludge particles to the amount of sorption of the substrate, degree of clarification of the supernatant, and the temperature of the medium.

Fate of Synthetic Detergents in Soils and Ground Water (wspc)
B. B. EWING,* R. S. ENGBRECHT, S. K. BANERJI, C. C. HSU

Study of the removal of alkyl benzene sulfonates (ABS) and condensed or orthophosphates from activated sludge process effluent by percolation through sand beds has continued. Effect of hydraulic loading and frequency of dosing were investigated. A comparison between ABS removal in sand columns fed synthetic nutrients with that in beds fed domestic waste showed greater removal in the beds fed a complex substrate.

A study has been started to compare the rate of biodegradation of ABS on heterogeneous bacterial cultures fed on nutrients varying from simple carbon and nitrogen sources to complex organic compounds.

A study is being conducted of the adsorption of ABS on bacterial cells under various conditions of metabolism. A mass balance is used to account for all the ABS in the system.


Effect of Natural Organic Compounds on the Ion-Exchange Reaction of Radioactive Ions with Soil Materials (ui)
B. B. EWING,* B. T. KOWN

The transport of radioactive ions in the environment is in part determined by the ion-exchange properties of the soil. The presence of natural organic ions in surface or ground water may affect the ion-exchange reaction between the radioactive ions and the soil. It is the purpose of this research to investigate the effect of natural organics on the ion-exchange reaction between radioactive ions and the soil. The natural organics present in the environment may react chemically with the radioactive ions and thereby prevent these radioactive ions from reacting. The natural organics may be adsorbed on the surface of the soil, thereby reducing the ion-exchange capacity of the soil. The over-all effects of natural organics on the ion-exchange reaction will be the objective of a study of the simultaneous equilibrium reactions in the system; natural organics-soil, natural organic-radioactive ions, and radioactive ions-soil.

Biological Removal of Colloidal Constituents of Waste in the Activated Sludge Process (ui)
B. B. EWING,* S. K. BANERJI

This investigation concerns the kinetics and mechanism of removal of pure colloidal wastes. The colloids chosen for study are soluble and stable colloids. Carbohydrates—potato starch and animal glycogen; proteins—bovine serum albumin and ovalbumin; lipids—cephalin and lecithin.
The influence of acclimation will also be studied. The temperature and pH will be maintained constant.

CONSTRUCTION ENGINEERING

Research in construction engineering is dedicated to the application of the fundamental principles of the mathematical and physical sciences to obtain an understanding of the factors influencing the economical and physical phenomena inherent in the construction process. Construction engineering can be considered to consist of three major subdivisions: construction productivity, construction planning, and construction cost estimates and analyses.

Our current research activity is concentrated in the division of construction planning. Construction systems are being synthesized by mathematical models. The solutions to these models will aid the constructor in making his decisions in the planning, execution, and controlling of construction operations. Major studies are in the following areas: (1) planning grading operations for least cost; (2) developing a systems design procedure for planning the construction operations in the building of highways; (3) forecasting construction productivity with the theory of queues; (4) developing competitive strategy models for contractor bidding practice; and (5) developing an automated project control system founded upon network planning.

Systems Design Procedure for Designing the Construction Operations in the Building of Highways (nsf)

L. R. SHAFFER,* J. J. BAKER, P. M. KRAMER, W. L. MEYER, J. B. O’SHEA, J. B. RITTER

A primary interest of highway constructors is to design all of the construction operations in the building of a particular highway in such a way as to keep the total cost of the project to a minimum. The purpose of this project is to establish a conceptual procedure with which the constructor can approach this problem as well as develop the general forms of mathematical theories which can be used to implement the procedure.

Progress to date has resulted in (1) the determination of the ordered arrangement of the components which comprise a systems approach for the highway contractor; (2) the extension of the critical path method via an integer programming model so that all mathematical forms of operation duration-cost curves can be considered; (3) the development and solution of a parametric type linear programming formulation for generating duration-cost trade-off curves for a grading operation; (4) the derivation, development, and solutions for forecasting via limited source, cyclic queuing theory, the production rates of excavators, and fleets of hauling units in earth excavation; (5) an evaluation of the reliability of the queuing theory model described in (4) by correlating productions so forecasted, with productions realized by shovel-truck fleets on three sites; (6) the development of a model of, and the computer programs for, obtaining the cash flow of a firm utilizing CPM networks for the firms’ projects; (7) the derivation of an extension to CPM to include logical restrictions resulting from resource availabilities; and (8) the development of models to forecast parameter values for the queuing theory models described in (4) but applied to tractor-drawn scrapers.

In all of these studies programs were prepared for the IBM 7094.


Application of Competitive Strategy Models in Contractor Bidding (ui)

L. R. SHAFFER,* B. J. CASEY

After determining his cost for doing a project, the contractor adds a profit. The amount of profit to be added is dependent in part upon his evaluation of what his competitors will bid on the project. Competitive strategy models can be used to develop measures of his chances of being the low bidder at various profit levels and in competition with known and unknown bidders.

Four competitive strategy models were developed for application in bidding certain classes of work in highway construction. Each of these models were analyzed with regard to reliability by using bid price information on projects which were bid by one or more of ten selected contractors during the years 1957 through 1962.


Cost Control via CPM Networks (ui)

L. R. SHAFFER,* A. C. ALBERGA

The use of critical path networks, i.e., linear graphs, for scheduling and controlling the operations of a construction project in terms of time criteria has become commonplace in the construction industry. However, in most—if not all—construction firms, cost control is done without direct reference to such networks. Because effective control of construction operations requires both time and cost controls, it appears important that these two measures be based upon the same frame of reference. Moreover,
the inherent characteristics of the critical path network are such that they appear to offer a natural frame of reference.

This research is directed toward developing a methodology for achieving the unification of time and cost controls utilizing the network as the basis of communication. A special purpose digital computer program for the IBM 7094 is in preparation wherein the cost accounts, the field reports, and the GPM networks of a selected firm are being used. The results obtained from these data are being used to examine the feasibility of the proposed methodology.

CIVIL ENGINEERING RESEARCH WITH OTHER DEPARTMENTS

The Department of Civil Engineering cooperates on several joint research projects that cross over into other disciplines, such as Geology, Nuclear Engineering, and Theoretical and Applied Mechanics. It should be recognized that in these joint research efforts, the best from each participating department’s faculty and equipment is made available for research. The results thus far have been most satisfactory as the close association with other department personnel has stimulated a better exchange of ideas and theories. Additionally, the costs of research have been minimized by the cooperative use of equipment and facilities. Research projects and thesis work conducted jointly are as follows:

Civil Engineering and Geology

Rockwell Hardness as an Index Property of Rocks (ui)
D. U. DEERE, P. KRAATZ

The Rockwell hardness of a variety of rock types is being determined and correlated with other physical properties of the rocks. Primarily, correlations with the compressive strength and Young’s modulus of elasticity are being investigated statistically. The research will ultimately lead to an M.S. thesis.

Stability of Steep Rock Slopes in the Bighorn Mountains, Wyoming (ui)
D. U. DEERE, F. D. PATTON

The shearing resistance along inclined bedding planes is being determined by studying both failed rock slopes and stable slopes. A variety of different rock types are included in the study, and it is the goal of the study to determine the “critical” stable angle for each rock formation. The research will ultimately lead to a Ph.D. thesis.

Civil Engineering and Nuclear Engineering

Studies in Nuclear Radiation Shielding and Related Aspects (ocd)
A. B. CHILTON*

This project is in part a continuation of work previously undertaken by departmental sponsorship at the University. Support was obtained from the Office of Civil Defense on 25 June 1963; and the project has not been previously reported.

This work has three main subdivisions. The first concerns analysis of the gamma-ray field from a point source near or at an interface between vacuum and a dense, semi-infinite medium. The calculations are performed for monoenergetic sources, and are readily extended to mixed energy sources.

The second part of this project concerns attenuation of broad, parallel beams of gamma radiation by “ribbed” slabs. The beams are monoenergetic and are incident on the slabs either normally or at an angle. The work involves both experimental and theoretical determinations. The theoretical work will include some highly accurate calculations, using the IBM 7094 computer, with the Monte Carlo technique.

The third part of this project is preliminary in nature, and it involves a study of certain aspects of radiation penetration through multilayered ducts. This work will only be of a theoretical nature and may be the basis for an extension of the project into the experimental field.


Engineering Methods of Predicting Neutron Radiation Penetration from Nuclear Weapons (dasa)
A. B. CHILTON*

Methods of predicting neutron shielding capabilities of various military structures and equipment will be pursued by: (1) reviewing existing information on the neutron environment at various distances from a nuclear weapon, characteristics of structures involved, and penetration information; (2) schematizing, idealizing, and categorizing practical situations and structures along potentially fruitful lines; (3) develop methods, graphs, and rules to be used for engineering prediction of neutron shielding capabilities of military structures.

Civil Engineering and Theoretical and Applied Mechanics

Study of Physical Factors Influencing Resistance of Concrete to Deicing Agents (idh; bpr)
C. E. KESLER, J. P. CALLAHAN, J. L. LOTT, W. MALISCH

The objective of this study is to develop methods based on selection and proportioning of materials and on mixing, placing, finishing, and curing techniques that will insure a minimum amount of cracking and a maximum resistance of plain and reinforced concrete to the deleterious effects of free moisture and deicing agents. The effects of adding water to the concrete surface during finishing, variation in air content due to overvibration, overmanipulation during finishing, and time lapse between placing and finishing are currently being investigated.
Motor Vehicle Registration and Titling Practices (hnb)
J. E. BAERWALD*

The basic objectives of this study are to determine:
(1) The current usage of motor vehicle registration and titling information.
(2) What additional information would be of value.
(3) If information of value to various types of agencies is or could be made available in the proper form.
(4) If any additional information that would be of value for planning, taxation, enforcement, or other purposes could be made available through the addition of other questions on the registration and titling form.
(5) If this desired information could be made available for use in an economical and practical manner.

The major activity has been an analysis of the results of a questionnaire to determine the usage of information presently obtained and if any additional information that would be of value should be obtained. Filing and data process methods and procedures have been reviewed in order to complete the study pertaining to the possibility of making additional information available.

The study results indicate that the information collected through the titling and registering of motor vehicles is of use to many different public and private agencies and should be made available more easily by the motor vehicle departments acting as service agencies.


A Study of Traffic Accident Reporting Criteria (asf; bpr)

A study team consisting of senior faculty members of the University of Illinois is considering in depth the varied uses of traffic accident data.

The objective of the study team is to determine the accident data usage criteria (information needed; degree of accuracy, completeness, and detail; allowable reporting delay; etc.) of the different users in the State of Illinois. After the usage criteria of these individual interests are identified and detailed, they will be combined and correlated in order to establish data usage criteria for a universal traffic accident reporting system, or for better coordination of multiple systems.

Members of the study team are interviewing public and private agencies who use traffic accident data. The study team also met with about 25 of the nation’s leading authorities in the traffic accident field during a two-day meeting in Urbana in July, 1964.
Coordinated Science Laboratory

DANIEL ALPERT, Director
M. E. VAN VALKENBURG, Associate Director
HANS FRAUENFELDER, Associate Director

The Coordinated Science Laboratory is an interdisciplinary laboratory in the College of Engineering devoted to a broad program of research in pure and applied science. A major goal is the development of thesis research in many areas of engineering and science in an environment which encourages the interaction between faculty and students in the different disciplines. Senior staff members typically have research activities in the Laboratory and teaching responsibilities in one of the departments of the College. Present activities include graduate research in such areas as electronics and electron physics, information theory and data processing, systems theory, and the utilization of computers in many problems engineering systems. A program of recent interest has been the development of a major effort in space science.

Following is a partial list of the Laboratory's activities.

NASA technicians prepare CSL's Nike-Apache rocket for firing on the launch pad at Wallops Island, Va. The nose cone payload was designed to measure electron collision frequency in the ionosphere.
Aerospace Science (nasa; jsep)


Rocket-borne experiments to measure properties of the upper atmosphere were initiated in April with a successful firing from Wallops Island, Virginia. This is a part of the program of firings in various parts of the world during the International Quiet Sun Years (IQS) which is being carried out in cooperation with Professor Sidney A. Bowhill of the Department of Electrical Engineering. The Coordinated Science Laboratory has responsibility in the IQS program for the design of the experimental equipment and for interpreting the experimental data from the firings. Progress has continued on the study of the feasibility of carrying out a new satellite-borne experiment to test the general theory of relativity by measuring effects described by Professor L. I. Schiff of Stanford University. This experiment is based on the Nordiack electric vacuum gyroscope which was invented and developed at CSL.


Surface and Atomic Physics (jsep)

H. Frauenfelder,* F. Probst,* T. Cooper, F. Franz, F. Hummel, T. Piper, G. Tibbetts

In studies of the interaction of ions with surfaces, total yields, and energy distributions of electrons ejected from polycrystalline tungsten by various ions have been measured for a range of ion kinetic energies. The effect of adsorbed layers of hydrogen and nitrogen have been studied. The study of the spin relaxation of polarized cesium vapor in various inert gases has been extended to include neon, argon, xenon, and krypton. Work on anomalous ion currents and gas production in ionization gauges due to electron bombardment has led to improved understanding of vacuum instrumentation.


Computer Sciences (jsep)


A program for on-line control of bubble chamber data processing has been established in cooperation with the High Energy Group of the Physics Department. The program makes use of the CSX-1 computer, which was designed and built under the leadership of Professor R. M. Brown. This system is an example of one calling for dialogues between man and machine in which the Laboratory has a strong research interest. Studies are under way for a system in which the CSX-1 will control time-sharing of the IBM 7094 of the Digital Computer Laboratory. One of the applications of this program will be the development of an experimental facility for nonlinear structural design by Professor S. J. Fenves of the Department of Civil Engineering.


Systems Research (jsep; aflor)

The three principal areas of research in engineering systems are (1) automata including self-diagnosis and self-repair, (2) automatic control systems, and (3) network theory including applications of graph theory to the analysis and synthesis of communication nets. Recently, a new approach has been found to the control of the sensitivity (or changes in the performance of a system as the result of the change of one or more of its parameters) in the design of complex feedback systems. Contributions have been made to the important field of the diagnosis and self-repair of sequential switching machines, such as the digital computer. A new procedure has been found for the design of networks for broadband matching of an arbitrary load to a source of energy. New techniques have been found for the analysis of important classes of equations that describe nonlinear systems. In all of the studies of this group, the CDC 160 digital computer of the Laboratory is used extensively.


**Automatic Teaching Systems — PLATO (jsep)**

D. L. BITZER,* E. R. LYMAM,* R. BLOEM, E. DeWAN, L. MORGAN, M. SECREST, S. SINGER, B. VOTH, R. WILLSON

The purpose of the PLATO project is the development of an automatic teaching system capable of tutoring simultaneously a large number of students in a variety of subjects. The central control element of the teaching system is a general purpose digital computer, a CDC 1604. The PLATO system differs from most teaching systems in that the single high-speed digital computer is used to control all student stations. Thus it has available the power of a large digital computer in teaching each student. During 1964 the PLATO equipment is being expanded to ten student stations. Several educational research projects are being carried out using PLATO in areas such as mathematical theorem proving, scientific inquiry training, and physiological correlates of mathematical discovery.


**Low-Pressure Measurements Studies (nasa; jsep)**

D. ALPERT,* W. SCHUENMANN, L. SIMONELLI, F. STEINRISSER

An apparatus has been built to measure the interaction of slow electrons with gases absorbed on the surfaces of various metals of different temperatures.

For the electronic collision with atoms of oxygen chemisorbed on Mo, a measurement of the threshold energy of the impinging electrons has given a value in agreement with the literature.

Preliminary measurements of the time rate of change of the ion current during continuous electron bombardment of the surface seems to show that there are two different reactions both of the first order but with different rate content.

Metals to be investigated in the future are Ni, O, and Pt. Useful data on the understanding of the mechanism of removal of gases from the surfaces will eventually be obtained.


**Plasma Physics (arpa; jsep)**

M. RAETHER,* A. BARGER, H. BOHMER, W. CARR, R. HOSKEN, T. LIE, C. MENDEL

Three studies are under way in this area:

Incoherent Scattering of Microwaves from Plasmas

A search is being made for the plasma resonance in the incoherent scattering cross section. A high-power microwave signal is propagated through a d.c. discharge contained in a wave guide. The upper sideband in the scattered radiation is filtered out and detected by a sensitive radiometer.

**Electron Run-away in a Plasma**

Electron run-away in a plasma is studied by subjecting the plasma to a large electric field in a linear induction accelerator. Special attention is paid to the influence of instabilities on run-away.

**Electron Beam—Plasma Interactions**

The interaction of a high-current pulsed electron beam with a plasma is being studied with emphasis on the electrostatic and the hose instability. The influence of collisions on the electrostatic instability is being investigated.


Solution of the Boltzmann Equation for Systems Far from Thermal Equilibrium (Jsep)

B. L. HICKS, M. A. SMITH

The Boltzmann equation describes the microstructure of gases. Studies in CSL that were started in 1960 have produced detailed numerical solutions of the Boltzmann equation for a strong shock wave. The Monte Carlo method used was devised by Dr. Arnold Nordieck. No accurate analytical methods are known for calculating states like those in a strong shock wave that are far from thermal equilibrium.

The stability and accuracy of Nordieck's method have been improved during the past year without seriously reducing the speed of computation. The structure of a shock wave, including velocity distribution functions at five positions within the shock wave, can be calculated for a given Mach number in about two hours, with an accuracy of 2 percent in the moments of the distribution function. Greater accuracy can be obtained, with no change of the program, by using larger Monte Carlo samples.

The successful development of the Monte Carlo method makes possible several new investigations in kinetic theory among which may be mentioned a study of the influence on shock structure of the nature of intermolecular fields of force and the evaluation of many approximate analytical theories of shock structure.


**Crossed Field Delay Lines (jsep)**

**H. G. SLOTTOW**

A delay line, based on the drift of charged particles in crossed electric and magnetic fields, has, in principle, two distinctive properties—continuously and rapidly variable delays and wide bandwidths. The first of these is easily achieved through electronic control of the electric field. Realization of the second, however, can be impeded by several effects, the most serious of which is space-charge induced dispersion. The goals of this research are to understand the properties of crossed field delay lines and to establish the principles upon which development can proceed.

Observations of pulsed signals have confirmed the expected dependence of the delays on the field magnitudes and have shown that electron bunches with a time spread of only 50 nanoseconds can be delayed by as much as 12 microseconds. They have also shown that signals can be carried not only on electron beams but also on both the electron and ion components of tenuous plasmas.


**High Magnetic Field Superconductors (jsep)**


Advances have been made in the preparation of superconducting materials, particularly niobium tin, and on the characterization of type II superconductors. Programs have been initiated with the thin film group to study the energy gap as a function of current density in a thin-film superconductor, and to study the possibility of Hall voltage in type II superconductors.


**Electrical Breakdown in High Vacuum (jsep)**

D. ALPERT, E. M. LYMAN, H. E. TOMASCHKE, D. A. LEE

Recent studies of electrical breakdown in clean vacuum systems indicate that breakdown is initiated by field emission current and occurs at a value of the electric field which is approximately a constant independent of the electrode geometry. It is believed that sharp projections on the cathode cause a local enhancement of the electric field, and the value of the breakdown field is the field at the tip of such a projection.

The present investigation was undertaken to study the characteristics of projections that exist on electrode surfaces and to determine the correlation between the geometry of the projections and the prebreakdown current-voltage characteristics of the electrodes.

Fowler-Nordheim plots of the prebreakdown currents predicted that the projections should be of the order of $10^{-4}$ to $10^{-5}$ cm in diameter and have a length about ten times the diameter. Direct observations of electrode profiles with an electron microscope confirmed that projections of the predicted size and shape did exist on the electrode surface. Electrical breakdown resulted in the disappearance of one or more projections and sometimes caused the formation of new projections. A study of the formation and destruction of emitting points on the cathode is being continued, using a modified field emission microscope.


**Physics of Thin Films (jsep)**

R. N. PEACOCK, M. G. CRAFORD, J. T. JACOBS, R. E. ZELAC

A number of experiments are under way in collaboration with the Coordinated Science Laboratory cryogenics group under Professor Satterthwaite. A proposed study of critical currents and electron degraining in superconducting films has required preliminary measurements of the tunneling characteristics of niobium-niobium oxide-indium junctions. This has itself become a very interesting research problem since new and unexpected detail has been found in the current-voltage characteristics of such devices at temperatures of a few degrees Kelvin.

The superconducting characteristics of electron beam evaporated films of V, Nb, and Ta are also being investigated. The superconducting properties are very sensitive to structure, and exceptionally good deposition techniques are required for such materials. For example, films of vanadium measured recently were found to have superconducting transition temperatures at 2K instead of the 5.2K of pure bulk vanadium.

There are at present many electrical and electronic applications of tin oxide films, but very little is to be found in the literature concerning the basic properties of this material. Such properties as the band gap, dependence of conductance on preparation and stoichiometry have been measured.

The perfection of metal films is dependent upon substrate temperature, the nature of the substrate, and the vacuum. Work is under way using ultra-high vacuum conditions and cleaved single crystal substrates to better relate these conditions to film properties.

The research laboratories of the Department of Electrical Engineering encompass many related scientific areas. Programs now in progress include such diverse fields as aeronomy, antennas and electromagnetic theory, biological computers, charged particles, cybernetics, gaseous electronics and plasmas, network analysis and synthesis, optical communication, physical electronics, radio astronomy and radiolocation, semiconductors and solid state devices, submillimeter microwaves and biophysics in engineering.

As scientific frontiers are explored and developed, the interrelationship between the various fields of science becomes more apparent. For example, the work of the biophysical research program represents an overlapping of scientific interests in the fields of biology, psychology, physics, and electrical engineering. The radio astronomy program brings together astronomy and electrical engineering. Cybernetics combines interests in biology and electrical engineering. In gaseous electronics, ultramicrowaves, and solid state studies, physics and electrical engineering merge in establishing interdisciplinary laboratories.

This helium-neon laser, built by the optical communications laboratory, is to be used for experiments on light modulation at microwave frequencies.
AERONOMY

This field encompasses the study of the physical and chemical processes which take place in the upper atmosphere and ionosphere of the earth. Until relatively recently, it was possible to study these regions only by optical means, through airglow and auroral emissions, or by means of radio wave sounding. Recently, however, it has been possible to carry increasingly complex environmental experiments into the upper atmosphere with sounding rockets and satellites, and the combination of these with the earlier types of measurement are now beginning to yield rich dividends in understanding the interaction between solar radiation and the atmosphere.

Organization of Lower Ionosphere Rocket Program for International Quiet Sun Years (nasa)

S. A. BOWHILL,* K. G. BALMAIN, A. B. GSCHWENDTNER

Various measurements are being studied on a synoptic basis during the International Quiet Sun Years (IQSY) from January 1, 1964, to December 31, 1965, to elucidate the aeronomy of the lower ionosphere, from 60 to 160 km height above the earth.

Based on these studies, recommendations are made for two types of scientific payload, to be carried on small solid-fuel rockets. These combine the techniques of direct environmental measurements of the ionosphere plasma with optical and radio propagation techniques for determining electron and neutron density.

Studies were also made of two types of environmental sensors developed in England and in Japan, and these were recommended to be flown simultaneously with the other experiments to check on the comparability of the results.

Study of Production and Loss Processes of Atmospheric Ionization (nsf)

S. A. BOWHILL,* J. E. GEISLER, G. G. KLEIMAN, P. PARAMASIVAIH

The purpose of this research is to study and identify the mechanisms by which the ionization in the D-, E-, and F-regions of the ionosphere is produced and disappears.

An analog computer program for solving the nonlinear differential equations for the production and loss of ionization in the E-region of the ionosphere has been set up. It has been used to determine rate coefficients for recombination of nitric oxide and molecular oxygen ions, from measurements of E-region composition from rocket mass spectrometer flights by day and by night. Results obtained are in good agreement with previous determinations.

A detailed investigation has been made of the coupling between the protonosphere and the F-region of the ionosphere, to determine whether the flow of ionization into or out of the protonospheric reservoir is adequate to explain some of the known anomalies of the F2-region. Because of the critical temperature dependence of this phenomenon, it was found necessary to make a careful investigation of the thermal structure of the upper ionosphere, from which it was found that currently accepted theories for heating of the electron gas are considerably in error. Computer programs have been set up to determine the electron and ion temperature as a function of altitude for a variety of ionospheric conditions.

Direct Measurements Conference (anc)

S. A. BOWHILL, K. G. BALMAIN

A conference on "Direct Aeronomical Measurements in the Lower Ionosphere" was held on October 21-23, 1963, at the University of Illinois, and was attended by 104 scientists from 10 countries. The purpose of the conference was the dissemination of viewpoints, technical information, and scientific results among a relatively small number of active researchers in the field of aeronomy. Sixty papers were presented orally at the meeting, and were incorporated in the report mentioned below.

An unusual feature of the meeting was the effort made to relieve individual authors of the burden of providing a detailed written version of their paper. Where this was not available, a transcript of their talk was used, together with photographic reproductions of the slides which illustrated their lectures.


Rocket Studies of the Lower Ionosphere During the IQSY (nasa)


This program, arising out of a study to determine the optimum form for an integrated approach to the problem of D- and E-region aeronomy during the IQSY, is carried out in cooperation with the Coordinated Science Laboratory of the University of Illinois, and the Physics Division of the Geophysics Corporation of America, Bedford, Mass. While responsibility for the development of instrumentation and procurement of data is shared between the cooperating groups, interpretation of the data obtained and over-all technical direction is carried out by the Aeronomy group.

Four rocket firings have thus far been carried out as part of this program, with good success in each case. A further seventeen are planned for the remainder of the IQSY at carefully selected times and locations, so as to provide the maximum information about the processes taking place in the quiet lower ionosphere.

Radio Propagation Experiment

Instrumentation developed by the Coordinated Science Laboratory of the University of Illinois furnishes data giving the differential absorption and Faraday rotation of a medium-frequency wave propagated from the ground to an ascending rocket. These data are then used to determine electron densities in the height range 50-100 km, and electron collision frequencies in a more limited height range.
Partial Reflection Experiment

To accompany the rocket measurements, a partial reflection sounder radiating 100 kw medium-frequency pulses has been developed and put into operation at the NASA launch site at Wallops Island, Virginia. The data from this technique will give a continuous record of electron densities and collision frequencies in the D-region of the ionosphere, for comparison with the rocket measurements.

Direct Plasma Measurements

Based on d.c. probe data for the rocket flights provided by the Geophysics Corporation of America, a theoretical analysis of the electron and ion mobility problem in the lower ionosphere is being carried out, to determine the positive and negative ion densities in the D-region. These theories will be experimentally checked using a vacuum system simulation of ionospheric conditions.

Analysis of the impedance of an antenna immersed in an anisotropic medium is continuing, to determine the possible importance of electroacoustic oscillations in producing radio frequency losses in an impedance probe and enhanced direct current in a resonance probe.

Pulse Compression System

Investigations are being carried out on the feasibility of utilizing pulse compression to improve the signal-to-noise ratio and the height resolution of a partial reflection system. An ultrasonic delay line is being used, with the first compression mode providing the necessary dispersion.

Mobile Launch Program

University of Illinois participation is planned in a program of rocket launching and associated measurements to be carried out in the South Pacific from a mobile launch facility on an aircraft carrier. Antenna pattern studies are being made to determine how a prescribed polarization can most readily be radiated vertically from a highly anisotropic body such as an aircraft carrier. A mobile partial reflection sounder is also being readied for this program.


ANTENNAS AND ELECTROMAGNETIC THEORY

The Antenna Laboratory has conducted work on basic electromagnetic theory and applications to antennas for high-speed aircraft during the past 16 years. The main emphasis recently has been on frequency independent antennas. Extremely large bandwidths (20 to 1 or more) have been achieved. Other problems considered have been antennas for millimeter wavelength, data processing antennas, impedance and radiation of antennas in the ionosphere and in magnetoplasmas.

Large Antenna Arrays with Random-spaced Elements (nsf)

Y. T. Lo,* V. Gylys

From the theory established previously an extremely high resolution antenna array could be achieved with very few elements. Unfortunately an experimental verification of this result, even with a scaled model, appears to be a task of immense magnitude. Therefore the Monte Carlo method is considered. Even in this case, the computation of the radiation pattern for a single planar array with 1 minute of arc in beamwidth is next to impossible, since it requires roughly 10^9 hours of computing time with IBM 7094. This is due to the fact that for such a type of array there exists no principal plane in the pattern function. As a result, in this investigation the verification is conducted for a linear array with an aperture equal to 10^4 wavelengths and with four different numbers of elements, ranging from 100 to 1,000. It is found that various statistics of the antenna response agree almost exactly with the theory. The actually computed sidelobe levels also agree remarkably well with the predicted values.

It is interesting and somewhat surprising to find that a linear array for producing 1 minute of arc in beamwidth and sidelobe level at −6 db can be achieved with only 100 uniformly excited isotropic elements. When the number of elements increases to 300, 600, and 1,000, the sidelobe level reduces to −13, −16, and −18 db, respectively. In contrast, if the conventional method is used, at least 5,000 elements would be needed. Moreover a much narrower beam can also be achieved with no additional elements, with no loss in directive gain, and with essentially the same sidelobe level by spreading the elements over a larger aperture.

This nearly perfect agreement given above makes the theory more valuable in understanding the behavior of arrays of higher dimensions since the evaluation of the latter becomes almost impossible by any other known method.


Research Studies on Problems Related to Millimeter Antennas (nsf)


This project was established to investigate basic problems related to advancements in antennas for use at millimeter wavelengths. Graphical methods have been developed to describe the electromagnetic fields in a beam wave guide
or a confocal resonator. A millimeter antenna in the form of a lens coupler, which couples electromagnetic energy from a beam wave guide to a pencil beam in free space, has been theoretically designed and experimentally tested. A theoretical study of the diffraction of plane waves by thick dielectric gratings and zone phase plates has been made.


Investigation of a Class of Boundary Value Problems (afcl)

R. MITTRA,* D. S. KARJALA, J. R. PACE

The project is concerned with the investigation of a class of electromagnetic boundary value problems using a new technique called the Generalized Scattering Matrix Technique introduced by the principal investigator and his associates. The technique is being applied to solve many problems for which satisfactory solutions are unavailable at the present time. Applications to the fields of millimeter waves and anisotropic media are under investigation.


Antenna Design for Antenna System for Navy Communications Ship (nel)


For adequate communications at sea the Navy requires many transmitters and receivers to operate on board a single communications ship. The purpose of this work is to do basic research which will increase the store of fundamental knowledge which can be applied to the design of shipboard antennas. It is desirable to use frequency-independent antennas as much as possible to reduce the number of antennas required. However, space available on board ship puts a limitation on the size of the antennas. This project seeks to determine whether it is possible to reduce the size of known frequency-independent antenna designs without seriously affecting their performance. An investigation of log-periodic arrays of helical dipoles has shown that reductions of 50 percent in the length of the dipoles are possible without serious degradation in patterns or impedance. Other approaches which have been proposed for size reduction are to use series-fed folded dipoles in a log-periodic array and to use helical conductors on log-periodic zigzag antennas.

Antenna arrays which conform to the ship geometry have an approximately elliptical locus. Little was known about methods for computing the patterns of such arrays. Several approximate methods have been devised for this computation. It has also been shown that the patterns of an elliptical array are simply related to those of circular arrays. A number of elliptical array patterns have been computed, and computer programs have been prepared which will assist in evaluation of new proposed systems.


Research Studies on Problems Related to Antennas (afal)


The goal of this project is to advance the knowledge of electromagnetic radiation in order to make possible the design of better antennas.

Frequency-independent antennas which were first developed in the Antenna Laboratory continue to be a major subject of investigation. Both theoretical and experimental studies of proven successful models are being used to compile design information and improve the understanding of the principles of operation. Interest in developing new models has been largely devoted to flush-mounted and low-silhouette types. Wide-band amplifiers have been tested which incorporate new semiconductor diodes in the antenna structure to produce an integrated antenna-amplifier. The phase patterns of multi-arm spiral antennas are also being studied.


Wide-Band Antenna System Having Wide Aperture and High Efficiency for Use in Direction Finding and Communication (bs)


This study is concerned with antenna systems showing a high level of performance over a wide (16:1) frequency range. The particular qualities being sought in this investigation are high efficiency, wide aperture to provide a high order of azimuthal resolution, and circular symmetry to permit azimuthal scanning of the directive patterns by electronic means. The immediate intended application of the system is to radio direction finding and radio communication tasks in the HF region of the radio spectrum.

The problem is being attacked through an investigation of unusual ways and means for applying log-periodic and frequency-independent antenna principles to the synthesis of an appropriate array. Initial studies have been concerned with the properties of individual elements suitable for use in such an array. Several new types of vertically polarized unidirectional frequency-independent antennas have been developed, and most of them are presently in use in some full-scale HF system. Appropriate models have been chosen for testing scale models of a complete ring array. Radiation pattern measurements on a 1/500 scale model of the system have been used to determine the optimum design parameters. Preliminary design has been completed on a 1/50 scale model.


**Selected Radiation and Propagation Problems Related to Antennas and Probes in Magnetoplasma Media (nasa)**


Some of the problems under consideration are:

1. Evaluation of the fields produced by sources in a magnetoplasma. This includes far and near fields for various values of the medium characteristics and various types of antennas.
2. Fields produced by sources inside of a waveguide filled with a magnetoplasma. The main purpose is to interpret laboratory experiments and use the result to measure magnetoplasma characteristics.
3. Determination of current distributions on radiators imbedded in a magnetoplasma.
4. Impedance of simple antennas (dipole, loops) in a magnetoplasma.

The solution of these problems has a direct bearing on the design of probes for use in the ionosphere and on the design of antennas for communication with vehicles in the ionosphere and the magnetosphere.


**BIOPHYSICS**

The research program of the Biophysical Research Laboratory of the Department of Electrical Engineering is concerned with the elucidation of structure and function of biological systems through the application of the approach and techniques of the physical and engineering sciences. The research of the Laboratory includes investigations concerning the fundamental organization and operation of biological systems, the study of the physical methods and instruments for studying such systems, and medical applications resulting from the fundamental biological investigations. Major emphasis has been placed on the use of high-intensity ultrasound as a research tool for investigating biological systems, in particular the central nervous system of experimental animals. As a result of this fundamental research program, it is now possible to use ultrasound, under precisely controlled dosage conditions, to produce selective changes in the central nervous system of animals. This discovery provides entirely new methods of attacking problems of brain mechanism, and it has provided the necessary information for application of this method to the modification of the human brain. Work on the use of high level focused ultrasound to modify the symptoms of various neurologic disorders of the human is carried out as a joint research project between the University of Illinois and the Division of Neurosurgery of the State University of Iowa. All instrumentation for this human work was designed and built at the University of Illinois.

No precision commercial instruments are available for producing ultrasonic fields of high sound levels. The Laboratory has, therefore, designed and developed all of its ultrasonic research instrumentation. One of the current research projects is concerned with the problem of producing high power ultrasonic beams. This is a complex problem requiring the investigation of a variety of systems for shaping sound fields. The successful results of such a study will have immediate application to tumor problems.

Although the medical applications are of great interest and importance, they are not the primary objective of the Biophysical Research Laboratory. As indicated, the Laboratory is attempting to devise new approaches to basic biological problems. In this regard, the personnel of the Laboratory represent a variety of disciplines—physics, physiology, engineering, psychology, etc. The Laboratory is unique in its ability not only to design and build very complex instrumentation, but also to carry out the basic biological studies for which the instrumentation was designed.

**Behavioral Alterations Following Ultrasonically Induced Lesions in the Rhinencephalon (nsf)**

G. J. THOMAS,* W. J. FRY

Research continues to elucidate behavioral functions of the mammillothalamic tracts. Current work concerns effects of tractotomy on learned behaviors involving “short-term” memory. Cats are trained to respond alternately to two stimuli which differ only in location by rewarding only responses made to the stimulus not responded to on the previous trial. The only cue the animal has to guide its decision is the “memory” of which stimulus it responded to last. The animals are tested after ultrasonic surgery aimed
at severing the mammillothamic tracts, to discover any changes in performance. Disturbances of short-term memory in humans have been reported after lesions in homologous brain structures. If similar phenomena can be discovered in lower animals (cats) it will be possible to investigate more specifically neurological mechanisms of memory.


Modification by Focused Ultrasound of Hyperkinesias, Dyskinesias, and Dysarthric Speech Exhibited by Cerebral Paired Individuals (ucpemf)

W. J. FRY, F. J. FRY, R. MEYERS

The program is concerned with the modification of the brains of cerebral paired individuals afflicted with involuntary movement and dysarthric speech. Objectives include: the development of a sound transparent rigid substitute for skull bone in order to provide a window through which repeated ultrasonic irradiation can be focused into selected brain sites of interest, the design of a focusing transducer with improved beam characteristics compared to the multilayer arrangement previously employed, and the histologic preparation and study of brains of previously irradiated patients. This latter phase of the studies will provide information on the accuracy with which specific anatomic sites can be located in the human brain by reference to ventricular landmarks, since the measurement methods employed and the head holder are the most precise and rigid of any thus far employed anywhere.


Effect of Ultrasound on Tissue (onr)

W. J. FRY, F. J. FRY, E. KELLY

This program was concerned with the use of high-intensity ultrasound for the investigation of basic biological functions. The work most recently completed was concerned with the use of ultrasound to investigate the mechanisms of muscle contraction. In order to implement this, it was necessary to investigate the effect of temperature and stimulating conditions on the muscle properties of frog skeletal muscle. The temperature studies were initiated to differentiate between the possible effects of ultrasound, apart from its temperature action. The temperature studies resulted in considerable information on the basic mechanisms of muscle contraction and indicated the need for investigation of other factors such as the electrical techniques normally applied for stimulation. The results of this study are in the process of publication.

An Experimental Analysis of the Micro-Neuroanatomy of the Central Nervous System (nasa)

W. J. FRY, G. LEICHNER, R. MALEK, J. PANKAU, A. VON LEHMENDEN

Attempts are being made to determine in quantitative detail the complex neural circuitry of systems of the brain to serve as a basis for the predictive description of function, to provide information necessary to incorporate man as an effective operating unit in systems of great complexity and sophistication.

The work has progressed to the stage where it is apparent that major systems of the brain are organized in a precise fashion and that the detailed microstructure can be derived and described quantitatively. Instruments and methods presently employed and others under development at this laboratory can provide the requisite information.

Up to the present time the anatomical structure of the major subdivisions of the brain have been described in only qualitative form. The research in progress under this grant represents the first to yield detailed quantitative descriptions of brain circuitry on a global basis. It places the understanding of brain systems on a much more basic level upon which function can be understood, predicted, and simulated.

Physico-chemical Factors in Ultrasonic Lesions of CNS (nih)

W. J. FRY, R. C. EGGLETON, F. J. FRY

This work is concerned with the elucidation of the mechanisms by which high-intensity ultrasound induces nonthermal, selective actions in the components of the central nervous system. The program for the coming year will include the determination of dosage relations (reciprocal of exposure time to produce a given endpoint as a function of acoustic pressure amplitude) over a wider range of base temperatures of the tissue and in obtaining more accurate data at the lower temperatures—0° to 10°C. These extended data will be compared with the results of theoretical calculations in order to identify specific acoustic parameters which cause the observed selective changes in the tissue components.

Additional effort will be applied to improving the instrumentation to further increase the accuracy of the measurements. For example, various additional modifications of the thermocouple probe design will be investigated from the viewpoint of reducing the percentage of incident sound reflected at the probe interfaces.

Fornix-mamillo-anterior Nuclear Complex (nih)

W. J. FRY, F. J. FRY, R. MALEK, J. PANKAU, A. VON LEHMENDEN

This project is concerned with a quantitative investigation of the mammillary nuclei and associated complex of
the brain. Neuron populations are determined for both unmodified preparations and for nuclei affected by processes of degeneration following the production of lesions. The structures now receiving attention include the lateral and medial mamillary nuclei, the anterior dorsal, ventral, and medial nuclei of the thalamus, and the ventral and dorsal tegmental nuclei of von Gudzen. In addition to the reconstruction of neuron populations of these structures, the program is concerned with developing methods of placing lesions to achieve greater anatomic accuracy and also with modifying and introducing techniques in the histological preparation of the material in order to increase the accuracy in the determination of the neuron population which furnish the basis for the derivation of detailed anatomic relationships.


Research on Ultrasound in Biology and Medicine (onr)

E. KELLY*

This symposium was held to exchange ideas, techniques, and results with investigators engaged in the use of ultrasound in biology and medicine. The program was organized to include sessions on high-level focused ultrasound as used in experimental animals to induce tissue changes (brain, pituitary); low-level ultrasound as used for investigative purpose on biological systems, including the use of acoustic techniques to visualize tissue structure and its dynamics (registration of movements of cardiac walls). The mechanisms of action of the acoustic energy on the tissue were also discussed.

Investigators were invited from all parts of the world to participate. Attendants included three from Japan, two from Sweden, two from Germany, one from Great Britain, and one from Australia. They presented graphically illustrated papers on the work being done in their laboratories as related to the subject matter of the symposium.

The results of the work done in the Biophysical Research Laboratory at the University of Illinois were also presented. During the past five years extensive developments in ultrasonic methodology and techniques have taken place which have resulted in the discovery of important biological results and the expansion of the Biophysical Research Laboratory into a number of new areas. Papers were given by various members of the staff of the laboratory at the symposium. These included a general review of the program of the past five-year period and predictions for the immediate future, an outline of requirements and approaches to the design of precision electronic instrumentation for use in the program, a paper on ultrasonic absorption in tissue, and reports of the action of high-level ultrasound on pituitary and muscle.

A wealth of valuable information was exchanged at the meetings and the conclusion was that the symposium constitu a most successful interchange of ideas on the use of ultrasonic energy in biology and medicine.


Interaction of Intense Noncavitating Ultrasound and Macromolecular Species in Solution (onr)

F. DUNN,* S. A. HAWLEY, R. M. MACLEOD

Ultrasound techniques are employed as tools for analysis of biological systems and as agents in medical diagnosis and therapy. However, the physical mechanism of the interaction of ultrasonic waves and biological structures remains in an unsatisfactory state of understanding. Previous research suggests that intense, noncavitation ultrasound affects tissue at the level of macromolecular structures. In order to study such interactions, solutions of macromolecules of different mechanical properties are irradiated with noncavitation ultrasound as a function of frequency, concentration, temperature, and acoustic intensity. Sedimentation velocity analysis and viscosity measurements are made to detect resulting molecular weight changes in the solute macromolecules, and analyses are made to determine the subsequent reduction in chemical activity. Initial studies in which DNA molecules (extracted from various bacteria in degassed standard saline citrate buffer) are irradiated as a function of acoustic intensity and time duration of exposure, reveal that the sedimentation constant is dependent upon both variables. It is considered that molecular degradation results from stresses established within the molecules due to relative motion which arises because of the density differences between the molecules and the fluid.

UHF Acoustic Attenuation (onr)

F. DUNN,* W. J. FRY, S. A. HAWLEY

This project deals primarily with the investigation of acoustic properties of liquids and liquid-like media at ultrahigh frequencies. The importance of such studies lies in the knowledge obtainable on the structure of liquids, including quantitative information on rate processes. Acoustic absorption spectroscopic measurements are made in dielectric liquids to frequencies as high as 2,000 mc. The current activity includes the design and fabrication of sources and detectors to extend further the frequency range of measurements.

Initial experiments dealing with the interaction of UHF acoustic waves and living systems (rotifers) have exhibited a harmonic relationship between animal response and frequency of the transmitted wave.


Hyperkinetic Disorders (nih)
W. J. FRY,* F. J. FRY, R. MEYERS

This program's objective is the elucidation of the mechanisms underlying nonpatterned abnormal movements in hyperkinetic disorders. Focused high-intensity ultrasound was used to produce lesions in various brain structures of patients afflicted with such disorders.

During the past year the work has been primarily concerned with histological aspects such as: the orientation of the brain and the sectioning of it for the purpose of staining to disclose any abnormalities and to permit the reconstruction of the ultrasonically induced lesions. The Weil stain is used to study the fiber distribution, and a cell-stain Luxol-creaylecht permits a study of neuron changes.

Histologic study in progress is concerned with the accuracy of lesion placement with respect to ventricular landmarks in the human brain and with correlating the modification of structure with the changes in symptoms.


Electron Microscope Study of Ultrasonically Irradiated Muscle (afosr)
W. J. FRY,* R. EGGLETON, E. KELLY

An electron microscope examination of ultrasonically irradiated muscle was conducted in an effort to identify structural changes produced by this form of energy in such tissue. The focused ultrasound was accurately controlled to produce lesions in excised frog muscle which is held under controlled conditions of temperature and stretch. Electron microscopic studies of frog sartorius muscle subjected to simple temperature changes in the range of 35°C to 44°C were also undertaken.

Semantic and Syntactic Properties of Many-valued and Morphogrammatic Systems of Logic (afosr)
G. GUNTER,* H. S. HSIEH, H. VON FORESTER

Since the applicability of conventional two-valued logic to some aspects of cybernetics and automata theory is of some doubt, this project is concerned with the examination of many-valued systems of logic for their utility. Even many-valued systems show some deficiency, and a novel logical concept, that of morphogrammatic logic, is being studied with the hope of developing logical systems in which morphogrammatic structures are the operational units. Both the material significance of morphograms and the mathematical manipulations appropriate to them are being studied.

CHARGED PARTICLE RESEARCH LABORATORY

The research in this laboratory is concerned primarily with the behavior of small but macroscopic single and multiple particles. The particles may be charged or uncharged, in field free space or in electromagnetic fields, and may be solid or liquid. Much of the research is directed toward studies of the production of such particles and their control. This involves producing suitable environments (various gases, vacuum, controlled humidity and temperature, etc.) and development of techniques for observation and measurement of the particle parameters.

Basic Research in Electrical Propulsion (afosr)
C. D. HENDRICKS,* J. SCHNEIDER

The purpose of the research reported here is to provide an understanding of the basic physical processes involved in the several methods of producing charged colloidal sized particles for propulsion purposes.

The experimental and theoretical study of the electrostatic spraying of liquids is being continued. The influence of the various physical constants of the liquids on the spraying process and in particular on the specific charge (q/m) distribution will be investigated.

The detection of specific charge distributions will be accomplished principally by means of mass spectrometer techniques. Both the electric quadrupole mass spectrometer and the time of flight mass spectrometer are well suited to the measurements involved and thus will be exploited.

High-speed photomicrography will be used as a method of determining the time-dependent characteristics of particle formation and subsequent particle behavior.

Other areas in which parallel efforts will be initiated are high vacuum electrical breakdown in heavy-particle accelerators and particle-beam forming techniques. Particle production techniques other than electrical spraying of liquids will be studied in order to provide realistic and conclusive answers to the questions of the applicability, advantages, and feasibility of electrical propulsion using heavily charged particles.

Electrically Sprayed Liquids for Propulsion (af)
C. D. HENDRICKS,* R. CARSON, L. STERRITT, J. TSUI

This work is directed toward the realization of sources of positively and negatively charged particles in quantities and qualities suitable for incorporation into an "electrodeless electrostatic thrustor” capable of efficient operation at specific impulses in the range from 1000 to 5000 seconds. The currently most successful source of charged particles uses the principle of electrostatically spraying liquids from capillary needles. However, the particle quantities and qualities thus far achieved are not sufficient for incorporation into an electrodeless electrostatic thrustor.
Research will extend the state-of-the-art in charged particle generation through experimental research on the electrical spraying technique. The goals of this research are:

1. Mass averaged particle charge–mass ratio between 10^6 and 10^9 coulombs per kilogram.
2. Particle beam merit factor greater than 0.75 where merit factor is defined by \( C^2 S/C \); \( C \) denotes charge–mass ratio and the bar notation implies mass weighted averages.
3. Particle current output per capillary needle in the range from 0.1 to 2 milliamperes.
4. Extraction potentials from 10^4 to 4 x 10^4 volts.
5. Both positively and negatively charged particle beams will be developed.

**Research on Charged Liquid Droplets** (nsf)
C. D. HENDRICKS,* R. J. PFEIFER, J. M. SCHNEIDER

The proposed research is directed toward the fundamental physical and engineering problems concerned with electrically spraying liquids as described below.

1. The continuous electrical spraying properties of a large number of liquids are to be studied. It is proposed to analyze the results by statistical methods in an attempt to isolate the influence of liquid parameters such as density, viscosity, and electrical conductivity on the specific charge distribution produced by the spraying mechanism.
2. It is proposed to study the specific charge distribution of several liquids as a function of accelerating voltage amplitude and time duration, and to seek some correlation between specific charge distribution and the shape of the current pulse. This may provide some insight into the intervals of emission of ions and droplets.
3. The theoretical treatment of Rayleigh on the stability of charged conducting droplets involves an infinite series of spherical harmonics whose coefficients oscillate sinusoidally in time. The original droplet shape must be known in order to calculate the relative magnitudes of these coefficients. It is proposed to correlate this theory with measurements by inducing ultrasonic oscillations on the surface of the liquid droplets, to study the surface oscillations in the presence of an electric field, and to then relate the induced surface shapes to the specific charge distribution produced by the electrical spraying process.
4. There is some experimental evidence which indicates that the electrical spraying process is influenced by light focused on the liquid at the tip of the capillary tube. It is possible that this is a photofeature which changes the conductivity of the liquid. Pertinent literature applies only indirectly to this problem, probably because the field of insulating-liquid conductivity is beset with differing theories and conflicting measurements. It is proposed to survey the entire field of electrical conductivity of liquids in order to compare techniques and results, and to study the photo-effect in liquids.

**CIRCUIT THEORY**

Circuit theory is divided into two important areas: circuit analysis and circuit synthesis. In analysis, we are concerned with such problems as determining the response of a circuit when a signal is applied. The efficient design of a circuit of resistors, inductors, capacitors, transistors, or other solid state devices to satisfy a given specification is known as synthesis. Areas of research interest include: (1) filter networks, as encountered in telephone systems; (2) distributed networks, as found in microelectronic circuits; (3) transistorized amplifiers and filters; and (4) switching circuits, as found in digital computers.

**Network Analysis and Synthesis** (aofsr)
M. E. VAN VALKENBURG,* D. A. CALAHAN, S. HWANG, G. KELLY, S. LEE, M. TAPIA

**Design of Linear Networks**

Effort in the area of linear networks has been in two directions: (1) to study the fundamental properties of network in areas 1–3 above; and to devise synthesis schemes for such networks; emphasis has been given to practical design factors such as sensitivity to environmental changes; (2) devise efficient computer techniques to analyze and design linear networks (1–3 above); thus, schemes have been developed which automatically find for a network of any form, the element values required to satisfy a given specification.

**Design of Nonlinear Networks**

The advent of many new devices, especially in the field of microelectronics, has prompted a search for mathematical models of these devices so that their behavior in a circuit could be predicted before the circuit is built. Such a search involves:

1. Conjecturing a model from the physical laws governing the device behavior.
2. Making laboratory measurements to find the parameter values of the model.
3. From the model computing the response a network with the device imbedded.

A digital computer program to accomplish (3) has been developed. Theoretical and experimental studies in the areas of (1) and (2) are anticipated.

**CYBERNETICS**

In the tradition of Norbert Wiener’s definition of cybernetics as “communication and control in the animal and the machine,” this group is concerned with the study and construction of systems displaying certain characteristics especially attributed to the animate world, as for example adaptation, self-organization, and intelligence.

The diversity of problems that emerge in this broad field of interest is met with a diversity of approaches that range from philosophy, epistemology, mathematical theory, circuit theory, to technology and construction of systems displaying biomorphic functions. Five projects that deal with this subject matter are briefly described here.
Biological Computers (nih)

Computational principles in living organisms are studied as a point of departure for analysis and construction of cognitive systems. Theoretical work is focused on fixed as well as adaptive information-reducing networks composed of parallel computation channels which extract from the set of all possible inputs certain specifiable invariants (properties). Experimental work is concentrated on the circuitry and technology of such networks. Systems incorporating parallel computation techniques have been constructed.


Theory and Circuitry of Systems with Mindlike Behavior (afosr)

This project is devoted to the development of conceptual and material techniques for the construction and quantitative evaluation of systems showing goal-directed selective reduction of information. Although the general concern is with the prediction and analysis of system behavior in terms of the connectivity and unit function of its equivalent net, particular attention is being directed to freely connected nets of elements whose logical functionality depends on output.


Theory and Circuitry of Property Detector Fields and Nets (afosr)
H. VON FOERSTER,* W. R. ASHBY, M. BABCOCK, K. CHEN, G. GUNTHER, A. INSELBERG, C. C. WALKER, P. E. WESTON

This project concerns itself with the theory and circuitry of information-reducing networks consisting of fixed-function parallel computation channels, each able to respond

This apparatus is used to balance very small water droplets in an airstream to determine their growth by a coalescence process.

Research assistant Ian Thomas speaks into the microphone of a computer designed to recognize different speech sounds. A bank of frequency filters permits the analysis of speech according to its frequency spectrum.
selectively to input subsets invariant under specified transformations. Such invariant subsets, or properties, are analyzed in terms of the connectivity and unit functions of the nets computing them. Formal relations between properties and these net parameters are developed. Physical circuitry and associated technology for selected properties and sets of properties are realized.

On the epistemological level, this project aims at operational definitions of recognition, cognition, abstraction, habituation, adaptation, learning, and consciousness.


GASEOUS ELECTRONICS AND PLASMAS

Electrical gaseous conduction phenomena in ionized gases are of broad interest in electrical engineering and related scientific areas. Rapid control of large currents in electrical power apparatus, and of electromagnetic power in high-frequency and microwave circuits, is widely utilized through applications of electrical conduction in ionized gases. The influence of the ionized gaseous regions in the high atmosphere on long-range radio wave propagation is of primary interest in electrical communications. The Gaseous Electronics Laboratory is equipped with microwave instrumentation to study ionization and deionization phenomena and associated processes in electrical gaseous discharges. The research program reported below is oriented towards understanding basic gaseous discharge phenomena in ionized gases.

Basic Properties of Gaseous Plasmas (afsc)


To further an understanding of the nature of slow collisions, maser techniques are being developed to enable measurements of low electron temperatures and to study the interactions of such a low temperature electron gas (10^4 to 40 K) with neutral helium atoms. In this cryogenic temperature range (liquid He), a rather low degree of ionization plasma (>10%) will already be coulomb-interaction dominated, provided the elastic collision cross section of the atoms with such slow electrons (4 K) does not increase drastically with respect to values at 77 K. This would enable researchers to study under ideal conditions most of the processes which depend upon the collective behavior of the plasma charges.

The second phase of a study of thermal conductivity in coulomb-effect-dominated plasmas is now nearing completion. This work involves the effect of magnetic fields on the thermal conductivity of gaseous plasmas in which the light constituents are weakly coupled to the heavy plasma constituents from the point of view of energy transfer.

In the course of the Laboratory's microwave investigations of electrically driven shock waves, a method of plasma diagnostics has been developed which enables one to determine rapidly varying gaseous plasma parameters. A detailed description of this method is being submitted for publication.

The following specific problems are being investigated:
(1) Collisional processes in quiescent helium plasmas at cryogenic (4.2-10 K) temperatures (completed). (P. Goldan, J. Berlande)
(2) Recombination processes in helium plasmas at cryogenic temperatures.
(3) Measurement of the (3S) metastable excited atomic concentration in helium afterglow by means of spin resonance techniques. (R. Huggins)
(4) Detailed study of the applicability of Saha's equation to shock-heated gases, particularly in nitrogen. (C. Gruber)
(5) Temperature dependence of the volume recombination of nitrogen atoms via the Rayleigh afterglow. (G. Carruthers)
(6) Interaction of microwaves with laserion gaseous plasmas. (L. Weaver and R. Frieberg)


Electromagnetic Wave Interaction Techniques (afsc)

L. GOLDSTEIN, A. K. BHATTACHARYA, J. CAHN, B. CERRINGTON, L. DREYER, E. A. MCLENNAN

In connection with a project designed to demonstrate the possible control by means of radio waves of ionospheric conditions for radio wave propagation, investigations were made in laboratory plasmas of basic processes and ionospheric plasma parameters on which ionospheric control could be based.

The details of electron cyclotron resonance in magnetoplasmas were studied, with particular emphasis on the energy transfer from electromagnetic waves to the electron gas of the plasma and the consequences of such energy transfer in altering those plasma properties which determine wave propagation in such media.

In view of the increase of the electron temperature of the plasma as a result of electromagnetic energy transfer to the free electrons at cyclotron resonance, all plasma properties are altered. Whether such a controllable change constitutes efficient means of altering the electromagnetic wave propagating properties of the plasma depends upon the effect of the electron temperature on these properties. Thus, parallel with the determination of the electron temperature associated with the electron collision frequency, changes with the electron temperature have been studied in detail in monatomic as well as atmospheric gases.

The method of wave interaction used in these studies has thus been further developed and its applicability ex-
tended to the study of low- or high-energy plasma problems, such as radio-frequency, heating of plasma, and plasma confinement by magnetic fields.

In the course of studies on electromagnetic wave propagation in magnetoplasma, Professor J. T. Verdeny has found a mode of propagation hitherto unknown. This rather significant result finds one application, among others, in high-density magnetoplasma diagnostics.

The following three problems are being investigated:
1. Electron attachment to oxygen molecules as a function of electron energy. (A. K. Bhattacharyya, J. Cahn)
2. Negative ion to free electron concentration in low-temperature quiescent oxygen plasmas. (A. K. Bhattacharyya, J. Cahn)
3. The problem of magnetoplasma confinement during and following cyclotron resonance heating of the electron gas component. Development of a new microwave method for the study of stability of magnetoplasmas. Application to ionospheric plasmas are being considered. (B. Cherrington)

Production of Acoustic Waves by RF Breakdown in Low-Pressure Gases (ams)
J. DAYTON, Jr., L. DREYER, R. KAWCYN, J. VERDENY, L. WEAVER

Acoustic waves which are produced as a result of an intense localized breakdown in low-pressure gases are being studied. The breakdown is caused by high-power electromagnetic radiation of one microsecond duration at microwave frequencies. Both rare gases and atmospheric gases are used in the study. Experiments are conducted to discriminate between the sound waves and ion acoustic waves, both of which appear to be present following the breakdown, and to determine whether the sound wave is a true sound wave or a shock wave. In conjunction with this, these acoustic waves are also being used as probing waves to determine the chemical and thermal effects of RF breakdown. Measurements are also being made to determine the amount of energy coupled into the gas from the electromagnetic field and the amount of energy carried by the acoustic waves.


Research Studies of High-Density Plasmas (scusa)
J. GERARD, M. A. GUSINOW, J. T. VERDENY

The utilization of a laser interferometer provides the means for making very sensitive measurements on the constituent gases in a plasma. This interferometer is unique in the sense that the laser acts as the light source as well as the detector for the interferometer. It can be shown that the laser interferometric technique is many times more sensitive than conventional interferometric method and, hence, yields information in greater detail.
OPTICAL ELECTRONICS

The research in this area is concerned with the control of light by electronic methods. More particularly, it has dealt with the modulation and detection of light of microwave frequencies. Progress in this direction promises to make possible new applications of light in communications and other electronic fields.

Problems Related to Optical Communications (afosr)

D. F. HOLSHOUSER, O. L. GADDY

During the year research was continued on methods of modulating light at microwave frequencies and on methods of demodulating this light. Travelling wave Kerr cells were studied in which several modulation signals could be impressed on a single light beam. Continued study of the dynamic crossed-field photomultiplier led to optimization of the field conditions for maximum gain and to improved configurations. Detector current gain exceeding $10^9$ and bandwidths exceeding $10^9$ were achieved. Helium-neon lasers were built and operated as part of the experimental program.


RADIOLOCATION, RADIO WAVE PROPAGATION, AND RADIO ASTRONOMY

Facilities at the University for radio wave propagation and radioastronomy studies are among the most extensive and complete in the country. Two antenna sites are in operation. The largest is a wide-aperture Wullenweber-type array 900 feet in diameter on a 40-acre site. The other antennas include two small-aperture Adeck installations located on a separate 80-acre site. A major on-line data processing system, purchased through a grant from the Office of Naval Research, provides digital computer facilities for data analysis. The
aim of the research is to advance the art of radio location by comparing the various systems and to obtain basic information about the propagation of ionospherically reflected radio waves.

The University of Illinois Radio Telescope, located at the Vermilion River Observatory, was dedicated in 1962 and is now used for research related to intergalactic radio sources.

Since the advent of man-made satellites, their tracking has been a challenging problem. Facilities at the University were immediately set up for this task and have been expanded since, now including a separate research site south of the University campus. Analysis of the signals received provides valuable information about the ionosphere.

A Theoretical and Experimental Study of the Ionosphere by Means of Signals from Earth Satellites (nasal)


For the past six years data were collected on the electron content of the ionosphere by means of Faraday rotation of radio signals from satellites. The scintillation of these signals has also been studied over the six-year period. Theoretical studies supporting this work have been carried on, relating to the formation of the ionosphere, the propagation of radio waves through ionized media, the propagation of radio waves through media with random inhomogeneities, etc. Field stations are maintained at Urbana, Illinois; Houghton, Michigan; Baker Lake, Northwest Territories, Canada; and Adak, Alaska.


Latitude Distribution of Radio Star Scintillation (nsf)

G. W. Swenson, Jr.,* B. J. Flaherty

A chain of three radio interferometers is being established along the 88th meridian to monitor scintillations on radio waves received from the four strongest discrete cosmic radio sources. This project will be carried out over a period of several years in order to determine the sun spot cycle variations of scintillation.

University of Illinois Radio Telescope (onr)


The design and construction of a very large radio telescope, operating on a novel principle, was completed and put into operation in November, 1962. It is currently used for conducting a detailed survey of radio-wavelength radiation from the sky at all declinations between +10 degrees and +70 degrees.


Behavior of Strong Radio Signals in a Magneto-Ionic Medium and Gyro-Interaction Experiments in a Rocket (nsf)

G. A. Deschamps,* R. R. Hodges, Jr.

The general purpose of this project is to extend the understanding of the interaction of radio frequency signals in a magneto-plasma such as the ionosphere. A specific goal is to apply the knowledge of these phenomena to the problems of in situ measurements of ionosphere properties. Previous work has included theoretical and experimental studies of the behavior of electromagnetic fields, particularly those of an antenna, in a magneto-plasma. Experiments have been performed both in the laboratory and in the lower ionosphere using rockets. In the latter the strong interaction of gyrofrequency energy, emitted from a rocket, with the ionospheric electrons has been used to produce localized distortions of electron energy and density. The processes involved in returning these disturbances to equilibrium conditions have been investigated by a cross-modulation technique. These experiments have yielded data regarding the rate of loss of excess electron energy near 95 kilometers and the electron attachment rate near 60 kilometers. The frequency dependence of the impedance
of an antenna in the ionosphere has also been studied experimentally. The present work involves the application of the previous results to the design of improved rocket-borne measurement techniques for use in determining the rate of loss of excess electron energy and the electron attachment rate in the lower ionosphere.


Studies and Investigations Leading to the Design of a Radio Direction Finder System for the MF-HF-VHF Range (usaerdl)

This work is a continuation and extension of two tasks: (1) Radio Direction Finding and Radiolocation Systems, Engineering. An interferometer-type RDF system has been instrumented and is being used to obtain data for the second task. A phase-comparison type direction finder using log-spiral antennas at VHF has been proposed and is being instrumented. A large aperture, six-element Adcock array was proposed for the MF range. It has been essentially completed.

(2) Directional Propagation Research. A direction-of-arrival experiment has been carried out over the 450-kilometer path between Columbus, Ohio, and Urbana, Illinois. The test frequencies were 5155 and 5345 Ka/s respectively. Both the horizontal and elevation angles of arrival have been measured. These data are then used with vertical incidence ionosounder data to attempt radiolocation or single-station fixing.


Applied Research in Radiolocation (bs)

Attempts at the operational use of radiolocation systems involve a variety of smaller research tasks which range from antenna problems, through receiving system and display problems, to signal analysis and evaluation of the statistical characteristics of signals. In the latter area, particular emphasis is placed on techniques for immediate or real time use, in contrast to post-mortem analyses.

During the current year particular emphasis has been given to two subjects. The first of these involves development of tools and techniques for the diagnostic and evaluation testing of large multiband periodic antenna arrays. The tools and techniques have been applied to the solution of a particular problem involving element intercouplings in such arrays. The second subject is signal fading in large antenna arrays. The common solution for signal fading is the use of multiple arrays. When the individual arrays become large, this practice becomes almost prohibitively expensive. There are, however, techniques by which equivalent action can be obtained within a single large array. Such techniques are being studied, and their efficiency determined by experimental means.


Research in Radiolocation and Radio Propagation (onr)

The subject of this program is the use of measurements made on radio signals at a receiving site (or sites) to locate accurately the source of a radio emission. The process requires detailed knowledge of the characteristics of the radio wave propagation, and of the morphology of the region through which the wave has propagated. Of particular interest is the frequency range over which the ionosphere plays a dominant role in radio signal propagation.

Studies are in progress in a number of areas, including (1) antenna systems and unusual receiver systems, (2) use of the elevation component of signal arrival angle in the radiolocation process, and (3) ray-tracing procedures, using digital techniques and improved models of the ionosphere.

Development of the best, or most suitable, model of the ionosphere is a specific objective.

Several of the studies being conducted on this program include an investigation of the application of digital techniques to the radiolocation problem. In addition to the use of digital processes for data processing and computation, other areas under investigation include: (1) the acquisition of experimental data in a digital format, (2) the simulation of radiolocation systems and problems in digital form, and (3) the use of digital techniques as an integral part of a radiolocation system.


R. F. Donnelly, "Matched Channel Amplifier Alignment and
Ionospheric Research and Propagation Studies
Using Moon Reflections (usaredl)

H. D. WEBB,* A. HARDY, F. ZIOLKOWSKI

The purpose of this project is to receive radio signals by
reflection from the moon, record them, and use the recorded
signals for studying the ionosphere above the earth and
the nature of the reflecting surfaces on the moon.

The signals are transmitted toward the moon at 150.6
mc from a transmitter operated by the U.S. Army Elec-
tronic Research and Development Laboratory, located at
Belmar, New Jersey. The receiving station is located on
the Vermilion River Observatory area, near Danville,
Illinois.

Signals have been recorded for over 3,000 hours dur-
ing more than 350 days of observation. The changes in
the Faraday rotation of the plane of polarization of the re-
ceived signal have been read out and used to calculate
the relative columnar electron content for most of the
days of observation. The relative electron content has been
plotted for each day of observation, and averages show-
ing the diurnal change in electron content have been
compiled for most of the observation periods of two to
three weeks. These averages show seasonal effects and
the effect of the decreasing solar activity from 1961 to 1964.
The daily plots show several kinds of irregularities, indi-
cating abnormal changes in electron content up to about
4 or 5 x 10^6 electrons per square meter column taking
place in time periods of several minutes, one hour, or
several hours.

The studies being pursued include: (1) correlation of the
changes in electron content with changes in the horizontal
component of the earth's magnetic field; (2) comparison
of methods for resolving the ambiguity in the Faraday
rotation angle; (3) use of the data to study the nature of
the lunar reflecting surface; (4) comparison of relative
electron content values calculated from data taken simulta-
neously at Danville, Illinois, and Hansom Field, Bedford,
Massachusetts; and (5) correlation of irregularities in
electron content with the occurrence of traveling iono-
spheric disturbances as determined from ionograms.

SEMICONDUCTORS AND SOLID
STATE DEVICES

Research on semiconductors and semiconductor devices covers
a broad area, including surface properties, light modulation
at PN junctions, junction lasers, and metal-oxide-semicon-
ductor (MOS) field effect devices. Among the facilities avail-
able for research are ultrahigh vacuum equipment for surface
studies, electron spin resonance equipment, furnaces for syn-
thesis of 3-5 compounds, diffusion of PN junctions, and
epitaxial growth of thin layers; high vacuum and metal
evaporation equipment for fabrication of MOS structures and
a variety of equipment for electrical and optical measure-
ments.

Surface studies are mainly on cleaved surfaces of ger-
manium and silicon, although some work is under way on
very thin metallic films on insulating substrates. Light modu-
lation studies are with PN junctions in silicon, germanium,
and gallium arsenide. Most of the work on junction lasers
is on 3-5 compounds, particularly the system Ga(As1-xP x).
The work on MOS structures is concerned with channel
conductance, noise and noise mechanisms, surface states at
the oxide-silicon interface, and investigation of possible causes
for instabilities.

The group conducting this research consists of J. Bardeen,
A. Free, P. Handler, N. Holonyak, Jr., C. Penchina, and
C. T. Sah.

Semiconductor Device Research† (uii)

N. HOLONYAK,* R. W. BURTNESS*

This work is intended to lead into productive areas of
semiconductor device research, in particular the area of
semiconductor laser work. Background information is being
gathered and general directions of pursuit are being deter-
dined.

†This research was conducted jointly by the Department of Electrical
Engineering and the Materials Research Laboratory.

Research in Semiconductors† (onn)

P. HANDLER*

Three different programs are under investigation directed
atward understanding the basic electronic properties of
solid surfaces:
(1) The electron spin resonance of a paramagnetic ion on the surface of a single crystal of ZnS.
(2) Two-dimensional conductivity of less than a monolayer of atoms on a single crystal surface. Studies are under way on ultra-thin films of magnesium on cleaved magnesium oxide substrates.
(3) Surface conductivity of cleaned germanium surfaces cleaved in a liquid nitrogen ambient.

A paper entitled “Transport Properties of Light and Heavy Holes in the Clean Germanium Surface” was presented before the International Conference on the Physics and Chemistry of Surfaces at Brown University, Providence, Rhode Island. A second paper entitled “The Surface and Micro Miniaturization” has been accepted for inclusion in a special IEEE issue on micro-electronics.

Clean Surface Studies on Semiconductors (râfc)
P. HANDELM, A. FROVA
The basic physical properties of clean silicon surfaces and their interaction with gases are under investigation. The experimental techniques include electrical, optical, and magnetic properties of silicon surfaces under ultrahigh vacuum conditions and also in the oxidized state. The clean surfaces are prepared in vacuum by cleavage. Also in process are the development of new optical techniques for the measurement of very small concentration of defects at the surface.

Research in Surface Physics (arpa; ul)
P. HANDELM, A. FROVA
This work is directed toward an understanding of the electronic properties of semiconductors and interfaces. At the present time the optical absorption properties of a wide-angle germanium grain boundary are under investigation. Analysis of the data should indicate how the distortion at the interface alters the band structure of the solid.

SERVOMECHANISMS
Nonlinear Discrete and Sampled-Data Control Systems (nsf)
B. C. KUC, K. R. CARR
Virtually all elements used in physical control systems have imperfections and limitations. In order to take into account the effects of these operating limitations, nonlinear analyses must be conducted. When nonlinearity and digital data appear in a control system simultaneously, new phenomena and problems arise which do not occur ordinarily in either linear sampled-data systems or nonlinear continuous-data systems. It is the objective of this research to analyze and design discrete and sampled-data control systems with nonlinear elements.
The principal areas in which the research work is conducted are the optimum design of systems with deadbeat response using signal controller and digital controller, statistical considerations, signal stabilization, dual-input describing function analysis, and multirate sampling.

**SUBMILLIMETER WAVE—FAR INFRARED RESEARCH**

The principal research objective of the Ultramicrowave Laboratory is the generation, transmission, and detection of coherent signals in the wavelength range 100 to 1000 microns.

Source studies include both classical and quantum electronics approaches to the problem.

Transmission studies have concentrated on the reflecting beam wave guide, an all-metal system originated in the Ultramicrowave Laboratory.

Detector studies have included semiconductor diodes, pyro-electric materials, and quantum photon counters.

**Megavolt Electronics — Submillimeter Research (asd)**

P. D. Coleman, M. D. Sirkis, J. R. Baird, W. Kunz, R. Heeren, C. Wang, R. Likuski

The research on classical electronics has been based primarily upon bunched, 1 Mev electron beams produced by 3 and 35 Ge Rebatrons (Relativistic Electron Bunching Accelerator Tubes).

Other studies involve quasi-optical electronic techniques and harmonic generation by means of electron beams. Classical electronics beam coupling structures being investigated include: Cerenkov radiators, transition radiation couplers, and plasma couplers.

Research on fast electron pumping of masers and lasers has recently been initiated. Materials being bombarded by 20–900 Kev beams are: GaAs, ZnS, CdS, and Ruby.


Studies in Quantum and Solid State Electronics (afosr)
P. D. COLEMAN,* D. AKITT, R. ROLDAN, W. JEFFERS, M. CHANG

The aim of this research is submillimeter wave spectroscopy and maser studies. Current work is concerned with the design and construction of a monochromator covering the 100–1000 micron range for studies on sources, detectors, and materials.

Nonlinear multiple photon studies in HCN have resulted in the production of some two watts of power at 105 Gc when the gas is pumped at 35 Gc.

Study of submillimeter spectroscopy of red ruby by means of optic fluorescence is continuing.


Submillimeter Receiver Techniques (rafc)
P. D. COLEMAN,* M. D. SIRKIS, J. DEGENFORD

The aim of this work is the investigation of heterodyne receivers based on components and detectors compatible with reflecting beam wave guides.

Wall current crystal detectors having loop coupling to the electromagnetic field have proven very successful. Recent results have yielded −86 dBm sensitivity at 75 Gc.


The research program in General Engineering currently involves engineering graphics, engineering meteorology, studies in the development of a sequence of project design courses, the unified, coordinated drafting standards for industrial and military production in this country and abroad, curriculum studies in Civil Engineering Technology and Machine Design Technology, and a study to determine the need for engineering technicians in Vermilion County. In addition to these projects, staff members are engaged in cooperative research efforts with other units of the Engineering Experiment Station, namely, the Department of Civil Engineering, and with such agencies as the Illinois State Water Survey. Principal outside sponsors include the U.S. Public Health Service, the U.S. Office of Education, the Illinois State Board of Vocational Education, Argonne National Laboratories, and the American Standards Association.

In the field of meteorology, studies are being conducted to investigate the effects of wind and related forces on the diffusion of gaseous, aerosol, and particulate matter through the atmosphere. The special vehicle chosen for investigation has been naturally radioactive radon, Rn-222, which escapes from the soil. The specific emanation rate of radon is being determined as a basic factor affecting other elements, using an alpha scintillation method, and distribution above ground is also being studied. Results should provide insights into the basic mechanisms of movement and diffusion for both gases and particles under varying meteorological conditions.

In the field of engineering technology, the Department has developed a curriculum guide in Civil Engineering Technology for the U.S. Office of Education. It provides an instrument that can be used by various institutions undertaking the establishment of a two-year program of Civil Engineering Technology leading to an associate degree. In addition, a 16-week training program for highway engineering aides has been developed.

Under a grant from the Illinois Board of Vocational Education, the Department of General Engineering is supervising the conducting of an Engineering Technician Need Study in Vermilion County. In addition to this, a program guide for a two-year associate degree in Machine Design Technology has also been developed.

In the field of standards, members of the Department have led the development of new means to increase production efficiency and interchangeability. Such efforts have included taking an important part in compiling, revising, editing, and improving the American Standards Drafting Manual. Work is also advancing on the international scene, particularly in reconciling United States, Canadian, and British standards, and in relation to the International Standards Organization.
Curriculum Development in Engineering Technology (ibve; ui)

J. S. DOBROVOLNY, D. S. BABB, C. E. BOWMAN, E. L. BROGHAMER, R. J. PLACEK

In order to provide a guide for teachers and administrators who are developing programs in machine design technology, this study has attempted to identify the needs of various engineering technology curricula and to develop specific course content for the various courses in this field; to help explain, in conferences, the philosophy of course and curriculum content and to publish the results. The data gathered for other technologies will be used in subsequent studies to develop further guides in engineering technology.

In gathering the data for the Machine Design Technology curriculum guide, personal interviews with industry representatives, engineering educators, and engineering technology educators, and junior college teachers have been conducted. Conferences were held with local advisory committees, with teachers of specific subject matter, and with persons at the national level involved in this type of education. A thorough search of the literature and, where appropriate, questionnaires were used to obtain supplemental information.

A follow-up study will be conducted after the curriculum guide is published to evaluate the effectiveness of the instrument and make such recommendations for revision as may seem appropriate.


Course of Study for Highway Engineering Aides (usoe)

J. S. DOBROVOLNY, E. DANNER, J. W. HUTCHINSON, B. O. LARSON, W. A. McCREE, T. H. THORNBURN

This project was concerned with the development of a course of study for the training and education of highway engineering aides. The program guide outlines a 16-week course of study, program objectives, scope and depth of instruction, entrance requirements of the trainee, written and shop or laboratory performance tests, training program outlines, suggested classroom, shop and laboratory equipment and lists of texts and references, audio-visual and other instructional aids, and suggested sequence and training hours for each phase of the training program.

This was published in a 40-page pamphlet entitled, Training Program for Highway Engineering Aides, and has been used in various programs sponsored by the Manpower Training and Development Act under the administration of the Department of Health, Education, and Welfare.

The purpose of the program is to assist administrators, supervisors, teacher-trainers, and teachers in the promotion and development of courses designed for technical personnel.


Development of a Suggested Guide for a Curriculum in Civil Engineering Technology (usoe)


The study aims to provide an instrument that can be used by various institutions undertaking the establishment of two-year programs of engineering technology, normally leading to an Associate Degree. The curriculum guide includes detailed course outlines for each of the technical courses listed in the curriculum, a list of detailed specifications of equipment needed for the laboratories required in the program, a list of major supplies with approximate costs, an annotated list of texts and references, a list of training needs, and some typical problems to be used in the various courses. Included are classroom and laboratory layouts with scale drawings of suggested equipment locations and curriculum patterns as well as sequences and contact hours for each phase of the training program.

Technician Need Study — Vermilion County, Illinois (ibve; ui)

C. A. MURPHY, P. E. BOOTHE, J. S. DOBROVOLNY, H. D. REID, W. J. SCHILL

This is a study of practicing technicians in Vermilion County, Illinois, and of the industries which employ these technicians. The report consists primarily of descriptive and parametric information relating to:

(1) The demands of Vermilion County industries for technicians.
(2) Identification and job functions of technicians.
(3) Educational needs of technicians as stated by:
   a. The technicians
   b. The employing firms
(4) Potential student enrollment in technical education.

The study is intended to be a pilot project in an effort to develop improved techniques for assessing technician needs in a community. All instruments used are included in the report.

The report is written for general distribution. Familiarity with statistics is not a necessity for the reader.


Technician Need Study — Lake County, Illinois (ibve; ul)

C. A. MURPHY, J. S. DOBROVOLNY, W. J. SCHILL

This study will be a further developed and improved version of "Technician Need Study—Vermilion County, Illinois." The report will include all instruments used and will be written so it can be understood by a reader who is not familiar with statistics. The study will use statistical inference from a sample which will be used to estimate:

(1) The demands of Lake County manufacturing industries for technicians, (2) Identification and job functions of technicians, (3) educational needs of technicians, and (4) potential student enrollment in technical education.
American Standards for Drawing and Drafting Practices (ui)
F. L. SPALDING*

The American Standards Association Sectional Committee, Y-14—Standards for Drawing and Drafting Practices—is engaged in the development of national standards for drawing and drafting practices. It is hoped that this will provide a basis for the standardization of these practices in industry. The total area to be covered has been divided into 19 sections, 13 of which have been issued and are now in the process of revision, and 4 of which are in preparation.

In addition to the preparation of national standards, Y-14 actively cooperates with the British and Canadian standards bodies in the preparation of unified drawing standards. A subcommittee of Y-14 has been organized to cooperate with the military in the preparation of military standards. Another subcommittee is now engaged in the coordination of American Standards Association, Society for Automotive Engineers, and Military standards on dimensions and tolerances.

American Standards are based on the consensus principle, so that membership in the various committees is from the widest possible variety of industries, professional societies, and trade associations. Members of the committees are selected as far as possible on the basis of competence in the areas involved. The American Standard is developed by men who work voluntarily, with or without special compensation of time or money by their employers. Fred L. Spalding of this department is chairman of this committee.

Design and Testing of a Form for Student Evaluation of Teaching (ui)

A rating form for student evaluation of instructors has been designed and used by 1,326 students enrolled in 80 sections of 16 different courses in the Department of General Engineering, University of Illinois.

Twelve factors considered to be involved in teaching were described in terms of operational or behavioral definitions depicting various levels of proficiency. Selection of a described proficiency is believed to permit a student more exactly to express his evaluation than is thought possible through the use of the hypothetical A, B, C, D, or E rankings.

Data are being machine processed and reliability is being obtained. An item mean rating intercorrelation matrix has been computed, and interpretations are being prepared. The results of the student evaluation will be used for administrative purposes and instructor information. Further statistical analysis will be accomplished to refine the rating form as a research instrument.

Direct Isometric Projection (ui)
W. L. SHICK*

Four claims have been formally allowed in the patent application for a device for orthographic-isometric projection. Patent will be issued in 1964. The device consists

Graduate assistant Gary Jones is collecting naturally occurring radon emanating from the soil. The radioactive gas is being used as a tracer in atmospheric diffusion studies.
of a plastic quadrangle which operates against three guide edges constituting a triangular frame. Projection is direct between top, front, side, and isometric views in an interrelated position.

An isosceles triangle has been developed to operate against the ruling edge of the standard drafting machine, or any straight edge, directly projecting an isometric view from the orthographic views of standard engineering drawings.


Investigation of “Life-Style” Occupational Images Held by High School Students (ui)

T. C. HARTLEY, L. E. AUKES

The occupational “life-style” images held by high school students were investigated, using the semantic differential method. Data were obtained from approximately 800 high school students attending Engineering Open House at the University of Illinois in March, 1964. Of particular interest is the “life-style” image of an engineer held by these students as it might relate to engineering recruitment. Semantic differential data together with data regarding sources of information about engineering and demographic data are being machine processed.

Preliminary results show the existence of a definite “life-style” image of an engineer among high school students, which differs from “life-style” images reportedly held by college students. Norms will be established for engineers in training and engineering graduates.

Results will relate to current informational materials regarding engineers being utilized for recruitment by the College of Engineering, University of Illinois.

The Transfer of Natural Radon into the Atmosphere (dap - phs)

J. E. PEARSON,* D. H. RIMBEY, G. E. JONES, S. SHIMIZU

This project is to determine the emanation rate of radon-222 from the soil-atmosphere interface using an alpha scintillation method. Radon collected at the earth’s surface is adsorbed on chilled coconut charcoal, transferred to counter bottles lined with a scintillating material, and the disintegrations are counted. From such counts, emanation rates are determined.

Experimental work is centered on the agronomy plot sector of the south farm of the University. Variation in the rate of emanation in a circular area within 8 miles of this site is being investigated. The variation with location (nine sites studied), soil type, wind speed, and soil moisture is included. Locations have also been investigated in Colorado and New Mexico where the emanation rate is approximately one thousand times that measured locally. A 24-hour study of emanation was made, samples being taken every 15 minutes, to determine diurnal change in emanation rate. The effects of season and time of year are also being evaluated.

In conjunction with radon emanation measurements, soil contents of radium-226, parent isotope of radon-222, have been determined. Various soils of Champaign County have been tested for emanating radium-226 content at different locations and depths as have soils from other parts of the United States and Iceland.

Automation Prototype (ui)

W. F. BERKOW*

Automation may be defined as a machine which tells another machine what to do. The governing machine may be a complex memory circuit which controls a sequence of operations, or a simple sensing device, as for instance a thermostat, which senses a change in temperature; a strain gauge, which senses a change in dimension; a photocell or a limit switch, which senses the approach of an object; or a spectroscope, which senses a change in color. The impulse from the sensing device may be utilized to open a valve, start a motor, or engage a clutch for desired effect.

The automatic function may be limited to do a job. In addition, auxiliary functions may be included, such as self-correction, self-lubrication and self-defense against improper material and inadequate operators.

An automatic machine need not be expensive. There are available in the market many types of sensing devices, pneumatic and hydraulic components, indexing tables, controls, instruments, etc., made to high precision specifications and mass produced for low price. Often a machine may be designed utilizing substantially standard components, to perform a desired operation efficiently and inexpensively.

A prototype of automatic machines was designed and built at the General Engineering Department of the University of Illinois, for the purpose of illustrating to students the above mentioned concepts and criteria. The main function of the machine is to locate work pieces within 0.001 inch of true position. The approach of each work piece is sensed by a limit switch, which actuates a locating mechanism. Provisions are made to illustrate subsequent operations, such as clamping, machining, assembling, and crimping each located work piece, also built-in safety devices.

The Effects of Atmospheric Stability and Shear on the Accumulation and Diffusion of Naturally Occurring Radon (ui; anl)

H. MOSES,* J. E. PEARSON,* J. R. STINSON*

Experimental data taken at Argonne National Laboratory are being analyzed. Data include measurements of radon (Rn-222), wind speeds, and temperatures at six levels, in addition to the regularly scheduled recordings of meteorological data. Profiles of wind speed, temperature, and radon concentration in the lowest sixteen meters of the atmosphere are being studied to determine their relationship to profiles appearing in the literature. Four of the wind profile laws were evaluated by comparison with measured data using least squares techniques.

Research in mechanical and industrial engineering during the past year has included programs in gas dynamics, heat transfer, thermodynamics and transport phenomena, metal cutting, heating and air conditioning, internal combustion engines, machine design, industrial engineering, and human factors in physical environment.

New facilities have been developed or are under construction, including a low-density, hypervelocity, continuous-flow wind tunnel; plasma tunnels; an analog equipment for the areas of heat transfer, automotive engineering, and controls; and unique test equipment for research in machine design.

An important factor in the development of research programs and expanded facilities is the cooperation between the department of Mechanical and Industrial Engineering with the departments of Aeronautical and Astronautical Engineering, Physiology and Biophysics, and the Coordinated Science Laboratory.

Professor W. E. Bair (right) and electronics technician J. L. Link are building a thermal analog computer for heat transfer studies.
Passive Thermal Analog (ui; aec)
L. D. SAVAGE*

A passive analog for transient potential field studies is being developed with a general three-dimensional representation as one facet of the device. It will be capable of representing sources and sinks as well as changes in the characteristics of the field.

At the present time construction is approximately 25 percent complete.

Supersonic Combustion of Hydrogen in the Wake of a Two-dimensional Blunt-based Body (ui)
L. R. DAVIS,* H. H. KORST*

The flow in the base region of a two-dimensional body with the presence of chemical reactions is being investigated. Combustion is obtained by injecting gaseous hydrogen from the body base into the wake where it burns along the turbulent mixing region between free jet and ambient air. An analytical analysis of the problem is being made assuming turbulent Lewis and Prandtl numbers of 1.0, existing mixing concepts, and a flame sheet concept. The ensuing governing equations are to be solved with an IBM 7094 computer to yield concentration, temperature, and velocity profiles. An experimental apparatus is to be used to determine these profiles for a free stream Mach number of 2.0.

Basic Research Investigation on Flow Mechanisms and Heat Transfer in Separated Flows (nasa)

Studies are concerned with the phenomena of separation, reattachment, and the dynamics and thermodynamics of fully separated flow regions.

Analysis is generally based on interaction between inviscid and viscous (compressible, non-isentropic) flow fields.

Theoretical flow models have been established for dealing with steady, quasi-steady and nonsteady flow problems of practical importance. In particular, new and unique methods of dealing quantitatively with cavity flows, supersonic ejector systems (thrust augmentation and altitude simulation of jet and rocket engines), the transonic buffet problem, base heating and base drag of missiles (prototypes, models, evaluation of short duration techniques), and fluid jet control devices have been developed.

The analytical work is supported by extensive experimental investigations within and outside of this institute (in the United States and abroad).


Bubble Motion in a Turbulent Liquid Stream (sec)
B. T. CHAO,* J. L. BAKER, L. W. FLORSCHUETZ

The motion of individual air bubbles in a water stream flowing turbulently in a vertical conduit was investigated by photographic means. The bulk water velocity ranged from 40.8 to 267 cm/sec, corresponding to a system Reynolds number of 48,600 to 386,000. Bubble sizes ranged from 0.076 to 1.60 cm in equivalent diameter. Results are summarized in charts showing the variation of drag coefficient with bubble Reynolds number with system Reynolds number as a parameter.

Another phase of the study is concerned with the mechanics of vapor bubble collapse. The relative importance of the effects of liquid inertia and heat transfer on the collapse rate has been delineated and a dimensionless parameter identified suitable for the characterization of the mode of collapse. Discriminating values of this parameter have been proposed for the simple case where the collapse is initiated by a step change in pressure or temperature. Experimental results give support to the theory.


B. T. CHAO,* B. G. JONES, K. MIN, M. A. SHIRAZI

Theoretical and experimental investigation of the motion of a particle suspended in a flowing turbulent field is being made utilizing fully developed core turbulence of water in tubes. Small solid particles, having varied densities and sizes, are introduced separately into the core region of the tube. The Lagrangian characteristics of their trajectories are determined and analyzed with respect to the Eulerian characteristics of the core which are obtained from anemometer measurements. These results are compared with theoretical predictions for the behavior of the particles and are examined in detail to establish the fundamental relationships between the statistical characteristics of turbulence in moving and fixed reference frames.

Parallel to the foregoing study is the measurement of electrostatic charge on solid particles in solid-gas suspension flow. A probe-type Faraday cage has been developed which, when used in conjunction with a pulse counting system, enables the determination of the charge spectrum of the particles. Using the basic information from the charge measurements, it has been theoretically established and experimentally verified that it is feasible to improve heat transfer in solid-gas suspension flow by subjecting the particles to a fluctuating electric field of moderate intensity. Experiments are conducted to test the validity of a theoretical model proposed for the analysis.


Thermal Transients in Steady, Incompressible, Laminar Boundary Layers (ui)

B. T. CHAO,* D. R. JENG

The initial phase of this analytical study concerns the thermal boundary layer response at a two-dimensional and axisymmetric front stagnation due to either a step change in surface temperature or heat flux. Two appropriate asymptotic solutions, valid for small and large times, are found and satisfactorily joined for wide ranges of Prandtl numbers. The small-time solution utilizes a transformation of the energy equation in the Laplace transform plane to an ordinary differential equation with a large parameter. An essential feature of the large-time solution is the use of Mckvyn’s boundary layer variable and the method of steepest descent in the evaluation of integrals.

The method of analysis is being extended to flow over flat plates, rotating discs with uniform suction, and to general three-dimensional stagnation flow of an electrically

Mechanical engineers are studying thrust vector control in supersonic Mach 2 wind tunnel.

This model is being employed for the study of the thermal resistance of dissimilar metals in contact in a vacuum environment.
conducting fluid in the presence of a normal magnetic field with simultaneous blowing.


Similarity Criteria for Thermal Modeling of Spacecraft (ui)

B. T. CHAO, G. L. WEDEKIND

Much of the complex electronic equipment and instrumentation being used on spacecraft must be maintained within narrow temperature limits if dependable operation is to be assured. As the size of spacecraft increases, there is an ever-increasing demand for testing scaled-down models and deducing therefrom the necessary information with reasonable accuracy. This investigation is prompted by such technological need.

General scaling criteria have been deduced from the governing equations of the temperature field with due consideration of the possible variation of the thermal properties with temperature and nondiffuse surfaces. Two techniques, namely, temperature preservation and material preservation, are examined in detail. It has been found that the control of apparent thermal conductivity of materials by mechanical means offers interesting possibility for both steady and nonsteady simulation. Future work needs to be supplemented by experimentation.

Theoretical and Experimental Study of Thermal Contact Resistance in a Vacuum Environment (nsa)

B. T. CHAO, A. M. CLAUSING, R. O. McNARY

An analytical and experimental investigation is being carried out on basic mechanisms underlying the thermal contact resistance across various metallic interfaces in a vacuum environment. The theoretical model which has been established allows a qualitative and quantitative analysis of the influence of varied parameters. This model is being applied for the study of the influence on the contact resistance in contacts between dissimilar metals.

Experimental results give good support to the conceptual correctness of the model and hold promise for its successful explanation of apparent discrepancies reported in the literature.


Vapor Bubble Collapse and Liquid Particle Entrainment (nsf)

B. T. CHAO, R. A. MEDROW, D. D. WITTKE

An experimental and analytical study on the mechanics of vapor bubble collapse in subcooled liquids has been continuously progressing in the Heat Transfer laboratory since 1962. Attention was focused on the behavior of a single bubble undergoing spherically symmetrical collapse in a quiescent liquid of large extent. The work is now extended to include the effect of bubble translational movement under conditions when heat transfer is the dominating mechanism. The important problem of evaluating vapor velocity at the bubble wall is examined.

Another phase of the project which has just begun concerns the mechanics of liquid particle entrainment, with special emphasis on the physical and electrical behavior of small drops in a moving gaseous or vapor stream. The problem of entrainment arises in steam generation, distillation, and evaporation processes. In nuclear power reactors, the carry-over of radioactive material in direct cycle steam generation is a subject of particular concern. This research aims at seeking an understanding of the fundamental processes which control the entrainment of small liquid droplets in a gas or vapor.

Surface Boiling Studies (ui)

R. F. LARSON

Boiling of a liquid on a heated surface has been classified as either nucleate or film, depending on how bubbles appear to originate and grow before they leave the surface. Nucleate boiling seems to be a characteristic of the smooth well-wetted surface, while film boiling is a characteristic of a non-wetted surface.

At sufficiently high heat fluxes, all heated surfaces develop a non-wetted or less of liquid contact characteristic, leading to less effective heat transfer and surface overheating, thus limiting their usage. The limiting-safe or incipient burnout heat flux appears to be a function of the liquid-to-surface specific wetting characteristic, the presence of or buildup of a surface contaminant, and to some extent the physical roughness of the surface. The influence of these factors is being investigated and evaluated. Both solid-liquid and liquid-liquid interfaces are being employed.

Radiant Heat Exchange for Nondiffuse Surfaces (ui)

R. E. HERING, A. HOUCHENS

Most materials used in engineering practice are neither specularly nor diffusely reflecting as assumed in calculations of radiant heat exchange processes but reflect energy in some manner between these two extreme cases. Recent measurements have verified the directional energy distribution for roughened surfaces predicted by theory. Analysis in progress to evaluate the importance of directional property dependencies on the radiant heat exchange predictions and develop methods of analysis which will adequately account for these effects in a reasonably simple manner.

Lattice Thermal Conductivity (ui)

E. A. JACKSON

The transport of energy through an anharmonic lattice is being investigated theoretically, using a purely mechan-
Physical and statistical approaches. The former consists in finding simple models which both exhibit energy flow and are amenable to normal mode analysis. The statistical approach involves a finite lattice coupled with two thermal reservoirs. The method consists in using an inhomogeneous Liouville equation, involving collision terms with the reservoirs.

Experimental Investigation of Burnett Equations (ui)

R. L. Smoot* (deceased July 15, 1964)

The validity of the Burnett equations as the governing flow equations applied to an enclosed rotating disk system is being investigated. The experimental system consists of a 12-inch-diameter disk rotating at 20,000 rpm in an isothermal atmosphere at pressures from 1 micron to 100 microns. The velocity field between the rotating disk and a stationary disk is measured, and the conventional flow parameters are determined from these data.

Properties of Two-Phase Flow—Electric Phenomena (onr)


Research includes measurement and generalization of electric phenomena relating to: (1) concentration and mass flow distribution of solid particles; (2) the effects of electric charges on solid particles due to charge distribution at surfaces, and thermal electrification by thermionic emission as limited by space charges; and (3) the removal of electrons by charged and uncharged solid particles. (1) and (2) concern the performance of a rocket with solid or metallized propellants; (3) concerns a means of reducing the attenuation of radio waves by an ionized gas.


This blowdown wind tunnel serves for the measurement of the flow of a gas-solid suspension through a two-dimensional nozzle.

Graduate assistants are using this vacuum chamber for the study of the behavior of a rarefied gas near the surface of a high-speed rotating disk.
Transport Properties and Processes in Partially Ionized Gas (nsf)
S. L. SOO,* M. N. BAHADORI, S. COLBURN, M. W. WOLF

Study includes a two-dimensional model with laminar boundary layer motion of ionized gas between parallel plates. The gases are helium and argon. With optical measurement of temperature profile and spectroscopic determination of ion concentration, the transport properties and velocity distribution are calculated from integral equations of momentum, concentration, and energy. The experimental range covers from low-temperature glow discharge to high-temperature arc discharge in the continuum flow range, with various degrees of recombination at the surface. The aim is to extend the present knowledge of boundary layer theory to include the state of ionized gas for design and engineering of apparatus involving high-speed flow of ionized gases.


Warm Air Furnace Research (nwahaca)
S. KONZO,* W. BURGOYNE, K. Y. CHAO, R. HENNINGER

Current research is concerned largely with studies of air flow at low velocities at entry to return intake openings, as affected by various configurations of vanes and of return ducts connected to the intakes. A parallel investigation is being conducted on air discharge from ceiling type register openings in which directional vanes are used to control the initial direction of air.

In both studies the experimental investigation was directed toward the use of the Water Table, a hydraulic analog equipment. Effort has been directed in the past toward a correlation between experimental results and theoretical analyses of low-velocity flow.

A tremendous number of different configurations are involved in the complete study, and any summary work will have to await the accumulation of the experimental evidence from these large numbers of types.

B. W. Hrycakewicz and J. H. Hoily, “Investigation of Modulated Heating in Research Residence No. 4,” University of Illinois Engineering Experiment Station research report FWA-14, August, 1962.


 ballet = Steam and Water Heating (fbrm)
W. S. HARRIS,* W. J. GRAHAM, R. R. LASCHOBER, D. F. SPURLING

This is a continuing research program which covers all phases of residential heating and cooling, using water systems. The specific projects included in the current year’s program are as follows:

(1) A statistical investigation of factors affecting output of single and multiple tier finned-tube units.
(2) A study of factors affecting the cleanliness of operation of baseboard systems.
(3) Boiler selection factors for zoned hydronic systems.
(4) A study of valance systems for cooling.


Safety of High-Temperature Water Systems (ash)
W. S. HARRIS,* C. P. ARMSTRONG

The current phase of this project is a study of the temperature profiles in the discharge jets from an 8-inch orifice. The scope of the tests includes water at 200°F, saturated steam, and high-temperature water at approximately 200°F, with upstream pressures on the orifice ranging from 75 to 150 pounds per square inch. Attempts will be made to measure the quantity of room air entrained in the discharge jet.

Steam and Condensate Flow in Pipes (ash)
R. R. LASCHOBER,* D. G. BARBEE

In order to study what effect steam and condensate flowing in opposite directions in the same pipe have on pressure drop and carrying capacity, an experimental piping system has been installed in the Mechanical Engineering Laboratory. The system includes all equipment necessary for accurately determining loads and pressure drops, in addition to glass pipe sections used for making visual observations of the steam and condensate flow patterns.

To date, tests have been completed on 1-inch and 2-inch copper tubing at pitches of ½-inch and 2 inches per 10 feet. Tests with 2-inch tubing at a pitch of 5 inches per 10 feet and ¼-inch tubing at 2 inches per 10 feet have also been completed. Currently, investigation of a ½-inch tube installed at a pitch of 5 inches per 10 feet are near completion.

Considering the condensate flow as channel flow within a circular channel, and applying Navier Stokes’ equations has lead to successful correlation of the data.
Residential Electric Heating (sii)
R. R. LASCHEBER,* R. B. THOMSON
An organized research program is currently being conducted to evaluate the space comfort provided by various types of currently available electric heating systems. Other system features, such as controls, methods of control, and over-all cost are also evaluated. The work is being done in the Electric Heating Research Residence (formerly the Warm Air Research Residence No. 4) which is a tri-level structure of frame and masonry construction.
During the course of this investigation several heating systems have been tested; namely, a baseboard system, a high-density output ceiling panel system, and a low-density output ceiling panel system. Each of these systems has been operated in conjunction with several different types of controls in order to evaluate the effect that the control system may have on space comfort. The results obtained from these investigations indicate that space comfort is significantly affected by the type of control system used.

Effect of Atmospheric Environment on Human Beings and Animals (ui)
M. K. FAHNESTOCK,* R. L. GALBRAITH
The current work—Study of the Comfort and Physiological Effects of Air Velocities on Clothed Human Subjects Under Different Environmental Conditions—is the fifth phase of a clothing and comfort study involving fabrics of widely different air permeability characteristics, and of both hydrophobic and hydrophilic fibers. Normally the clothed female subjects were exposed to several environmental conditions which cover the range commonly encountered by the general population. The emphasis was on air velocity effects. The clothed subjects were studied in a comfortable environment of 74°F and 45% r.h. prior to, and after being exposed to, a hot-humid environment of 94°F and 80% r.h., with three different air velocities in the comfortable environment. The data are being processed and will be the basis for a technical paper.

Selection and Application of Air Measuring Devices (ash)
W. F. STOECKER,* F. C. HAYES
Following the installation of an air conditioning system the rates of air flow at the supply- and return-air registers must be adjusted to conform to the design. The objective of this project is to develop procedures for accurately measuring the air-flow rates.
All commonly used velocity meters are affected by the direction of the air flow, and in the return-air registers that have been studied so far the direction varies from one point to another at the face of the register. An analytical method has been developed, based on potential flow theory, that will permit correction for the directional effects on the readings of the instruments.

Response Characteristics of a Refrigeration Evaporator (ash)
W. F. STOECKER,* G. WEDEKIND
The speed at which a refrigeration evaporator reacts to a change in conditions influences the stability of control of the system. A test loop is under construction which will permit both transient- and frequency-response analyses of an evaporator. The input function will be the rate of flow of refrigerant that is fed to the evaporator, and the output function will be the amount of superheat of the refrigerant leaving the evaporator. A 30-foot-long glass tube, electrically heated from the outside, will serve as the first evaporator in order to observe visually the flow regimes and the behavior of the refrigerant during unsteady-state conditions. A metal evaporator tube is planned for later tests.

Response Characteristics of a Superheat-controlled Expansion Valve (ui)
W. F. STOECKER,* D. SPURLING
One type of expansion valve used in refrigeration systems is one in which the valve controls the flow rate to the evaporator in a manner that maintains a constant superheat of the refrigerant leaving the evaporator. Knowledge of the response characteristics of the valve is necessary for a stability analysis of the expansion valve-evaporator control loop.
The tests conducted so far have indicated that the time constant of this type of valve is of the order of magnitude of several seconds if the sensing-bulb temperature is taken as the input function and the valve position is the output. This time constant appears short, relative to the time constant that occurs in the heat-transfer process from the suction line to the sensing bulb.

Investigation of the Mechanism of Surface Ignition in Internal Combustion Engines (ui)
W. L. HULL,* J. O. BECKER
A theoretical model for the determination of surface ignition has been established on the basis of thermal and chemical properties of deposits as related to heat transfer rates in an internal combustion engine. A numerical solution was obtained by using the IBM 7094 computer.
This model replaces the earlier concepts of surface ignition utilized by other investigators. It has the flexibility of determining the effects of various parameters which are prevalent in surface ignition. The thermal properties of the deposit, the thickness of the deposit, engine speed, intake conditions, compression ratio, and combustion properties of the deposit can be evaluated as to their effects on surface ignition.
An experimental investigation was carried out using an adiabatic compression machine to establish combustion characteristics of various hydrocarbon fuels. Ignition temperatures in conjunction with ignition delay were established. Previous investigators have used hot wires or surfaces for ignition, resulting in extremely high values of questionable validity.


**Load-carrying Capacity and Viscous Friction Losses of Oil Films in Hydrodynamically Lubricated Involute Spur Gears (ui)**

E. I. RADZIMOVSKY,* R. W. ADKINS

The oil films separating the mating surfaces of involute spur gears operating under hydrodynamic lubrication conditions are analyzed. The actual motion of the involute profiles is considered in deriving expressions for the pressure, shear stress, and power loss in the oil films at any phase of engagement. A method is developed in which these expressions are applied to determine the film thickness at any instant and the power loss for a given load, speed, and lubricant viscosity considering the actual number of teeth engaged at any instant.

A numerical example illustrates the cyclic manner in which the film thickness varies for a constant input load and speed. In this example the losses computed from the input and output powers show excellent correlation with those computed by integrating the viscous friction loss over the total volume of the oil films.


**Efficiency of Gear Drives (ui)**

E. I. RADZIMOVSKY,* W. ADKINS, D. H. OFFNER

An experimental study is being conducted of power losses in a differential planetary gear train. The influence of oil viscosity, gear speed, and flow rate on energy losses is being investigated. The influence of speed ratio upon the gear efficiency has been established experimentally and correlated with a theoretical analysis.


**Dynamic Strength of Machine Elements in Component Assemblies (ui)**

E. I. RADZIMOVSKY,* C. S. LARSON, D. H. OFFNER

This theoretical and experimental research deals with factors which influence the fatigue strength of machine elements in component assemblies. Examples of assemblies to be considered are bolts in connecting rods and engine heads. During the past year a testing machine has been completed as well as calibration and instrumentation. Initial tests are being run on bolts to determine the influence of axial and bending loads on bolts. The experimental part of the project is aimed at establishing data for reliable design of bolts operating under dynamic conditions.

**Conjugate Spur Gears: Their Load Capacities and Lubrication Characteristics (ui)**

E. I. RADZIMOVSKY,* T. M. BRITTAIN

The wearing qualities and, hence, the load capacities of various pairs of conjugate spur gear profiles are being compared. The wear characteristics of each pair of profiles will be analyzed for the case of hydrodynamic lubrication as well as for the case of dry contact—conditions which bound the actual operating condition for a pair of spur gears. The results of the analysis of each pair of profiles will be compared and, based on the findings, an attempt will be made to design a pair of spur gears with appreciably higher load capacity than involute spur gears of the same nominal size.

The IBM 7094 computer is being used in preparing the theoretical portion of this investigation. A photelastic analysis will complement the theoretical analysis for the case of dry contact.

**Analytical Evaluation of Spur Gear Form Factor (ui)**

D. H. OFFNER*

This investigation was to show the influence that velocity ratio, fillet radius, addendum, pressure angle, and tooth number have on the geometrical strength factor of spur gears. The strength factors have been determined analytically, using a digital computer. The results were summarized in tabular and graphical form and incorporated into class lecture material.

The next step in this investigation will be to combine strength, scoring, and pitting criteria used in gear design into a computer program for use in gear design applications.

**Determination of Coefficient of Friction in Instrument Spur Gears (sc)**

R. W. ADKINS,* E. I. RADZIMOVSKY, H. DIEME, Jr.

This is an experimental investigation to determine the coefficient of friction for high precision, 96-pitch, instrument spur gears under a wide range of operating conditions. Pitch line velocities up to 6000 fps are being considered with tangential tooth loads as high as 10 pounds. Several different gear materials with a wide range of lubricants such as oil, grease, and solid films will be considered in this investigation.

The design of the test machine for this particular investigation has been completed and the unit is now under construction. Basically the design principal of the test unit follows that of the four-square or locked-gear type of test unit. There are several unique features designed into this particular test unit which include a pneumatic loading device permitting the gears to be loaded while running. Another feature will provide for measuring the gear train bearing friction so the gear friction losses can be isolated. The unit is constructed so that environmental temperatures can be varied from −65°F to 160°F.
Heat Transfer Characteristics of Molding Material (asc)
J. L. LEACH*

The purpose of this study is to determine the heat transfer characteristics of different mold materials used to back up a shell mold for the casting of precision parts. Since the cooling rate of many of our ferrous alloys is very critical, it is felt that mold material can be selected to alter the cooling rate. Very dense material with high conductivity characteristics may be utilized to back up a shell for rapid cooling, whereas low-density material with low conductivity characteristics may be used where a slow cool is desired.

By being able to control the cooling rate, one could expect a better control of the physical and metallurgical properties of many materials.

Measurement and Control of Temperature of Molten Metal Above 2700°F (ft)
J. L. LEACH*

The precise pouring temperature of a great many of the ferrous alloys and the exotic materials has necessitated not only a method to determine the magnitude of the temperature, but also to precisely control temperature in the range of 2500°F to 3200°F.

The experimental phase of this study is to be conducted in a Brown Bovari induction melting furnace in the foundry laboratory.

Undergraduate students of mechanical and industrial engineering are checking measurements of a test specimen for stress analysis.

Professors B. F. von Turkovich (left), K. J. Trigger (center), and a graduate assistant are using this apparatus for the study of chatter and other self-excited vibrations during cutting operations which involve plastic deformation of the metal.
Friction Welding of Metals (ui)
M. B. Singer, M. Lebegue
Conditions for welding different metals and the weldability of such metals by friction welding are experimentally determined. Physical properties and metallurgical characteristics of metals so welded are being investigated. At the present time dynamic properties are under study.

Optimization of Rigidity-Weight Ratio in Large Precision Machine Elements (ui)
B. F. Von Turkovich, I. Silberstein
The investigation of rigidity-weight ratio of machine tools structural components is slanted toward the optimization analysis required for design of automatic control systems for such machines. The principal objectives are the development of analytical methods for the determination of rigidity-weight ratio in the preliminary design stage and establishment of parameters for stability calculations. Experimental work is performed on a special testing structure using a large milling machine column as a typical structural component.

Theory of Metal Cutting (ui)
The project is concerned with all phases of metal cutting theory, involving specifically, theory of chip formation, chatter phenomena, and physical aspects of deformation processes taking place along tool face and in the shear zone. New experimental and analytical methods are developed to correlate the basic information with the results obtained in other areas of metal processing. Special emphasis is placed on the workpiece surface damage and its consequences.


Research on Tool-Work Compatibility (ui)
K. J. Trigger, A. B. Draper, L. L. Lehn, V. P. Rao, J. Slutzky
The mechanism of wear, at metallic contacts such as those encountered in metal cutting, is influenced by the tendency toward interfacial diffusion at the contacting surfaces. This investigation with tool-work pairs of widely different asperity interactions was conducted as part of the background information for the students' future program.


Selection and Design of Metal Cutting Tools Automatically by Means of Digital Computers (astme)
L. E. Doyle, L. L. Lehn
Means for designing and selecting single-point tools by means of digital computer programs are being studied. The principles of tool design have been formulated, and a logical diagram of procedures is being constructed. Plans are being made to extend the project to the design of form tools and multiple point tools.

The Effect of Background Music on Productivity (mcc)
Stephan Konz
Twenty non-college women were hired for two weeks. Each worked on four different tasks (manual assembly, mark sensing IBM cards, addition, and anagrams). No over-all effect of music on productivity was demonstrated, nor did it have a differential over-all effect depending on type of task. Some significant individual changes in productivity were demonstrated.
In the research program of this department, the interrelated fields of metallurgical, mining, and petroleum engineering are concerned with the problems of extraction, investigation, and application of various minerals and metals. In addition, research in materials and nuclear engineering has opened up entirely new areas of study for the metallurgist.

A highly trained professional staff conducts research sponsored by both private and government agencies. Qualified graduate students are encouraged to participate in the research program, which allows them to gain technical skill and, at the same time, to become more aware of the opportunities available to them.

For each of the three broad research areas, the currently active projects are described on the following ten pages.

This transmission electron micrograph (enlarged 30,000 times) shows the stacking faults that occur in an Fe-25% Mn alloy during the f.c.c. to h. c.p. transformation.
METALLURGICAL ENGINEERING

The research program in metallurgical engineering covers a considerable part of the broad spectrum from pure metal physics to problems of an applied character. Much of the work is being done by M.S. and Ph.D. candidates and research associates, and almost all of it is supported by contracts with U.S. government agencies.

At one end of the spectrum, theoretical and experimental studies of the interaction of point and line defects are being made. A large effort devoted to the nature of damage produced in solids by cyclotron radiation is being carried out cooperatively by this department and the Department of Physics. Several critical experiments have been performed by this group recently. The mechanism of diffusion and the effect of mechanical history on it are being studied. All types of transformation in many pure metals and alloys are being investigated. These include the precipitation of small particles in bcc iron and the martensitic (diffusionless) transformation in several alloys. The program on alloying behavior of transition elements includes some significant recent experiments on the specific heat of alloys at liquid helium temperatures and the X-ray diffraction studies of CsCl-type intermediate phases. The metallic properties of semiconducting materials are also being studied.

A considerable amount of work is being done on mechanical properties of metals and the effect of thermal history. Studies of the annealing of cold-worked metals and the heat treatment of ductile cast iron are also being made. At the more applied end of the spectrum there are studies of the criteria for cathodic protection. These preceding projects are included in the detailed description below.

Phase Transformations† (sec)


The theoretical and experimental studies of solid state transformations being conducted in this laboratory are on the kinetics, thermodynamics, and crystallography of phase changes with emphasis on the part played by imperfections. Equipment includes an electron microscope, a microfocus X-ray unit, a diffractometer, and standard units for determining crystal structure and orientation, metallographs and other optical instruments including a goniometer, resistance bridges, furnaces, temperature controllers and baths, and vacuum systems. Special equipment such as radiation detecting and counting devices (of the Materials Research Laboratory) is currently being employed in these investigations.

Massive Transformations in Cu-Ga and Cu-Ga-Ge Alloys

Massive transformations occur very rapidly and are diffusionless like martensitic transformations. But no definite parent-product orientation relationship exists, and massive transformations do not exhibit surface relief effects.

Evidence for the absence of an orientation relationship in massive transformations has come from rather indirect observations, and furthermore, the product phase which forms massively frequently exhibits a straight, planar interface, which are suggestive of martensitic growth mechanism. Preliminary transmission electron microscope observations on the massive zeta phase in Cu-Ga, and Cu-Ga-Ge alloys shows the planar interfaces in many cases to be parallel to stacking faults on the (0001) plane. The significance of this is yet open, and further efforts are being directed towards a more detailed comparison of the massive transformation to the martensitic transformation and classical nucleation and growth transformations.

Phase Transformations in Fe-Os, Fe-Pt, Fe-Ir, and Fe-Ru

Early work based mostly on magnetic analysis suggests that martensitic transformations occur in the binary alloys Fe-Os, Fe-Pt, Fe-Ir, and Fe-Ru. These systems exhibit substantial transformation hysteresis and characteristic Ms and As temperatures, and in this respect are similar to the Fe-Ni systems. A program has been initiated to study the γ to a′ transformations in these “new” systems, with particular emphasis on kinetics, crystallography, and the fine structure of the martensite.

The Nature of the Transformation in NH₄Cl at Subzero Temperature

NH₄Cl undergoes a transition from a cubic structure to one of lower symmetry at about −40°C. The nature of this transition is not understood, although the results from this investigation show that it is not an order-disorder transformation as has been suggested in the past. Cold stage microscopy and X-ray diffraction are presently being carried out. Dilatation measurements on single crystals and on polycrystalline compacts have revealed a typical first-order dilatation vs. temperature hysteresis loop (about 10 degrees in width). However, the single crystals also show a pronounced expansion which occurs a few degrees below the temperature at which the transformation is completed. This effect is not observed in polycrystalline specimens.

The Theory of Martensitic Transformations

The general matrix algebra theory of the crystallography of martensitic transformations has given extremely good agreement with experimental results in certain cases. The theory is based on an interface plane between the two phases which is assumed to be either completely undistorted or uniformly distorted. Such hypotheses lead to good predictions of the habit plane, orientation relationship, etc., in some cases, but fall short in others; particularly, the results from the martensitic transformation in Ti and the (225) transformation in steels cannot be explained adequately with the present theoretical approach. Additional theoretical and experimental work is now under way which deals with a generalized anisotropic interface distortion. If significant interface anisotropy exists, vectors in the interface itself would be rotated, and this should be detectable with interference microscopy. Such measurements are presently being made.

†This research was conducted jointly by the Departments of Mining, Metallurgy, and Petroleum Engineering and the Materials Research Laboratory.
Phase Transformations in Iron Whiskers

Numerous investigations have been concerned with the nature of the gamma-to-alpha transformation in pure iron, but there has been little work on the alpha-to-gamma transformation. Iron whiskers can be grown in the bcc single crystal condition by hydrogen reduction of molten FeCl₃ at 730°C. Whiskers are always grown as single crystals, and their purity is quite high. Owing to the well-defined geometrical nature of the whiskers, crystallographic studies are rather easily carried out. The experiments to date have involved transforming the (bcc) whiskers in a temperature gradient, using a specially designed hot stage optical microscope. Studies of the alpha-gamma interface as well as the transformation distortion suggest rather conclusively that the alpha-to-gamma transformation in pure iron is of the martensitic type, with a well-defined habit plane, etc. Kinetic information has also been obtained by taking high-speed moving pictures of the interface during transformation.

Martensitic Transformations in Other Alloys

Preliminary studies of Va-Ru alloys indicate a magnetic transition which may be associated with a martensitic transformation. Such transformations in ordered AB alloys in this part of the Periodic Table also provide a convenient and unique method for studying the interaction of crystal structure and symmetry on physical properties and phenomena.

The Effect of Stacking Fault Energy on the Austenite-Martensite Transformation

One of the interesting characteristics of the austenite-martensite transformation in iron alloys is that the habit plane of the martensite is dependent upon the composition of the parent austenite which undergoes transformation. Particularly in the case of Fe-C alloys, the high carbon austenite (i.e., about 2 percent C) transforms into martensite with a (259) habit plane, whereas austenite containing 1.4 percent or less carbon transforms into martensite having a (225) habit plane. This habit plane transition is apparently abrupt and occurs in the vicinity of 1.4 percent C. The reason for this transition is not certain but may be linked to the stacking fault energy of the austenitic phase, which itself may strongly depend on the carbon content. The finding is that the (259) transformation results from a high-stacking-fault-energy austenite, whereas the (225) transformation may result from austenite of lower stacking fault energy. In each case, the dislocation reaction giving rise to the formation of the martensite nucleus would presumably be different. In examining these ideas, various Fe-C alloys are being studied by means of thin-film electron microscopy. Also, Fe-Mn alloys containing from 15 to 28 percent Mn, whose stacking fault energy is strongly dependent upon Mn content, are under investigation.

Epitaxial Growth of Cobalt Films

Thin films are being made by vacuum evaporation of cobalt onto heated substrates of ionic salts. Both single crystals and polycrystalline films can be made, depending upon the nature of the substrate, its temperature, etc. When the films are cooled to room temperature, they remain fcc, although bulk cobalt undergoes the fcc-to-lcp transformation at about 400°C. However, these films, when removed from the substrate and annealed at 800°C undergo partial transformation (about 30%) upon cooling. The major purpose of the present work is to investigate the effect of deformation on the transformation characteristics of the evaporated films. This is done inside the electron microscope with a specimen straining device.

Transmission Microscopy Studies of the Bainite Transformation

The nature of the bainite transformation in iron alloys and steels is not yet well understood. It is known that carbon diffusion occurs during the formation of bainite, and in this respect there is a similarity between bainite and pearlite formation. On the other hand, well-defined crystallographic characteristics have been observed, and these suggest a similarity between bainite and martensite.

The present work hypothesizes that the bainite transformation is fundamentally martensitic in nature, to be followed by the diffusion of carbon. That is, it is supposed that bainite plates form as do martensite plates, and carbon diffusion occurs after the fact. Several alloys are being investigated, principally by means of transmission electron microscopy. Habit plane analysis, orientation relationship measurements, and observations of the fine structure (i.e., lattice invariant shear) of the bainite are being made.

The Beta-Zeta Transformation in Silver-Zinc Alloys

This phase change is of particular interest because of the unusual structural change involved. The initial phase has a cesium chloride structure; in the final structure two thirds of the zinc atoms are aligned along parallel [111] directions (of the former cubic phase) while the remainder of the atoms are randomly distributed among the other lattice sites. The initial structure has cubic symmetry while after the atomic rearrangement the symmetry is hexagonal with the c-axis parallel to the lines of zinc atoms. The maximum distortion of the unit cell is, however, only about two percent. After partial transformation most of the regions with the zeta structure exhibit an apparently reproducibly crystallographic relationship with the initial phase. As yet only qualitative observations have been made, but single crystals of the initial phase have now been made with flat faces parallel to the (111), (100), and (100) planes. After various partial amounts of transformation, quantitative morphological and crystallographic studies will be made of the zeta phase regions, including those which are visible at the free surface as well as those in the interior of the crystal. Measurements of surface rumpling will be made for the former case with the interference microscope.


**Thermodynamics of Martensitic Transformations**† (see)

C. J. ALTSTETTER,* R. ADAMS

Calorimetric measurements are being carried out on materials which undergo martensitic transformation. Enthalpy changes are being determined in a calorimeter designed specifically to allow for the athermal nature of the transformation. The calorimeter can be used both above and below room temperature and utilizes specimen of simple geometry requiring no machining. Specimens can be annealed under high vacuum within the apparatus and then cooled through the transformation without the necessity of transferring them from an annealing furnace to the calorimeter.

†This research was conducted jointly by the Department of Mining, Metallurgy, and Petroleum Engineering and the Materials Research Laboratory.

**The Effect of Stress on Solid State Transformations** (see)

C. J. ALTSTETTER,* M. S. RASHID

Research on the diffusionless transformation in cobalt (FCC→HCP) has involved the effect of stress on the initiation and propagation of the transformation. This has led to the conclusion that such a transformation should be thought of in terms of the mechanisms of slip and twinning, but with some important differences. High-purity cobalt single crystals are easily produced, and experiments involving stressing, etch pitting, anelastic behavior, and X-ray line broadening have been carried out. Cerium and lanthanum have transformations involving a complex hexagonal low-temperature phase instead of the close-packed hexagonal as found in cobalt. Research on the cerium and lanthanum transformations is now being carried out to determine if these transformations are similar to that in cobalt.


**Interstitial Solutions of Nitrogen in Columbiaum Alloys** (see)

C. J. ALTSTETTER,* E. DELAMOTTE, Y. C. HUANG

Interactions of the interstitial atoms with each other and with solvent metal atoms, other solute atoms, or dislocations have been hypothesized to explain certain mechanical, as well as contamination, characteristics of the bcc refractory metals. These interactions are thought to explain not only the effect of the gases which contribute the interstitial atoms, but also the effect of other substitutional alloying elements which modify the distribution of interstitial atoms in solution. The present research is concerned with how the behavior of nitrogen in dilute solution in columbium is affected by small amounts of zirconium, which is thought to have a stronger affinity for nitrogen than columbium. The partial pressure of nitrogen in equilibrium with pure columbium and with dilute Nb-Zr alloys has been measured from 1400°C to 2200°C for a number of different alloy compositions.


**Radiation Damage**† (see)

R. W. BALLUFFI,* D. BEAMAN, J. R. PARSONS, R. W. SIEGEL, J. YTTERHUS

An extensive program has long been involved with the study of the effects of heavy bombardment on crystalline properties of solids. Studies of the basic properties of the crystal defects created by irradiation are also emphasized. This program is being carried out cooperatively with the Department of Physics. Projects involving members of the present department include:

1. Measurement of the equilibrium concentration of lattice vacancies at elevated temperatures in dilute alloys of Al-Ag and Al-Mg by combined length and lattice parameter expansion measurements.

2. Electron microscope study of the behavior of interstitial defects produced in the noble metals by \( \sim 200 \text{ eV} \) \( \text{A}^+ \) ions.

3. Electron microscope study of displacement spike crystallization in amorphous germanium during neutron bombardment.

4. Electrical resistivity and electron microscope studies of the annealing of quenched-in vacancy defects in gold.


D. R. Beaman, "Direct Measurement of Equilibrium Vacancy

†This research was conducted jointly by the Department of Mining, Metallurgy, and Petroleum Engineering and the Materials Research Laboratory.


Alloy Chemistry of the Transition Elements (aro)


Binary, ternary, and in some cases, quaternary alloy systems of transition elements with either Si, Ge, Sn, or Al are studied to determine the occurrence and the composition range of stability of various types of intermediate phases. Typical “phases of variable stoichiometric ratio” tend to form elongated phase fields extending along lines of constant electron concentration. Crystal structure and atomic ordering in these phases are studied by means of X-ray diffraction.

The β-Mn Phase in Ternary Systems

Isothermal boundaries of the β-Mn phase field are being studied in a large number of ternary systems with transition elements and with either Si, Ge, Sn, or Al. The results indicate that the alloying behavior of Si and Al may be described in terms of their usual valency, i.e., the number of electrons outside closed shells. On the other hand, Ge and Sn behave as if the electrons in their filled d-band would also contribute to the “effective electron concentration.” The β-Mn phase is related in its alloying behavior to γ, δ, ε, R, and α-Mn, and, in the same sense as they are, it is an “electron-compound.”

Study of Alloy Systems with V and Si

Isothermal sections of the ternary V-Fe-Si, V-Co-Si, and V-Ni-Si systems and of the quaternary system V-Mn-Fe-Si at two constant Mn levels have been investigated. The boundaries of the γ, α-Mn, β-Mn, R, and of the newly discovered D, I, and B phases have been determined. All these phases are shown to have quaternary phase fields extending parallel to each other, showing that they are closely related to each other.

New Phases in the Mn-Fe-Si System

A new binary Mn-Si phase and a new ternary Mn-Fe-Si phase near the Mn-Si binary system have been found. Their powder X-ray pattern and phase boundaries have been determined.

Laves Phases in Ternary Systems with Si

The effective Si-radius was determined in various Laves phases formed in ternary systems and extending along lines of the constant stoichiometric ratio AB5. In these alloys with transition elements, Si has an effective radius much smaller than that derived from the nearest neighbor distance in elemental Si.

The G, E, V, and J Phases in Ternary Systems

A systematic survey has been made of the occurrence of the G, E, V, and J phases in various ternary systems with

*Crystal structure and atomic ordering in phases of variable stoichiometric ratio are studied by means of X-ray diffraction.

Here, Judy Drake is adjusting a specimen in the precision diffractometer.

For studies of the dissipation of energy in a vibrating solid and of the elastic moduli, this apparatus is being used to obtain information about the behavior of dislocations and point defects. Research assistant W. Robinson is mounting a specimen.
either Si or Ge. These phases were found in all cases to occur at fixed stoichiometric ratios. The parameters locating the various atoms in the orthorhombic unit cell of the various E-phases are being determined.


**Electronic Structure of the Transition Elements and Their Alloys† (nsf arpa)**


Measurement of the electronic specific heat coefficient, which is proportional to the density of states at the Fermi surface, is used as a means of studying the d-band in alloys of transition elements. The results show that in first approximation the rigid band picture is fairly adequate, so that one can vary the electron concentration by changing the alloy composition. This procedure has been used for studying the d-band in bcc and fcc alloys of transition elements with one another. Recently, the investigation has been extended to include also the effect of non-transition element solutes on the d-band of bcc transition elements.

**Study of the Effect of Non-Transition Solutes on the d-Band in BCC Alloys of Transition Elements**

An extensive study is being conducted of the way in which certain non-transition elements affect the d-band in transition elements and in their alloys, when added in substitutional solid solution. Contrary to earlier theories based on magnetic saturation moment measurements with Fe-Al and Fe-Co-Al alloys, the results of electronic specific heat measurements show that the non-transition element solutes do not contribute electrons to the d-band.

**Study of the Effect of Atomic Ordering in VFe on the Electronic Specific Heat**

It has been found that the effect of heat treatment developing CsCl-type long-range order in bcc alloys near the VFe composition is to increase somewhat the electronic specific heat coefficient. This effect is so slight, however, that ordering is seen to have very little effect on the band structure, even though the magnetic saturation moment is appreciably decreased by it. This result is similar to that found by other investigators for ordering in non-magnetic alloys.

**Electronic Specific Heat of Intermediate Phases**

Measurements of low temperature specific heat are being made with various intermediate phases of transition ele-

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†This research was conducted jointly by the Department of Mining, Metallurgy, and Petroleum Engineering and the Materials Research Laboratory.

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**Point Defect — Dislocation Interactions† (aac)**

H. K. BIRNBAUM, M. WUTTIG, H. AARON, D. CARROLL, C. HEIPLE, W. ROBINSON, B. D. TROTT

This investigation is an attempt to study the number and type of point defects formed during plastic deformation, the mechanisms of their formation, the nature of the annealing processes after deformation, and the role of point defects in work hardening. Both theoretical and experimental investigations into several aspects of these problems have been initiated in cooperation with the Materials Research Laboratory.

**Low-Temperature Strain Aging**

The interaction of point defects with dislocations can be studied using accurate measurements of the flow curves as this interaction results in a small yield point. High purity copper and aluminum are being studied with this technique. Analysis of the kinetics of the strain aging results in estimates of the energies of motion of the interstitial and vacancy in the lattice and along the dislocations. The interaction energies of these defects with the dislocations can be obtained from the temperature dependence of the yield point.

**Internal Friction Studies**

Studies of the dissipation of energy in a vibrating solid and of the elastic moduli can yield information about the behavior of dislocations and point defects. These techniques are being used to study the annealing behavior of point defects after plastic deformation and after quenching. The
interaction of point defects at the dislocations are under study. These techniques are being used to study the annealing behavior of point defects after plastic deformation and after quenching. The interaction of point defects at the dislocations are under study. These techniques will be applied to a study of the role of point defects in the border peaks in fcc metals.

An examination of the possibility of observing anelastic damping peaks due to the stress-induced reorientation of point defects after deformation and after quenching has been undertaken.

Dislocation Pipe Diffusion

Self-diffusion along isolated dislocations is being investigated using a technique which has adequate sensitivity to allow the use of specimens of low dislocation density. Both high-stack fault energy and low-stack fault energy metals will be investigated. The initial work is being carried out on high purity Ni. The diffusion along edge, screw, and mixed dislocations will be investigated. It is hoped that these studies will lead to an understanding of the configuration of vacancies at dislocations.

Magnetic Measurements

Measurements of the low field magnetic permeability and of the stabilization magnetic field are being applied to a study of the point defect configurations in fcc metals. The initial experiments are being performed on quenched and irradiated nickel. The objective of these experiments is to obtain information about the configuration and characteristic energies of lattice defects.

Radiation Damage of LiF

Electron, X-ray, and heavy ion bombardment damage in LiF is being investigated using transmission electron microscopy techniques. The structural changes accompanying color center formation and annealing are being examined.

H. Aaron, “Low-Temperature Strain Aging of Aluminum,”

Carbide Monocrystals† (aec)
J. J. GILMAN,* G. T. MAW

Large crystals of the carbide type are not generally available because high temperatures and unusual techniques are required to grow them. Yet they are of considerable scientific and technical interest because of their abnormally high binding energies, surface energies, large elastic constants, and the low mobility of dislocations in them. The existence of metallic electrical conductivity by such hard substances is also of interest. Technically, they are of special interest because they can form the basis of extremely strong materials. Growth of these crystals is the first phase of the program that is planned. The method to be used consists of precipitation from a molten flux at about 1500°C.

†This research was conducted jointly by the Department of Mining, Metallurgy, and Petroleum Engineering and the Materials Research Laboratory.

Surface and Fracture Energies of Solids (aro)
J. J. GILMAN,* H. C. TONG

This project is concerned with two problems. First, why do the cube faces of bcc metals have lower surface energies than the more closely packed dodecahedral faces at low temperatures? This is being investigated by means of field ion microscopy. Second, how does dislocation dynamics affect the energy absorbed by a moving crack? The first step here in the solution of this latter problem is to develop and test a theory of plastic wave propagation.

Micromechanical Mechanisms in Solids (onr)
J. J. GILMAN,* R. BULLOUGH

It is believed that experimental and theoretical techniques that have been developed to investigate the mechanical behavior of inorganic solids can be fruitfully applied to organic substances, especially high polymers. Quantitative studies of the cleavage of monolayers are planned as a means of determining the cohesion of polymers. Application of the dynamical dislocation theory of plasticity to polymeric substances is also planned.

Defects and Defect Structures in Ordered Alloys† (aec)
D. S. LIEBERMAN,* K. MUKHERJEE

Simultaneous radioactive self-diffusion studies of both elements in an ordered Cs-Cl type alloy were measured for the first time in a joint project with Dr. Lazarus of the Physics Department. These results which showed an interesting behavior as a function of stoichiometry were in the Au-Cd system which also exhibits a phase transformation above room temperature and hence involved additional experimental difficulties. Similar studies are now under way in Au-Zn and other alloys which do not exhibit such a transformation. These will reveal information about the activation energies and the presence of a defect structure as one deviates from stoichiometry. These studies should also contribute to our understanding of alloy theory.


†This research was conducted jointly by the Department of Mining, Metallurgy, and Petroleum Engineering and the Materials Research Laboratory.

Vibrational Entropies of Solute Atoms in Dilute Substitutional and Interstitial Solid Solutions and Beta-Phase Alloys† (aec)
R. B. MCELLENAN

Equations have been set up for the solubility of solute atoms in dilute interstitial solutions where the solution is in equilibrium with a gaseous phase which dissociates and provides the monatomic solute. The gaseous phase may be a simple diatomic gas or a mixture of complex gases. In setting up these equations the solute atoms in the solution are treated as independent localized elements having only vibrational degrees of freedom. Experimental solubility data have been analyzed in the light of this technique and vibra-
tional entropies obtained for the solute atoms in dilute Fe-N, Fe-C, and Ag-O solutions.

Effusion apparatus is being built which will enable the gas/metal equilibrium in β-phase alloys to be investigated. From the results of these measurements it is hoped to obtain data for the vibrational entropy change accompanying the insertion of a solute atom in the β-phase sub-lattices.


Dislocations and Surface Barriers† (aec)

M. METZGER,* J. C. BILELLO, R. W. LEONARD, C. K. LI, C. F. LIN

Surface films provide barriers to the motion of dislocations produced during deformation of the substrate. The nature of the interaction between the dislocations and the barrier is being studied from several points of view, using mechanical testing, etch-pit methods, and electron microscopy. The strengthening action of the film is being studied in copper and zinc crystals with various metallic films with reference to the origin of the barrier effect, to the secondary effects produced by it, and to the differences between the interactions involving edge and screw dislocations. The work so far has indicated certain phenomena requiring closer examination, and present efforts are directed toward microstrain studies aimed at providing information on work hardening mechanisms.


†This research was conducted jointly by the Department of Mining, Metallurgy, and Petroleum Engineering and the Materials Research Laboratory.

Grain Boundary Structure and Corrosion† (aec)

M. METZGER,* O. P. ARORA

This work is concerned with the metallurgical and chemical conditions under which enhanced chemical reactivity is associated with lattice defects and with the reactivity associated with different defects. Recent work has been concerned mostly with grain boundaries. The corrosion of boundaries in aluminum bicrystals was studied as a function of misorientation and boundary type. Rather small differences were found between different types such as tilt and twist boundaries or random and symmetrical ones except for a few boundaries of special orientation. Further studies of the significance of structural and crystallographic factors are in progress.


†This research was conducted jointly by the Department of Mining, Metallurgy, and Petroleum Engineering and the Materials Research Laboratory.
Annealing of Cold-Worked Metals† (aec)
B. G. Ricketts,* R. W. Balluffi, W. T. Becker,
L. C. Michels, D. N. Seidman, W. Shieh

Recrystallization
A clarification of the mechanism of nucleation of recrystallization and the role of concurrent polygonization is sought by means of transmission electron microscopy. The thin foils used are made from high-purity aluminum in the form of single crystals which have been cold-rolled and annealed. The isothermal annealing kinetics are being examined with the intention of determining any correlation which may exist with lattice curvature.

Stacking Faults
Estimates of stacking fault energy have been made for a series of copper-silicon alloys. The calculations were made from shapes of extended dislocation nodes obtained by transmission electron microscopy. A correlation with the amount of dissolved silicon was obtained for alloys with 2 percent or more silicon. Nodes were unextended, however, for lower-silicon alloys. This was also true for copper containing small percentages of phosphorous. Further examination of extended nodes by means of cold- and hot-stage techniques has been undertaken to determine any observable effects of temperature.

Annealing Textures
The orientation texture formed by annealing after cold-rolling apparently is related to the kind of softening process. Softening may occur either by recovery or recrystallization, and the relative rates of the two processes are influenced by such variables as the degree of deformation, the presence of impurities, and the kind of heat treatment prior to rolling. An evaluation of these variables has been undertaken in a study of high-purity aluminum containing small additions of iron. Standard X-ray techniques are used to determine variations in texture, while the nature of the structural changes is determined by transmission electron microscopy.

Vacancies
An investigation of the mechanism by which vacancies are created in metal crystals under non-equilibrium conditions is being carried out. The roles which dislocations and grain boundaries play as vacancy sources and sinks in gold are under investigation by transmission electron microscopy. Specimens are rapidly heated and quenched, or simply quenched after equilibrium at elevated temperatures, and the resulting vacancy distribution in the vicinity of dislocations and grain boundaries is observed by direct microscopy. Auxiliary measurements are being carried out using electrical resistivity to monitor the number of vacancies created or destroyed.


Nuclear Magnetic Resonance Studies† (aec)
T. J. Rowland,* D. Cutler, R. C. McAllister
An investigation of the nuclear magnetic resonance absorption amplitude of copper as a function of zinc concentration in dilute (<1 atomic percent) copper base copper-zinc alloys was completed. Data were collected for cold-worked samples and also in some cases for annealed material. First order quadrupole interactions were responsible for the major effect noted, and estimates of the extent of the electric field gradients caused by solute atoms and lattice imperfections were made.

A search for the nuclear resonance of gold (197) in metallic gold is in progress. The nuclear magnetic moment is not known except through relatively old spectroscopic results, so the study requires an extensive search using very carefully prepared pure gold.

A study of the nuclear resonance absorption of silver in dilute alloys of silver with B subgroup solutes is planned. The purpose is to better characterize the electron distribution in the vicinity of solute atoms in solid solution.

Experimental apparatus is being completed which will allow a variety of pulsed resonance work to be done. The technique generally involves the use of two closely spaced radio frequency pulses which are either in phase or just 90 degrees out of phase with each other. It has been used to measure the second moment of aluminum in the metal and will be used for further experiments on aluminum and its alloys.


Dislocations in Solids (afosr)
R. Thomson,* M. H. Miles, D. Gray, M. Meyer,
J. Rubio-Bernal, Z. Usmani
A theory of dislocation mobility in semiconductors has been worked out to explain both damping experiments and mobility experiments. The theory uses the concepts of smooth kinks and dragging points, and predicts the observed stress and temperature dependence.

Experiments are under way on the optical properties of dislocations in Ge. So far, both screw and edge dislocations are shown to have observable changes in the tail of the absorption edge. Polarization effects are observed on 60-degree dislocations. When completed, the work will be interpreted in terms of bound states associated with the dislocations.

Fundamental studies of the electronic structure of imperfections in solids, with a view to explaining such effects as

†This research was conducted jointly by the Department of Mining, Metallurgy, and Petroleum Engineering and the Materials Research Laboratory.
stacking fault energies, bound states on impurities, etc., are under way. This work involves the use of modern Green's function techniques; it will be given major attention in the future.


**Quenched-in Defects in Alloys† (aec)**

C. M. Wayman,** K. Mukherjee, T. Saburi

Previous experiments with various β-phase alloys such as AuZn, AuCd, and various Cu-Au-Cd ternary alloys have shown that these Hume-Rothery compounds having an electron atom ratio of 3/2 exhibit unusually high vacancy concentrations when quenched. Calculation of the activation energy for defect formation in these alloys yields an activation energy of only 0.4 eV, which suggests that one in every 100 atomic sites is vacant at temperatures near the melting point of the alloys. This behavior is in marked contrast to that found in pure metals, where the melting point vacancy content is at least a factor of ten lower. There are several experimental programs under way at the present time. One of these involves a kinetic study of the annealing behavior of the quenched-in defects. This is being studied by both physical property measurements and by transmission electron microscopy. Preliminary results indicate that a relatively high activation energy is associated with the migration of the quenched-in defects. The relatively high vacancy concentration in the quenched alloys should lead to interesting consequences during annealing, and it is hoped that the electron microscopy experiments will shed light on the atomic details of the annealing process.


**Diffusion in Metals† (aec)**

C. Wertz,** R. Peart

The diffusion of radioactive tracers in metals offers an excellent method by which diffusion coefficients, D, can be measured. An extensive study has been made of self-diffusion in V metal using this technique. Diffusion (including self-diffusion) commonly obeys the expression

$$D = D_0 - H/RT$$

when one diffusional mode is operative. For V, however, two equations of this type are needed, one above 1200°C and one below. Both equations have the form, but the constants D₀ and H are different for the two. Vanadium, therefore fits into the group of transition metals which show this anomalous behavior. We have made attempts to find the reason for this behavior but have been unable to up to now to find a satisfactory reason.

To see if this phenomenon can be reproduced in self-diffusion in a similar metal, measurements are being started in Cr.

Pressure effects in diffusion can serve to measure a quantity called the activation volume. This quantity, usually positive, is the volume change which occurs when one mode of the diffusing entity is put at the saddle point configuration. Usually it is a positive number, i.e., an increase occurs, but for some materials it is negative. Our investigations show that for Nb diffusing in Ti near 1000°C, the activation volume is negative. The significance of this is being assessed.

**Interactions Between Interstitial Impurities and Dislocations (arl)**

C. Wertz,** S. Diamond, R. Gisala, R. Hoffman

A major factor in the strength and other mechanical behavior of the bcc metals is the role of interstitial alloying elements such as C, N, and O. A study has been made, using internal friction methods principally, of some of the roles played by these alloying elements. The determination of binding energies of these elements to dislocations has been one of the goals, and energies of the goals and energies of about 0.5 eV per atom have been determined. The rate at which impurities segregate to dislocations has been determined under specified conditions of temperature, degree of deformation, and concentration of impurities. Extensive use of both the Snoek internal friction peak and the cold-work peak has been made in this part of the investigation. The relationship between degree of segregation and strain aging (defined in the metallurgical sense) is being determined. The direct interstitial-dislocation interactions and the self-interactions between interstitials are under investigation; they form small clusters. Again, binding energies are a primary goal, but considerable effort is being spent on the kinetics of cluster formation, their diffusion rate, and their geometry. This latter has necessitated the use of single crystals, which have been easily grown using a floating-zone electron beam melter. Because the phenomena under investigation occur in the refractory metals (Nb, Ta, and V) in a convenient temperature range 0°C to 500°C, most of the investigations are being carried out in these metals.


Nature of Solid Solutions in Metals (afosr)
C. WERT,* R. PEART, M. COLEMAN, G. MAH, R. ODLLE

The motion of atoms in solids may be studied by several methods. One, the internal friction method, is most useful for the investigation of interstitial atoms in solid solutions. Although the Snoek effect, most useful in studying motion of isolated single atoms dissolved in bcc metals, has been used for a great many years, use in diffusion studies of relaxation under stress of clusters of two and three interstitials is more recent. We are currently measuring the diffusion of C-C pairs in Ni as a function of temperature. By proper choice of experimental conditions, measurements can be made on both sides of the ferromagnetic Curie temperature; we will thereby be able to see if the diffusion rate is affected anomalously by the transition from the ferromagnetic to para-magnetic state.

A second investigation is the use of radioactive tracers in determination of diffusion rates in bcc metals. In V metal (see adjoining report) the mode of self-diffusion changes markedly at 1200°C. Other transition metals have been found to behave similarly, some at a sharp temperature, others more gradually. We have begun a study of diffusion in Cr to see if it has this anomalous behavior or not.

A third investigation is the use of NMR methods in elucidating the properties of alloys. At this time a study is being made of the alteration of charge distribution in Cu which is produced by the addition of alloyed atoms of different valence and size.


MINING ENGINEERING

Research engineers in mining are confronted with the task of discovering and correlating new information for the benefit of mining methods. The primary concern of present investigations is with characteristics of various explosives, mechanisms of blasting, action of shock waves in breaking rocks, and the physical and mechanical properties of different kinds and structures of rock or rock layers. Moreover, drill patterns to obtain controlled fragmentation, new drill developments, mechanical miners, underground ventilation methods, grinding and separating equipment, and transportation from mine to industry are continually being studied for improvement.

The major areas of investigation presently being conducted are rock mechanics, operations research, and ventilation.

Temperature Dependence of Surface Conductivity (acs)
N. STREET,* T. FINCH

Surface conductivity has been studied both theoretically and experimentally in narrow slits, capillaries, and networks of fibrous materials and suspensions. The latter studies, although experimentally simpler, are more difficult to interpret. The current work is concentrated on measurement of surface conductance arising in the narrow gap between optically flat Pyrex discs. By studying the temperature effect it becomes possible to calculate the activation energy for ionic movement of the double-layer ions. It is hoped by this means to gain more information about the double layer generally, and in particular about the location of the plane of shear at which the zeta potential is measured.

Surface Potentials and the Deformation of Solids (api)
N. STREET,* R. W. HEINS, F. D. WANG

The effect of adsorbed substances on the deformation behavior of minerals has been studied as has the effect of a polarizing potential on the deformation of metals. The intent of this work is to investigate the deformation behavior of inorganic solids as a function of their surface potentials in solutions of potential determining electrolytes and in the absence of specific adsorption effects. Preliminary experiments have indicated that certain solids are harder in the region of the zero point of charge.

Rheology of Mineral Suspensions (ui)
N. STREET,* T. FINCH

Mineral suspensions generally exhibit non-Newtonian flow behavior. Mostly the flow pattern is of the Bingham type permitting description of the flow at any shear rate in terms of a yield stress and a plastic viscosity. The former can be controlled by suitable alteration of the surface potentials with resulting lowered apparent viscosity with lowered yield stress. This relationship has been well studied in the case of kaolins; currently, coal slurries are being studied whose behavior is Bingham in character. The effect of additives on surface potentials of these coals has yet to be investigated.


Rock Mechanics Research (ui)
F. D. WRIGHT,* M. B. MIRZA, L. ADLER, P. H. H. LU

This is a continuing project dealing with various problems in rock mechanics. A more accurate determination of stresses in bedded roof rocks has been obtained using as a
mathematical model an elastic slab on elastic supports. Under investigation are the contact stresses in a fractured roof. The action of a hydraulic jet on coal is also being investigated.


PETROLEUM ENGINEERING

Petroleum engineering is that branch of petro-physics which deals with the occurrence and recovery of petroleum fluids from the subsurface. The current and projected research activities emphasize those petrophysical aspects of the subject which are fundamental not only to the modern practice of petroleum engineering, but which also have meaning for the broad spectrum of activities connected with the physics of rock systems. The graduate program at this University deals with the hydrodynamics of fluid-rock systems, phase behavior and the physical chemistry of aqueous and hydrocarbon fluids in the earth’s crust, rock mechanics, propagation of electromagnetic and acoustic energy in rocks, and, in situ, petrophysical measurements such as well-logging.

Aspects of Reservoir Engineering (ui)

W. ROSE, N. CHAUDHARI

In the broad sense, reservoir engineering deals with using, controlling, forecasting the future performance and interpreting the past performance of the bounded porous rock systems of the subsurface that may serve as reservoirs, conductors, and sources of fluids, and that also may serve as chemical reactor environments. Groundwater and natural gases along with liquid petroleum are the fluids of special interest and importance. The aspects of reservoir engineering that are emphasized in this study include: (1) the nature of transport phenomena (especially fluid flow and diffusion) in porous solids such as sedimentary rocks; (2) the role of capillary forces in multiphase saturated porous systems; and (3) the properties of scaled laboratory models of natural reservoir occurrences.


A Specialized Type of Seismic Research (afor)

A. E. SCHEIDEGGER, H. FARA, H. PULPAN

It has been noted for some time that the upper strata of the earth are subject to large-scale tri-axial stresses. These are the stresses that are at the root of tectonic activity and thus cause the building of mountains and similar phenomena. Their knowledge is of great importance in connection with mining and petroleum engineering operations. These stresses are also connected with earthquake activity; conversely, from an analysis of earthquakes, one can also determine these stresses. A project, sponsored by the VELA UNIFORM program of the U.S. Air Force is now under way in which an attempt is made to ascertain the large-scale tectonic stresses prevalent in various areas of the world from seismic data. Apart from being of importance in mining operations, this has also a bearing upon the problem of distinguishing earthquakes from atomic bomb explosions.


Mixing in Porous Media (ui)

A. E. SCHEIDEGGER, N. CHAUDHARI

A project, supported directly by the Engineering Experiment Station, is connected with the flow of fluids through rock strata, particularly as it affects the spread of a contaminant in a stream of flowing fluid. This problem is of great significance in connection with modern methods of petroleum production (miscible displacement) and in the study of pollution of ground water. This problem is treated by means of the theory of statistical mechanics.
ROSS J. MARTIN, Chairman of the Committee

The Nuclear Engineering Program is operated by a committee of 24 senior staff members representing 12 departments of the University. This organization is designed to exploit interdisciplinary aspects of Nuclear Engineering and encourage interdepartmental cooperation at both the teaching and research levels.

The total experimental installation for nuclear engineering represents an investment of more than $600,000 and includes such facilities as the TRIGA reactor, subcritical assemblies, heat transfer equipment, nuclear metallurgy laboratory, and radiochemistry equipment.

The above-ground, tank-type TRIGA reactor offers a major advantage in local production of high intensity and short-lived isotopes. It also provides a unique facility for the experimental study of reactor transients. A recent modification of the facility license has permitted an increase in steady state power from 100 to 250 kilowatts and an increase from 250 to 1000 megawatt pulses.

Although research in the nuclear engineering field has been in progress a relatively short period of time, the research efforts have covered numerous areas of interest. The brief summaries which follow are examples of the kinds and varieties of research being performed by the Nuclear Engineering staff. The subdivision of areas of interest are provided for convenience of classification and do not represent divisions into departmental areas.

A view from the top of the TRIGA reactor shows the reactor core, control rod drives, and instrumentation leads.
REACTOR SYSTEMS AND REACTOR KINETICS

Computer-controlled Reactor Fuel Management in Non-Equilibrium Conditions (nsf)
F. T. ADLER,* D. COATES, L. MILLER
Fuel management, the optimization of reactor fuel costs through programming of fuel renewal and relocation in a power reactor, will become of increasing interest. This study has two objectives: First, to adapt mathematical methods such as dynamical and nonlinear programming, variational methods and related optimization schemes to the problems encountered in reactor optimization; second, to reduce the problem to a model which can be investigated by means of digital computer procedures. A survey of interaction of engineering and economic parameters has been completed.

The mathematical model for any real system needs to encompass two aspects: the description of the economic environment, and the long-term changes in isotopic composition and neutron distribution in the reactor. A simple model combining these features has been completed and is being tested.

Analysis of Low-Energy Neutron Cross Sections in Fissile Elements: Multilevel Formulæ for Fissile Element Cross Sections Below 100 eV (sec)
F. T. ADLER,* D. BARONCINI-ADLER,* R. APRAHAMIAN
The multilevel-multichannel formalism of Wigner and Eisenbud has been cast into a form suitable for the analysis of neutron resonance reactions.

The quantitative analysis of the total and fission cross sections of U-233 and U-235 has shown that the single-level approach leads to incoherences, while the multilevel-multichannel approach provides a successful description of the asymmetrical behavior of the low-energy cross sections of such elements.

As a result of this formalism, the cross section is expressed as a superposition of interfering single lines; each level is assigned four parameters, describing the energy level, the width of the resonance, and the coefficients of the symmetrical and asymmetrical line shape functions respectively.

On this basis, a general program of analysis of experimental data has been undertaken. Total and fission cross sections of U-235 and U-233 have been analyzed by least squares fit data analysis.

The procedure employed is the Gauss method, generally employed for fitting nonlinear functions. The advantage of this method consists in the possibility of establishing best values for the resonance energy and width. This program has been carried out on the IBM 7094 of the University of Illinois.

The results obtained for the energy range 0-30 eV are sufficient to describe successfully the fission and total cross section as functions of energy and medium temperature. On the other hand, from the application of dispersion relations the scattering cross section was derived from the total and the capture cross section obtained from the difference. Thus the method provides a complete picture of the set of cross sections of a given element.

Reactor Neutron Pulse Propagation (ul)
G. H. MILEY,* G. BECK, P. K. DOSHI, P. RODRIGUEZ
Earlier measurements demonstrated the feasibility of measuring neutron pulse propagation velocities during pulsed operation of the Illinois TRIGA reactor.

Recent work has been directed towards improvements in theory and application of the method to measure neutron diffusion parameters for graphite. The latter measurements used the TRIGA thermal column, and recently a five-foot extension requiring 3 tons of graphite was constructed for the column to improve accuracy and provide more flexibility in the experiment.

A study of propagation through multiplying media has been initiated using a sub-critical assembly placed in the TRIGA bulk shielding tank. Preliminary results indicate that fairly accurate determinations of reactivity, control rod worths, etc., should be possible using this technique.


Short Interval Repetitive Pulse Operation of a TRIGA Reactor (ul)
G. H. MILEY,* H. KURSTEDT
Experimental and analytical studies of repetitive pulse operation of the University of Illinois TRIGA reactor have been initiated for time intervals between pulses ranging from 20 to 120 seconds. With such short separation times, each pulse is strongly affected by prior pulses due to temperature feedback. The studies will focus on the measurement and theory of this feedback mechanism, and also the measurement of the reactor temperature coefficient at high temperatures and the equilibrium pulse amplitude achieved after many pulses.

Experimental Reactor Kinetics (ul)
M. E. WYMAN,* G. H. MILEY, K. HORNYYK
A variety of conditions for reactor kinetics will be studied. These include oscillations, ramp, and step insertions of reactivity. A digital computer model for calculational purposes will be used to correlate the experimental data.

Temperature Transients in Reactor Fuel Elements (nsf)
M. E. WYMAN,* C. H. ADAMS, W. A. GOODWIN
By monitoring the temperatures as seen by thermocouples located at various radial positions, the source term in the heat balance equation can be evaluated. A study was made of the fission rate in the TRIGA fuel shortly after a 250 megawatt pulse. A new instrumented element is needed to continue the studies.

A further extension of this work could involve the study of heat transfer systems during and after the reactor pulse.
In this case the reactor would be a “heat driver.” Liquid-solid and partially melted solid systems might be studied.


**Anelasticity in Some Group V and VI Uranium Compounds for Ceramic Fuel Elements** (anl)

**A. W. ALLEN,* R. FORLANO**

Dynamic methods of determining Young's modulus, rigidity modulus, and internal friction in single crystals, bicrystals, and/or polycrystalline specimens will be used to characterize the deformation mechanism as related to structure, orientation, and microstructure. Materials will involve uranium oxide, carbide, or phosphide.

**REACTOR PHYSICS, NEUTRON PHYSICS, AND NUCLEAR PHYSICS**

**Theoretical Research in Reactor Physics** (nsf)


The low-energy neutron cross sections in fissile elements have been investigated using the multilevel-multichannel formalism of Wigner and Eisenbud. Preliminary values for the resonance parameters have been obtained which are of interest for reactor physics calculations.

To test the relevance of the multilevel formalism in practical applications, the Boltzmann equation for neutron slowing down and transport has been solved for homogeneous media both for the new parameters and for the old single-level parameters. Interesting changes in the Doppler effect have been observed, and in some cases the sign of the temperature coefficient of reactivity may even change.

A study of the Boltzmann equation for neutron migration and slowing down in reactor lattices has led to the calculation of the resonance escape probability in heterogeneous media containing several resonance absorbers. Digital computer programs have been developed by E. E. Lewis suitable for these calculations and applicable to cases where many different nuclear species are present.

These programs are used to investigate further the role of the interference between resonances predicted by the multichannel formalism for reactor physics calculations.

The Doppler coefficient of reactivity in mixtures of fissile and fertile materials in the presence or absence of light nuclei is also being investigated. Media of such nature are of interest for reactor physics work pertaining to the theory of fast and intermediate reactors.

Another objective of the work supported by this contract has been the investigation of stability problems as they occur in nuclear reactors and, in general, in control systems. The methods of classical mechanics developed by Poincaré and Liapunov, and extended during the past decades in the field of nonlinear mechanics, have been used to investigate stability problems in the nonlinear range.

Professor M. E. Wyman, of Nuclear Engineering and Physics, at control panel of the new University of Illinois TRIGA reactor. Diagram on wall shows arrangement of fuel elements and controls in reactor core.

The TRIGA reactor core is illuminated by the Cerenkov radiation of “blue glow.”
Division of Nuclear Charge Between Primary Fission Fragments of Thermally Fissioned U-235 (ui)
M. E. WYMAN,* L. BRIDWELL, B. WEHRING
A study is being made of X rays from fission fragments in order to determine the charge of the fragments. An X-ray spectrometer is being built for the analysis.
An exploratory study has begun to ascertain the possibility of determining the timing and mechanism of production of the low-energy radiation from fission fragments.

Time Dependence of the Beta Spectrum from Fission Fragments (NSF)
M. E. WYMAN,* T. DOLAN, Jr., J. W. KUTCHER, W. LEE, Y. N. LWIN, N. TSOUFLANIDIS
The absolute yield of betas per fission will be measured. In particular, the time dependent character of the energy spectrum will be studied for three cases.
A sudden burst of fissions at \( t = 0 \).
(2) A constant fission rate is started at \( t = 0 \).
(3) After a constant fission rate permits the fragment decay to reach equilibrium, the fission rate is stopped at \( t = 0 \).

SHIELDING AND RADIATION EFFECTS ON MATERIALS

Studies in Nuclear Radiation Shielding and Related Aspects (NSF)
A. B. CHILTON*
This project is in part a continuation of work previously undertaken by departmental sponsorship at this University. Support was obtained from the Office of Civil Defense on 25 June 1963; and the project has not been previously reported.
This work has three main subdivisions. The first concerns analysis of the gamma ray field from a point source near or at an interface between vacuum and a dense, semi-infinite medium. The calculations are performed for monoenergetic sources, and are readily extended to mixed energy sources.
The second part of this project concerns attenuation of broad, parallel beams of gamma radiation by “ribbed” slabs. The beams are monoenergetic and incident on the slabs either normally or at an angle. The work involves both experimental and theoretical determinations. The theoretical work will include some highly accurate calculations, using the IBM 7094 computer, with the Monte Carlo technique.
The third part of this project is preliminary in nature, and it involves a study of scaling aspects of radiation penetration through multilayered ducts. This work will only be of a theoretical nature and may be the basis for an extension of the project into the experimental field.

Engineering Methods of Predicting Neutron Radiation Penetration from Nuclear Weapons (DASA)
A. B. CHILTON*
Methods of predicting neutron shielding capabilities of various military structures and equipment will be pursued by: (1) reviewing existing information on the neutron environment at various distances from a nuclear weapon, characteristics of structures involved, and penetration information; (2) schematize, idealize, and categorize practical situations and structures along potentially fruitful lines; (3) develop methods, graphs, and rules to be used for engineering prediction of neutron shielding capabilities of military structures.

HEAT AND MASS TRANSPORT

B. T. CHAO,* B. G. JONES, K. MIN, M. A. SHIRAZI
Theoretical and experimental investigation of the motion of a particle suspended in a flowing turbulent field is being made, utilizing fully developed core turbulence of water in tubes. Small solid particles, having varied densities and sizes, are introduced separately into the core region of the tube. The Lagrangian characteristics of their trajectories are determined and analyzed with respect to the Eulerian characteristics of the core which are obtained from anemometer measurements. These results are compared with theoretical predictions for the behavior of the particles and are examined in detail to establish the fundamental relationships between the statistical characteristics of turbulence in moving and fixed reference frames.
Parallel to the foregoing study is the measurement of electrostatic charge on solid particles in solid-gas suspension flow. A probe-type Faraday cage has been developed which, when used in conjunction with a pulse counting system, enables the determination of the charge spectrum of the particles. Using the basic information from the charge measurements, it has been theoretically established and experimentally verified that it is feasible to improve heat transfer in solid-gas suspension flow by subjecting the particles to a fluctuating electrical field of moderate intensity.
Experiments are conducted to test the validity of a theoretical model proposed for the analysis.


Vapor Bubble Collapse and Liquid Particle Entrainment (nsf)
B. T. CHAO,* R. A. MEDROW, D. D. WITTKE

An experimental and analytical study on the mechanics of vapor bubble collapse in subcooled liquids has been continuously progressing in the Heat Transfer Laboratory since 1962. Attention was focused on the behavior of a single bubble undergoing spherically symmetrical collapse in a quiescent liquid of large extent. The work is now extended to include the effect of bubble translational movement under conditions when heat transfer is the dominating mechanism. The important problem of evaluating vapor velocity at the bubble wall is examined.

Another phase of the project which has just begun concerns the mechanics of liquid particle entrainment, with special emphasis on the physical and electrical behavior of small drops in a moving gaseous or vapor stream. The problem of entrainment arises in steam generation, distillation, and evaporation processes. In nuclear power reactors the carry-over of radioactive material in direct cycle steam generation is a subject of particular concern. This research aims at seeking an understanding of the fundamental processes which control the entrainment of small liquid droplets in a gas or vapor.

Bubble Motion in a Turbulent Liquid Stream (aec)
B. T. CHAO,* J. L. L. BAKER, L. W. FLORSCHUETZ

The motion of individual air bubbles in a water stream flowing turbulently in a vertical conduit was investigated by photographic means. The bulk water velocity ranged from 40.8 to 267 cm/sec. corresponding to a system Reynolds number of 48,600 to 386,000. Bubble sizes ranged from 0.076 to 1.60 cm in equivalent diameter. Results are summarized in charts showing the variation of drag coefficient with bubble Reynolds number with systems Reynolds number as a parameter.

Another phase of the study is concerned with the mechanics of vapor bubble collapse. The relative importance of the effects of liquid inertia and heat transfer on the collapse rate has been delineated and a dimensionless parameter identified suitable for the characterization of the mode of collapse. Discriminating values of this parameter have been proposed for the simple case where the collapse is initiated by a step change in pressure or temperature. Experimental results give support to the theory.


PLASMA PHYSICS AND DIRECT ENERGY CONVERSION

Direct Radiation-Electrical Energy Conversion (ui)
G. H. MILEY,* P. RODRIGUEZ

Two major devices are under study—the fission-electric cell and the gamma battery. The former is of interest for nuclear reactor rocket energy conversion schemes while the gamma battery can be used as a “topping” device to convert some of the energy normally lost in a reactor shield or as a gamma detector.

Work on the fission-electric cell has been confined to theoretical efficiency calculations. A detailed treatment of fragment energy losses and charge exchange while traversing matter shows that efficiencies may be considerably different from those previously reported in the literature.

Experimental gamma battery studies have used both the Illinois TRIGA reactor and a Go-60 assembly at Argonne National Laboratory as gamma sources. The investigation of energy spectrum and polarization or charge effects has been stressed.


Research Studies of High-Density Plasmas (scusa)
R. L. HIRSCH,* E. P. BIALECKE, L. GOLDSTEIN

The energy states of a high-density gaseous plasma in low pressure hydrogen have been studied experimentally. The method used to produce the plasma for these studies was magnetic compression in a theta pinch. Electron density variations in space and time were determined using the Stark broadening of the Hα spectral line. Peak densities were found to be of the order of 10¹⁶ per cc. for initial pressures of the order of 1000 Hg. The spatial density distributions were shown to agree well with a modified Bennett model.

Correlation of the results of magnetic probe, electrical conductivity, spectral, and plasma expansion techniques yielded a detailed description of the compressed plasmas and shows the plasmas to be very nearly in a state of local thermodynamic equilibrium. Temperatures were found to be of the order of 50,000°K.

A method for diagnostics in rapidly compressed plasmas has been developed. It involves the study of a controlled plasma expansion and provides a measure of the energy of the plasma. Two methods of analysis of the expansion were shown to provide good correlation with the results of other techniques. The various diagnostic techniques were evaluated with regard to their flexibility and usefulness in high-density plasma studies.


**ACTIVATION ANALYSIS AND RADIATION CHEMISTRY**

The Chemical Reactions of Energetic Atoms Produced by Nuclear Recoil or by Heterogeneous Flash Photolysis (aec)

J. G. KAY,* M. M. DeMAINE, M. G. GARRETT, P. S. LEE, R. PAUL, A. C. WANG, J. GALL, J. A. MATUSKA

The hot atom chemistry of tin, cobalt, and manganese in inorganic crystals has been under investigation. These studies utilize thermal neutron capture reactions produced in the University of Illinois TRIGA reactor operating either in the steady state or pulsed mode. The investigations involve studies of recoil and annealing effects in a variety of solid compounds for various irradiation doses and dose rates. During the coming year, a systematic study of a series of cobalt complexes will be completed and the scope broadened to include coordination compounds of other transition elements.

Flash heating of KMnO₄ crystals and other solids will continue in an effort to study thermal decomposition mechanisms. High-temperature reactions involving metals and refractory materials will be carried out using flash heating techniques. Kinetic absorption spectroscopy coupled with flash heating will continue to be useful for observing reaction rates and obtaining spectroscopic information on radicals and other species produced.

**ENVIRONMENTAL RADIATION — ANALYSIS AND CONTROL**

The Transfer of Natural Radon into the Atmosphere (dap-phs)

J. E. PEARSON,* D. H. RIMBEY, G. E. JONES, S. SHIMIZU

This project is to determine the emanation rate of radon-222 from the soil-atmosphere interface using an alpha scintillation method. Radon collected at the earth's surface is adsorbed on chilled coconut charcoal, transferred to counter bottles lined with a scintillating material, and the disintegrations counted. From such counts, emanation rates are determined.

Experimental work is centered on the agronomy plot sector of the south farm of the university. Variation in the rate of emanation in a circular area within eight miles of this site is being investigated. The variation with location (nine sites studied), soil type, wind speed, and soil moisture is included. Locations have also been investigated in Colorado and New Mexico where the emanation rate is approximately one thousand times that measured locally. A 24-hour study of emanation was made, samples being taken once every fifteen minutes, to determine diurnal change in emanation rate. The effects of season and time of year are also being evaluated.

In conjunction with radon emanation measurements, soil contents of radium-226, parent isotope of radon-222, have been determined. Various soils of Champaign County have been tested for emanating radium-226 content at different locations and depths as have soils from other parts of the United States and Iceland.

The Effects of Atmosphere Stability and Shear on the Accumulation and Diffusion of Naturally Occurring Radon (ul; anl)

H. MOSES,* J. E. PEARSON,* J. R. STINSON*

Experimental data taken at Argonne National Laboratory are being analyzed. Data include measurements of radon (Ra-222), wind speeds, and temperatures at six levels, in addition to the regularly scheduled recordings of meteorological data. Profiles of wind speed, temperature, and radon concentration in the lowest sixteen meters of the atmosphere are being studied to determine their relationship to profiles appearing in the literature. Four of the wind profile laws were evaluated by comparison with measured data using least squares techniques.


**Effect of Natural Organic Compounds on the Ion-Exchange Reaction of Radioactive Ions with Soil Materials** (ul)

B. T. KOWN,* B. B. EWING

The transport of radioactive ions in the environment is in part determined by the ion-exchange properties of the soil. The presence of natural organics in surface or ground water may affect the ion-exchange reaction between the radioactive ions and the soil. It is the purpose of this research to investigate the effect of natural organics on the ion-exchange reaction between radioactive ions and the soil. The natural organics present in the environment may react chemically with the radioactive ions and thereby prevent those radioactive ions from exchanging. The natural organics may be adsorbed on the surface of the soil, thereby reducing the ion-exchange capacity of the soil. The over-all effects of natural organics on the ion-exchange reaction will be studied by a study of the simultaneous equilibrium reactions in the system, natural organics—soil, natural organic-radioactive ions, and radioactive ions-soil.
Experimental research in the Physics Department is carried on principally in the broad areas of nuclear and elementary particle physics, and in solid state and low temperature physics. Theoretical studies cover the above areas and others, including the foundations of quantum theory and aspects of classical dynamics.

The teaching faculty initiates and guides the research of the department. In 1963–64 more than 100 graduate students were engaged in Ph.D. thesis research. Approximately 45 postdoctoral physicists were distributed among the research projects. In the summaries of research the names of the faculty and postdoctoral physicists are marked with asterisks.


X rays are guided through this tube into a target chamber containing an appendix which contains He. The particles from the resulting disintegration are then detected by two groups of counters, each of which is arranged as a telescope.
NUCLEAR AND ELEMENTARY PARTICLE PHYSICS

Theoretical Research in Particle and Nuclear Physics and in Quantum Fields (nsf; onr)


The research activities of this theoretical group cover a wide spectrum of topics, including the mathematical structure of quantum field theory, dynamical theories of the weak and strong interactions of fundamental particles, analysis of high-energy electron scattering by nuclei and the related problems of $\mu$-mesonic atoms, the structure and use of dispersion relations, and studies of classical and quantum many-body problems.

In the area of quantum field theory, the principal objective is a clarification of the mathematical structure and the basic concepts. This involves a formulation of the assumptionsbasic principles in concise mathematical terms, the derivation of physical consequences that depend on these principles alone, and the discussion of specific models. Current work is concerned with a purely algebraic formulation of quantum field theories, with the asymptotic behavior of the solutions for large separations in position space and with the relation between particle aspects and field aspects.

The research on dynamical theories of weak and strong interactions is based on the mathematical similarity between bound states and weak interactions. The technique used in the theory of bound states is being exploited to determine such fundamental parameters as coupling constants and masses as eigenvalues and to derive selection rules in weak interactions. This method was applied to the calculation of the $\mu$-meson electron mass ratio with a fairly reasonable result. The connection of the present formalism with the SU(3) group is being studied.

Research in theoretical nuclear physics has included the structure and the use of dispersion relations in studying the physics of elementary particles. These analyticity properties of probability amplitudes are used both for correlating and interpreting experimental data and for investigating the formal aspects of the relationship with field theory.

Some of the formal problems of current interest involve the possibility of using dispersion relations as eigenvalue equations which can provide restrictions on the possible masses and coupling constants of the fundamental particles. The muon-electron mass ratio is presently under consideration. Another area of investigation is concerned with determining the analyticity properties of vertex functions.

Formulas derived by the use of dispersion theory are being compared with experimental data on various meson-nucleon scattering processes in order to determine the parameters of the formulas and the correctness of the physical assumptions used in the derivation. In this way the effects of $\pi - \pi$ and $\pi - K$ resonances $\pi^+ \rightarrow p\pi^-$, $\pi^- \rightarrow p\pi^+$, and $K^+ \rightarrow p\pi^0$ scattering and on pion-photoproduction can be studied to increase our understanding of the details of these reactions.


P. Y. Pao, "A Note on the Regge Trajectory in \lambda^4 Theory," Progress of Theoretical Physics, 30 (1963), pp. 201-206.

Research with the Cyclotron (onr)


The primary aim of the research undertaken at the University of Illinois Cyclotron is to study the interaction with atomic nuclei of protons, deuterons, and alpha particles obtained from the cyclotron. In realizing this objective, various properties of these nuclei are investigated, i.e., energy level structure, the spins and parities of energy levels, transition probabilities for various radiations emitted from these energy levels, etc. At the present time these investigations are concerned primarily with proton and alpha beams.
Proton-Gamma Reactions

The purpose of this experiment is to define and elucidate the nature of the states composing the giant dipole resonance in Ca$^{40}$. The yield of gamma rays in the reaction $p + K^{38} \rightarrow Ca^{40*} \rightarrow Ca^{40} + \gamma$ (G.S.) was studied for protons whose incident energy was varied from 6 to 15 MeV, covering the region of excitation in the Ca$^{40}$ system of 14 to 23 MeV. In this region of excitation, a giant resonance of approximately 3 MeV width was found. This giant resonance was found to be split into eight resolvable fine structure peaks between 18 and 22 MeV. Peaks at 15.2 and 16.2 MeV were also observed.

In addition to $\gamma$ rays leading directly to the ground state of Ca$^{40}$, $\gamma$ rays corresponding to transitions to the first few excited states of Ca$^{40}$ were also detected but could not be distinctly resolved from each other. These $\gamma$ rays will be restudied after the stability and energy resolution of the $\gamma$-ray detection system has been improved, because it is of considerable interest to determine the existence of giant resonances built upon these excited states.

Other reactions of the same type to be studied in the near future are the $N\omega(p,\gamma)\alpha$ and $Y\omega(p,\gamma)\Delta^*$ reactions.

Polarization of Protons Scattered from Carbon and Nitrogen

An important characteristic of nuclear reactions is the polarization of the outgoing radiations. In order to measure the polarization of protons classically scattered from carbon at an energy of 13.2 MeV, the double scattering technique has been employed. In this technique, one measures an asymmetry, $\epsilon$, of the scattering process which is proportional to $P_xP_y$, where $P_x$ and $P_y$ represent the polarization that the particular scattering induces from an originally unpolarized beam. $P_x$ refers to the first scattering; $P_y$ to the second scattering. If $P_x$ or $P_y$ is known, the other can be determined by a measurement of $\epsilon$. In the case studied, $P_y$ (called the analyzing power) was known from other measurements, and $P_x$, the polarization of protons classically scattered from carbon, was measured throughout the angular range 20°–140° in the center of mass system. For the second scattering ($P_y$), both carbon and nitrogen targets were used.

The results of these measurements indicate that the polarization induced from carbon elastic scattering fluctuates from 0.3 to 0.8 when the proton energy is varied from 12 to 13.5 MeV. This has the practical consequence that a carbon analyzer is not very suitable for use in a polarization experiment at these energies. The angular distribution data of the polarization from carbon at 13.2 MeV will be subject to a theoretical analysis using an optical model potential containing a spin-orbit term.

Additional experiments are planned to measure the polarization induced by scattering protons inelastically. Inelastic scattering polarizations have usually been performed utilizing an initially polarized beam (a known $P_z$). It is of considerable interest to see how well such measurements agree with those where the initial incident beam is unpolarized, as it is the case just studied.

Scattering of Alpha Particles

Alpha particles, being composite particles composed of two protons and two neutrons, interact with nuclei on a different basis than do individual nucleons. It is the ultimate object of this program to understand these interactions. In doing so, insight into the characteristics of nuclei in general will be gained. The cyclotron produces alpha particles whose energies can be varied between 16 and 28 MeV. No systematic study of alpha particle scattering in this energy range has been made prior to this time. Hence plans are being made to undertake such studies with several elements ranging throughout the periodic table. Li, Li, Mg, and Si are presently being studied; elastic and inelastic scattering angular distributions are being measured. In Mg and Si, the excitation of "unnatural" parity ($J = 3/2$) states of the residual nuclei is of particular interest. Such states have been observed in proton inelastic scattering but it was not clear whether or not they would be excited by alpha particles. More complex reactions, where particles other than alphas are emitted from the excited nuclei, will be investigated.

He-3 Scattering

The scattering of He$^3$ particles from complex nuclei can be expected to produce much new information about nuclear structure in the coming years. The cyclotron has the capability of producing He$^3$ beams in the energy range of approximately 12 to 36 MeV. This energy region is admirably suited for nuclear structure investigations, and has not been extensively studied heretofore. A gas handling system for the relatively expensive He$^3$ gas is being constructed to permit the cyclotron to accelerate He$^3$ with low cost.


Mössbauer Effect Experiments (onr)

H. FRAUENFELDER,* P. DEBRUNNER,* G. DEPASQUALI,* R. L. INGALLS,* M. GARRELL, D. HAFEMEISTER R. MORRISON

Research in low-energy nuclear physics has been concentrated on Mössbauer effect for several years. Applications of the well-known transitions in Fe$^{57}$ and Ti$^{49}$ in solid state physics and chemistry have been explored. New isotopes are being investigated in an effort to determine their relevant nuclear parameters. In the same experiments the dependence of the recoilless fraction on the dynamical properties of the host lattice is studied.

Mössbauer Scattering

The scattering technique developed for a study of Fe$^{57}$ is being used in a search for higher Mössbauer transitions. Since the recoilless fraction decreases very rapidly, even at zero temperature, with increasing gamma-ray energy it is not surprising that no Mössbauer effect has been reported for gamma-ray energies beyond 136 keV. According to present knowledge, however, it should be possible to observe
recoilless transition at energies up to 200 keV. Extending the range of the Mössbauer technique to these limits looks promising since it would allow one to study a number of isotopes among the heavy transition metals. The nuclear aspects as well as those in the solid state look very interesting for these isotopes. As a first success of the scattering technique, a Mössbauer line of 155 keV was recently found in Os.

Mössbauer Effect in Iodine—129

Mössbauer experiments done with various compounds of I\(^{129}\) at liquid nitrogen temperature yielded the following results. The spectrum observed with alkali iodide and with KIO\(_3\) consisted of a single line indicating a site of cubic symmetry for the iodide in these compounds. In KIO\(_3\), on the other hand, a quadrupole split pattern was observed and from the known quadrupole moment of I\(^{129}\) in its ground state the quadrupole moment of the first excited state could be determined. A correlation was discovered between the isomeric shift of the various alkali iodides and the number of 5p holes in the iodine ion as determined by a completely different method. It was found that the I\(^{129}\) nucleus changes its charge radius by 3 parts in 10\(^{-2}\) in the decay. Neither the nuclear shell model nor the collective model can account for this number. The fraction of the recoilless gamma rays was measured for various alkali iodides and the little variation which was found disagrees with theoretical predictions.


**Research with the 25 MeV Betatron (onr)**

P. AXEL, D. DRAKE, A. O. HANSON, D. C. SUTTON, A. I. YAVIN, M. BLECHER, S. E. CARY, F. KUCHNIR

The 25 MeV betatron generates high-energy gamma rays which are used to probe nuclear structure. There are four different types of experimental study, all of which exploit the Bremsstrahlung Monochromator. This monochromator is a unique facility which permits the identification of a gamma-ray energy from the knowledge of the energies of the incident and final electrons in a bremsstrahlung process.

**Giant Resonance Elastic Scattering**

Gamma rays have their strongest interaction with nuclei in a relatively narrow energy region near about 15 MeV. This "giant resonance" has been the subject of intensive study, but many of its features are still unknown. The resonance will be studied with the monochromator by measuring the energy dependence of both the elastic and inelastic gamma-ray scattering for many nuclei.

**Studies of Isolated Nuclear Levels**

The study of isolated levels varies, depending on whether the levels are easily separable or have too small a spacing to be studied individually. In light nuclei and exceptionally heavy nuclei (such as the mass number 208 isotope of lead), the level spacing is large enough to permit detailed studies of individual levels. The parameters of some individual levels in carbon, magnesium, silicon, and lead have been determined. Additional similar experiments are scheduled.

The class of experiments involving the isolated, but unresolvable, levels is also very interesting. A program was started several years ago to measure the average level spacing and average strength in zirconium, tin, bismuth, and lead (isotope 206). In addition to giving some average quantities, these measurements supplied the very unexpected results that the average strength was concentrated in energy implying new surprising nuclear structure. These studies are being continued and will be extended to other nuclei.

**Neutron Spectrum Studies**

The monochromator makes it possible to determine energies of emitted photoneutrons by measuring their time-of-flight. The electronic system, which was built and tested in a preliminary way in 1963, is now being used to study the decay of a nucleus excited by gamma rays.

** Charged Particles Emitted by Silicon**

The emission of charged particles following photoexcitation of nuclei, in principle, contains the same type of information as the photoneutron emission mentioned above. Although the energy of charged particles can be measured much more precisely, in most cases the experiments are impractical because the thin samples needed for good energy measurements do not contribute enough charged particles. The element silicon has the unusual advantage of acting simultaneously as a sample and a precise energy detector. Preliminary experiments have indicated that both protons and alpha particles can be detected. More extensive measurements are planned with somewhat improved equipment.


N. Stein, "Photon Scattering Cross Sections Below the Photoneutron Threshold for Pb\(^{208}\), Pb\(^{209}\), and Bi\(^{205}\)," Ph.D. thesis directed by P. Axel, June, 1964.


**Research with the 300 MeV Betatron (nsf; onr)**

C. S. ROBINSON,* J. H. SMITH,* D. C. SUTTON,*
W. P. SWANSON,* A. I. YAVIN,* E. BEIER,
K. D. BORDER, J. D. FOX, E. R. GRAY, L. GRIKE,
D. HERZO, S. KIERGAN, R. A. MEYER, J. R. O’FALLON,
N. M. O’FALLON, J. C. H. PARK, J. D. SIMPSON,
B. M. SMITH, J. TODOROFF, J. R. VAN HISE,
W. B. WALTERS, T. S. YOON
Photon Scattering and Neutral Pion Production (Hanson, Moscato, Fox, Gray, Kiergan)

The scanning, measurement, and analysis of the spark chamber pictures of phonons interacting with deuterons have been completed. The results supplement those of a previous experiment and agree with the previous results within the limits of error.

Plans have been made to complete the measurements on Compton scattering and \( \pi^- \) production from hydrogen and deuterium using 330 MeV bremsstrahlung after the radio-frequency cavity has been installed in the betatron. Longer range plans include the scattering of photons and photoproduction of \( \pi^- \) mesons from He\(^4\).

Pion Photoproduction in Complex Nuclei (Yavin, DePasquali, Grike, B. M. Smith)

Pion photoproduction in complex nuclei is being investigated using activation analysis on the polonium isotopes resulting from

\[ \gamma + ^{209}\text{Bi} \rightarrow \pi^- + ^{209}\text{Po} - \nu + x_n, (n = 0, 1, 2, 3, \ldots) \]

In this fortunate case, six of the resulting isotopes are detectable by means of their alpha radiation and have half-lives long enough to allow a quantitative separation. Preliminary results indicate a cross section (about 2.5 mb) compatible with a surface production model. As a by-product, the energy of \( ^{209}\text{Po} \) alphas was determined as \( 4.895 \pm 0.10 \) MeV.

In the near future positive pion photoproduction will be investigated in the case

\[ \gamma + ^{209}\text{Bi} \rightarrow \pi^+ + ^{209}\text{Pb} \]

For quantitative results, a good \( ^{209}\text{Pb} \) beta spectrum is necessary. This has not been achieved yet, due to scattering out of the detector. A very thin source placed between two face-to-face solid state detectors in a nearby 4\( \pi \) geometry is expected to overcome this difficulty.

Angular Distribution for the Reaction \( ^{4}\text{He}(\gamma, \pi^+)^{4}\text{He} \) (Koester, Smith, Yavin, J. R. O’Fallon, N. M. O’Fallon, Beier, Herzo)

The photoproduction of \( \pi^+ \) mesons from \( ^{4}\text{He} \) is one of the very few two-body photoproduction experiments that can be performed with complex nuclei, especially with both outgoing particles charged. It affords a form-factor type of measurement on the overlap of the three-body wave functions of \( ^{4}\text{He} \) and \( ^{4}\text{He} \). The results have allowed determination of a form factor for the \( ^{4}\text{He} \) nucleus and comparison with the form factor recently obtained here by Berman from the low energy photodisintegration of \( ^{4}\text{He} \).

Search for a Long-Lived \( ^{3}\text{He} \) (Nefkens, Moscato)

A search was made for the \( \beta \) decay of a long-lived \( ^{3}\text{He} \), produced by 250 MeV bremsstrahlung in lithium. The existence of a long-lived \( ^{3}\text{He} \) was predicted by Werratz and Brennan. No evidence was found for this isotope. This corresponds to an upper limit for the production of cross sections of \( \sigma_p \leq 0.7 \times 10^{-4} \mu b \) assuming the half-life of \( ^{3}\text{He} \) is 3 minutes.

For experiments on the scattering of alpha particles, graduate student Van Bleumel is using this evaporation apparatus for fabricating target foils for the cyclotron.
The $\delta$ detector was also sensitive to gamma rays, but no evidence for delayed gamma rays was found.

**Search for Anomalous Photopion Production from Helium** (Neffens, Criegee, Moscati, and Smith)

This group has investigated the production of negative and positive $\pi$ mesons from helium by 200-275 MeV $\gamma$ rays using a magnetic spectrometer and counters. The yield of 117 MeV/c $\pi$ mesons was recorded at three laboratory angles as a function of the peak bremsstrahlung energy. The $\pi^-/\pi^+$ ratio was found to be consistent with the theoretical one from free neutrons and protons, corrected only for differences in the reaction thresholds and the Coulomb interactions in the final states $^8\text{He} + p + \pi^-$ and $^8\text{He} + n + \pi^-$. The data excluded a large difference in the nuclear interaction in these final states as suggested by Argan et al. An upper limit of 15 percent for the production of an $\pi^- + \pi^+$ final state was obtained.

**Production of $\text{Be}^4$ from $\text{Be}^3$, $\text{C}^{12}$, and $\text{O}^{16}$ and the Photodisintegration of $\text{Al}^{27}$** (Moscati, Neffens, Todoricoff)

Beryllium, anthracene, and water targets were irradiated with the bremsstrahlung beam from the betatron from 45 to 275 MeV in intervals of about 20 MeV. $\text{Be}^4$ was detected by following the 53 day half-life of the characteristic 0.48 MeV $\gamma$ activity. An IBM 7090 computer was used to obtain the best fit to each half-life curve. The excitation curves are now being analyzed using the Penfold-Leiss method, also programmed for a computer. Preliminary results indicate a second maximum in the cross section for the production of $\text{Be}^4$ from $\text{Be}^3$ and $\text{C}^{12}$ by high energy photons. The magnitude of the integrated cross section of the second maximum is comparable to that of the first maximum in the giant resonance region. The peak for the second maximum occurs at about 160 MeV for $\text{Be}^3$ and at about 220 MeV for $\text{C}^{12}$. The production of $\text{Be}^4$ from $\text{O}^{16}$ has also been observed.

Using techniques similar to those described for the work on $\text{Be}^3$, the long-lived gamma activities induced in $\text{Al}^{27}$ by bremsstrahlung from 30 to 275 MeV have been investigated. By pulse-height analysis in a 4" NaI crystal and by half-life measurement, $\text{F}^{19}$, $\text{Na}^{23}$, and $\text{Na}^{24}$ have been identified among the spallation products of $\text{Al}^{27}$. Yield curves for the production of these isotopes have been obtained and analysis of the yield curves is under way.

**Bubble-Chamber Study of Photoproduction of $\pi^+$ and $\pi^-$ Mesons near Threshold** (Ascoli, Goldwasser, Kruse, Swanson, Park, Simpson, Yoon)

The pion photoproduction data obtained in hydrogen and deuterium bubble-chamber runs during the past two years have been analyzed. The experimental results are coming well up to expectations in that the quantity and reliability of the data represent a significant improvement over previously available results. The predictions of dispersion relation calculations seem to be verified, in outline. The previously questioned rise of the matrix element near threshold is now clearly established. The $\pi^-/\pi^+$ ratio has been analyzed using the observed ratio in deuterium and applying a Baldwin calculation. It has also been obtained by using the Chew-Low extrapolation procedure to obtain the cross section of free neutrons for $\pi^-$ photoproduction. This result, combined with hydrogen results for $\pi^+$ photoproduction, gives a threshold ratio which is in good agreement with the theoretical prediction of 1.3.
The present π⁻ results are based on an analysis of only half of the available data. The remaining data have yet to be analyzed.

**Photonuclear Reaction Studies (Huettel, Borden, Meyer, Van Hise, Walters)**

The objective of this research program is to obtain information about the mechanisms of photonuclear reactions by studying their yield behaviors. The reaction yields are generally determined by measuring the radioactivities of the nuclei produced when target materials are irradiated with bremsstrahlung from the 300 MeV betatron. Recent work has been concentrated on two projects. One of these involves the measurement of yield ratios for the production of pairs of nuclear isotopes in several different types of reactions. Since the isomeric pairs differ in their nuclear spins, these yield ratios should be sensitive to the part that angular momentum effects play in the reaction mechanisms. The yield ratios for the production of Mn⁵⁸,⁵⁹ from Fe⁵⁶ and Mn⁵⁸ targets of Y⁵⁷,⁵⁸ from Zr⁴⁰, Zr⁴¹ and Nb⁹² targets at 150 and 300 MeV have been determined. These yield ratios being interpreted in terms of a compound nucleus mechanism in which the relative densities of high and low spin levels in the nuclei involved are important in determining the yield ratio. The results indicate that there are more high spin levels in the Mn⁵⁸ region than in the Y⁵⁷ region. Plans have been made to extend the measurements to other isomeric nuclei (Sc⁶⁴,⁶⁵ and Ce⁹⁲,⁹³ in particular).

The second project involves the determination of the relative yields of (γ,2n) and (γ,3n) reactions at 250 MeV in several different target nuclei. The (γ,2n)/(γ,3n) yield ratio for Ce⁵⁸, Fe⁵⁶, Y⁵⁷ and Os⁹⁳ targets has recently been measured. The results vary widely from nucleus to nucleus, ranging from 0.1 for Ce⁵⁸ to 10 for Y⁵⁷. This is strongly suggestive that a compound nucleus mechanism is involved although confirmation of this conclusion by any detailed theoretical calculations has not been made. Future plans for this project involve doing some quite detailed studies of the energy dependences of these ratios.


**Elementary Particle Physics (bec)**


Studies of the Decay of the K⁺ Meson (Abashian, Nefkens, Smith, Wattenberg, Abrams, Carpenter, Fisher, Fletcher, Mischke, Thatcher)

The 100,000 spark chamber photographs taken at the Brookhaven National Laboratory of the K⁺ decays have been measured and are being analyzed. Preliminary results giving the forms of the interaction have been reported at meetings of the American Physical Society.

A continuation of these studies is under way at the 10 BeV Zero Gradient Synchrotron at the Argonne National Laboratory. The polarization of the μ meson from the K⁺ decays will be measured. From these studies it is hoped to obtain information as to whether the electron and μ-meson interactions with K mesons proceed via the same mechanism. It will also be possible to check whether the fundamental time reversal invariance is obeyed when a K meson decays via a leptonic mode.


**Elementary Particle Studies with Bubble Chambers (Ascoli, Goldwasser, Kruse, Sard, Downing, Firebaugh, Hanft, Park, Richardson, Simpson, Yoon)**

During the past year the first results have been forthcoming from the bubble-chamber investigations which were started over a year ago. An initial experiment involving the bombardment of protons by 2.5 BeV/c π⁻ mesons has been almost completely analyzed. A related exposure in which deuterium was bombarded by 2.5 BeV/c π⁺ mesons is also well under way. The complementary π⁻ and π⁺ interactions are being studied. Data on the interaction of two K mesons are scant, but promise to make some small contribution to the events already accumulated at Brookhaven and at Berkeley.
Scanning and measuring procedures have been improved over the past year and analysis programs have been developed. The measuring facilities will be augmented during the coming year by the availability of new scanning-measuring-projector systems which are now under construction.

A proton-proton bombardment is planned for the Brookhaven 80 inch bubble chamber and should be performed during the summer of 1964. The group has also been deeply involved in the development of facilities for bubble-chamber experiments at the new Zero Gradient Synchrotron at Argonne. There the separated beam will be tuned, and a 30 inch bubble chamber with a 30 kilogauss magnetic field will be put into operation. The Illinois group is scheduled for the first operation period of this new instrument. It is planned to take 130,000 pictures of K+, K−, and anti-proton interactions at momenta between 4 and 6 BeV/c.


The Berkeley-Illinois Collaboration in Bubble-Chamber Experiments (Geiger, Hulsizer, Pripstein, Swanson, Lathrop, Mortara, Requa, Trower)

About 600,000 pictures of K± mesons scattering on protons in 72 inch liquid hydrogen bubble chamber at Berkeley have been studied. The K± mesons had a momentum of 1.34 BeV/c. The total cross section, the total elastic scattering cross section, the differential elastic scattering cross section, the total and differential cross section for charge exchange scattering, and the scattering with the production of K± + p → π0, K± + n + π+, K± + p + π± final states were studied. In the last three reactions, appreciable (60 percent) K± (888 MeV) production occurred and some N± (1238 MeV) production occurred.

A second bubble-chamber run with K± mesons at 2.63 BeV/c and 2.70 BeV/c has taken place and the pictures of that are being studied. In the reaction K± + p → K± + p + π± + π±, considerable K* and N* production was observed, and the angular distributions of the decay of the K* and N* are being studied. Production of other final states is being examined.

Three bubble-chamber photograph measuring machines, SMP's, copies of the one built at Berkeley and brought here in March, 1962, are being constructed. The Berkeley model is, and the three new ones will be operated on line to the University of Illinois CSX-1 computer.


W. P. Trower, R. I. Hulsizer, and W. P. Swanson, “K− + p Cross Sections for K+n and A π0 Final States at 1.34 BeV/c,” (ibid).

Interaction of Slow K Mesons with Nuclei (Hill, Ficenc, Lansford, Shapiro)

The main investigations proposed and in the course of preparation are the interactions of low energy K mesons and hyperons with hydrogen and deuterium. Several bubble chamber runs have been made at the high-energy accelerators in Brookhaven and Berkeley, and part of the film is now being analyzed for interaction events. A preliminary report on K-deuterium reactions made to the American Physical Society at the Washington meeting, April, 1964.

Completed research includes an investigation of Auger electron emission from K−-meson atoms of Ag and Br. Also an investigation of K−-meson nuclear scattering by Ag and Br is in the process of being written up. Both of these investigations were carried over from previous techniques using photographic nuclear emulsions.


Development of Electronics for High-Energy Experiments (Koester, Beier, Herzo, Keller, Stenberg)

The modular system of fast logic circuits for high-energy experiments was mentioned in last year's report. A pool of circuit types used in the largest quantities has been organized; circuits can be borrowed for an experiment and then returned. A handbook has been prepared with complete descriptions of all circuits and is being kept up to date with revisions.

The use of increasingly complex arrays of these modules by diversified groups of experimenters has shown the need for versatility and reliability. If it is possible to interconnect modules in some way that will cause them to malfunction, the experimenters will do it sooner or later. To this end, several of the logic circuits have been substantially improved.

There is a steady demand for new types of circuits. A special development project for bubble-chamber beam monitoring and another for track analysis are in progress. Circuits are being designed to perform analogue functions such as pulse, height, and time discriminations. New logic circuits stress complex events and short dead times.


NUCLEAR REACTOR PHYSICS

Theoretical Research in Reactor Physics (nsf)
F. T. ADLER, A. BAXTER, D. KAYA, E. E. LEWIS

The low-energy neutron cross sections in fissile elements have been investigated using the multilevel-multichannel formalism of Wigner and Eisenbud. Preliminary values for the resonance parameters have been obtained which are of interest for reactor physics calculations.

To test the relevance of the multilevel formalism in practical applications, the Boltzmann equation for neutron slowing down and transport has been solved for homogeneous media both for the new parameters and for the old single-level parameters. Interesting changes in the Doppler effect have been observed, and in some cases the sign of the temperature coefficient of reactivity may even change.

A study of the Boltzmann equation for neutron migration and slowing down in reactor lattices has led to the calculation of the resonance escape probability in heterogeneous media containing several resonance absorbers. Digital computer programs have been developed by E. E. Lewis suitable for these calculations and applicable to cases where many different nuclear species are present.

These programs are used to investigate further the role of the interference between resonances predicted by the multichannel formalism for reactor physics calculations.

The Doppler coefficient of reactivity in mixtures of fissile and fertile materials in the presence or absence of light nuclei is also being investigated. Media of such nature are of interest for reactor physics work pertaining to the theory of fast and intermediate reactors.

Another objective of the work supported by this contract has been the investigation of stability problems as they occur in nuclear reactors and, in general, in control systems. The methods of classical mechanics developed by Poincare and Liapunov, and extended during the past decades in the field of nonlinear mechanics, have been used to investigate stability problems in the nonlinear range.


**Computer-controlled Reactor Fuel Management in Non-Equilibrium Conditions (nsf)**

F. T. ADLER,* D. COATES

Fuel management, the optimization of reactor fuel burnup through reprocessing of fuel renewal and relocation in a power reactor, will become of increasing interest. This study has two objectives: First, to adapt mathematical methods such as dynamical and nonlinear programming, variational methods, and related optimization schemes to the problems encountered in reactor optimization; second, to reduce the problem to a model which can be investigated by means of digital computer procedures. A survey of the interaction of engineering and economic parameters has been completed.

The mathematical model for any real system needs to encompass two aspects: the description of the economic environment, and the long-term changes in isotopic composition and neutron distribution in the reactor. A simple model combining these features has been completed and is being tested.

**Analysis of Low-Energy Neutron Cross Sections in Fissile Elements: Multilevel Formulæ for Fissile Element Cross Sections Below 100 eV (aec)**

F. T. ADLER,* D. BARONCINI-ADLER,* R. APRAHAMIAN

The multilevel-multichannel formalism of Wigner and Eisenbud has been cast into a form suitable for the analysis of neutron resonance reactions.

The quantitative analysis of the total and fission cross sections of U-233 and U-235 has shown that the single-level approach leads to inconsistencies, while the multilevel-multichannel approach provides a successful description of the asymmetrical behavior of the low energy cross sections of such elements.

As a result of this formalism, the cross section is expressed as a superposition of interfering single lines: to each level are assigned four parameters, describing the energy level, the width of the resonance, and the coefficients of the symmetrical and asymmetrical line shape functions respectively.

On this basis, a general program of analysis of experimental data has been undertaken. Total and fission cross sections of U-235 and U-233 have been analyzed by least squares fit data analysis.

The procedure employed is the Gauss method, generally employed for fitting nonlinear functions. The advantage of this method consists in the possibility of establishing best values for the resonance energy and width. This program has been carried out on the IBM 7094 of the University of Illinois.

The results obtained for the energy range 0-30 eV are sufficient to describe successfully the fission and total cross section as functions of energy and medium temperature. On the other hand, from the application of dispersion relations the scattering cross section was derived from the total and the capture cross section obtained from the difference. Thus the method provides a complete picture of the set of cross sections of a given element.

**SOLID STATE PHYSICS**

**Theoretical Problems in the Physics of Condensed Systems**


During the past few years a number of new mathematical methods, including techniques of quantum field theory, have been developed for treating systems of large numbers of interacting particles. The group has been concerned with the further extension of these methods and their application to problems in solid state and low-temperature physics.

Work currently under way includes the theoretical study of elementary excitations in solids, superconductivity, superfluidity, solid state plasmas formed in semiconductors and semimetals, He4, and He3, and liquid metals.


*This research was conducted jointly by the Department of Physics and the Materials Research Laboratory.

**Theoretical Studies on Crystalline Materials**

**K. H. BENNEMANN,** F. GARCIA-MOLINER,**

**N. H. HINDLEY,** L. KADANOFF,** D. MATZ,** F. SEITZ,**

**D. Y. SMITH**

One of the problems being studied in this general area of crystalline solids is the electronic transport properties of semiconductor and insulating crystals, including high electric field effects. A project is also under way to study the properties of defects in solids and to apply some of the mathematical methods developed in other theoretical areas. The studies so far carried out have been concerned with lattice properties (internal friction) as well as with electronic properties. Work concurrently in progress is concerned primarily with the latter topic.

The goal of the present research of Dr. Smith is to gain an understanding of the changes in electronic properties of insulating crystals that occur when impurity atoms are substituted for normal atoms or when normal atoms are displaced. With this in mind, two types of simple solids have been investigated: the system of impurity atoms in rare gas solids, and color centers in alkali-halides.

The main topic under investigation by Dr. Matz (with Dr. F. Garcia-Molinier) has been the study of the influence of a transverse magnetic field on non-ohmic properties of semiconductors. Three different problems have been investigated by assuming the Shockley model for hot electrons.

The interaction between phonons and hot electrons is being examined. A variational method of solving the Boltzmann equation which includes magnetic field terms is being applied to the problem of electron transport properties. The same method is being used to attack the electron phonon interaction in ionic crystals where the electron scattering is due chiefly to interaction with the optical modes of the lattice. A comparison of theory and experiment for mobility in the silver halides is currently in progress.

Another class of problems under attack concerns the electronic properties of metals with randomly distributed impurities. Approximate band structure calculations for transition metal alloys are being performed. Also under investigation is the behavior of superconducting alloys—particularly the effect of impurities upon spin-lattice relaxation times.


**Cyclotron Resonance and Magneto-optical Phenomena in Ionic Crystals**

**F. C. BROWN,** K. K. KANAZAWA,** J. MORT,**

**R. A. AHRENKIEL, J. BORDERS, F. LÜTY**

Electronic and optical phenomena are being studied under very high magnetic field in crystals of the alkali and silver halides. A superconducting solenoid of 1-inch inside diameter has been installed which produces steady magnetic fields as high as 57 kilogauss. This solenoid has been employed to study the Faraday rotation effect for point defects such as the F center in alkali halide crystals. Extensive measurements have been made for the F center in various alkali halides from NaCl to CsBr. The results show that the excited state of the F center possesses structure due to spin-orbit interaction. The spin-orbit splitting Δ increases with atomic number of the alkali atom, more or less as in the atomic case, except that for the F center Δ is found to be negative. This has to do with the location of the nuclei which for a sort of a cage outside of the electron in the case of the F center. The Faraday rotation technique has turned out to be a powerful tool for investigation of point defects as well as band phenomena in solids.

Cyclotron resonance due to conduction electrons in CdTe has been observed at 700 °C and at 4.2°K. The conduction band turns out to be isotropic, and an accurate value of the band mass has been obtained. The experiments are being extended to other ionic materials. A cross modulation technique for the observation of cyclotron resonance is under investigation.


*This research was conducted jointly by the Department of Physics and the Materials Research Laboratory.

**Electronic Structure of Ionic Crystals**

**F. C. BROWN,** G. SPINOLO,** B. D. JOESTEN, M. MIKKOR**

The Hall mobility of electrons released from F centers by light has been observed for KBr, KCl, and NaCl in the little explored temperature range 7°K to 100°K. Intrinsic scattering by optical modes is observed above 40°K in pure crystals, extrinsic effects at lower temperatures. The low-temperature mobility is sometimes as high as 15,000 cm²/volt sec, but can be drastically reduced by the incorporation of charged defects such as F′ and α centers. The results bear on our understanding of transport processes in ionic crystals.

Magnetoresistance measurements have been successfully carried out on KBr at low temperature and indicate a conduction band of standard form and fairly light electron
masses. Experiments in high electric and magnetic fields are continuing.

The lifetime of excited \( F_A \) centers (\( F \) centers with nearby impurities) has been measured in several different cases. The results are similar to the \( F \) center and indicate a diffuse excited state following lattice relaxation. Measurements are under way on the quantum mechanical tunneling of electrons out of the excited \( F \) center at low temperature. These experiments are adding greatly to the understanding of the luminescent properties of the \( F \) center.

Certain additional work is under way on the silver halides, viz., optical absorption in mixed crystals AgCl-AgBr, and on carrier absorption.


**Radiation Effects in Semiconductors (nasa)**

W. D. Compton, E. A. Davis, G. W. Anderson, R. Heves, R. Spry

Irradiation of semiconductors with high-energy photons, charged particles, or fast neutrons generates a variety of defects. The properties of these defects are being studied by optical and electrical measurements.

The location of the energy levels associated with these defects is being determined by measuring the minority carrier lifetime as a function of temperature for samples irradiated with \( \text{Co}^{60} \) gamma rays. Samples with varying resistivities and oxygen content are being used in an effort to determine whether a correlation exists between the type of defect and the oxygen content.

Recombination of an electron and hole via a recombination center might be expected to yield a luminescence. For recombination centers which are effective in limiting the minority carrier lifetimes, the energy of the luminescence plus the energy separation of the recombination level from the nearest band edge should approximately equal the band gap energy. A search for this luminescence is under way.

The introduction of acceptors into highly doped \( n \)-type germanium increases the compensation. For reasonably small changes in compensation, the conductivity will be only slightly affected for temperatures above \( 10^4 \) K. At lower temperatures, where conduction is by the impurity band mechanism, this increase in acceptor concentration can produce significant changes in the conductivity. Studies of defect introduction rates are being made. The dependence of the impurity conduction process upon the relative concentration of donors to acceptors is also being studied.

**Color Centers in the Alkali Halides† (nsf)**

W. D. Compton, H. Mizuno, J. Boettler, S. Schnatterly

Various types of color centers are generated in an alkali halide crystal by \( x \) irradiation at room temperature. It is known that an equilibrium is established among the electron excess defects. This equilibrium relationship has been used to establish that the \( R \) centers consist of three nearest neighbor \( F \) centers, that the \( N_2 \) centers consist of four nearest neighbor \( F \) centers, and that the \( N_1 \) centers consist of two nearest neighbor \( F \) centers that are probably located near an impurity or a vacancy. The approach of the system to equilibrium is believed to arise from interstitial motion. The activation energy for this motion is about 0.07 eV.

It is known that the efficiency for luminescence of the \( F \) center decreases as the concentration increases. It has been suggested that this quenching results from an interaction of the \( F \) centers. If this is correct, the spectral distribution of luminescence may also be affected by this interaction. This is being studied as a function of \( F \)-center concentration.

The excitation spectra of the luminescence of \( F \) centers are being compared with the excitation spectra of the luminescence of \( M \) centers with light in the vicinity of the \( F \) band. This should show whether the \( F \) light is being directly absorbed by higher excited states of \( M \) centers which occur under the \( F \) band or whether it is being absorbed by \( F \) centers and then transferred to nearby \( M \) centers which luminesce.

Studies of the strain-induced dichroism of the color centers are being made. The magnitude and the spectral distribution of the dichroism are sensitive to the nature of the excited states of the centers. These studies will be made on \( F \), \( K \), \( L \), and \( M \) centers.

A separate study on the mutual interaction of two nearby \( F \) centers in \( \text{KCl} \) crystal is being investigated. It is known that randomly distributed \( F \) centers tend to coagulate at room temperature when irradiated with light absorbed by these centers. During the initial stages of coagulation, the efficiency for luminescence decreases. It has recently been found that the \( F \) absorption band broadens with coagulation. The extent of the broadening is independent of the measuring temperature. This broadening has been interpreted as arising from a dipole interaction of two near \( F \) centers. The influence of high external electric fields upon the absorption spectrum of \( F \) centers is also being investigated.


†This research was conducted jointly by the Department of Physics and the Materials Research Laboratory.

**Conduction Mechanisms in Semiconducting Glasses (soc)**

A. L. Friedberg, W. D. Compton, R. M. Brown, P. J. Roeder

(See Ceramic Engineering, p. 30)

**Surface Studies by Radioactive Methods (afosr)**

H. Frauenfelder, P. Debrunner, G. DePasquale, E. Lüscher, F. Perdrisat, J. Burton, R. Godwin, D. N. Pirkorn

A systematic study of adsorption energies of various metals on clean surfaces has been completed. The last system in-
vestigated was copper and gold on polycrystalline tungsten. A fraction of a monolayer of radioactive Cu-64 and Au-198 was evaporated onto a thermally cleaned tungsten target in an ultrahigh vacuum system. From a measurement of the activity left on the target after heating it to a temperature between 1000°K and 1500°K for a given time the binding energy was found to be 3.6 eV and 3.5 eV for gold and copper, respectively.

A first successful Mössbauer experiment with Fe-57 on a polycrystalline tungsten surface revealed a variety of interesting facts, some of which are being checked in more detail at present. About one-tenth of a monolayer of the parent isotope Co-57 was evaporated onto a clean tungsten foil under ultrahigh vacuum. The Mössbauer spectrum of the gamma rays emitted by the decaying Fe-57 nuclei was measured at two different angles with respect to the surface and as a function of the temperature and the thermal treatment of the target. A spectrum was observed consisting of two components, a single line due to iron atoms diffused into the cubic tungsten lattice and a doublet due to iron atoms sitting on the surface where large field gradients give rise to quadrupole splitting. For the surface atoms the intensity of the Mössbauer lines was larger normal to the surface than parallel to it since the binding forces are strongest perpendicular to the surface. Upon heating, the atoms on the surface diffused into the bulk and the unsplit line increased at the expense of the doublet.

Similar experiments using different substrates are in preparation.

An investigation of the Mössbauer effect in iron under high pressures has been completed. The results of studies of the Mössbauer effect in Fe at 1000°K when contained in crystals are described in publications shown in the section entitled "Mössbauer Effect Experiments" (see pp. 131-134).


Anharmonic Effects in Solids† (aec)

A. V. GRANATO,* Y. HIKE,* K. SWARTZ

Anharmonic properties of solids are to be studied using ultrasonic techniques. Data are to be collected on the elastic constants, together with the temperature and stress coefficients of the elastic constants of a wide range of materials. The immediate objectives of the program are the development, collection, and testing of equipment, the preparation of specimens, and the measurement of the second order elastic constants of some materials in the alkali halides and the noble metal groups. In the case of the alkali halides, theories are fairly well developed and the measurements should serve as a check for the theories. In the case of the noble metals, theoretical work seems to be less firmly based, and the measurements may be useful in guiding further developments.

Longer range objectives of the program are the collection of data accurate enough (1) to be useful in the checking of relations which may exist between various anharmonic effects, (2) to serve as a check and a guide for theories of the solid state, (3) to establish useful equations of state for solids, (4) to determine interatomic potentials, and (5) to calculate defect properties in crystals.


†This research was conducted jointly by the Department of Physics and the Materials Research Laboratory.

Radiation Damage† (aec)


The primary aim of this research is to understand the production, the properties, and the annealing out of defects introduced by nuclear irradiation. Experiments have been done to decide whether the defect migrating in Stage III is a simple or complex defect. The experiment attempted to break up the defect by a thermal pulse. No breakup was observed.

A new method for treating the interaction of point defects is being examined. The method is applicable to all kinds of point defects and defect clusters. The method gives the strength of interaction provided the form of interaction is known.

The migration energy of defects introduced into gold by 200 eV argon ion bombardment has been measured. It is 0.76 ± 0.05 eV. Arguments for the identification of this defect with the interstitial are given.

Annealing measurements on gold quenched from low temperatures give a migration energy of 0.71 eV ± 0.03 eV. The defect could be a single vacancy or a divacancy. Further experiments are planned to decide which defect is responsible.


Imperfections in Crystals (nsf)

J. S. KOEHLER,* A. V. GRANATO,† G. DEN OUDEN,* B. VON TURKOVITCH,‡ R. YEH*

The Eschelby-Lidiard theory of the clouds of charged point defects surrounding dislocations in ionic crystals has been improved in three ways: (1) the appropriate boundary condition at the dislocation core has been established, (2) the nonlinear differential equations have been solved, and (3) the influence of the association of positive ion vacancies and negative ion vacancies has been allowed for.

Experiments to determine the energy to form a positive ion vacancy are in progress. This energy can be obtained if the temperature at which the charge cloud disappears can be measured in crystals containing known divalent ion concentrations. The critical temperature can be ascertained by making damping and elastic constant measurements as a function of temperature.

Experiments also are in progress to determine the rate at which a charged cloud forms if the surface of a cleaved crystal.

Experiments on the small angle x-ray scattering of silver in aluminum are in progress. The aim is to determine whether the apparatus is sufficiently sensitive to detect vacancy clusters.

In addition, experiments are being done to study the dislocation–phonon interaction. These experiments are aimed at deciding whether phonon scattering occurs as a result of strain field scattering or by re-radiation scattering. Measurements will be made on pure single crystals as a function of frequency, orientation, temperature, and dislocation density.

Point Defects in Solids† (aec)


This program is concerned with experimental and theoretical investigations of point defects in solids, with particular emphasis on their role in diffusion. Experimental techniques employed include radioactive tracer studies, nuclear magnetic resonance, internal friction, and microvolt potentiometry to determine the effects of temperature, pressure, impurity content, and electric field gradients on the generation and motion of defects. Studies have been completed on the internal friction of quenched gold, and the resistivity changes in quenched dilute gold alloys. Current work centers about investigations of the effects of large electric currents in self-diffusion in gold, diffusion in bcc refractory metals, vacancy-impurity and solvent-impurity interactions in alloys, and effects of high pressure on thermal conduction and electrical resistivity of metals.


Plastic Deformation (onr; arc)

J. S. KOEHLER,* JOHN HOLDER, C. LUND, P. F. SCHULTZ

Experiments have been done on the generation of vacancies in gold which is pulsed to a definite temperature for a known time and then is quenched. Results on polycrystalline grains indicate that not all of the vacancies come from large-angle grain boundaries. Some probably originate at dislocations.

The activation energy required to anneal out vacancy tetrahedra in gold is 2.2 ± 0.6 eV.

Experiments are under way to pulse gold single crystals. In addition to the pulse measurements, attempts will be made to determine the dislocation density by etch pit methods.

Experiments on the quenching of zone refined aluminum give $E_{\text{vac}} = 0.50 ± 0.04$ eV for the energy to move a divacancy and $B_2 = 0.17 ± 0.5$ eV for the energy required to dissociate a divacancy.

Experiments on aluminum plus 0.1 percent gold give the binding energy of a gold vacancy complex to be $0.35 ± 0.05$ eV.

Additional quenching experiments are in progress on gold and on aluminum alloys.

The theory of solvent and solute diffusion in dilute alloys is under examination.

*This research was conducted jointly by the Department of Physics and the Materials Research Laboratory.

†This research was conducted jointly by the Department of Physics and the Materials Research Laboratory.


**Dielectric and Semiconducting Solids (onr)**

R. J. MAURER,* N. A. ECONOMOU,* H. OHKURA,* P. SASTRY,* R. FULLER

The diffusion coefficient of the chloride ion in potassium chloride is being measured as a function of temperature and concentration of the deliberately added impurity, strontium. Radioactive chloride is used as a tracer for these measurements. The purpose of the work is to determine the mechanism of the ionic mobility. It is believed that the chloride ion diffuses in potassium chloride by exchanging position with either an anion vacancy or a vacancy pair. The measurements will yield information concerning the properties of vacancy pairs if these pairs are found to have a role in the diffusion process.

The technique for analysis of trace impurities in the alkali halides with the mass spectrograph is being developed. A procedure that works well with potassium chloride has been devised. An example of the results which have been obtained is that in zone refined potassium chloride the concentration of the magnesium impurity varies from 0.02 parts per million at one end of the ingot to 1.0 parts per million at the other end.


**Electronic Properties of Non-metallic Crystals (afos)**

R. J. MAURER,* H. OHKURA,* T. SRINIVASAN,* R. CRANDALL, H. ROCKSTAD

The research of this program is primarily concerned with the mobility and trapping of electrons in alkali halide crystals. The work has involved the preparation of ultrapure crystals by zone refining and an examination of the properties of these crystals.

Pure potassium chloride crystals were found to possess a dielectric loss at high temperature in the megacycle region of the spectrum. The characteristics of the loss indicate that it is due to vacancy pairs. Good agreement was found between the experimental and theoretical heats of formation of vacancy pairs and their relaxation time.

An extensive study of the Z zone in potassium chloride has been made. These centers are formed when electrons are trapped at a lattice imperfection that includes an impurity divalent cation. It was shown that the Z zone center is the product of photo-ionization of the Z center and explicit atomic models of both centers were determined.

The capture cross section for electrons of the alpha center (the anion vacancy) and the F center were determined as a function of temperature between 20°K and 120°K.

The quantum yield for the optical destruction of H centers, the substitutional hydrogen ion, in potassium bromide at 78°K was measured as a function of wave length. The quantum yield is 0.5 at 225 nm, the peak of the H absorption band, and decreases at shorter wave length.


**Noble Gas Crystals† (aer)**

R. O. SIMMONS,* D. N. BATCHelder, O. PETERSON

The crystal lattice dynamics and statistical mechanics of noble gas crystals can be developed in extensive and fundamental detail. This project has developed apparatus and techniques for growth and manipulation of massive single crystals of neon and of argon which are then studied by x-ray diffraction methods. Accurate measurements of lattice constants, thermal expansivities, isothermal compressibilities, and intensities of diffraction maxima, as a function of temperature, then provide critical tests of theory. Emphasis is presently focused upon properties in the temperature interval 2°K to 30°K and in the pressure range below 100 atmospheres. A study of zero point and anharmonic effects is under way on isotopically pure Ne and Ne° crystals.


†This research was conducted jointly by the Department of Physics and the Materials Research Laboratory.
Electron and Nuclear Magnetic Resonance
(aec)

P. MANSFIELD,* P. R. MORAN,* C. P. SLICHTER,*
D. AILION, J. ASIK, J. BUSHNELL, N. C. FERNELIUS,
J. FRANZ, J. GARTH, C. HENRY, J. PIFER

Work is in progress in both nuclear and electron spin
resonance.

Nuclear resonance studies of the validity of the concept of
spin temperature when applied to a rotating reference
system have led to the discovery of a new method of observing
the ultra-slow motion of atoms. They also have led to
modifications of the technique of nuclear double resonance
for studying point imperfections in metallic and insulating
crystals.
The structure of Fe+++ in AgCl appears to be yielding to
the technique of electron-nuclear double resonance. The
resonance of Mn+++ in PbSe has been observed as a pre-
liminary to observing the extent to which the Mn induces
magnetic polarization in neighboring atoms (as determined
by the coupling to the nuclear moments of neighbors).
Studies have begun to measure the cross section for flipping
electron spins when conduction electrons collide with
various foreign atoms in metals. This cross section is analo-
gous to the cross section for no-flip processes which deter-
mines the role of impurities in determining electrical re-
sistance.
Theoretical studies are under way on the Faraday rotation
of F centers. In particular, the importance of the lattice
potential has been discovered and an effect similar to the
principle of spectroscopic stability enunciated.

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*This research was conducted jointly by the Department of Physics and the
Materials Research Laboratory.

Paramagnetic Relaxation and Dynamic
Nuclear Polarization† (arp; apsf)

H. J. STAPLETON,* E. R. BOESMAN,* R. C. MIKKELSON,
L. J. RAUBENHEIMER, D. S. WOLLAN

The interaction between the electronic magnetic mo-
mments of transition metal ions and quantized lattice vi-
bractions, i.e., phonons, is being studied in various single
crystals. The rate at which the magnetic system returns to
thermal equilibrium after a disturbance is a measure of the
strength of this interaction. A study of the temperature de-
pendence of this rate in the liquid helium range has been
made for several ions of the rare earth and actinide groups. This interaction is also being utilized to dynamically polarize nuclei also present in the crystals. At the low microwave frequency presently employed, proton polarizations have been enhanced by a factor of 100 over the thermal equilibrium value. At higher frequencies the proton polarization is expected to approach 70 percent.

†This research was conducted jointly by the Department of Physics and the Materials Research Laboratory.

Analytical Mass Spectrograph Laboratory† (arp)

R. J. MAURER,* N. A. ECONOMOU*

The mass spectrographic laboratory is in operation. Its major instruments are a Model Ms-7 mass spectrograph which was obtained from Associated Electrical Industries, England, and a National Spectrographic Laboratories microdensitometer. The mass spectrograph is designed for analysis of trace impurities in solids. The primary work to date has been the development of a method for analysis of potassium chloride crystals. This work has been performed by Dr. H. Okura in conjunction with his studies of color centers. The analysis of potassium bromide and the silver halides will be started in the near future.

As a part of the work on the characterization of the properties of the alkali halides, Professor N. A. Economou has examined the high-temperature, high-frequency dielectric constant of potassium chloride containing the impurity, strontium, and pure sodium chloride. A dipole relaxation contribution to the dielectric loss which appears to be due to vacancy pairs has been observed. Theory and experiment are in excellent agreement concerning the heat of formation and the relaxation time of the vacancy pairs.

(For the published report of this work see page 145).

†This research was conducted jointly by the Department of Physics and the Materials Research Laboratory.

LOW-TEMPERATURE PHYSICS

Far Infrared Absorption and Electron Tuning in Superconductors† (apsf; nsf; arpa)

D. M. GINSBERG,* S. BERMON, R. L. CAPPALLETTI, W. N. HUBIN, A. E. JACOBS, J. D. LESLIE, J. S. SHIER, J. E. SMITH

A group of related experiments is being carried out to determine the way in which the energy gap in a superconductor is affected by electron concentration, electron mean free path, and crystal structure. The experiments also yield information concerning the lattice vibration spectrum and the properties of the excited electron states in superconductors. The techniques involve either the measurement of the absorption of far infrared radiation in superconductors or the determination of the rate at which electrons quantum-mechanically tunnel between two metals which are separated by a thin insulating barrier. The results of these measurements for a series of superconducting alloys are expected to yield information concerning the influence of electron concentration and mean free path on the excited electron states and the lattice vibrations in superconductors.


†This research was conducted jointly by the Department of Physics and the Materials Research Laboratory.

Low-Temperature Thermal Conductivity and Optical Studies in Alkali Halides† (aec)

M. V. KLEIN,* R. CALDWELL, W. R. FENNER, B. WEDDING

Thermal conductivity is being used as a tool to study point defects in alkali halides. One investigation involves the role of monovalent impurities such as Ag, K, Br, in NaCl. Systematic departures from perturbation theory (Rayleigh Scattering) prediction for phonon scattering by the defects are being sought. Another investigation is on hydroxyl ion impurity, which scatters phonons in an anomalous way that differs from one alkali halide to another.

Infrared absorption studies at high resolution and at low temperatures are under way to learn about the energy levels of hydroxyl-doped halides. Ultimately the results of the optical and thermal conductivity measurements will be correlated. An investigation of the hydroxyl center and ultimately other centers by the Raman effect also is under way.


†This research was conducted jointly by the Department of Physics and the Materials Research Laboratory.

Superconductivity in Metals and Alloys† (aro; arpa)

D. E. MAPOTHER,* E. P. HARRIS, R. E. HARRIS, D. MONTGOMERY, W. WILKES

Precise thermodynamic measurements are used to investigate various aspects of superconducting behavior. Work now in progress includes measurement of the effect of hydrostatic pressure on the critical field curve of pure superconductors below 1°K, and the effect of alloying addi-
tions on the normal electronic and lattice specific heats of tin.

New experiments have been started to clarify fundamental superconducting properties of alloy systems showing Type II superconducting behavior. The predicted second order phase transition will be investigated using simultaneous magnetic calorimetric measurements on the same sample.

Another project has as its purpose the extension of previous work on the properties of superconducting Al alloys. Calorimetric measurements are planned to study the volume fraction of material whose superconducting transition temperature is controlled by controlled precipitation of Mg-Si in an Al-Mg-Si alloy.

This research was conducted jointly by the Department of Physics and the Materials Research Laboratory.

Low-Temperature Properties of He\textsuperscript{3} (ae)


The purpose of this project is to study the properties of He\textsuperscript{3} over a temperature range extending as low as possible. Since techniques are just being evolved for working at the extremely low temperatures required by this research, much of the work of the last year has been directed toward the development of technology, particularly regarding the thermal and magnetic properties of materials at low temperatures. A research on the thermal boundary resistance between liquid helium and a solid has been completed. At very low temperatures, He\textsuperscript{3} and He\textsuperscript{4} have qualitatively different behavior for this phenomenon. A new station for ultralow temperature work has been put into operation. The present experiments conducted by the senior investigators are aimed at measurement of the thermal and magnetic properties of He\textsuperscript{3} below 0.01 K, although the experiment is planned which deals with the zero sound phenomenon. Thesis students are working on the thermal conductivity of He\textsuperscript{4} under pressure (Connolly), a nuclear free precession thermometer for determining the relationship between the self-diffusion coefficient of He\textsuperscript{3} and the Kelvin temperature (Sarwinski), properties of ions in liquid helium (Kuchni), and properties of solid He\textsuperscript{3} at low pressures and temperatures (Roach).


ELECTRODE PHYSICS

Corrosion and Passivity of Metals (rcr)

J. H. Bartlett,* D. J. DaSmet

The purpose of this research project on corrosion and passivity of metals is to study the formation, removal, and electrical properties of anodic layers of metals such as iron, nickel, and chromium. The practical application of these studies should result in improved methods of corrosion protection, better electrodes for batteries, fuel cells, and capacitors, and a better understanding of electrode processes in general.

The electrical characteristics of iron have been studied in detail, and similar techniques are being used in the study of nickel. The anodic layers of both metals have been found to be similar in many respects, each layer having a large nonohmic resistance; however, nickel exhibits a more complicated current-voltage behavior and time dependence than iron. A study of temperature dependence of the parameters associated with the layer on nickel is also being pursued.

THREE-BODY PROBLEM

Periodic Motion of Small Mass Under Attraction of Two Heavy Masses (nfa)

J. H. Bartlett,* C. Wagner, D. W. Wilson

This problem deals with the periodic motion and stability of a small mass under the gravitational attraction of the two heavy bodies. The simpler symmetrical periodic solutions of the restricted three-body problem have been obtained as a function of the mass-ratio of the two heavy bodies. This work has been accompanied with the aid of the 7094 computer. Investigations of stability are now being made, using the Iliac II computer.

A close correlation is maintained between the educational and research programs of the Department of Theoretical and Applied Mechanics; strong emphasis is placed on the fact that the functions of teaching and research should go hand in hand for the most complete and effective development of both students and staff. Research is conducted on a part-time basis by most of those on the teaching staff and part-time teaching is done by most of the research staff. The diversity of interest in research is illustrated by the fact that the staff members have educational backgrounds and training in civil, mechanical, architectural, aeronautical, and electrical engineering, metallurgy, physics, and mathematics.

In general, the research studies undertaken are of a fundamental nature that supplement the regular educational functions of the University. Some of the projects are primarily theoretical and involve highly complex mathematical analyses of stresses, vibrations, fluid flow, or basic material behavior; others involve both analytical and experimental approaches and may include the development of new equipment or instrumentation and the interpretation and correlation of experimental data with theory.

In practice, the research in engineering mechanics emphasizes application of the engineering sciences to the theoretical aspects of problems in widely divergent fields and to the development of new knowledge of the behavior or the verification of theory in terms of carefully planned and instrumented experiments. The current projects are grouped below under the headings of: (1) behavior of materials; (2) mechanics of solids; (3) dynamics; and (4) fluid mechanics. However, no sharp distinction or division of responsibilities exists within the department, and close coordination is maintained for free and regular interchange of concepts and ideas that will contribute to the solution of current problems and to the continuing development of the educational program.

U of I fellow W. F. Swinson is making a stress analysis of a doubly connected torsion model using the scattered light technique of three-dimensional photoelasticity. The source of light is a continuous gas laser.
BEHAVIOR OF MATERIALS

Strong emphasis is placed on seeking a greater depth of understanding of the fundamental factors controlling flow or fracture of materials subjected to external loadings. Basically, the research encompasses studies of metals and nonmetals (including concrete, plastics, wood, glass fibers, etc.), and includes the inherent influence of environment on the mechanical behavior in modern engineering applications. Wherever possible, analyses of flow or fracture are approached by theoretical considerations. Frequently, the behavior of the elemental particles of which the material is composed is involved. The crystal lattice (and presence of foreign atoms) in a metal, the long-chain polymer molecules of plastics, and the aggregate and cement paste of concrete are examples.

In most cases, critical examination of the material is needed when it is subjected to a unique set of simulated service conditions. These include the resistance to elevated temperature, corrosive environments, impact loads, repeated loads (fatigue), and loads sustained for long periods (creep and relaxation). Major objectives include the prediction of the performance of a structural member or machine part in a given environment and service loading history from theoretical concepts, plus a knowledge of only minimal test information.

Deformation and Fracture of Crystalline Solid Under Dynamic Loading (af)
G. M. SINCLAIR,* B. GAIN, C. E. FELTNER, S. K. METROPOLE

Deformation effects associated with combined creep and fatigue loading are being investigated for several metals over a range of homologous temperatures. The phenomenon of cyclic stress induced creep is being investigated for copper, aluminum, and cadmium at room temperature and 78°C. In repeated tensile tests, varying the maximum load produces a set of strain versus cycle curves which are similar to strain versus time curves obtained in static creep. The accumulation of strain during combined creep and fatigue loading is cycle-dependent in the homologous temperature range T/Tn < 0.25, time-dependent in the range T/Tn < 0.5, and both cycle- and time-dependent in the temperature range 0.25 < T/Tn < 0.5.


Time and Temperature Dependence of the Ductile-Brittle Transition in Metals (af)
G. M. SINCLAIR,* P. E. BENNETT

The yield behavior of polycrystalline body-centered cubic metals is being studied. A literature survey is being made to summarize data relating to the effects of state of stress, strain rate, temperature microstructure, and chemical composition on the yield behavior and fracture of these metals. Some supplemental experimental work on tungsten is also being carried out.

Various mechanisms which have been proposed to explain the yield behavior of these metals are being examined in terms of available data. It is desired to determine analytical expressions which relate the variables over a wide spectrum of values.


Mechanical Behavior of Dilute Alloys of Niobium (abc)
G. M. SINCLAIR,* D. C. HUFFAKER

The yield behavior of niobium single crystals being studied over the temperature range 78°K to 400°K and at strain rates ranging from 2 per minute to 0.0004 per minute. Several different substructures are being produced in the crystals by plastic prestraining under controlled conditions and subsequent heat treatment. Details of the effect of substructure on the frequency factor, friction stress, and activation volume in the deformation-rate equation for this material are being examined.


Applications of Fracture Mechanics to Steels (aro)
H. T. CORTEN,* A. K. SHOEMAKER, W. A. VANDERSLUYS

Work on this problem is divided into two parts:

Low Stress Fracture of Mild Steel

Low stress fracture of strain rate and temperature sensitive structural steels has been studied by A. K. Shoemaker using linear elastic fracture mechanics. The fracture toughness decreases as the strain rate is increased and/or the temperature decreased. Because of current experimental limitations on the maximum attainable rate of loading, it has not been possible to produce strain rates comparable to those experienced at the tip of a running crack. Based on the hypothesis that Gc would be identical for a rapid loading test and a running crack test if the strain rate and temperature at the crack tip were identical, a time–temperature parameter, T/νA/4, has been investigated.

Combined Effect of Water Vapor and Repeated Loading on Slow Crack Growth and Fracture Toughness

W. A. VanDersLuyss used round notched bars of SAE
Mechanics of Failure of Glass Fiber Reinforced Plastic (onr)

H. T. CORTEN,* J. BADER, N. M. CAMERON, J. GILLMAN, J. MELVIN, D. SHADMAN, I. C. WANG, E. WU

Work on this problem is divided into the following projects:

Glass Fibers

Using the electron microscope, N. M. Cameron is investigating the nature and density of “damage sites” on glass fibers caused by various environmental treatments, particularly heat and moisture. During the last year extensive experience was gained with tape replica techniques on both rods and fibers. A carbon self-shadowing technique on glass rods was used to obtain higher resolution. Future plans call for the testing of fibers both in air and vacuum to correlate strength with surface observations.

Elastic Constants and Modes of Failure

J. Melvin is investigating a single layer (1/32 in. thick) parallel filament composite in which the matrix is rubber. By testing at various low temperatures where the properties of the rubber change rather drastically, the influence of the relative moduli of elasticity, relative strengths, and relative elongations of the fibers and matrix may be studied in essentially the same specimen. Both an analytical and experimental study of the elastic constants of the composite and an experimental study of modes of fracture of the composite are in progress.

Fracture Toughness of Parallel Filament Composites

E. Wu recently completed an investigation of the fracture toughness under tension, shear and combined tension, and shear loading of orthotropic plates. Experiments on wood were very encouraging. Work on parallel filament glass fiber reinforced plastics is nearing completion. Later the study will be extended to multidirectional wound fiber glass cylinders. Exploratory experiments in this latter area are under way.

K Values

D. Shadman has nearly completed the problem of an analytic solution for the K factor in an edge crack in a semi-infinite plate loaded by two opposite point forces in the plane of the plate at any one of a number of locations relative to the crack tip.

Fracture Toughness of Glass–Resin Bond

The fracture toughness, \( G_{\text{f0}} \), for separation between a glass rod imbedded in a cylinder of epoxy resin has been undertaken by D. Shadman.

Epoxy Resin

J. Bader has been engaged in a study of the mechanical properties of epoxy resin (Dow DER 332) cured with several different hardeners including DETA, MDA, and most recently TEPA. Tensile properties (modulus, tensile strength, and relative fracture elongation) and fracture toughness (\( G_{\text{c}} \)) are being measured.

Compression Modes of Failure

J. Gillman has been studying modes of failure in compression. Thus far considerable effort has been expended in avoiding end or gripping failures. Failure strengths (end failure) have progressed successively from 50 ksi to approximately 150 ksi, but end failures still plague this effort.

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4340 steel with a Rockwell C hardness of 48 and tested them in tension, both in a controlled environment and at room temperature. The compliance of the specimen was measured on each cycle and was used to determine the amount of crack growth. It appears that the \( G_{\text{f0}} \) values (fracture toughness) may be lowered slightly as the moisture content of the atmosphere increases. It was also found that water vapor alone assists slow crack growth, but that water vapor combined with repeated loading has a greater effect. The effect can be easily seen by looking at the ratio \( \frac{\sigma'_{\text{f0}}}{\sigma_{\text{pp}}} \), where \( \sigma'_{\text{f0}} \) is the stress level sufficient to cause either slow crack growth or failure in less than 100 cycles. The amazing result is that if a specimen was cycled in the 100 percent relative humidity condition and with a natural crack present, the \( \frac{\sigma'_{\text{f0}}}{\sigma_{\text{pp}}} \) ratio was found to be about 0.30, whereas it was about 0.55 if no moisture was present.

More recently a similar study on SAE 4340 steel sheet, 0.07 in. thick has been completed. Again a marked influence of water vapor was found.

Plans are now under way to investigate the fundamental influence of water vapor on fracture of steel.


Time of Mission Profile Compression During Elevated Temperature Fatigue Testing of Full-Scale Vehicles (mac)

H. T. CORTEN,* G. HALFORD, R. ROWLANDS

A general method is presented for compressing the elevated temperature fatigue test time of supersonic aircraft, gust or maneuver critical, in the Mach 2 to 5 range. The problem is approached by dividing creep diagrams into realms of material behavior, which are used, in conjunction with mission characteristics, to define basic environments for which time compression criteria are developed. These individual “building blocks” are then combined to reproduce complex supersonic aircraft missions and to compress the time required for testing.

The time compression method is applied to a representative wing panel of a Mach 3.2 supersonic transport. The resulting time compression ratio is from 9.3 to 18.0, depending upon the type of construction and the number of load cycles in the spectrum. A two-part test program for evaluating the method is proposed. In part one, coupon specimens are used to evaluate criteria for compressing the basic environments separately and as parts of a mission; in part two, components incorporating typical joints with thermal stresses are tested. Test techniques and problem areas associated with full-scale testing are discussed.

The intent was to observe the one or several dominant modes of failure (delamination of outside layers, filament buckling, 45-degree progressive shear failure) to establish a basis for analysis of compression failure and an improvement in compressive strength.


**Shelling of Crane Wheels (also)**

F. G. BAULING, J. O. SMITH, H. R. WETENKAMP, T. MITSUDA

Cranes which are subjected to very large loads frequently experience wheel failure due to contact stresses. The loads involved are large enough to cause inelastic action in the tread material. Theoretical and experimental investigations are being made to evaluate the relationship between load and the expected life of various materials.

**Stored Energy of Cold Work from Cyclic Deformation (ul)**

G. R. HALFORD, J. D. MORROW

The objective of this project is to gain fundamental knowledge of the role played by mechanical hysteresis, heat dissipation, and the stored energy of cold work during cyclic deformation. Significance can be found in a better understanding of cyclic strain hardening and softening, the cyclic steady state, fatigue crack nucleation, repair of fatigue damage, accelerated creep under repeated stress reversal, atomistic mechanisms of cyclic deformation, and the mechanisms of energy dissipation in solids.

Hysteresis energy measurements during fatigue loading have been made by numerous investigators, but little or no interpretation has been given, although an analysis of fatigue has been made using this energy as a means of describing S-N curves. Values of the stored energy of cold work in fatigued specimens have been obtained by three different groups of workers, but the data are extremely sparse and the specimens were of such geometry that correlation of the measurements with mechanical properties is impossible.

Experiments are planned which will alleviate these difficulties. Mechanical testing will be accomplished by torsion of thin walled tubes of pure metals. Thermal measurements will include rise in temperature during deformation and power difference during subsequent calorimetric annealing.

**Effect of Repeated Stress Reversals on Creep Deformation (ul; ct)**

J. D. MORROW, G. R. HALFORD

It has been discovered that multiple reversal in direction of creep stress results in a large and continued deterioration
of the creep resistance of lead at room temperature. This observation has led to an informal, University sponsored research program into the causes for the observed acceleration of creep. A search of the literature for similar observations has been made. It was found that virtually no creep experiments have been reported in which the stress was periodically reversed. Static creep deformation theory has been reviewed and possible ways by which reversal of stress could cause an acceleration of creep have been studied.

Additional testing of lead and other materials are being undertaken to determine the cause and significance of accelerated creep due to repeated stress reversals.


**Mechanism of Fatigue Failure in Concrete**

(idh; bpr)

C. E. KESLER,* S. H. L. KUNG, J. L. LOTT, J. A. NEAL

It was determined that fatigue failure in plain concrete could be attributed, on a macroscopic scale, to the failure of the bond between the coarse aggregate material and the binding matrix. Subsequent tests have supported this conclusion. Plain sand-cement mortar specimens containing single, two, and three pieces of preshaped aggregate material of two different materials have been tested in repeated flexure, with the load varying from near zero to a maximum. In addition, models of the specimens have been examined photoelastically to determine the effects on the stress conditions of certain geometrical features of the specimens.

The question has been raised about whether the results of the fatigue tests are invalidated due to the frequency of the applied loads, and an investigation is currently in progress to determine the effect of the rate of load application on the indicated modulus of rupture of the specimen.

In recent years the fracture mechanics approach to the problem of crack propagation in several materials has proved fruitful. When concrete fails in flexure it does so by propagation of cracks. Thus fracture mechanics may provide a more basic approach to the problem and this possibility is currently being investigated.


**Creep in Structural Concrete**

(idh; bpr)

C. E. KESLER,* I. ALI, G. BIGG, K. K. JAIN, S. H. L. KUNG, R. L. YUAN

A general study of the nature of creep in concrete and in particular, a study of the feasibility of predicting creep behavior under compressive, tensile, and flexural loads from short time tests performed at early ages is being conducted. Preparation of a critical review of available information on the rheology of concrete forms part of the study.

Compression and flexural creep tests conducted earlier are being supplemented with creep tests in direct tension using 5-inch by 5-inch by 60-inch prisms. Damping characteristics are being determined by sonic tests on 6-inch by 12-inch companion cylinders. Recovery behavior is being studied by unloading some of the previously loaded specimens.


Studies of Welded Wire Fabric for Reinforced Concrete (aisi)

C. E. KESLER,* A. ATLAS, A. C. BIANCHINI, C. P. SIESS

This investigation aims to increase the basic knowledge of the behavior of welded wire fabric when used as reinforcement in concrete. The investigation has involved five main studies: (1) pull-out studies to obtain information for predicting the maximum pull-out stress in a pull-out specimen, (2) fatigue studies to obtain information on the fatigue behavior of one-way slabs, (3) splicing studies to determine the amount of overlap needed to develop stresses in longitudinal wires, (4) long one-way slab studies to obtain information on the behavior of one-way slabs greater than 12 feet in length, and (5) one-way slab studies using large diameter wires.

A study has been carried out to determine the impact of this research on design, codes, and specifications concerning with reinforced concrete.


Control of Cracking in Concrete Reinforced with High-Strength Steel Bars (aisi)

C. E. KESLER,* A. C. BIANCHINI

This study is concerned with developing an understanding of the formation of cracks, determining critical crack widths, and methods of controlling cracks in concrete reinforced with high-strength steels.


Behavior of High-Strength Steel in Columns (aisi)

C. E. KESLER,* A. C. BIANCHINI, C. E. TODESCINI

The behavior, mode of failure, and load capacity of eccentrically loaded, tied concrete columns reinforced with modern high-strength steels are being studied. The following variables are included: steels with marked yield points, steels without marked yield points, concrete strength, amount of reinforcement, and eccentricity. All column specimens are 11 inches by 11 inches in cross section and 80 inches high and reinforced with four vertical bars. The experimental phase has been completed.


**Turbulent Boundary-Layer Flow Towards a Normal Step (ui)**

J. M. ROBERTSON, D. B TAULBEE, H. F. JOHNSON

Mean-flow field and turbulence structure of separated turbulent boundary-layer flow ahead of a forward-facing (up step) step is being studied. Experiments in a low-speed air tunnel with several step heights and boundary-layer thicknesses are complemented by analytical studies. Details of the separation bubble and turbulence are of prime concern. Initial indications that relative length of bubble is independent of relative boundary-layer thickness are being checked in a second tunnel, which also permits more detailed studies of the turbulence structure.

Analysis of the upstream boundary-layer development towards separation has been successful in terms of simultaneous solution of momentum and energy integral equations, when account is taken of difference in pressure between wall and edge of boundary layer. This difference, as well as a depiction of the separated flow pattern is found to be well described by a numerical solution on the basis of the frozen-vorticity analysis. Additional flow situations are being verified on this basis.


**Hemodynamic Simulation of the Circle of Willis (nih; nsf)**

M. E. CLARK, J. M. ROBERTSON, J. D. MARTIN, R. C. HANSEN, R. A. WENGLARZ

The circle of Willis, lying at the base of the skull, supplies blood to the brain. In vivo experimentation is limited by the inaccessibility of the circle and the small size of arteries. A true model would permit many simultaneous pressure and flow measurements and flow variations to be made in one parameter while others were kept constant. To date, a steady flow, rigid-walled, 8-scale model of the circle has been constructed based on the Reynolds criterion. Both the complete circle and components thereof have been studied for flow deployment by the photographing of dye patterns and for quantitative measurements of flow and pressure. Model verification requires further information on efferent flow resistances which is being sought by physiological prototype measurements in conjunction with digital and analog computer simulation. Ramifications associated with collateral vessels, vessel dilations, and efferent and afferent occlusions are being studied via the digital computer model.

As the modeling is extended from the present steady flow rigid approximation towards the more sophisticated pulsatile elastic representation, greater emphasis will have to be placed on the associated concepts of wave mechanics. In order to correctly depict the flow and pressure distributions in the circle of Willis, it will be necessary to adequately represent the efferent vessel networks of arteries, arterioles, and capillaries. In order to reproduce equivalent resistances and impedances of these networks, more detailed information will be required regarding the vessels and flow wave reflections which occur at branching points in the flow vessels. Theoretical and experimental analyses of these problems are currently being explored.


**Velocity Distribution in an Open Channel Having a Triangular Cross Section (ui)**

W. M. LANSFORD

The distribution of velocity in an open channel having a triangular cross section has been under study for some time. Various measurement methods have been employed. Currently an electronic hot wire probe is being considered. This would allow measurements to be taken quickly and accurately within close proximity to the wall or boundary. In order to calibrate such a probe a rotating channel has been built.

**DYNAMICS**

Current advances in engineering and space technology are bringing to the fore problems involving the dynamic and vibrational behavior of mechanical systems. Because of this, the department has become involved in dynamics research on an ever broadening base during the past several years. Whereas the solutions to many engineering problems can be effected without regard to the motions of the bodies involved, these new fields of interest require that a study of the motion be made. In some cases this may be kinematic in nature, i.e., an analysis of the motion itself without reference to the forces which cause the motion, or it may be kinetic, in which case a study is made of the interrelation between the causative forces and the resulting motion. The solutions to problems in dynamics usually require the involvement of other areas, such as the mechanics of fluids and solids or the behavior of the materials, in order to achieve an over-all picture of the behavior of a given mechanical system.

**Torsional and Bending Oscillations of a Shaft Subjected to Distributed Pulse Loads (ui)**

J. C. WILEY, W. J. WORLEY

When a circular shaft is subjected to periodic forces not passing through a principal axis, torsional and bending oscillations ensue. These are studied with the assumptions that the torsional wave equation and Euler-Bernoulli beam equation apply.

The distributed load applied is represented by step functions along the length of the shaft (finite) and by a pulse
train in time. Since these are most conveniently handled by means of transform techniques, both governing equations are studied with multiple Laplace transformations. Solutions of these and frequency equations are obtained in this study.

This information should be valuable for the design of slings used in agricultural and industrial machinery.


Structural Damping in Vibration Systems (ui)
H. C. WANG,* W. J. WORLEY

Structural damping includes the connection damping and material damping. Under this project, emphasis is placed on the vibration response of the system with material damping only.

The material damping, a study of the internal friction of solids, involves the stress-strain relationship, material properties, stress history, and the displacement amplitude. Since a large variety of experimental techniques are used to measure material damping, the damping factors or damping constants are expressed in many different ways. An extensive review of the different measurements of structural damping is in process, and a general relationship between the different expressions of structural damping factor is being developed.

The response of the vibration is considered from the viewpoint of energy dissipation. The energy curves in the phase plane are fully discussed for different systems. The general Maxwell approach and dynamic modulus concept are used to investigate viscoelastic materials.

Synthesis of Linear Mechanical Vibration Systems (ui)
J. A. KASUBA,* W. J. WORLEY

Techniques for designing systems capable of reproducing previously assigned performance characteristics have been investigated. The study includes (1) a review of several analysis concepts, (2) a description of methods for obtaining mathematical expressions from graphs depicting desirable system performance characteristics, (3) a discussion of procedures for testing the mathematical expressions to determine if such a system can actually exist, and (4) a presentation of several synthesis techniques that can be used to obtain both the geometrical configuration and element values of the system. Suitable examples are used to illustrate important concepts.

The mathematical procedures of synthesis are carried out step by step, each step reducing the complexity of the mathematical expression describing the prescribed performance characteristics. The systematic application of synthesis techniques may lead directly to a satisfactory solution or to several possible solutions. Considerations of space or economic limitations may be used to determine the best of the available solutions.


Geometrical and Inertial Properties for a Class of Shells of Revolution and for a Larger Class of Shells (nasa)

W. J. WORLEY,* C. C. FRETWELL, K. C. FU, H. C. WANG

The general elliptic type equations \( \frac{x^2}{a^2} + \frac{y^2}{b^2} = 1 \) and \( \frac{x^2}{a^2} + \frac{y^2}{b^2} + \frac{z^2}{c^2} = 1 \) are under consideration; the first equation is revolved about the x-axis to generate shells of revolution, while the second equation describes a more general shell. The properties listed in the title are readily obtained in terms of gamma functions for solids; however, the lengths of lines and surface areas cannot now be determined since integrals of the required type had not been evaluated previously.

A large high-speed digital computer is being used to compute the values of the line and surface integrals and the other integrals which arise in the computation of the items listed in the project title.

Information obtained may prove useful for the design of space craft, aircraft, ocean surface vessels, and undersea vessels.


Educational Films in Dynamics, Shock, and Vibration (cee)

W. J. WORLEY,* W. H. WALKER

The project is a joint effort of the departments of Civil Engineering and Theoretical and Applied Mechanics in cooperation with a national committee. The major portion of the filming will probably be done at Purdue University, Lafayette, Indiana.

The T&M Department has a newly completed 16-foot-long air track for filming of an in-line system of up to 20 degrees of freedom. The system makes possible the accurate control of damping characteristics and spring characteristics, the use of nonuniform mass distribution, and transient and steady state excitation. Both linear and nonlinear spring and damping characteristics may be demonstrated.

The Civil Engineering Department has a model of multi-story building frames which may be used to illustrate natural frequencies and modes, response of the system to sinusoidal force applied at an arbitrary story, the effect of a base motion in the form of a simple pulse, sinusoidal base motion, and earthquake type motion.

MECHANICS OF SOLIDS

The mechanics of solids treats the stresses, the deformations, and the stability of solid bodies that are subjected to various types of essentially constant loads and to various thermal environments. One phase of this science has developed into a large body of physical investigations known as "experimental stress analysis." Another analytical phase involves
the behavior of bodies having idealized deformational response as stipulated by several mathematical theories; among these are the theories of elasticity, elastic stability, and plasticity. Applications of the mechanics of solids are usually intended to provide assurance that parts or assemblies are proportioned efficiently and economically and that they are sufficiently strong, durable, stable, and rigid or deformable to function properly throughout their anticipated lifetimes.

**Prediction of Time-dependent and Time-independent Deflections of Circular Plates (ui)**

G. T. Taoka, O. M. Sidebottom

Using an energy approach and the Rayleigh-Ritz procedure, a theory was developed to predict time-independent and time-dependent (creep) deformations of concentrically loaded circular plates. Nonsteady-state creep was considered. In the case of creep, the stress–strain–time relation for the material at a specified time was assumed to be given by the isochronous stress–strain diagram for that time. Both the stress–strain diagram and the isochronous stress–strain diagram were approximated by an arc hyperbolic sine function. The material was assumed to be homogeneous and isotropic, and the deformations were assumed to be small.

Circular plates and accompanying tension and compression specimens were machined from plates of half-hard brass and high-density polyethylene. The theory made use of material constants obtained from the tension and compression specimens to predict deformations of the plates to compare with the measured values. The theory and experiment were generally in good agreement.


**Comparison of Some Popular Creep Theories with Elevated Temperature Data from Columns and Torsion Members Made of SAE 1035 Steel and OFHC Copper (ui)**

O. M. Sidebottom, N. R. Bauld, Jr.

Available literature lists several analytical creep theories, depending on the relation used to approximate the creep properties of the material. This investigation was undertaken to evaluate the steady-state theory, the Marin and Pao theory, the arc hyperbolic sine theory, and the incremental theory for solid circular torsion members, and to evaluate the arc hyperbolic sine theory for columns.

The experimental part of the investigation included tests of members made either of SAE 1035 steel at 950°F or OFHC copper at 800°F. Creep properties were obtained using tension, compression, and hollow torsion specimens; the three types of specimens gave nearly identical properties. Good agreement was found between the column test data and the arc hyperbolic sine theory. In the case of test data for the solid torsion members, the arc hyperbolic sine theory was by far the most accurate in predicting both the creep rates and the total deformations. The steady-state and the Marin and Pao theories predicted identical steady state

Fluid impedance measurements in a rubber conduit containing a pulsatile flow are being obtained by NIH Fellow J. D. Martin, using an electromagnetic flowmeter and an electronic pressure transducer.

Professor C. E. Bowman (center) is instructing students on the proper procedures to use in determining stresses in structural members via the brittle lacquer method.
creep rates with good accuracy; the latter theory also predicted steady-state total deformations with good accuracy. The incremental theory was the least reliable.


**Thermal Shock of Conical Shell (ui)**

J. O. Smith,* R. B. Carr

One 2017 T4 aluminum alloy conical shell was tested, measuring temperatures and strains on the inner surface during thermal shock of the outer surface. With the results, the variation in the film conductance coefficient with temperature for various thermal shock conditions can be calculated. The stress as calculated by assuming a constant value of the film conductance coefficient is within plus or minus 12 percent of the experimental values.


**Inelastic Buckling of Tapered Column (ui)**

J. O. Smith,* F. J. Appl.

An analytical method which consists of an enclosure theory that gives an upper and lower bound on the critical buckling strength of columns has been developed. The method is applied to obtain the elastic and/or inelastic strength of columns that have a smooth taper of three types: (1) columns with no taper, (2) columns with constant width and linearly tapered thickness, and (3) columns of constant thickness and linearly tapered width. A total of 44 columns of all three types were tested to failure. The agreement between theory and experiment was good.


**Particular Theoretical and Experimental Photoelastic Stress Solutions of Doubly Connected Circular Torsion Bars of Varying Diameter (ui)**

W. F. Swinson,* C. E. Bowman

This project is concerned with formulation of the stress problem and with particular solutions for the stress distribution in circular shafts of varying diameter which also have a doubly connected cross section and which are subjected to pure torsion.

Particular solutions to the theoretical formulation can be found from Bessel Functions of the First and Second Kind, from Associated Legendre Polynomials and Associated Legendre Functions of the Second Kind, plus some functions that have no specific name. These solutions are being investigated for the stress distribution with some of the work being done on the IBM 7094 computer.

The experimental solutions using scattered light photoelasticity are serving as a means to complement the theoretical work and to demonstrate a technique for solving complex doubly connected torsion bars. A continuous gas laser is being used as a light source and is proving to be very advantageous.

**Studies in Photoplasticity and Application to Fracture Mechanics (onr)**

C. E. Taylor,* H. E. Corten, R. E. Rowlands

The object of this research is to extend the techniques of photoelasticity to inelastic problems and to use this method to investigate the elasto-plastic states of stress and strain around the tip of static crack in a thin plate. Analytical solutions to such problems are extremely difficult.

In fracture mechanics the approach has been to modify the elastic solution to account for plastic flow. However, knowledge of the plastic zones is important since fracture theory predicts that a crack will become unstable when the released strain energy becomes equal to, or exceeds, the sum of the energy required to form a fresh surface plus that needed to cause plastic deformation ahead of the crack. Furthermore, in many cases there is sufficient plastic deformation at the top of a crack to cause a "slow growth" prior to catastrophic fracture.

The fundamental relations between stress, strain, and birefringence during plastic flow will first be determined. From these relationships, and from considerations of deformation and equilibrium at a point, methods of determining the six independent components of stress and strain are obtainable. The proposed method will also provide the directions of the principal stresses and strains. This is important since once plastic flow occurs, these two principal directions need not coincide.

The feasibility of extending the techniques to three-dimensional and cyclic problems will also be considered.

**Basic Studies in Photothermoelasticity (b & w)**

C. E. Taylor,* J. Hemann

Several techniques are being studied which may be used to analyze thermal stress problems photoelastically. Isolation of the photoelastic model in a vacuum is being attempted in order to compensate for the poor thermal conducting properties of the plastics. This is necessary in order to make the thermal boundary conditions of the model and prototype similar. The second area of study is the embedded polariscope technique. In particular, nonsymmetric problems are being studied to see what effect rotations have on the embedded polariscope and also to understand the heat conduction properties of a model which has the polariscope embedded in it.
The Use of a Laser to Study Stress Waves in a Solid (ui)
C. E. Taylor,* W. North, T. Pryor

The experimental photoelastic method of stress analysis is one of the most powerful means of studying stresses in solid bodies and probably the only experimental method to study stresses in three dimensions in a solid body. The light source used in the experimental photoelastic stress analysis technique must provide certain characteristic properties, and since the ruby laser output possesses all of these properties it is here proposed to use a solid state pulsed ruby laser, in conjunction with an output control system utilizing a Kerr cell, as the light source in a dynamic photoelastic arrangement. This system, which will first be used in a two-dimensional analysis, will ultimately be extended to three-dimensional dynamic stress analysis employing the phenomenon of scattered light, the latter being unattainable to date due to a lack of intensity of conventional light sources.

The random pulsed laser system will provide more intensity by a factor of two orders of magnitude and with suitable modulation by five orders of magnitude. This will be used in conjunction with a high-speed camera recording system to record the propagation of stress waves in a solid due to an impact load.

Large Deflections of Elastic Columns with Various Supports (ui)
J. Healey,* G. A. Costello

An analysis is made of the large deflections of an elastic column supported at the end by rotational springs and at the center by a spring. The solution is obtained in closed form involving elliptic integrals. Several load-deflection curves are constructed and the results are compared with experiments. The results of the tests are in good agreement with the theory.


Axisymmetric Elastic Shells of Moderate Thickness (nsf)
R. J. Nikolai,* A. P. Boresi

A theory is proposed for analyzing the axisymmetric shell problem. The theory inherently assumes that the shell remains elastic and retains its axial symmetry under load. The analysis is not restricted to thin shells; however, nonlinear effects are neglected. The problem is formulated in terms of the displacement vector, and the solution is governed by equilibrium equations and boundary conditions on the faces and edge(s) of the shell.

The present work departs significantly from the classical approach to the problem. The Kirchhoff-Love hypothesis, which implies that transverse strains are zero, is not employed; here the transverse shear strains are assumed to vary in a parabolic fashion through the shell thickness, and the transverse normal strains are taken to be linear in the thickness coordinate. The shell equilibrium equations are augmented by the enforcing of Hooke's law on the faces of the shell. The form of the normal stresses in the directions of surface coordinates is suggested by the distribution of circumferential stresses in curved beams.

The mathematical problem involves a set of three simultaneous differential equations in the displacements. The theory has been specialized for cylindrical shells, and numerical results are sought, with the help of a digital computer, to specific problems for which the classical solution is known. A comparison of solutions using the classical and proposed analyses gives a quantitative indication of the thickness and transverse stress effects in the particular cases examined.


Deformations and Stresses in a Hollow Circular Cylinder (ui)
C. C. Fretwell,* A. P. Boresi

Deformations and stresses which occur in an isotropic, infinitely long, hollow circular cylinder under the action of opposing radial spot loads are being determined. The governing equations which are considered are those of the classical three-dimensional elasticity theory and are solved using the Papkovitch-Neuber solution. Using cylindrical coordinates the governing partial differential equations are solved by methods of separation of variables. The transformed solution is given in terms of modified Bessel functions of the first and second kind and trigonometric functions. Using the transformed boundary conditions, the constants of integration are then determined. Making use of the appropriate inverse transform, the final equations are used to obtain numerical results for the stresses and displacements.

The Axisymmetric Elasticity Problem of the Spherical Ring (ui)
J. L. Hill,* A. P. Boresi

The solution of the spherical ring subjected to general surface stresses on the spherical surfaces and integral conditions on stresses and single point conditions on displacements and rotation on the conical boundaries is obtained from a general solution to the axisymmetric problem of elasticity for the hollow sphere (region between two concentric spheres) presented by Strenberg, Eubanks, and Sadowsky. Numerical results were obtained for five combinations of conditions on the conical surfaces.


An Analytical and Experimental Investigation of Shallow Hyperbolic Paraboloid Shells Subjected to Concentrated Load (ui)
R. M. Vernet,* A. P. Boresi

A hyperbolic paraboloid shell, bounded by parabolic generators and supported in such a way that normal dis-
placements, normal stress resultants, and bending moments vanish at the supports, is considered. The shell is assumed to be homogenous, isotropic, linearly elastic, thin, and shallow.

With the aid of the Kirchhoff-Love approximation and for the case of small deflections, expressions for the normal deflections, stress resultants, and bending and twisting moments for a shell subjected to a concentrated, normally applied load are derived. These expressions are in the form of double sine series, and they are easily evaluated using a digital computer.

In the course of deriving the above expressions, numerous approximations are made. In an attempt to assess the validity of the resulting expressions, two experimental models were constructed and loaded with concentrated weights. Deflections and strains were measured, and the corresponding stress resultants and moments obtained by using Hooke's law. The agreement between theory and experiment appears to be best for bending moments. This agreement is very fortunate since shallow shells of this type are predominantly flexural members, and the associated flexural stresses are without doubt the critical ones for engineering purposes.

Numerical results are presented in tabular form, making a comparison of theoretical and experimental results a simple straightforward process.


A Contact Problem for an Elastic Quasi-rectangular Region (ul)
G. E. Sliiter,* A. P. BORESI

A plane elastic region in the form of a rectangle with one of its edges very slightly curved is brought into contact with a smooth rigid half-plane by means of a uniform pressure. The object of this investigation is the determination of the length of the segment of contact.

A stress function which satisfies the biharmonic equation of compatibility is chosen in the form of an infinite series containing trigonometric and hyperbolic functions. The mixed boundary condition on the contact edge is handled by means of the point-matching technique, in which appropriate conditions are satisfied at a finite number of points along the boundary. Application of boundary conditions leads to a set of simultaneous linear equations from which the arbitrary constants in the truncated series solution are determined.

Numerical results are obtained by means of a digital computer. The results are inconclusive due to the presence of a large truncation and round-off errors. Since the method shows promise of being successful for this and other problems of the same class, recommendations for further study are made.


Postbuckling Configurations of Axially Loaded, Circular Cylindrical Shells (ul)
R. M. JONES,* A. P. BORESI

This work relaxes certain restrictions on the solution of the problem that have been characteristic of earlier studies. Particularly, periodicity in the circumferential displacement pattern is imposed. The analysis is restricted to isotropic elastic behavior even though the shell undergoes large deformations. (A good example of a material with this capability is Mylar, which is used in inflatable, artificial earth satellites.) End effects are of no consequence since the shell is restricted to be very long (tending toward infinite length); however, it is not long enough to buckle as an Euler column. Because of the restriction to infinite length, the results of this analysis tend toward a lower bound on the results for finite length shells if the deflection configuration used is sufficiently close to the exact deflection configuration.


Effect of Transverse Shear on the Equilibrium and the Stability of Shells Undergoing Large Displacements (nsf)
A. P. BORESI,* R. J. NIKOLA

The objective of this investigation is to appraise the effects of transverse shear on the equilibrium and the stability of shells for large displacements.


Theory of Piecewise Linear Plasticity (nsf)
E. M. SHOEMAKER,* W. P. CHEN, T. MULCAHY

Theoretical work is being continued on a theory of piecewise linear perfect plasticity for plane strain. Investigations include: (1) development of a parallel theory, (2) investigation of discontinuous stress and velocity fields, and (3) the complete solution of some problems in plane strain.
Activities of the Materials Research Laboratory of the University of Illinois are focused on the aspects of solid state research that are basic for materials development. It is an interdisciplinary group primarily concerned with those aspects of the properties of materials that can be best understood in terms of atomic physics and chemistry. General objectives of the Laboratory are to increase the quality and quantity of research on the solid state of matter and also to increase the standards and the number of scientists trained for this area of research.

Five departments of the University have cooperated in the establishment of the Materials Research Laboratory: Ceramic Engineering; Chemistry and Chemical Engineering; Electrical Engineering; Mining, Metallurgy, and Petroleum Engineering; and Physics. The present research program is being conducted by members of these departments who are associated with it.

The University of Illinois has acquired international recognition for its research achievements in the fields of solid state physics and chemistry. A few of the areas in these fields in which the Laboratory hopes to expand research are: structure and composition of crystalline materials; atomic, molecular, and charge transport; properties of semiconductors; cryogenics at, and far below, helium temperatures; high-pressure physics and chemistry; radiation effects in solids; electron and nuclear resonance; superconductivity; spectroscopy of solids; color centers; mechanical properties of solids; and phase transformations.

This is an architect's sketch of the new Materials Research Laboratory building, which will be completed in the fall of 1965.
Much work is currently under way on campus concerning the macroscopic properties of materials which is closely related to the Materials Research Laboratory program. Departments involved in this research are Civil Engineering, Geology, Mechanical and Industrial Engineering, and Theoretical and Applied Mechanics. A useful interaction between this research and that of the Materials Research Laboratory is expected to provide mutual benefit.

In addition, the Laboratory will provide specialized service facilities which would be difficult or impossible for a conventional University department to support. Chemical analysis, emission spectrographic analysis, and mass spectrographic analysis laboratories are planned. An electron microscope service facility, a toxic materials laboratory, and radiochemistry laboratory will also be established. The availability of these services to physicists, chemists, ceramists, and metallurgists in a single integrated organization will not only support traditional programs but will also stimulate unconventional and interdisciplinary programs.

A major objective of the Materials Research Laboratory is to increase the number of graduate students receiving training at the doctoral level. A doubling of the present output of Ph.D. degrees in the area of materials research is anticipated within a period of five to ten years. The laboratory will also provide training at the postdoctoral level for a few of the most able graduates who wish to further their experience with the most sophisticated research problems.

Because of the interdisciplinary nature of the Materials Research Laboratory, only titles, names of investigators, and sponsors of research projects are listed here. A summary of the actual research may be found at the department section and page indicated after each.
The following projects are sponsored by the Advanced Research Projects Agency, Department of Defense.

J. Bardeen, Theory of the Condensed State of Matter, Department of Physics, p. 140 (see Theoretical Problems in the Physics of Condensed Systems).

F. C. Brown, Polaron Cyclotron Resonance, Department of Physics, p. 141 (see Cyclotron Resonance and Magneto-optical Phenomena in Ionic Crystals).

J. L. Brownlee, Nuclear Methods of Analysis, Analytical Chemistry.

D. M. Ginsberg, Measurements of Energy Gap Widths in Superconductors, Department of Physics, p. 147 (see Far Infrared Absorption and Electron Tunneling in Superconductors).

P. Handler, Research in Semiconductors, Department of Electrical Engineering, p. 95.

N. Holonyak, Junction and Related Effects in Compound Semiconductors, Department of Electrical Engineering, p. 95 (see Semiconductor Device Research).

D. E. Mapother, Experimental Properties of Superconductors, Department of Physics, p. 147 (see Superconductivity in Metals and Alloys).

R. J. Maurer, Analytical Mass Spectrograph Laboratory, Department of Physics, p. 147.

C. B. Satterthwaite, High-Field Superconductors, Coordinated Science Laboratory, p. 78.

H. J. Stapleton, Paramagnetic Relaxation and Dynamic Nuclear Polarization, Department of Physics, p. 146.

The following projects are sponsored by the United States Atomic Energy Commission.


P. A. Beck, Electronic Specific Heat Study of the Alloys of Transition Elements, Department of Mining, Metallurgy, and Petroleum Engineering, p. 118 (see Electronic Structure of the Transition Elements and Their Alloys).

C. G. Bergeron, Structural Changes in Simple Glass Systems During Nucleation of Crystalline Phases, Department of Ceramic Engineering, p. 28.

H. K. Birnbaum, Point Defect–Dislocation Interactions, Department of Mining, Metallurgy, and Petroleum Engineering, p. 118.

W. D. Compton, Color Centers in the Alkali Halides, Department of Physics, p. 142.

H. G. Drickamer, Use of Very High Pressure to Investigate the Structure of Matter, Division of Chemical Engineering.

A. L. Friedberg and W. D. Compton, Conduction Mechanisms in Semiconducting Glasses, Departments of Ceramic Engineering and Physics, pp. 30 and 142.

J. J. Gilman, Crystal Growth and Surface Properties, Department of Mining, Metallurgy, and Petroleum Engineering, p. 119 (see Carbide Monocrystals).

A. V. Granato, Anharmonic Effects in Solids, Department of Physics, p. 143.

M. V. Klein, Low Temperature Thermal Conductivity Studies, Department of Physics, p. 147 (see Low Temperature Thermal Conductivity and Optical Studies in Alkali Halides).

J. S. Koehler, Research on Radiation Damage, Department of Physics, pp. 116 and 142.

D. Lazarus, Point Defects in Solids, Department of Physics, p. 144.

D. S. Lieberman, Defects and Transformations in Solids, Department of Mining, Metallurgy, and Petroleum Engineering, p. 119 (see Defects and Defect Structures in Ordered Alloys).

M. Metzger, Dislocations and Surface Barriers, Department of Mining, Metallurgy, and Petroleum Engineering, p. 120 (see also Grain Boundary Structure and Corrosion, p. 120).

T. A. Read, Diffusionless Phase Changes in Non-ferrous Metals and Alloys, Department of Mining, Metallurgy, and Petroleum Engineering, p. 114 (see Phase Transformations); Vibrational Entropies of Solute Atoms in Dilute Substitutional and Interstitial Solid Solutions and Beta-Phase Alloys, p. 119; and Quenched-in Defects in Alloys, p. 122.

B. G. Ricketts, Annealing of Cold-Worked Metals, Department of Mining, Metallurgy, and Petroleum Engineering, p. 121.

T. J. Rowland, Nuclear Magnetic Resonance Studies, Department of Mining, Metallurgy, and Petroleum Engineering, p. 121.

R. O. Simmons, Properties of Rare Gas Solids, Department of Physics, p. 145 (see Nobel Gas Crystals).

G. P. Slichter, Electron and Nuclear Magnetic Resonance, Department of Physics, p. 146.

V. J. Tennery, Dielectric and Structural Investigation of Complex Compounds of the Perovskite Type ABO₃, Department of Ceramic Engineering, p. 31.

C. A. Wert, Clustering of Impurities in Solid Solutions in Metals, Department of Mining, Metallurgy, and Petroleum Engineering, p. 122 (see Diffusion in Metals).

J. C. Wheatley, Properties of He⁺ Below 0.01 K, Department of Physics, p. 148 (see Low-Temperature Properties of He⁺).
The functions of the Digital Computer Laboratory are: research in the design of high-speed computers, research in, and teaching of, the mathematical problems associated with such computers, and the provision of digital computer facilities as a research tool for all departments of the University.

The computers currently available in the Laboratory are ILLIAC II and an IBM 7094-1401. ILLIAC II is a very high-speed, general purpose, binary computer, the central part of which was completed by the Laboratory in August, 1962.

In its own research work, the Laboratory cooperates with various departments on campus, notably the Departments of Electrical Engineering, Mathematics, and Physics.

Professor B. H. McCormick (left), designer of ILLIAC III; Professor F. Seitz, Dean of the Graduate College (center); and Professor J. R. Pasta, Head of the Digital Computer Laboratory, discuss the progress in construction of ILLIAC III, the Illinois Pattern Recognition Computer.
ILLIAC II (abc)


Emphasis is now being placed on improved input-output facilities for the ILLIAC II processing system which ran its first major problem during September, 1962. New circuits utilizing 20,000 transistors and 80,000 diodes bring the operating totals to 250,000 semiconductor elements. Production and code checking now occupy about 20 percent of the 24-hour schedule, the remainder being shared by new equipment checkout, routine maintenance, and a background load of diagnostic programs. The mean time to failure is about 20 hours.

Two independent generally distributed input-output systems now exist. The most powerful, Interplay, operates independently of the central processor and can service as many as 32 peripheral devices simultaneously within the limitation of a 10-megacycle bit rate. The system of 64 13-bit Special Registers saturates main control at a 10-megacycle bit rate.

Interplay channels presently service an IBM 1401, ten IBM 729 VI tape units, two 1301 disc files, and a DCL drum having 64,000 32-bit words available at 7.8 microsecond intervals, as well as provide communication to ILLIAC III.

In conjunction with each such channel, Special Registers relay status and control information from ILLIAC II. In addition, Special Registers help implement a powerful interrupt system as well as service paper-tape, remote typewriters, real-time clock, etc. A total of fourteen are in use.


ILLIAC III (abc)


The Illinois Pattern Recognition Computer (ILLIAC III), an all-digital processor for visual information, is under

This component tester, designed by Dr. S. Yamada, is used to test components and logic assemblies under program control from ILLIAC II. It is being used by Electronics Technician Dave Foster to test components to be incorporated into ILLIAC III.

A monitor station for the Illinois Pattern Recognition Processor is in process of construction. Two such units as shown in the designer's sketch will provide cathode ray tube display as well as typewriter and paper tape input/output to the machine.
construction at the Digital Computer Laboratory. This
vishual recognition digital computer is designed for auto-
matic scanning and concomitant numerical analysis of
massive amounts of relatively homogeneous visual data.
The design is an outgrowth of studies of a computer system
capable of scanning, measuring, and analyzing in excess of
10^4 bubble-chamber negatives a year.

Engineering design of the high-speed oscilloscopic scan-
ers, for rapid ingestion of photographic information
digitized on a black-white raster, is largely complete. Construc-
tion of a 35-mm scanning system and two monitoring
stations is well under way.

In like manner the engineering design of the Pattern
Articulation Unit (PAU), the unique visual data processor
of the computer, is nearing completion. Construction of the
first half of the unit is continuing.

A preliminary manual of the computer, illustrating the
full instruction set of the machine, slated for late summer
1964, will be available to all prospective users.

R. Narasimhan, “Labeling Schemas and Syntactic Descrip-

B. H. McCormick, “The Illinois Pattern Recognition Com-
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R. Narasimhan, “A Programming System for Scanning Digitized

R. Narasimhan, “Syntactic Descriptions of Pictures and Gestalt
Phenomena of Visual Perception,” DCL Report 142, July 25,
1963.


J. H. Stein, “User’s Manual for PAX, an IBM 7090 Program to
Simulate the Pattern Articulation Unit of ILLIAC III,”

B. H. McCormick, “The Illinois Pattern Recognition Com-

K. Ishiki, “The Taxerine Unit of ILLIAC III: A Tentative

J. H. Stein, “Program Description of PAX, an IBM 7090 Pro-
gram to Simulate the Pattern Articulation Unit,” DCL

S. Yamada, “With Performance Characteristics of Fast Logic for
ILLIAC III: Basic NAND and NOR Circuits,” DCL Report
152, September 18, 1963.

S. Yamada, “Design of the Program-controlled Semiconductor
and Printed Circuit Board Test Console,” DCL Report 154,
October 21, 1963.


Circuit Research (ont)
W. J. POPPELBAUM,* C. AFUSO, D. CASASENT,
M. FAIMAN, T. K. KOD, L. MARTHE, S. NUSPL,
S. T. RIBERIO, D. TABAK, G. UJHELYI

The Circuit Research Group has broadened its interests
both in the direction of devices and in that of systems.

The device projects encompass the theoretical and experi-
mental aspects of tunnel diodes and microplasma junction
breakdown. A multiband theory of excess currents is de-

A medium-density printed circuit card is being inserted
into a channel adapter designed and fabricated at DCL for
the connection of IBM tape units to ILLIAC II.

A close-up of a circuit card used in the Pattern Articulation Unit
of ILLIAC III. This card measures approximately 5 by 6 inches.
veloped for tunnel diodes. For microplasma junctions the results of lattice cooling and photon coupling between neighboring microplasmas is studied in order to use these devices in pulse generators.

The circuit work is still centered around the use of coupled transmission lines with (constant) negative impedances. A small array using such amplifiers (due to Guckel) and hot electron diodes will be used in a fast adder. Another project is concerned with the use of tunnel diodes in one-shot multivibrators with directivity obtained by impedance ratios.

A major fraction of the group's efforts was in the area of photocopied circuits. It has been possible to build GaAs lamp-fiber-photodiode-amplifier loops with delay times of less than 10 nanoseconds. These loops will be incorporated in a simple logical system. Using the same general ideas, i.e., fiber-optics and photodiodes, a scanning device is being built by which a prescribed combination of digits can be searched for in relatively long words written on photographic film.


Expansion of Computing Facilities in the Digital Computer Laboratory (nsl; ul)

J. N. SNYDER*

The IBM 7090-1401 computing system was acquired in late 1962. During 1963 the system was improved by converting the main 7090 computer to a 7094, thereby increasing the computing speed by a factor of 1.6, by adding a 1301 disk file of 55,000,000 digits storage capacity to the 7094, and by acquiring a second 1401 computer to provide more input-output capacity. Further additions were made to the program library and the programming system for these computers. A connection is being installed between the 7094 and the CSX-1 computer in the Coordinated Science Laboratory so that this latter computer can act as a buffer and peripheral processor through which on-line devices (such as remote consoles and the scanning-measuring projector for analyzing bubble chamber data) can be connected to the 7094. The research and educational programs of the University now occupy the 7094-1401 system 24 hours per day seven days per week.

The Use of the Scanning-Measuring Projector (SMP) for the on-Line Reduction of Bubble Chamber Data (ui)

J. N. SNYDER*, R. I. HULSIZER, J. F. LATHROP, P. TROWER

This project was carried out in collaboration with Lawrence Radiation Laboratory, University of California, Berkeley, which supplied one of these devices for on-line attachment to the IBM 7094 computer. After checking out the hardware connections and after converting the standard bubble chamber data reduction programs to this system, the SMP was placed in service. During this initial period the 7094 time not needed for normal University programs was placed at the disposal of the SMP. A sufficient amount of bubble chamber film was analyzed to result in several publications on K± meson-proton interactions. In order to allow operations of the SMP simultaneously with the normal computing load of the 7094, the CSX-1 computer in the Coordinated Science Laboratory is being connected to the 7094 to act as a buffering intermediary between it and the SMP. The SMP itself has been checked out to such an extent that its development phase can be regarded as complete. It has now been turned over to the Physics Department as a pure production device.
Several major research facilities are available to the engineering research program that are not a part of any individual department's laboratories. These facilities, including the Digital Computer Laboratory, provide invaluable support in many research areas.

Operating area of the ILLIAC II high-speed, general purpose digital computer, designed and built at the Digital Computer Laboratory.
MEASUREMENT PROGRAM

H. N. HAYWARD, Director
W. O. RISLEY, Assistant Director
H. C. ROBERTS, Consultant

Among the services offered by the Measurement Program are the maintenance, repair, and checking for accuracy and operation of various types of instruments. Others are the making of precision measurements of electrical quantities such as voltage and resistance, which includes checking standard cells and standard or other high-quality resistors. Facilities for checking standard cells recently have been improved by the acquisition of a group of saturated cells in a constant-temperature bath, providing a more stable and reliable reference than was previously available. Additional equipment for frequency measurement and the checking of frequency meters also has been added. A recording spectrophotometer, with operator, is available for obtaining data on either the reflectance or transmission of light in the range from 400 to 700 millimicrons. To a somewhat limited extent, consultation assistance is provided on measurement problems and on the selection, use, and operation of instruments, as well as the design of special instruments or the conversion of commercial instruments to meet the requirements of unusual or highly specialized applications. A small staff trained in the field of measurement is available to supplement both the research and teaching programs of the College of Engineering and the entire University. As a result of the University-wide experience of this group, new techniques and tools are being developed for large-scale instrument maintenance and repair programs, and a central pool of information and experience on all types of measurement problems and equipment is being built up. To an increasing extent, the Measurement Program is providing some of the facilities of a standards laboratory in response to more numerous requests for such service. Accordingly, gradual improvement is being made in the quality and variety of standards and associated measuring and accessory equipment needed to make high-accuracy measurements of voltage, resistance, and related quantities and to check the accuracy or calibration of instruments used for making such measurements on a routine basis. Efforts also are continuing to extend and improve the stock of instrument parts, accessories, and supplies in order to meet the increasing demand for such items.

THE ELECTRON MICROSCOPE LABORATORY

B. VINCENT HALL, Director

The Electron Microscope Laboratory is a central facility for instruction and research in behalf of all University departments. The laboratory is equipped with a Siemens Elmiskop 1, an Hitachi HS-6, and RCA models EMU-3C, EMU-2F, EMT, and EMC electron microscopes. Ancillary equipment includes two ultramicrotomes, a shadow-caster, an RCA electron diffraction unit, and complete darkroom facilities.

The instructional program consists of the following courses: Lectures on the Electron Microscope and Electron Microscopy, Electron Microscope Laboratory, Advanced Electron Microscopy—Biological Ultrastructure, seminars, and special workshops. The facilities are available for research conducted by qualified faculty staff members and graduate students. The laboratory is completely air conditioned and located in the basement of Bevier Hall.

RADIOCARBON LABORATORY

ROBERT F. NYSTROM, in Charge

The Radiocarbon Laboratory, an all-University facility with a permanent staff, conducts research on chemical, physical, and biological problems by use of the tracer technique with carbon-14 and hydrogen-3. Modern radiochemical equipment for the synthesis, degradation, isolation, and assay of radioactive compounds is available.

PHYSICAL ENVIRONMENT UNIT

MAURICE K. FAHNESTOCK, Chairman
(to October 31, 1964)
BRUCE A. HERTIG, Chairman
(from September 1, 1964)

The facilities of the Physical Environment Unit include the services of an experienced environment laboratory operator and basic medical and physiological instruments and rooms and an altitude chamber in which ranges of temperature, humidity, and pressure can be controlled. They are available for use by any department or division of the University needing controlled environmental conditions and instrumentation for special teaching or research. Most notable use in engineering research has been made by the Departments of Mechanical and Industrial Engineering, and Theoretical and Applied Mechanics. Other divisions of the University using the facilities include the Departments of Home Economics, Agricultural Engineering, Physiology, Health Education, Physical Education for Women, Physical Education for Men, Animal Science, Psychology, Geography, State Natural History Survey, and the Institute of Aviation.

SMALL HOMES COUNCIL—BUILDING RESEARCH COUNCIL

RUDARD A. JONES, Director

The Small Homes Council—Building Research Council is a University agency for research, publication, education, and public service in housing and building which serves prospective home owners, the construction industry, and those financing home construction. Research has included studies on insulation of concrete slab floors, frost action on foundation floors, nail-glued roof trusses, roofing, thermal comfort, electrical heating, house framing systems, wall panel construction, design standards for space use in dwellings, and dwelling and land design for high-density housing.

Other departments of the University cooperate in the SHC-BRC research program. Members of the Department of Mechanical and Industrial Engineering are working with the SMC-BRC on electrical heating studies and have
assisted in preparing publications on home heating systems, fuels and burners, summer comfort, insulation, storm sash, construction of chimneys and fireplaces, and home hazards. Members of the Department of Civil Engineering have served as advisors in work concerned with preparation of professional guides for the Office of Civil Defense, U. S. Department of Defense.

STATE GEOLOGICAL SURVEY

The research program of the Illinois State Geological Survey is concerned with the location, development, utilization, and beneficiation of the state's mineral resources. In several areas, including coal utilization and beneficiation, mining engineering, petroleum engineering, engineering geology, and the effect of engineering geology on various problems in sanitary engineering, several departments in the University College of Engineering are cooperating with the Survey in its research program.

STATE WATER SURVEY

Study of the available amounts and chemical quality of water in Illinois is the primary concern of the Illinois State Water Survey, one of the three state scientific surveys located on the Urbana campus. The Water Survey has long been closely allied with the University in engineering research, and it is now a cooperating agency and active participant in research activities of the University Water Resources Center.

A comprehensive program of water resources data gathering and analyses has been a continuing function of the Water Survey, and new methods of measurement and evaluation are constantly being developed and applied. Its more than fifty current research projects may be grouped within these broad areas: evaluation and development of surface-water resources; hydrologic investigation and evaluation of ground-water resources; artificial recharge of ground water; physical and chemical quality of water resources; water use and conservation; and meteorological studies related to water resources, atmospheric physics, and weather modification. Specific cooperative projects include studies of electronic analog models that simulate ground-water aquifers with the Department of Civil Engineering, and the investigations of water droplet coalescence with the Department of Electrical Engineering.

Water Survey scientists also from time to time cooperate directly in College of Engineering teaching programs, and the Survey's hydraulic research laboratories are used for graduate student projects. The Water Resources Building is located adjacent to the engineering campus, and an addition currently being constructed will more than double the Survey's laboratory and office facilities.
# Key to Sponsors

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<td>Association of American Railroads</td>
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<tr>
<td>acs</td>
<td>American Chemical Society</td>
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<tr>
<td>aec</td>
<td>U.S. Atomic Energy Commission</td>
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<tr>
<td>af</td>
<td>U.S. Air Force</td>
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<tr>
<td>afal</td>
<td>Air Force Avionics Laboratory, Wright-Patterson Air Force Base</td>
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<tr>
<td>afcl</td>
<td>Air Force Cambridge Research Laboratories</td>
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<tr>
<td>afmnl</td>
<td>Air Force Materials Laboratory, Air Force Systems Command</td>
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<tr>
<td>afosr</td>
<td>Air Force Office of Scientific Research</td>
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<tr>
<td>afscc</td>
<td>Air Force Systems Command</td>
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<tr>
<td>afswc</td>
<td>Air Force Special Weapons Center, Air Force Weapons Laboratory</td>
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<tr>
<td>agc</td>
<td>Aerojet-General Corporation</td>
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<tr>
<td>aid</td>
<td>Agency for International Development</td>
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<tr>
<td>airmi</td>
<td>Amsied Industries Research Laboratories</td>
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<tr>
<td>aise</td>
<td>Association of Iron and Steel Engineers</td>
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<tr>
<td>aisi</td>
<td>American Iron and Steel Institute</td>
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<tr>
<td>amc</td>
<td>Air Materiel Command, Wright-Patterson Air Force Base</td>
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<tr>
<td>anl</td>
<td>Argonne National Laboratory</td>
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<tr>
<td>api</td>
<td>American Petroleum Institute</td>
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<tr>
<td>apsf</td>
<td>A. P. Sloan Foundation</td>
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<tr>
<td>arl</td>
<td>Aeronautical Research Laboratory, Wright-Patterson Air Force Base</td>
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<tr>
<td>aroc</td>
<td>Army Research Office, Durham</td>
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<tr>
<td>arpa</td>
<td>Advanced Research Projects Agency</td>
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<tr>
<td>ars</td>
<td>Agricultural Research Service</td>
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<tr>
<td>asc</td>
<td>Avnet-Shaw Corporation</td>
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<tr>
<td>asd</td>
<td>Aeronautical Systems Division, Wright-Patterson Air Force Base</td>
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<tr>
<td>asf</td>
<td>Automotive Safety Foundation</td>
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<tr>
<td>ash</td>
<td>American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc.</td>
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<tr>
<td>astme</td>
<td>American Society of Tool and Manufacturing Engineers</td>
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<tr>
<td>avce</td>
<td>AVCO Corporation</td>
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<tr>
<td>b &amp; w</td>
<td>Babcock &amp; Wilcox</td>
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<tr>
<td>bc</td>
<td>Bendix Corporation, Bendix Aerospace Products Division</td>
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<tr>
<td>bpr</td>
<td>Bureau of Public Roads, U.S. Department of Commerce</td>
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<tr>
<td>brl</td>
<td>Ballistics Research Laboratories, U.S. Department of the Army</td>
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<tr>
<td>bs</td>
<td>Bureau of Ships, U.S. Department of the Navy</td>
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<tr>
<td>byd</td>
<td>Bureau of Yards and Docks, U.S. Department of the Navy</td>
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<tr>
<td>cbif</td>
<td>The Chicago Bridge and Iron Foundation</td>
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<tr>
<td>cccc</td>
<td>Chicago Copper and Chemical Company</td>
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<tr>
<td>cee</td>
<td>Commission on Engineering Education</td>
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<tr>
<td>crc</td>
<td>Corrosion Research Council</td>
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<tr>
<td>ct</td>
<td>Caterpillar Tractor Company</td>
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<tr>
<td>dac</td>
<td>Douglas Aircraft Company</td>
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<tr>
<td>dap- phs</td>
<td>Division of Air Pollution - Public Health Service</td>
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<tr>
<td>dei</td>
<td>Edison Electric Institute</td>
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<td>eocj</td>
<td>Edward Orton Jr. Ceramics</td>
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<tr>
<td>ff</td>
<td>Ford Foundation</td>
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<td>fi</td>
<td>Foundry Industry</td>
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<td>fss</td>
<td>F. S. Services, Inc.</td>
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<td>fws</td>
<td>Fish and Wildlife Service, U.S. Department of the Interior</td>
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<td>g whc</td>
<td>G. and W. H. Corson, Inc.</td>
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<tr>
<td>gc</td>
<td>Garrett Corporation</td>
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<td>gda</td>
<td>General Dynamics/Astronautics</td>
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<td>gi</td>
<td>Gregory Industries</td>
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<tr>
<td>hip</td>
<td>Hammond Lead Products, Inc.</td>
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<tr>
<td>hrb</td>
<td>Highway Research Board</td>
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<tr>
<td>iaes</td>
<td>Illinois Agricultural Experiment Station</td>
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<tr>
<td>ibrm</td>
<td>The Institute of Boiler and Radiator Manufacturers</td>
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<tr>
<td>ibve</td>
<td>Illinois Board of Vocational Education</td>
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<tr>
<td>idh</td>
<td>Illinois Division of Highways</td>
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<tr>
<td>ifec</td>
<td>Illinois Farm Electrification Council</td>
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<tr>
<td>isws</td>
<td>Illinois State Water Survey</td>
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<tr>
<td>jsed</td>
<td>Joint Services Electronics Program</td>
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<tr>
<td>ls</td>
<td>LaSalle Steel</td>
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<tr>
<td>mac</td>
<td>McDonnell Aircraft Corporation</td>
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<tr>
<td>mc</td>
<td>Muzak Corporation</td>
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<tr>
<td>nas</td>
<td>National Academy of Sciences</td>
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<tr>
<td>nasa</td>
<td>National Aeronautics and Space Administration</td>
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<tr>
<td>ncel</td>
<td>U.S. Naval Civil Engineering Laboratory</td>
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<tr>
<td>ncrcc</td>
<td>North Central Regional Research Committee</td>
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<tr>
<td>nel</td>
<td>U.S. Navy Electronics Laboratory</td>
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<td>nih</td>
<td>National Institutes of Health</td>
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<td>nla</td>
<td>National Lime Association</td>
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<td>nsic</td>
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<tr>
<td>nsf</td>
<td>National Science Foundation</td>
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<tr>
<td>nwahaaca</td>
<td>National Warm Air Heating and Air Conditioning Association</td>
</tr>
<tr>
<td>ocd</td>
<td>Office of Civil Defense, U.S. Department of Defense</td>
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<tr>
<td>ocfc</td>
<td>Owens-Corning Fiberglas Corporation</td>
</tr>
<tr>
<td>omc</td>
<td>Ohmite Manufacturing Company</td>
</tr>
<tr>
<td>onr</td>
<td>Office of Naval Research</td>
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<tr>
<td>phs</td>
<td>U.S. Public Health Service</td>
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<tr>
<td>prf</td>
<td>Petroleum Research Fund of the American Chemical Society</td>
</tr>
<tr>
<td>raic</td>
<td>Rome Air Force Center</td>
</tr>
<tr>
<td>rcrlsbj</td>
<td>Research Council on Riveted and Bolted Structural Joints, Engineering Foundation</td>
</tr>
<tr>
<td>sc</td>
<td>Sandia Corporation</td>
</tr>
<tr>
<td>scusa</td>
<td>Signal Corps, U.S. Army</td>
</tr>
<tr>
<td>ucpref</td>
<td>United Cerebral Palsey Research and Educational Foundation, Inc.</td>
</tr>
<tr>
<td>ui</td>
<td>University of Illinois</td>
</tr>
<tr>
<td>usael</td>
<td>U.S. Army Electronics Research and Development Laboratory (now U.S. Army Electronics Laboratory)</td>
</tr>
<tr>
<td>usda</td>
<td>U.S. Department of Agriculture</td>
</tr>
<tr>
<td>ussc</td>
<td>U.S. Steel Corporation</td>
</tr>
<tr>
<td>ver</td>
<td>Illinois State Board of Vocational Education and Rehabilitation</td>
</tr>
<tr>
<td>wrc</td>
<td>Welding Research Council, Engineering Foundation</td>
</tr>
<tr>
<td>wrg</td>
<td>W. R. Grace &amp; Co., Davison Chemical Division</td>
</tr>
<tr>
<td>wspsc</td>
<td>Division of Water Supply and Pollution Control, Public Health Service, U.S. Department of Health, Education, and Welfare</td>
</tr>
</tbody>
</table>
Map of College of Engineering Campus

ALPHABETICAL LISTING

36 ABOTT POWER PLANT
33 ADMINISTRATION BLDG.
 9 AERONAUTICAL LAB.
12 AERONAUTICAL LAB. 3
29 ALGEO HALL
30 BIO PHYSICS RESEARCH
 7 BRAKE SHOE LAB.
10 CERAMICS BLDG.
18 CHARGED PARTICLE LAB.
25 CIVIL ENGINEERING HALL
 2 DIGITAL COMPUTER LAB.
 19 DIRECTION FINDING
33 EAST CHEMISTRY BLDG.
34 ELECTRICAL ENGINEERING BLDG.
31 ELECTRICAL ENGR. RESEARCH LAB.
13 ENGINEERING RESEARCH LAB.
 5 FILTRATION PLANT
 4 FOUNDRY
30 GASEOUS ELECTRONICS LAB.
15 HYDRAULIC ENGR. LAB. 1
16 HYDRAULIC ENGR. LAB. 3
32 ILLINOIS UNION

NUMERICAL LISTING

 1 RADIO TRANSMISSION LAB.
 2 DIGITAL COMPUTER LAB.
 3 WATER RESOURCES BLDG.
 4 FOUNDRY
 5 FILTRATION PLANT
 6 TRANSPORTATION BLDG.
 7 BRAKE SHOE LAB.
 8 MINING & METALLURGY LAB.
 9 AERONAUTICAL LAB.
10 CERAMICS BLDG.
11 TALBOT LABORATORY
12 AERONAUTICAL LAB. 5
13 ENGINEERING RESEARCH LAB.
14 NUCLEAR REACTOR LAB.
15 HYDRAULIC ENGR. LAB. 1
16 HYDRAULIC ENGR. LAB. 2
17 SANITARY ENGINEERING LAB.
18 CHARGED PARTICLE LAB.
19 DIRECTION FINDING
20 GASEOUS ELECTRONICS LAB.
21 ELECTRICAL ENGINEERING RESEARCH LAB.
22 MECHANICAL ENGINEERING LAB.
23 NUCLEAR RADIATION LAB.
24 ELECTRICAL ENGINEERING BLDG.
25 CIVIL ENGINEERING HALL
  (COLLEGE OF ENGINEERING ADMINISTRATION)
26 PHYSICS LAB.
27 MECHANICAL ENGR. BLDG.
28 PHYSICS BLDG.
29 TALBOT HALL (MATHEMATICS)
30 BIO PHYSICS RESEARCH
31 NUCLEAR ENGR. OFFICE
32 ILLINOIS UNION
33 ADMINISTRATION BLDG.
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35 EAST CHEMISTRY BLDG.
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37 PHYSICS RESEARCH LAB.
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