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ABSTRACT

This document was prepared to provide a comprehensive view of the programs in biomedical engineering in existence in 1969. These programs are supported by the National Institute of General Medical Sciences and are located at 18 universities. This compendium provides information as to the intent and content of these programs from data provided by the respective training program directors. Each program description includes a description of the training program, entrance requirements, the research training staff, research equipment and facilities, departmental graduate body and sources of additional information. (BR)

BIOMEDICAL ENGINEERING

A COMPENDIUM OF RESEARCH TRAINING PROGRAMS

SUPPORTED BY
THE NATIONAL INSTITUTE
OF GENERAL MEDICAL SCIENCES

NATIONAL INSTITUTES
OF HEALTH

BIOMEDICAL ENGINEERING

A Compendium

of Research Training Programs

supported by the

National Institute of General Medical Sciences

National Institutes of Health

September 1969

FOREWORD

At the present time biomedical engineering is still an experimental discipline. However, the field is clearly on the move, and this is not surprising when one considers that engineering science has considerable to give conceptually and practically to the world of biomedicine, and that the health industry is on its way to becoming the number one industry in the country by the mid 1970's.

Over the past nine years the National Institute of General Medical Sciences has gradually developed a national doctoral training program in biomedical engineering. Some eighteen programs have been assembled that are now supported at a cost of approximately $1.5 million per year. To date, these programs have produced some 100 graduates (25 postdoctoral trainees, 50 doctorates, and 25 masters-level graduates). Presently, there are approximately 220 trainees in the program and if funding were held level, the estimated output of doctorates would be some 35 to 45 per year. Of the 18 programs, 10 are in engineering departments, 2 are in medical schools, and 6 are split between engineering and medical school departments. In response to numerous requests for information as to the intent and content of these programs, we have assembled this compendium from data provided by the respective training program directors.

In addition to the formal doctorate programs, there is an important fellowships program in which biomedical engineering trainees are supported at the predoctoral, postdoctoral, special, and career development levels. Currently there are some 100 trainees in this fellowships program supported at a level of $1 million per year. An interesting feature of these training and fellowships programs has been the rather low percentage of dropouts to date. This is encouraging and it is felt that it is due to high motivation on the part of the students and good selection of trainees.

The Institute, in supporting biomedical engineering training programs, has taken the position that in a period of an extreme shortage of qualified people and in a rapidly developing field, it has been most important to train men for research who will go into the academic environment and hopefully reproduce their own kind. It has been felt that this has been necessary, at least initially, and that through this route it probably has been possible to achieve the most rapid development of the field. It is for this reason, coupled with restricted funds, that to date the Institute has encouraged the Ph.D. and has not supported masters candidates per se. This does not mean in the slightest that it is not recognized that, if an overall purposeful effort is to be carried out nationally in biomedical engineering, there is a definite need for training people at the masters level and at the technician level.

There has been considerable controversy from time to time with respect to the need for the hybrid-trained biomedical engineer. What is beginning to emerge is that true hybrid training will be desirable in some instances but not necessarily across the board. Probably from the point of view of professional

recognition, the greatest need for the hybrid biomedical engineer will be in the area of fundamental undifferentiated research where the crucial value judgements are mainly biomedical. In the areas of development and the delivery of health services, where team efforts can be extremely effective, the need for a true hybrid would appear to be less. Be that as it may, precisely what the character of the training should be in each instance is not clearly definable as yet.

As we look to the future and to the evolution of a new type of training, especially designed for the biomedical engineer and tailored to his needs, one recognizes that the future biomedical engineer cannot be all things to all men and, at the same time, stay current at the advancing edge of expertise. The fact is that biomedicine and engineering are too vast for one man to be competent in it all. Rather, men of truly professional attainments in biomedical engineering will likely be composites, such as the combination of a chemical engineer and a metabolism specialist, or a combination of a structural engineer and an orthopedic surgeon.

In an overview, it is apparent that we are still in the formative stages of the emergence of biomedical engineering and that we do in fact await more answers than we now have. It is likely that there are several satisfactory ways to interface engineering with biomedicine and they should be provided every opportunity to sort themselves out with the passage of time and no unnecessary rigidites of theory or fact should be prematurely imposed. We should be particularly reserved about contentions with respect to the necessity of formalized structure at this time. In fact, the time is opportune in the development of the field to conduct experiments in biomedical engineering training with smart, well-motivated students--experiments that could profitably include the development of courses with them. It is likely that at the present time more may depend on the trainer himself than the type of system he actually uses. In the midst of it all, it is clear that every attempt should be made to seek out and promote excellence wherever it arises.

In general, it would appear that increases in the funding of training programs for biomedical engineering will come via awards for new programs. To date, there has been some leveling off in formal applications for new programs, indicating that rapid expansion is not likely nor compatible with the maintenance of quality. Institutions contemplating new programs are developing curricula, coordinating multidisciplinary research, and securing faculty personnel trained in biomedical engineering, all of which require a firm commitment on the part of the university and program director. Additionally, successful training programs exist and flourish only in the presence of a strong biomedical engineering research base and this, along with a core faculty, is lacking in some cases. All in all, it may well take time for new programs of quality to emerge. Nevertheless, the National Institute of General Medical Sciences, for its part in the total picture, will continue to support the development of research and training programs in biomedical engineering and will continue to encourage the field to the best of its ability.

Frederick L. Stone, Ph.D.
Director, National Institute
of General Medical Sciences

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COLLEGE OF ENGINEERING
UNIVERSITY OF CALIFORNIA
Berkeley, California 94720

1. Program of Research Training under GM-1418 - A graduate program in biomedical engineering leading to the M.S. and Ph.D. degrees is offered. A limited number of postdoctoral trainees are also included in the program. There is no separate department of biomedical engineering. Predoctoral biomedical engineering students are placed in the Departments of Electrical, Mechanical, Nuclear or Industrial Engineering where courses and research effort most closely represent their interests. Students are encouraged to enrich their programs by courses in physiology, biophysics, biochemistry and other life-science related departments. Biomedical engineering courses offered in the engineering departments include control theory, diffusion transport theory, neural network analysis, human factors and performance and biological effects of radiation.

   The program is aimed at preparing engineers for careers in research, development and teaching. The attempt is to prepare the biomedical engineer to be a member of a team of biologists and engineers. The biomedical engineer in this program specializes in a basic science or engineering field such as control theory, information theory, heat transfer, fluid mechanics, or elasticity. He takes courses in the life sciences that help him apply his science and engineering to the biomedical engineering problem chosen for his thesis research.

   An M.S. degree can usually be obtained in one calendar year. The Ph.D. requires 3 to 5 years.

2. Entrance Requirements - The university requirement is a B.S., B.A. or A.B. degree in engineering or science and a scholarship standing of at least B in the undergraduate program. The biomedical engineering program prefers students with a background in engineering or the physical sciences.

3. Research Training Staff

   Irving Fatt, Ph.D. 1955, U. Southern Calif.; Prof.; Transport processes.
   C. Susskind, Ph.D. 1951, Yale Univ.; Prof.; Bioelectronics.
   E.R.F.W. Crossman, Ph.D. 1956, U. of Birmingham; Prof.; Human factors and performance.
   E. I. Jury, Sc.D. 1953, Columbia Univ., Prof.; Information theory.
   C. W. Radcliffe, M.S. 1951, Univ. of Calif., Berkeley; Prof.; Biomechanics.
   D. M. Cunningham, M.S. 1944, U. of Calif., Berkeley; Prof.; Biomechanics.
   G. Thomas, Ph.D. 1956, Cambridge Univ.; Prof.; Electron microscopy.
   R. E. Barlow, Ph.D. 1960, Stanford Univ.; Assoc. Prof.; Operations research.
   J. L. Lewis, M.D. 1954, Illinois; Lecturer; Biomechanics.
   L. Stark, M.D. 1948, Albany; Prof.; Control theory.
   P. O. Vogelhut, Ph.D. 1962, Univ. of Calif., Berkeley; Asst. Prof.; Membranes and nerve impulse transmission.

E. R. Lewis, Ph.D. 1962, Stanford Univ.; Assoc. Prof.; Neural systems.
D. M. Auslander, Sc.D. 1966, M.I.T.; Asst. Prof.; Control theory.
R. R. Donaldson, Ph.D. 1965, M.I.T.; Asst. Prof.; Biomechanics.
G. J. Trezek, Ph.D. 1965, U. of Ill.; Asst. Prof.; Energy transport in tissue.

4. Research Equipment and Facilities - The entire area of departments of engineering is 383,000 sq. ft. The fraction of all graduate students who are in biomedical engineering is 51/1350. Therefore, 7700 sq. ft. is devoted to biomedical engineering. Libraries available, in addition to the main university library, are the engineering, biology, biochemistry, chemistry, physics, and mathematics libraries. A one-day delivery service is available from the medical school library in San Francisco. A complete high-speed digital computer center (IBM 7094) is available, together with many smaller digital and analog computers. Research requiring extensive animal or hospital facilities is carried out in cooperation with the faculty and staff of the University Medical School in San Francisco. Specialized laboratory equipment available to biomedical engineering trainees includes nuclear magnetic resonance spectrometers; infra red, ultra violet, visible, and microwave spectrometers; transmission electron microscopes; scanning electron microscopes; and a research nuclear reactor.

5. Departmental Graduate body - The total number of trainees in biomedical engineering program is 51. Of these, 50 are predoctoral and one is postdoctoral. A breakdown in fields of study is: Transport processes, Neural networks, Control theory, Human factors and performance.

6. Sources of Additional Information - For additional information, write to:

Irving Fatt, Director
Biomedical Engineering
Training Grant
Engineering Graduate Office
University of California
Berkeley, California 94720

OR

Paul O. Vogelhut, Assoc. Dir.
Biomedical Engineering Training
Grant
Department of Electrical
Engineering
University of California
Berkeley, California 94720

CALIFORNIA INSTITUTE OF TECHNOLOGY
Pasadena, California 91109

1. Program of Research Training under GM-1335 - A four-year predoctoral training course, leading to the Ph.D. degree only, is offered under this grant; postdoctoral research positions are also available in the same research area under other sources of support.

   This training program is an interdisciplinary activity between the Division of Biology and the Division of Engineering and Applied Science. The aim is to train engineers, mathematicians and biologists to work together towards an improved understanding of life processes.

   In order to undertake advanced study in this field, a research worker needs a grounding in biology, mathematics, and its application to systems analysis. During the early part of the graduate study program the student will be required to take a broad-based curriculum selected from such topics as psychobiology, physiology, mammalian anatomy and histology, genetics, communication theory, feedback control systems, data processing systems and switching theory, numerical analysis and statistics. Later he will undertake advanced study and research in a more specialized field chosen from: physiology and modeling of invertebrate neural networks; reflex physiology of mammals; interaction of eye scanning motions and perception in the human visual systems; information processing in insect nervous systems; analysis of cerebral mechanisms for perception, learning and memory; embryogenesis and regeneration of behavioral nerve nets.

2. Entrance Requirements - An applicant for Graduate standing at the California Institute of Technology must possess a Bachelor's degree in science or engineering. His scholastic record and his recommendations must indicate that he is fitted to pursue advanced study and research with distinction.

3. Research Training Staff

   Fender, D. H., Ph.D. 1956, University of Reading, England; Professor (Biology and Applied Science); Human vision, eye movements and acuity.
   Ingargiola, G., Ph.D. 1967, University of Pennsylvania; Assistant Professor (Applied Science); Automata theory.
   McCann, G.D., Ph.D. 1939, California Institute of Technology; Professor (Applied Science); Information processing in insect visual systems.
   Strumwasser, F., Ph.D. 1957, UCLA; Associate Professor (Biology); Reflex physiology of mammals.
   Thompson, F. B., Ph.D. 1952, University of California; Professor (Humanities and Applied Science); Mathematical linguistics.
   Wiersma, C. A. G., Ph.D. 1933, University of Utrecht, Holland; Professor (Biology); Physiology and modeling of invertebrate neural networks.

4. Research Equipment and Facilities - Biological Systems Laboratory (1880 sq. ft.) contains facilities for research on living nervous systems. It is close to and integrated with the Willis H. Booth Computer facilities and includes newly developed experiment control and data analysis systems. In addition, special facilities have been developed for advanced research on stimulus and response instrumentation.

5. Departmental Graduate Body -

Predoctoral

Subject Area	No. of Students
Human Vision	3
Insect Visual System	4
Computer Languages for Biodata	3
Color Vision in Crayfish	1
Neural Modeling	2
Uncommitted	2

6. Sources of Additional Information - For additional information, write to:

D.H. Fender
Professor of Biology and Applied Science
California Institute of Technology
1201 East California Blvd.
Pasadena, California 91109

OR

G.D. McCann
Professor of Applied Science and Director, California Institute of Technology Computing Center
1201 East California Boulevard
Pasadena, California 91109

BIOTECHNOLOGY PROGRAM
CARNEGIE-MELLON UNIVERSITY
Pittsburgh, Pennsylvania 15213

1. Program of Research Training under GM-1455 - Biotechnology at Carnegie-Mellon University is a multidisciplinary research and instructional program studying the interface between biological organisms and engineering devices or machines (the latter intended in the broadest sense to include electrical and chemical actions, and complex organizations such as life support systems or hospital systems). The program is intended primarily for graduate students with different backgrounds in engineering, the physical sciences, and life and medical sciences. Both the M.S. and Ph.D. degrees are offered, with particular emphasis on the latter. Students can enroll for a degree in biotechnology or for a degree in a traditional field, either with biotechnology specification (e.g. Ph.D. in Biology--Biotechnology), or without. Opportunities for postdoctoral fellows as well as for special students interested in acquiring specific training in certain areas of biotechnology without becoming a candidate for a degree are available.

   Currently, 7 graduate courses are offered by the program: Membrane Transport Theory, Biological Flows, Biological Materials, Physiological Systems, Physiological Pattern Recognition, Biotechnology Seminar, and a Seminar on Problems of Biotechnology Innovation. Other graduate courses offered at CMU relevant to the program include Sensor and Perceptual Processes, Cognitive Processes, Engineering Psychology, Physiological Psychology, Biophsyics, Biochemistry, Advanced Organic Chemistry, Feedback Control Systems, Advanced Topics in Control Theory, Information Theory and Environmental Systems Design.

   Major research areas in the biotechnology program include medical system engineering, comprehensive engineering study of biological transport processes (with emphasis on biological flows, blood rheology, mass and heat transfer, and membrane transport problems), design of artificial organs, biological materials (including the development of heart-assist devices), modeling of physiological systems, design of hospital and health information systems, biochemical kinetics, environmental bioengineering, bionics, coupling between technology and health problems, psychology and biomedically-oriented computer sciences.

2. Entrance Requirements - These include the general requirements of the Graduate School. There are no life science prerequisites for candidates with backgrounds in engineering or physical sciences and no formal engineering or physical sciences prerequisite for candidates with backgrounds in life or medical sciences.

3. Research Training Staff

   R. L. Longini, Ph.D. 1948, Univ. Pgh.; Prof., Med. Eng.; materials and electronics.

J. J. Wolken, Ph.D. 1949, Univ. Pgh.; Prof.; Vision; photosynthesis, photo excitation, energy transfer systems, nervous excitation.
H. Brenner, Ph.D. 1957, N.Y.U.; Prof.; Slow viscous flow hydrodynamics of biological flows.
J. F. Osterle, Ph.D. 1952, Carnegie Tech.; Prof.; Fluid mechanics, thermodynamics.
T. Au, Ph. D. 1951, Univ. of Ill.; Prof.; System design of hospital system.
L. E. Jarrard, Ph.D. 1959, Carnegie Tech.; Assoc. Prof.; Neuropsychology.
E. M. Krokosky, Sc. D. 1962, M.I.T.; Assoc. Prof.; Mechanical properties of biological and prosthetic materials.
D. Gall, Sc.D. 1964, M.I.T.; Asst. Prof.; Automatic controls, mathematical modeling of physical systems, physiological control systems.
T. Calvert, Ph.D. 1967, Carnegie Tech.; Asst. Prof.; Medical system engineering, physiological pattern recognition.
T. K. Hung, Ph.D. 1967, Univ. Iowa; Asst. Prof.; Biomechanics, biological flow hydrodynamics, numerical analysis.
M. Weissman, Ph. D. 1967, Northwestern; Asst. Prof.; Biomed. Eng.; hemodynamics, artificial internal organs, physiology of circulation and respiration.
E.B. Christophersen, M.D. 1962, Univ. of Oslo; Lect.; Artificial organs.
M. Wholey, M.D. 1953, Hahnemann; Lect.; Vascular-radiology.

4. Research Equipment and Facilities - The program makes available to its teaching and research program the following facilities of its participant units of the University:

The Medical Systems Engineering Laboratory--Standard facilities of an electronics lab, a multiplexing tape recorder, a two-pen EKG, a PDP8 computer with high-speed tape recorder analog-to-digital conversion system photospectrometers, and a semi-conductor lab.
The Biological Flows Laboratory--A unique towing tank for model studies of erythrocytes, apparatus for high-speed microcinematography of biological flow phenomena, viscometric equipment and facilities for model studies of the flow of suspensions.
The Biological Materials Laboratory--Facilities for determining the properties of biological and prosthetic materials including an aortic test section operated at the Oakland V.A. hospital.
The Biophysical Research Laboratory--Facilities for research primarily in the biophysics of vision and biochemical energy conversion, electrophysiology and tissue culture.
The Laboratories of the Biological Sciences Department--Facilities for instruction and research in microbiology, genetics and animal physiology.
Mellon Institute--Usually well equipped for research in biochemistry and biophysics, in synthesis and characterization of prosthetic and biological materials, in viscoelasticity, and in radiobiology.
Computer Center--3 large digital computers, a CDC G-21, an IBM 360-67, and a UNIVAC 1108, with 80 teletype stations and a large hybrid computer with 100 amplifiers.
Animal Facilities--Animal facilities are in the Dept. of Biological Sciences and Dept. of Psychology, as well as in the West Penn Hospital, and in the surgical research unit at the Oakland V.A. Hospital.

5. Departmental Graduate Body - 18 M.S. candidates (9 E.E.; 4 M.E.; 4 C.E.; 1 Ch.E.) and 15 Ph.D. candidates (6 E.E.; 4 M.E.; 4 C.E.; 1 Biol. Sc.) currently enrolled in the program.

6. Source of Additional Information - For additional information, write to:

Professor T. Calvert
Acting Chairman, Biotechnology Committee
Carnegie-Mellon University
Pittsburgh, Pennsylvania 15213

DEPARTMENT OF BIOMEDICAL ENGINEERING
CASE WESTERN RESERVE UNIVERSITY
Cleveland, Ohio 44106

1. Program of Research Training under GM-1090 - The Department offers a Ph.D. through the School of Engineering and postdoctoral training either through the School of Engineering or Medicine. Advanced degrees in Biomedical Engineering may be earned by postdoctoral trainees who are M.D.'s or who have received their Ph.D.'s in the life sciences. The predoctoral training program is designed to provide a balance between formal course work in engineering, the physical sciences, the life sciences, and mathematics. Its primary aim is to prepare an independent investigator and for this reason the formal academic requirements are substantial. The average duration of training is from four to five years beyond the Bachelor's degree. Trainees are expected to complete a selected sequence of courses in Biomedical Engineering. The training program is supervised primarily by the faculty from the department with the cooperation of other faculties within the Schools of Engineering, Medicine, and the Department of Biology. Requirements for the doctoral degree include qualifying examinations in an area of engineering specialization and certain aspects of the life sciences as well as the Departmental qualifier in Biomedical Engineering. The final requirement is the successful completion of independent research followed by the submission and defense of thesis.

   The areas of specialization within the Department are Physiological Systems Analysis, including renal function, respiration, the cardiovascular system, neuroendocrinology, neuromuscular control; the Neural Sciences, including information processing in neurons, field interactions among neurons, properties of excitable tissue, and electrocardiography; and Transport Physiology, which encompases membrane transport--pulmonary and renal transport and mass transport. In addition, formal course work and research opportunities exist in hemodynamics, both theoretical and experimental. Another option available is in the area of instrumentation, primarily microelectronics and telemetry. The program is unique in its flexibility for matching both the didactic course work and the research areas to the trainee's interest. The postdoctoral program offers comparable flexibility.

2. Entrance Requirements - Supplementing the University requirement of a minimum grade point average of 2.5/4 (C+) for admission, a bachelor's degree with a good record in any branch of engineering or any field of the life or physical sciences is the basic departmental requirement for trainees. Deficiencies which may exist in mathematics, physical or biological science may be made up after admission (though without graduate credit).

3. Research Training Staff

Donald S. Gann, M.D. 1956, Johns Hopkins U.; Prof.; Neuroendocrinology control mechanisms, electrolyte metabolism, application of systems analyses to biological systems.
Jerald S. Brodkey, M.D. 1960, U. Nebraska; Asst. Prof.; Visual neurophysiology; neuromuscular control.
Albert H. Burnstein, Ph.D. 1968; New York U.; Asst. Prof.; Biomechanics, mechanisms of fracture, head injury.
Ronald L. Cechner, Ph.D. 1967, Case Inst.; Asst. Prof.; Neuroelectrodynamics, neural information processing.
Edward H. Chester, M.D. 1956, New York U.; Asst. Prof.; Respiratory physiology, pulmonary mechanics, obstructive pulmonary disease.
David G. Fleming, Ph.D. 1952, U. Calif. (Berkeley); Prof.; Biological control systems, physiological systems analysis, homeostatic and neuromuscular systems.
Victor H. Frankel, M.D. 1951, U. Pennsylvania; Assoc. Prof.; Biomechanics, mechanisms of fracture, head injury.
Donald F. Gibbons, Ph.D. 1950, U. Birmingham, England, Prof.; Biomaterials, tissue reaction, clotting mechanisms.
Peter G. Katona, Sc.D. 1965, M.I.T.; Assoc. Prof.; Communications and control aspects of electrical engineering, analysis of physiological systems, blood pressure regulation, hospital computer systems.
Wen H. Ko, Ph.D. 1959, Case Inst.; Prof.; Solid state electronic devices and circuits, microelectronics and biomedical applications.
Matthew N. Levy, M.D. 1945, Western Reserve; Assoc. Prof.; Cardiovascular physiology and control.
Martin Macklin, Ph.D. 1967, Case Inst.; Asst. Prof.; Control of cell differentiation and growth, analysis of kidney function.
Paul J. Martin, Ph.D. 1967, Case Western Reserve; Adj. Asst. Prof.; Cardiovascular physiology and control.
Floro D. Miraldi, Sc.D. 1959, M.I.T.; Assoc. Prof.; Nuclear engineering, radiation scanning, radiation biophysics.
John T. Mortimer, Ph.D. 1968, Case Western Reserve; Asst. Prof.; Orthotic and prosthetic devices, myoelectric control.
Michael R. Neuman, Ph.D. 1966, Case Inst.; Asst. Prof.; Solid state electronics, microelectronics, perinatal care.
Nils A. Normann, M.D. 1943, U. Oslo, Norway; Asst. Prof.; Cardiovascular assist devices, neural-vascular interactions.
Lee E. Ostrander, Ph.D. 1966, U. Rochester; Asst. Prof.; Systems control and computer methods, respiratory and endocrine systems.
John C. Petersen, Ph.D. 1969, Johns Hopkins; Asst. Prof.; Sensory and integrative aspects of neurophysiology, neuroendocrine control.
Robert Plonsey, Ph.D. 1956, U. Calif. (Berkeley); Prof.; Field theory applied to cardiography and electrophysiology.
James B. Reswick, Sc.D. 1954, M.I.T.; Prof.; Orthotic and prosthetic devices, myoelectric control.
Kiichi Sagawa, M.D. 1950, Yokohama Medical College, Assoc. Prof.; Cardiovascular physiology.
Gerald M. Saidel, Ph.D. 1964, Johns Hopkins; Asst. Prof.; Transport processes in biological systems, dynamics of cell populations.
James D. Schoeffler, Ph.D. 1960, M.I.T., Prof; Control and systems engineering, neuroendocrine control.

Lawrence P. Schramm, Ph.D. 1969, U. Rochester; Asst. Prof.; Nervous system ontogeny, neurophysiology, neural-cardiovascular interrelations.

4. Research Equipment and Facilities - The Department of Biomedical Engineering has 23,000 sq. ft. of space on the 2nd, 5th, and 6th floors of the Wickenden Building. Animal facilities are on the 2nd and 6th floors. Eight fully-equipped laboratories for animal research are in operation, and others are under development. The Department is adjacent to the simulation laboratory of the Systems Research Center.

   Departmental equipment includes several multichannel tape recorders, two 4-channel, one 6-channel, and two 8-channel pen recorders with associated low-noise DC amplifiers, preamplifiers, and transducers; an average response computer with digital printout; a 7-channel wide band light beam galvanometer; two EAI TR-20 analog computers; a variety of stimulators and low-noise amplifiers and preamplifiers; microelectrode puller, precision micromanipulators; stereotaxic apparatus, and electrometer amplifiers for intracellular recording; equipment for the measurement of ventilation, pO, pCO, pH, and blood flows; a number of high-quality oscilloscopes with multiple sweeps, storage, and polaroid camera attachments; a liquid scintillation spectrometer and other equipment for measurement of radio-activity; gas-liquid chromatograph and other equipment for biochemical separations; spectrophotometers; microscopes; an autoclave; two incubators; a complete tissue culture laboratory; histological facilities; and surgical instruments. Two laboratories have wet facilities which are also being extended to other rooms. There is an animal surgery room for experimental studies with two others under development; two shielded rooms; a recording room; a sound room; and a small shop. Direct cables are available to the CSI analog and GE 4060 digital computers in the Systems Research Center for online computation and control as well as a large-scale digital computing facility (Univac 1108) at the Jennings Computing Center.

   Facilities for the development of instrumentation are available in the Engineering Design Center, including shops. Other laboratories are in the Center for the Study of Materials. In addition, there are both laboratories and areas for patient observation in University, Cleveland Metropolitan General, Highland View, and Veterans Administrations Hospitals--all associated with the work of the Department.

5. Departmental Graduate Body - There are 46 graduate students in the Biomedical Engineering and the Medical Engineering and Instrumentation curricula. Graduate student interests include: electrophysiology, electrocardiography, physiological systems analysis, cybernetics systems for the disabled, biomedical instrumentation, and biomechanics. Two graduate students are involved in studies of pulmonary mechanics and one is studying transport processes in the kidney.

6. Source of Additional Information - For additional information, write to:

   Donald S. Gann, M.D., Director
   Department of Biomedical Engineering
   Case Western Reserve University
   University Circle
   Cleveland, Ohio 44106

BIOLOGICAL SCIENCES GROUP
REGULATORY BIOLOGY SECTION
DEPARTMENT OF ELECTRICAL ENGINEERING
UNIVERSITY OF CONNECTICUT
Storrs, Connecticut 06268

1. Program of Research Training under GM-1388 - The program is primarily predoctoral, but individual faculty members welcome postdoctoral candidates where mutual benefit is assured.

   a. Program aims are as follows:
      1. To provide facilities and faculty to train students in the techniques of modern quantitative biology, including mathematics, systems analysis electronics, model-building and computer-data processing technology;
      2. To attract physical scientists, especially engineers, into biological research;
      3. To establish research programs in specific areas of Bioengineering that will provide students with the opportunity to apply their theoretical information in the generation of new knowledge; and
      4. To cooperate with other University departments and schools in advancing the quality of graduate training and research in biology.
   b. Course offerings which are designed primarily for the Bioengineering Program are: Mathematical Methods in Biological Problems; Communication and Control in Physiological Systems; Biomedical Instrumentation; Laboratory in Bioengineering; and Neurophysiology I and II.
   c. Areas of specialization are: neurophysiology, the physiological basis of behavior; membrane physiology, active transport and electrophysiology; linguistics, vocalization; mathematical modeling in biochemistry and immunology; mechanical properties of muscle; and insect flight aerodynamics and control.
   d. Duration of training for well prepared students is four years.
   e. Degrees offered are the M.S. and Ph.D. in Bioengineering.
   f. Special features of the program are that the cooperative program makes available to students the facilities of a well-staffed and equipped School of Engineering and an excellent Biological Sciences Division.

2. Entrance Requirements - A B.A. or B.S. degree from a recognized Liberal Arts or Engineering School, with a quality point ratio of 26 (B average = 30), is required. A personal interview is desired where possible. A general biology course, a year of calculus and a year of chemistry are suggested minima. Students may have majored in Engineering, Biological Sciences, Physical Science or Mathematics.

3. Research Training Staff

Edward Boettiger, Ph.D. 1939 Harvard; Professor (Regulatory Biology); Muscle and receptor physiology; insect flight.

Robert Northrop, Ph.D. 1964 University of Connecticut; Associate Professor (Electrical Engineering); Integration of visual information, neuromodeling.
William Chapple, Ph.D. 1965 Stanford; Assistant Professor (Regulatory Biology); Neurophysiology, integration.
Tobias Schwartz, B.S. Engineering, 1949; Ph.D. 1966 State University of New York at Buffalo, Biophysics. Assistant Professor (Regulatory Biology); Membrane Physiology; Electrophysiology.
Richard Norman, Ph.D. 1967 University of Michigan, Communication Science, Assistant Professor (Regulatory Biology); Neural integration.
Arnon Cohen, Ph.D. 19[illegible] University of Pittsburg, Biomedical Engineering, Assistant Professor (Electrical Engineering), Biomedical instrumentation.
Philip Lieberman, Ph.D. 1965 Massachusetts Institute of Technology; Assistant Professor (Electrical Engineering); Sound production and analysis, Linguistics.

4. Research Equipment and Facilities

a. General facilities
   1. Animal - Marine laboratory with salt water collecting and storage facilities - Insectary - Small mammal animal house.
   2. Other - Environmental control rooms; photographic laboratories; Computer Center with 360 and 1620 computers plus console extension in Life Sciences Building; Library - well supplied for graduate work; Electron Microscope Center.

b. Special Facilities - TMC Average Transient Computer; PDP 339 on Line Digital Computer; Instrument Tape Recorders; Applied Research Signal Correlator; Servo-controlled Movement Generator; Hot Wire Anemometers; High Speed Camera; Pulse Code Generator.

c. Neurophysiological equipment includes oscilloscopes, amplifiers for recording intra- and extra-cellular potentials, and high quality optical equipment.

d. Space consists of 3500 square feet, air conditioned laboratories.

5. Graduate Students - There are a total of 6 Ph.D. candidates.

Thesis topics consist of: Aerodynamics of Insect Flight; Integration of Visual Information in Insects; Motor Integration in Anthropods; Responses of Isolated Insect Ganglia; Neuromodeling; Control of Eye Movements; Membrane Physiology; and Neural Integration.

6. Sources of Additional Information - For additional information, write to:

Dr. Edward G. Boettiger
University of Connecticut
Regulatory Biology, Box U-42
Storrs, Connecticut 06268

OR

Dr. Robert Northrop
University of Connecticut
Department of Electrical Engineering
Box U-37
Storrs, Connecticut 06268

BIOMEDICAL ENGINEERING GROUP
PHYSIOLOGY DEPARTMENT
UNIVERSITY OF ILLINOIS
Chicago, Illinois 60680

1. Program of Research Training under GM-1436 - The program includes formal course study and active apprentice research for both pre- and postdoctoral students in the biomedical engineering area lying within both physiology and engineering. Two main aspects of bioengineering are stressed in the training program: first, the application of the theory of information, communication and control to complex physiological systems; second, the teaching of problem-formulation and research strategy in fundamental areas, such as artificial intelligence and mathematical modeling of physiological and psychological function, that also bear upon the solution of applied problems in the medical world.

   Examples of a few areas in which engineering principles can be applied as a research activity to the medical and biological sciences are: the development of pattern recognition and artificial intelligence programs, as in computer diagnosis of electrocardiograms; biomedical instrumentation and medical data processing; research in artificial organs; radiation biology; cardiovascular dynamics; and endocrine control systems. In order to develop new biological applications of engineering science or to carry out independent scientific research in these areas, we feel that a properly trained bioengineer should have the necessary background in both the engineering and the life sciences. For students with life science degrees, this background includes concentration in mathematics, engineering and the physical sciences. Similarly, students with physical science degrees will concentrate on the life sciences.

   At the present time, the Ph.D. is awarded through the Physiology Department of the University of Illinois. Normally, two and one-half to three years are required for completion of degree requirements for those individuals who have a Master's degree. For those individuals with a Bachelor's degree, three to three and one-half years are normally required for completion of degree requirements.

2. Entrance Requirements - Entrants must have an undergraduate degree in life sciences, physical science or engineering. A grade-point average of at least 4.0/5.0 for the last 60 hours of study is normally required for admission, but applications will be considered on an individual basis for those with averages between 3.5 and 4.0.

3. Research Training Staff

   Arne Troelstra, Ph.D. 1964, U. of Utrecht (Holland); Assoc. Prof.; Visual systems, biological control systems.
   Gyan Agarwal, Ph.D. 1965 Purdue Univ.; Asst. Prof.; Peripheral versus central adaptation in human motor coordination systems.

Robert Arzbaecher, Ph.D. 1960, U. of Ill.; Assoc. Prof.; Analysis and synthesis of electrocardiographic lead systems.
Jerald Brodkey, M.D. 1960, U. of Neb.; Asst. Prof. Embedding of neurophysiological experiments in a neurological control system background.
James W. Dow, M.D. 1944, Tufts; Professor; Cardiovascular control systems, automated management of the critically ill.
Earl E. Gose, Ph.D. 1960, U. of Calif. (Berkeley); Assoc. Prof.; Pattern recognition and artificial intelligence.
Derek P. Hendry, Ph.D. 1960 Yale; Assoc. Prof.; Physiological control mechanisms, behavioral control mechanisms, motivation, punishment, information theory.
Joel A. Michael, Ph.D. 1965, MIT; Asst. Prof.; Physical basis of behavior, application of cybernetics to behavioral sciences.
William D. O'Neill, Ph.D. 1965, Notre Dame; Asst. Prof.; Human lens accommodation servo-mechanisms.
Bert L. Zuber, Ph. D. 1965 MIT; Asst. Prof.; Physiological control systems, neurophysiological correlates of visual and oculomotor function.

In addition, faculty in other departments of the university who have bioengineering interests may serve as thesis advisors (always jointly with a bioengineering faculty member), teachers of special courses and seminars and as members of the research training staff.

4. Research Equipment and Facilities - The Biomedical Engineering Department has maintained itself as a distinct entity and successfully retained the unique scientific and educational advantages represented by the combined facilities of the University and Presbyterian-St. Luke's Hospital. The department provides consultation services to hospital staff, devises instruments and systems for hospital use, and operates the IBM 1800 computer for analysis of scientific problems generated within the hospital. Space - 12,000 sq. ft. of the Jelke Research Bldg.; 3,200 sq. ft. of laboratory space for research and instruction; 1,000 sq. ft. of laboratory space organized around an on-line, real-time computer system. Computer Facilities - GE 225 at the university and IBM 1800 at the hospital. Another IBM 1800 and a 360/50 are on order at the university. Tele-communication system available for remote computer control. Library facilities at the university and hospital are more than adequate.

5. Departmental Graduate Body - Our graduate student population is 16, with two postdoctoral and 14 predoctoral students comprising this group. Of this group, two have Medical degrees, five have Bachelor degrees, and nine have Master's degrees. Their undergraduate backgrounds include physics, electrical engineering, psychology, zoology and mathematics. The graduate students have diverse research interests, which include pattern recognition in medical diagnosis; network models of brain function; neural modeling; neurophysiology control theory applications; and non-linear mechanisms in biological systems.

6. Source of Additional Information - For additional information write to:

Dr. Arne Troelstra
Assoc. Professor of Bioengineering
Univ. of Illinois Chicago Circle
Box 4348
Chicago, Illinois 60680

BIOMEDICAL ENGINEERING
DEPARTMENT OF MEDICINE
JOHNS HOPKINS UNIVERSITY
Baltimore, Maryland 21205

1. Program of Research Training under GM-576 - The principal aim is to provide the fields of medicine and biology with a group of scientists having advanced training in engineering, physical sciences and mathematics, coupled with a thorough understanding of basic biological sciences. Graduate students are candidates for the Ph.D. degree. Postdoctoral study is also available. Program of training is tailored to the individual needs. The program is supervised by an interdisciplinary committee composed of faculty members from the School of Medicine and the Faculty of Arts and Sciences. (The latter includes the Engineering Departments.)

   Student work in the biological sciences, including biochemistry, anatomy, and physiology, is usually done in the first graduate year of the School of Medicine. An alternative is to follow a program of courses from the departments of Biophysics and Biology. Formal courses in engineering, physical sciences, and mathematics are taken in the Faculty of Arts and Sciences.

   Thesis research is a substantial part of the training. The areas of research open to the students are widespread. The work is done in one of the many laboratories of Johns Hopkins concerned with medical or biological problems. Theses are usually jointly supervised by the faculty member directing the laboratory where the student works and by an engineering faculty member. Current thesis areas include: Muscle dynamics; oculomotor system; neurophysiology of somathesis; hormonal control; neurophysiology of vision; neurophysiology of audition; cardiovascular physiology; and heart-assist devices.

   Courses designed especially for biomedical engineering students include signal representation, biological control systems and models of biological processes and systems. The curriculum is typically of five years' duration. First and second years are devoted to graduate courses in engineering, physical sciences and mathematics, as well as courses in basic biomedical sciences. Summers are spent working in laboratories. In the third and subsequent years the emphasis is on the dissertation research. By January 1970, ten Ph. D. degrees will have been awarded.

2. Entrance Requirements - A bachelor's degree background in engineering, engineering science or applied physics provides a suitable base. Courses in introductory biology, organic chemistry and physical chemistry are prerequisites. Students lacking one or two of these prerequisites may be admitted on condition that they obtain them before starting or early in the program.

3. Research Training Staff - Biomedical Engineering Committee and Teaching staff:

Stanley Corrsin, Ph.D. 1947, Cal. Tech.; Professor (Fluid Mechanics); Turbulent flow and other random processes.
Moise H. Goldstein, Jr., Sc.D. 1957, M.I.T.; Professor (Electrical Engineering); Sensory neurophysiology, especially audition.
John M. Heinz, Sc.D. 1962, M.I.T.; Assistant Professor (Laryngology) and Otology); Speech communication, acoustics, and computer simulation.
William H. Huggins, Sc.D. 1953, M.I.T.; Professor (Electrical Engineering); System theory, signal representation.
Richard J. Johns, M.D. 1948, Johns Hopkins; Professor (Medicine); Neuromuscular function in man, applications of engineering principals to medical problems.
David A. Robinson, Dr. Eng. 1959, Johns Hopkins; Associate Professor (Biomedical Engineering); Oculomotor system, systems analysis, modelling.
Howard Seliger, Ph.D. 1954, University of Maryland; Professor (Biology); Photobiology, energy transfer mechanisms.
Richard H. Shepard, M.D. 1946, Johns Hopkins; Associate Professor (Medicine); Medical computing.

Faculty supervising thesis research include the above and the following:

Donald W. Benson, M.D. 1950, University of Chicago; Professor (Anesthesiology); Pharmacological problems in anesthesia.
John E. Dowling, Ph.D. 1961, Harvard University; Associate Professor (Ophthalmology); Retinal biochemistry, physiology, anatomy.
Vincent L. Gott, M.D. 1953, Yale University; Associate Professor (Surgery); Artificial heart, surgery of coronary arteries.
William B. Kouwenhoven, Dr.Eng. 1913, Karlsruhe, Technische, Hochschule; Professor Emeritus (Electrical Engineering); Traumatic and therapeutic effects of electricity.
William B. Marks, Ph.D. 1964, Johns Hopkins, Assistant Professor (Biophysics); integrative neurophysiology-mathematical methods in neurophysiology.
Vernon B. Mountcastle, M.D. 1942, Johns Hopkins; Professor (Physiology); Physiology of the CNS in particular of the neural mechanisms in sensation and perception.
Richard S. Ross, M.D. 1947, Harvard Medical School; Professor (Medicine) Coronary artery disease (arteriographic and clinical studies).
Kenneth L. Zierler, M.D. 1941, University of Maryland; Professor (Medicine and Physiology); Muscle: metabolism, mechanics, and hormonal responses. Biomembranes: transport kinetics, ion transport and hormone action.

4. Research Equipment and Facilities - The facilities of the University are available to the students. They may take their required year of studies in basic biological science at the Medical School or select courses offered in the Departments of Biology, Biophysics, and Psychology at the Homewood Campus. Students do research at various laboratories at the Medical School and at the Homewood Campus. The number of laboratories seeking participation of medical engineering graduate students exceeds the number of students. The students have access to the Welch Library at the School of Medicine and to the Milton S. Eisenhower Library on the Homewood Campus. Computation facilities are available through the University Computing Center and the Medical School Computing

Center. A high speed digital laboratory instrument computer in the Subdepartment of Biomedical Engineering is available for training and use in research.

5. Departmental Graduate Body - There are currently 20 predoctoral students and 3 postdoctoral trainees in Biomedical Engineering.

6. Sources of Additional Information - For additional information, write to:

Concerning Predoctoral Work

Dr. David A. Robinson, Chairman
Committee on Biomedical Engineering
505 Traylor Research Building
720 Rutland Avenue
Johns Hopkins School of Medicine
Baltimore, Maryland 21205

Concerning Postdoctoral Work

Dr. Richard J. Johns, Director
Subdepartment of Biomedical Engineering
518 Traylor Research Building
720 Rutland Avenue
Johns Hopkins School of Medicine
Baltimore, Maryland 21205

COLLEGE OF ENGINEERING
MARQUETTE UNIVERSITY
Milwaukee, Wisconsin 53233

1. Program of Research Training under GM 1051 - The principal objective of this effort is to provide an integrated program of courses and research activity leading to the Ph. D. degree in bioengineering. A program for those with backgrounds in engineering is well established. A program for those with backgrounds in the life sciences (including those with the M.D.) leading to the M.S. degree has been initiated and is currently being developed and expanded. Some 40 research projects are currently active in the following areas: the cardiovascular system, the nervous system, the body water-electrolyte system, the cellular system, biomechanics and radioisotope techniques. The program of study includes courses in engineering, courses in the life sciences and special courses in bioengineering, such as simulation of physiological systems and bioengineering neurology.

2. Entrance Requirements - Graduates of approved colleges or universities with a Bachelor's or equivalent degree are eligible for admission to the graduate school. Those applicants are admitted whose undergraduate record shows promise of success in graduate school. Prerequisites are organic chemistry and physiology. Students are encouraged to take physical chemistry, biochemistry and biology.

3. Research Training Staff

James D. Horgan, Ph.D. 1957, Univ. of Wisconsin; Professor; Cardiopulmonary system.
Anthony Sances, Jr., Ph. D. 1964, Northwestern U.; Assoc. Professor; Nervous system.
Josep G. Llaurado, M.D. 1950, Univ. of Barcelona; Assoc. Professor; Cellular membrane transport phenomena.
Ramon L. Lange, M.D. 1949, Duke Univ.; Professor; Cardiology.
Sanford J. Larson, M.D. 1954 & Ph.D. 1962, Northwestern Univ.; Professor; Neuroanatomy, neurophysiology.
Mary P. Murray, Ph.D. 1961, Marquette Univ.; Asst. Professor; Kinesiology.
Robert C. Meade, M.D. 1950, Univ. of Minnesota; Assoc. Professor; Nervous and renal systems.
James T. Botticelli, M.D. 1955, Loyola Univ.; Assoc. Professor; Postural hypotension.
Arthur Houston, Ph.D. 1958, Univ. of British Columbia; Assoc. Prof.; Cardiovascular-respiratory homeostasis.
Arthur S. Wilson, Ph.D. 1962, Northwestern Univ.; Asst. Professor; Psychophysiology.
John B. Baker, M.D. 1955, Univ. of Buffalo; Asst. Professor; Neurology.
Irving Lutsky, V.M.D. 1955, Univ. of Pennsylvania; Asst. Professor; Veterinary science.
Kenneth Siegesmund, Ph.D. 1960, Univ. of Wisconsin; Asst. Professor; Electronmicroscopy and biology.
Sherman Wu, Ph.D. 1965, Northwestern Univ.; Assoc. Professor; Systems analysis.

Ernest C. Henschel, M.D. 1945, Charles Univ., Prague; Professor; Effects of anesthesia on the cardiovascular, pulmonary and CNS.

4. Research Equipment and Facilities - Approximately 20,000 sq. ft. of space is used for the research training of bioengineering students, including areas in the School of Medicine, the College of Engineering, the Milwaukee County General Hospital, the Veterans Administration Hospital and the Allen Bradley Medical Science Laboratory. The Bioengineering Neurosciences Laboratory at the VA Hospital includes complete equipment for neurophysiological studies, including a screen room, animal care facilities and the LINC 8 laboratory computer for on-line studies. Equipment in the fully equipped Radioisotope Laboratory includes four-probe renogram instrumentation and a scintillation camera for organ scan studies.

   Bioengineering research training is carried on also at the County Hospital in the Biophysics Laboratory and the Cardiopulmonary Laboratory. The Biophysics Laboratory contains EEG recording equipment, biological pre-amplifiers and recorders and a fixed program digital computer of average transients. The fully equipped Cardiopulmonary Laboratory includes both an analog computer and a LINC 8 digital computer for research in cardiovascular systems and patient monitoring.

   The College of Engineering houses an IBM 7040 computer, analog computers and peripheral equipment for biomedical analysis.

5. Departmental Graduate Body - There are at present 26 graduate students, of whom 17 are full-time. Of these, six have completed the M.S. degree.

6. Sources of Additional Information - For additional information, write to:

   James D. Horgan, Professor
   Dept. of Electrical Engineering
   Marquette University
   1515 W. Wisconsin Avenue
   Milwaukee, Wisconsin 53233

   OR

   Anthony Sances, Jr., Assoc. Prof.
   Neurosciences Laboratory
   Veterans Administration Hospital
   Wood, Wisconsin 53226

DEPARTMENT OF ELECTRICAL ENGINEERING AND
RESEARCH LABORATORY OF ELECTRONICS
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Cambridge, Massachusetts 02139

1. Program of Research Training under GM-1555 - Training includes both a predoctoral program leading to the Sc.D. or Ph.D. degree, and a post-doctoral program of 1-2 years duration. Communications bioengineering is intended to mean the application of modern communications, control and computer theory and technology to problems arising in the life and biomedical sciences. More than a dozen academic subjects are offered at MIT in such areas as sensory communication, speech communication, bioelectric and neuro-electric signals, man-machine systems, models for human processing of information and artificial intelligence. In addition, a full range of subjects is offered in biology, biochemistry, physiology, psychology and linguistics, and cross-registration can readily be arranged with many schools in the Boston-Cambridge area, including the Harvard Medical School. The research experiences of the trainees are concentrated in the communications biophysics, cognitive information processing, speech communication and neurophysiology groups of the interdepartment Research Laboratory of Electronics. These groups are concerned primarily with physiological and psychological studies of the sensory systems (visual, auditory, olfactory and tactile) and man-machine studies involving the generation and perception of communication symbols, including speech, handwriting, pictures and tactile patterns. The training program is designed to be flexible, in general, but each trainee's program will contain substantial advanced study in both the life sciences and in the physical sciences or engineering.

2. Entrance Requirements - Predoctoral trainees must be competitively admitted to some department as regular graduate students. Although trainees will be accepted from many backgrounds, including the life sciences, most will have degrees in electrical engineering, physics or mathematics. In general, students will not be accepted as trainees until their second year of graduate study.

3. Research Training Staff

W. M. Siebert, Sc.D. 1952, MIT; Professor (Elec. Eng.), Prog. Director; Auditory theory.
M. Eden, Ph.D. 1951, U. of Maryland; Professor (Elec. Eng.); Pattern recognition.
L. S. Frishkopf, Ph.D. 1956, MIT; Professor (Elec. Eng.); Sensory physiology.
J. Y. Lettvin, M.D. 1943, U. of Illinois; Professor (Comm. Physiol.); Neurophysiology.
S. J. Mason, Sc.D. 1952, MIT; Professor (Elec. Eng.); Sensory aids.
W. A. Rosenblith, Ing. Rad., Ec. Sup. (Paris) 1937; Professor (Comm. Biophys.); Sensory communication.
K. N. Stevens, Sc.D. 1952, MIT; Professor (Elec. Eng.); Speech communication.

F. F. Lee, Ph.D. 1966, MIT; Assoc. Professor (Elec. Eng.); Speech synthesis
W. T. Peake, Sc.D. 1960, MIT; Assoc. Professor (Elec. Eng.); Auditory physiology.
W. F. Schreiber, Ph.D. 1953, Harvard; Assoc. Professor (Elec. Eng.); Picture processing.
J. Allen, Ph.D. 1968, MIT; Asst. Professor (Elec. Eng.); Speech communication.
L. D. Braida, Ph.D. 1969, MIT; Asst. Professor (Elec. Eng.); Auditory psychophysics.
S. K. Burns, Ph.D. 1967, MIT; Asst. Professor (Elec. Eng.); Medical electronics.
J. L. Goldstein, Ph.D. 1965, U. of Rochester, N.Y.; Asst. Professor (Elec. Eng.); Sensory physiology.
J. J. Guinan, Jr., Ph.D. 1968, MIT; Asst. Professor (Elec. Eng.); Sensory physiology.
W. L. Henke, Ph.D. 1966, MIT; Asst. Professor (Elec. Eng.); Man-machine systems.
T. S. Huang, Sc.D. 1963, MIT; Asst. Professor (Elec. Eng.); Information processing.
D. H. Klatt, Ph.D. 1964, U. of Michigan; Asst. Professor (Elec. Eng.); Speech and audition.
D. E. Troxel, Ph.D. 1962, MIT; Asst. Professor (Elec. Eng.); Sensory aids.
T. F. Weiss, Ph.D. 1963, MIT; Asst. Professor (Elec. Eng.); Sensory physiology.
N. I. Durlach, M.A. 1954, Columbia; Research staff; Auditory psychophysics.
R. D. Hall, Ph.D. 1960, Brown; Research staff; Neurophysiology of learning.
N. Y. S. Kiang, Ph.D. 1955, U. of Chicago; Research staff; Auditory physiology.

4. Research Equipment and Facilities - The research facilities of the four RLE groups mentioned above currently occupy some 25,000 sq. ft., and expect to move into new and larger quarters early in the 1970's. In addition to general office space (including a desk for each trainee) and laboratory space, the facilities encompass a number of special areas such as two anechoic chambers, a number of shielded rooms, animal quarters, shops, special libraries and conference rooms. A full range of electronic instrumentation is available, including five medium-sized general-purpose computers. The full scope of the MIT shops, libraries, computers, etc., is, of course, available when required. In addition, there are many cooperative arrangements with other organizations, such as the Massachusetts General Hospital, which include the sharing of staff and facilities.

5. Departmental Graduat Body - Approximately twelve to fifteen predoctoral and two to four postdoctoral trainees are involved in the program at any one time. Most of the predoctoral trainees are registered as students in the Electrical Engineering Department. The total graduate student enrollment of the Electrical Engineering Department is approximately 400; of these about 50 are interested in one aspect or another of the

subarea of Communications Bioengineering. In addition to the two to four postdoctoral trainees involved in this program, there are on the average about 25 other postdoctoral fellows and visiting faculty associated with the four research groups.

e. Source of Additional Information - For additional information write to:

Professor William M. Siebert
Massachusetts Institute of Technology
77 Massachusetts Avenue
Room 20B-231
Cambridge, Massachusetts 02139

COLLEGE OF ENGINEERING
THE UNIVERSITY OF MICHIGAN
Ann Arbor, Michigan 48104

1. Program of Research Training under GM 1289 - The Bioengineering Research Training Program in the Horace H. Rackham School of Graduate Studies is supported by the College of Engineering and the Medical School. It is designed to train the student to seek solutions to those engineering problems as presented by the performance of the living system.

   The predoctoral program includes an academic preparation, directed research training, and an independent research investigation. The academic preparation includes comprehensive zoology, comparative and/or mammalian physiology, bioengineering physiology, bioelectric measurements, biochemistry, introduction to neural control, introduction to skeletal-motor systems, introduction to sensory system, advanced technological topics and mathematics and an in-depth study in the biological area of research interests.

   The postdoctoral programs are individually planned, based upon student background, student research objective, and facilities that are available at the institution.

2. Entrance Requirements -

   A. Bachelor of Science in Engineering including general and organic chemistry, 14 hours of biology as anatomy, biochemistry, physiology, psychology and zoology.
   B. Bachelor of Science, Bachelor of Arts including two terms college physics, integral calculus, 17 credits of biology, organic chemistry, mechanics, thermodynamics and fluid mechanics.

3. Research Training Staff

   P. H. Abbrecht, Ph.D. 1953, M.D. 1962, Univ. of Mich.; Asst. Prof.; Renal and endocrine physiology.
   J. E. Bean, Ph.D. 1931, M.D. 1936, Univ. of Mich.; Prof.; Blood flow in tissue.
   S. L. BeMent, Ph.D. 1967, Univ. of Mich.; Asst. Prof.; Electro-physiology.
   D. B. Chaffin, Ph.D. 1967, Univ. of Mich,; Asst. Prof.; Skeletal-motor response.
   G. B. Edmonson, M.E. 1949, Univ. of Mich.; Professor; Impact stress-cortex.
   D. G. Green, Ph. D., Northwestern; Asst. Prof.
   W. M. Hancock, Ph.D. 1954, Johns Hopkins; Prof.; Physiology of manual task.
   R. M. Howe, Ph.D. 1950, M.I.T.; Prof.; Propriceptive feed-back control.
   K. E. Jochim, Ph.D. 1941, Univ. of Chicago; Prof.; Cardio-systems control.
   R. C. Juvinall, M.E. 1950, Univ. of Ill.; Prof.; Prosthetics and orthotics.
   L. L. Kempe, Ph.D. 1948, Univ. of Minn.; Prof.; Oxygen transfer-membrane.
   M. Lawrence, Ph.D. 1941, Princeton; Prof.; Inner ear properties.
   H. J. Magnuson, M.D. 1932, U.S.C., M.Ph. 1942, Johns Hopkins; Prof.; Toxicology.

Herman Merte, Jr., Ph.D. 1960, Univ. of Mich., Prof.; Heat transfer.
J. R. Pearson, M.Sc. 1946, M.I.T.; Prof.; Prosthetics and orthotics.
R. W. Pew, Ph.D. 1963, Univ. of Mich.; Prof.; Physiology of human performance.
J. W. Rae, Jr., M.D. 1943, Univ. of Mich., M.S. 1950, Univ. of Minn., Prof.; Physical medicine.
J. B. Ranck, Jr., M.D. 1955, Columbia University, Assoc. Prof.; Electrophysiology.
J. S. Schultz, Ph.D. 1958, Univ. of Wisc.; Assoc. Prof.; Membrane transport.
J. R. Smith, M.D. 1951, MSEE 1964, Northwestern; Assoc. Prof.; Pulmonary physiology.
H. H. Swain, M.S. 1951, M.D. 1951, Univ. of Ill.; Prof.; Heart muscle stimulation.
W. P. Tanner, Jr., Ph. D. 1960, Univ. of Mich.; Prof.; Sensory systems.
W. W. Tourtellotte, Ph. D. 1948, M.D. 1951, Univ. of Chicago; Prof.; Multiple sclerosis.
W. J. Williams, Ph.D., 1963, Univ. of Iowa, M.S. 1966, Univ. of Mich.; Assoc. Prof.; Feed-back control in sensory-motor systems.
C. S. Yocum, Ph. D. 1952, Stanford; Prof.; Plant physiology.

4. Research Equipment and Facilities - The bioengineering program is interdisciplinary. A very large portion of the total space in which training and research is conducted is, therefore, assigned to the departmental structure of five units of the University with which students in the program interact. Special facilities, staffed by specific personnel, are likewise available to the program. These include the University Animal Care Unit, Computing Center (System 360 --Model 67), Electron Microscope and Electron Probe, Nuclear Reactor, High Energy Cyclotron, Infrared and Laser and Holography.

Libraries available include the Graduate Library, Undergraduate Libraries, Medical School Library, Engineering College Library, all Departmental Libraries, and the Bioengineering Program Library.

Participating University units are the College of Engineering, Medical School, School of Public Health, College of Literature, Science and the Arts, and School of Dentistry.

5. Departmental Graduate Body

Sub-Field	Academic Only	Predoctoral Directed Research	Thesis Investigation	Post-Doctoral
Biomechanics	4	3	2	
Control and Information		6	2	
Sensory Systems		2	4	
Sensory-Motor		2	5	1
Central Nervous		2		
Membrane Transport			1	2
Renal and Endocrine		2		2

Cardiovascular		3	2	
Electrophysiology		4		
Mathematics			1	1
Totals	4	24	17	6

6. Sources of Additional Information - For additional information, write to:

Professor Glenn V. Edmonson
Director, Bioengineering Program
College of Engineering
207 W. Engineering Building
University of Michigan
Ann Arbor, Michigan 48104

OR

Dr. Peter Abbrecht
Department of Physiology
Medical School
University of Michigan
Ann Arbor, Michigan 48104

UNIVERSITY OF NORTH CAROLINA
Chapel Hill, North Carolina 27514

1. Program of Research Training under GM-1504 - This program offers the M.Sc. and Ph.D. degrees in the combined fields of Bioengineering and Biomathematics. Postdoctoral programs are also available. A full complement of course work in basic and advanced topics in Bioengineering, Biomathematics, and Biomedical Data Processing has been established. The program also has close working relationships with two Schools of Engineering (North Carolina State University at Raleigh and Duke University at Durham) and the Departments of Physiology, Biostatistics, and Information Science on this campus. The program has been officially established as a Curriculum in the Graduate School.

   Individual programs are worked out according to the needs and interests of each student. Student preparation for graduate study in this field varies widely, so that the specific study curricula also vary widely. Some areas of specialization are Mathematical Modeling of Physiological Control Systems, Biomedical Computing, Medical Electronics, Hemodynamics, Computerized Patient Monitoring, Optimization Theory in Biology, Neural Information Processing, and Robustness of Discriminant Analysis. The program enjoys a uniquely close relationship with clinical facilities. Administratively, it is in the Department of Surgery, with training affairs administered by the Graduate School of the University. Trainees have a rare opportunity to apply their work directly to the patient care situation.

2. Entrance Requirements - The applying trainee must satisfy all normal requirements for admission to the Graduate School. In addition, he is expected to have demonstrated abilities and interests which make him suitable to this program. The undergraduate field is not specified, and trainees may come from Biology, Mathematics, Biometry, the Physical Sciences or Engineering. Deficiencies in the recommended course preparation can be made up in early years of graduate work. Actual final approval of trainee applications is done by the working faculty in executive session.

3. Research Training Staff

   Norman A. Coulter, Jr., M.D. 1950, Harvard University; Professor (Bioengineering and Biomathematics in Surgery); Engineering analysis of blood flow systems, biological control systems, biophysics of the nervous system.
   Roy Keubler, Jr., Ph.D. 1958, University of North Carolina; Professor (Biostatistics); Mathematical description of biological phenomena, probability theory in biology.
   Peter Lachenbruch, Ph.D. 1965, University of California, Los Angeles; Assistant Professor (Biostatistics); Multivariate analysis of biological data, validity of multivariate techniques.
   Donald M. Woods, Ph.D. 1963, University of North Carolina; Assistant Professor (Psychometrics); Medical electronics, computer analysis of psychometric data.

W. R. Mann, Ph.D. 1949, California; Professor (Mathematics); Optimization theory.
Benson R. Wilcox, M.D. 1957, University of North Carolina; Associate Professor (Surgery); Effects of surgery on pulmonary hemodynamics.
Ben J. Cerimele, Ph.D. 1963, University of Cincinnati; Assistant Professor (Biomathematics), North Carolina State University; Biomathematical modelling; Stochastic point processes in biology.
C. Frank Starmer, Ph.D. 1968, University of North Carolina; Assistant Professor (Medicine) Duke University; Biomedical computing; Computerized patient monitoring.
J. W. Tolle, Ph.D. 1966, University of Minnesota; Assistant Professor (Mathematics); Optimization theory.
Michael D. Feezor, Ph.D. 1969, University of North Carolina; Instructor (Biomedical Engineering and Mathematics); Biomedical instrumentation.

4. Research Equipment and Facilities - Special equipment available includes a complete selection of devices for transduction of physiological variables, two 7-channel analog magnetic tape recorders, several strip chart recorders, and a wide variety of oscilloscopes, signal generators and other electronic equipment.

Laboratories in the complex include an electronics laboratory (400 ft.^{2}), a computer laboratory (200 ft.^{2}), an analytical laboratory (250 ft.^{2}), an animal study laboratory (400 ft.^{2}), and a bioengineering laboratory (400 ft.^{2}). Appropriate office space and carrels for 12 students are available.

The complex is close to the University Medical Library and extensive animal facilities, and is in the North Carolina Memorial Hospital, with complete access to the hospital facilities, Gravely Sanitorium, etc. The complex also connects with the attached Medical School building, and is adjacent to the Departments of Physiology, Anatomy, Pathology, Biochemistry, and Bacteriology. Special working relations exist with the Departments of Physiology, Medicine, Surgery, Information Science, and Biostatistics, as well as with engineering facilities at Duke University and North Carolina State University.

The program is well endowed with computing facilities, having an IBM 1130 and a LINC computer under its immediate control. Also available are an IBM 360/40 in the University Computation Center and IBM 360/75 at the Triangle Universities Computation Center.

5. Departmental Graduate Body

a. Predoctoral - A total of ten trainees with specialties in biomedical data processing, bioengineering analysis and physiological systems analysis.

b. Postdoctoral - Two trainees, both working on computerized patient study methods.

6. Sources of Additional Information - For additional information, write to:

Dr. N. A. Coulter, Jr., Professor
Department of Surgery
North Carolina Memorial Hospital
Chapel Hill, North Carolina 27514

BIOMEDICAL ENGINEERING CENTER
TECHNOLOGICAL INSTITUTE
NORTHWESTERN UNIVERSITY
Evanston, Illinois 60201

1. Program of Research Training under GM-874 - There are three specific programs in Biomedical Engineering at Northwestern. The first of these at the undergraduate level permits the student to take, as electives, courses in the regular engineering program that will prepare him for graduate work in biomedical engineering. Engineering students who enter the program are very likely to be deficient in undergraduate training in certain areas. For this reason, the program makes available undergraduate work in biology and chemistry. These courses are offered as electives in the undergraduate school. Specific programs are available through the Departments of Electrical Engineering and the Engineering Sciences of the Technological Institute. The second program is specifically designed for individuals with a B.S. degree in the life sciences or the M.D. degree. This program leads to the degree of Master of Science in Biomedical Engineering. Completion of this program will give the individual a background of sufficient depth to permit completion of the work in biomedical engineering at the doctorate level. The third and principal program in biomedical engineering is open to graduates of the first and second programs outlined above. It consists of appropriate courses outlined in the graduate catalog as well as specialized ones (detailed outline available upon request). Completion of this program of study leads to the degree of Doctor of Philosophy through the appropriate departments of the Technological Institute, the Medical School, the College of Arts and Sciences and the Graduate School.

   Inasmuch as each individual's program is subject to the advice and counsel of his committee, each student will not be expected to complete all of the courses outlined. A typical schedule for the program will be furnished upon request.

2. Entrance Requirements - Applicants for admission to the Graduate School must hold the Bachelor's degree from an institution of accepted standing. Selection is based on evidence that the applicant is able to pursue creditably a program of graduate study in his chosen field. His scholastic record must, therefore, show distinction and his undergraduate program must show breadth as well as adequate preparation in the applicant's chosen field. It is necessary to select from among the qualified students who apply for admission. The final decision in all cases rests with the Graduate School. Undergraduate students who are interested in graduate studies in bioengineering, therefore, are urged to complete studies in biology and chemistry before completing their B.S. program. Students who already hold the B.S. degree without such courses are encouraged by an understanding faculty to apply, provided they meet the other normal entrance requirements for graduate studies and have a high degree of interest in bioengineering.

3. Research Training Staff

Elliott J. Bayly, Ph.D.; Asst. Prof.; Biological controls.
Peter J. Dallos, Ph.D.; Assoc. Prof.; Physiological acoustics.
Christina Enroth-Cugell, M.D.; Asst. Prof.; Neurophysiology of vision.
Robert C. Gesteland, Ph.D.; Assoc. Prof.; Neurophysiology, sensory mechanisms.
Thomas K. Goldstick, Ph.D.; Asst. Prof.; Fluid mechanics.
John I. Hubbard, Ph.D.; Prof.; Neurophysiology.
John E. Jacobs, Ph.D.; Prof.; Specialized computers and camera tubes.
Gordon J. James, M.D.; Asst. Prof.; Muscular control systems.
Richard W. Jones, M.S.; Prof.; Biological controls.
Esmail Koushanpour, Ph.D.; Asst. Prof.; Renal physiology.
Lyle F. Mockros, Ph.D.; Assoc. Prof.; Fluid mechanics, hemodynamics.
Milton H. Paul, M.D.; Prof.; Electrocardiology.
Hans Wessel, M.D.; Assoc. Prof.; Transducers and small computer design.

4. Research Equipment and Facilities - Students enrolled in the Biomedical Engineering Training Program have available to them fully equipped laboratories in the Technological Institute, Evanston Hospital, the Medical School, Childrens Memorial Hospital and the Veterans Administration Research Hospital. Specialized instrumentation includes a PDP-9 computer that is used exclusively for patient diagnosis and care studies. The University CDC-6400 computer is available to the graduate students as required. A fully equipped special transducer laboratory, capable of fabricating scanning type electron beam tubes, thin film transducer and other semiconducting devices, is available. Each student is assigned a laboratory especially tailored for his research interest at the appropriate time. Total laboratory space available to the program in the various locations listed above is 20,127 sq. ft. Animal care facilities as well as adequate libraries, are available in each of the sites listed.

A pool of instrumentation which includes tape recorders, average response computers, special amplifiers, transducers and oscilloscopes is available for the exclusive use of those students enrolled in the biomedical engineering program. Faculty of many other departments are cooperating in the graduate training program.

5. Departmental Graduate Body - There are a total of 31 graduate students enrolled in the biomedical engineering training program, 26 predoctoral and 5 postdoctoral (M.D. Program). They are involved in the following research areas: 9 in patient diagnosis and care including pediatric studies; 5 in transducer development and imaging systems; 8 in prosthetic devices and artificial organs; 3 in biological control systems; 5 in physiological systems and 1 in biophysical studies.

6. Sources of Additional Information - For additional information, write to:

Dr. John E. Jacobs, Director
Biomedical Engineering Center
Northwestern University
Technological Institute
2145 Sheridan Road
Evanston, Illinois 60201

OR

Dr. F. John Lewis
Department of Surgery
Northwestern University
Medical School
Searle Building
Chicago, Illinois 60611

BIOMEDICAL ENGINEERING DEPARTMENT
THE MOORE SCHOOL OF ELECTRICAL ENGINEERING
UNIVERSITY OF PENNSYLVANIA
Philadelphia, Pennsylvania 19104

1. Program of Research Training under GM-606 - Predoctoral and postdoctoral programs in Biomedical Engineering are offered. The curriculum is oriented toward the physical and engineering aspects of bioengineering. Our special course offerings in biomedical engineering are: Electrical Properties of Biological Systems, Biological Impedance Techniques, Cardiac Electrophysiology, Hemodynamics, Interaction of Bio-Matter with Radiation, Ultrasonics, Ionizing Radiation, Neural Models, Preceptorship, Engineering Aspects of Biosystems, Computers in Biomedical Research and Special Topics in Biomedical Engineering. A Ph.D. candidate is required to select a balanced program from these courses, from courses in the life sciences (such as those offered by the departments of Biology, Physiology, Biochemistry, Biophysics, etc.) and from courses in other engineering departments, Physics, and Mathematics. The program is designed to provide the student with a knowledge of basic and advanced topics in biology and engineering, together with intensive training in specific areas of their interaction. A program leading to an M.S. in Engineering is also available. The Ph.D. degree can be obtained in five years; the Master's degree typically requires two years. Primary interest is in students pursuing the Doctorate. Opportunities for specialized research for graduate and postdoctoral students include the following fields:

   a. Passive electrical properties of biomatter, including measurement techniques; interpretation in terms of structure, composition and membrane properties; applications to pharmacology, hematology and cardiology.

   b. Ultrasonics, including ultrasonic spectroscopy applied to tissues, blood and macromolecular suspensions; visualization of anatomical structures, especially the heart, utilizing echo sounding techniques.

   c. Microwave effects on biological tissues and systems, including thermal and non-thermal aspects; diathermy; mechanism of heat sensation.

   d. Cardiac electrophysiology including electrocardiography; studies involving artificial pacemakers; clinical applications.

   e. Hemodynamics, including design and development of special-purpose analog computer; modeling physiological control mechanisms; clinical applications.

   f. Radiology, including dosimetry problems in x-ray therapy; physics of diagnostic radiation; aspects of radiation safety.

   g. Neurophysiology, including neural modeling, instrumentation, and studies of information processing in the nervous system.

2. Entrance Requirements - The basic requirement is a baccalaureate degree in engineering, the physical sciences or the life sciences. Students with degrees in the life sciences may find it necessary to take several undergraduate courses in physics and mathematics.

3. Research Training Staff - Graduate Group Committee in Biomedical Electronic Engineering:

Herman P. Schwan, Ph.D. 1940, Dr. Habil. 1946, Univ. of Frankfurt; Professor; Passive electrical properties of biomatter, microwave effects, ultrasonics.
Stanley A. Briller, M.D. 1947, N.Y.U. College of Med.; Assoc. Prof., Cardiology.
Peter D. Edmonds, Ph.D. 1959, Univ. of London; Asst. Prof.; Ultrasonics.
George Gerstein, Ph.D. 1958, Harvard U.; Assoc. Prof. (Biophysics); Neurophysiology.
David B. Geselowitz, Ph.D. 1958, U. of Penn.; Assoc. Prof.; Cardiac electrophysiology.
Belmont G. Farley, Ph.D. 1948, Yale U.; Assoc. Prof. (Biophysics); Electroencephalography.
John Hale, Ph.D. 1957, U. of Penn.; Professor; Radiological physics.
George Karreman, Ph.D. 1951, U. of Chicago; Assoc. Prof. (Physiology); Mathematical biology.
Abraham Noordergraaf, Ph.D. 1956, U. of Utrecht, Netherlands; Assoc. Prof.; Electrical Engineering, Hemodynamics.
Lysle H. Peterson, M.D. 1950, U. of Penn.; Prof.; Cardiovascular physiology.
Lawrence D. Sher, Ph.D. 1963, U. of Penn.; Asst. Prof.; Nonthermal effects of microwaves on biological systems.
Shiro Takashima, Ph.D. 1951, U. of Tokyo; Asst. Prof.; Dielectrics.

In addition, students work under other members of the faculty of the University:

Christian J. Lambertsen, M.D. 1943, U. of Penn.; Professor (Pharmacology); Aerospace and underwater physiology.
William S. Yamamoto, M.D. 1949, U. of Penn.; Prof. (Physiology); Regulatory respiration.

4. Research Equipment and Facilities - A total of 17,000 sq. ft. are available for training in the Moore School of Electrical Engineering. Included here are a DEC PDP-9 digital computer, special ultrasonic apparatus, special precision equipment for electrical impedance measurements from 1 Hz to 2 GHz, centrifuges, spectrophotometers and an anechoic microwave room. A laboratory in the Hospital of the University of Pennsylvania includes facilities for animal work, a DEC LINC-8 digital computer and a variety of multichannel electronic recording devices. Students working in other departments generally have available specific equipment for their research projects. At present, our students are also engaged in research work in the Departments of Physiology, Pharmacology, and Medicine, in the Bockus Research Institute, and in the Presbyterian Hospital. In addition

to the computers mentioned above, the University of Pennsylvania has a large computing center with an IBM installation and a DEC PDP-6 computer in the Johnson Foundation which is specifically supported by NIH for biomedical applications.

5. Departmental Graduate Body - At present, there are 34 predoctoral students enrolled in Biomedical Electronic Engineering. Of those who have already selected an area of specialization for their Ph.D. research, 2 are working in ultrasonics, 1 in electrical impedance studies, 2 in cardiac electrophysiology, 1 in neurophysiology, 1 in pharmacology, 3 in radiology, 1 in pharmacology (hyperbaric aspects) and 3 in hemodynamics.

6. Source of Additional Information - For additional information, write to:

Dr. Herman P. Schwan
Chairman, Biomedical Engineering Department
The Moore School of Electrical Engineering
University of Pennsylvania
Philadelphia, Pennsylvania 19104

DIVISION OF BIOENGINEERING
POLYTECHNIC INSTITUTE OF BROOKLYN
Brooklyn, New York 11201

1. Program of Research Training under GM-1066 - The Division of Bioengineering at the Polytechnic Institute offers the M.S. and Ph.D. degrees in Bioengineering. It is also possible for students to take graduate degrees in other disciplines, with majors or strong minors in bioengineering.

   To obtain the M.S. degree in bioengineering students must complete 30 credits including the following: 12 credits in required bioengineering courses (chiefly in the area of physiology and related subjects); 5 credits in mathematics; either a 4-credit project or an 8-credit thesis; the rest in technical electives.

   To obtain the Ph.D. degree in bioengineering the student must first pass the Doctoral qualifying examination (the first such examination was offered in September of 1968). He must complete between 35 to 40 credits in his major field of bioengineering (included herein are 5 credits of mathematics, 2 credits of biochemistry, and at least 10 credits of electives in biology, as well as the required bioengineering courses); he must complete requirements in two minor fields (examples include engineering, biochemistry, applied mathematics, etc.); he must select a Doctoral Advisory Committee composed of two representatives from his major field of bioengineering, and one each from his two minor fields; he must pass the language examination; he must complete the dissertation and successfully defend it before the faculty.

2. Entrance Requirements - As the program services students with varied backgrounds, it is not possible to stipulate across-the-board requirements. Presently, each case is examined individually by a Bioengineering Program advisor. Normally, however, a baccalaureate from an accredited school must show (or make up) approximately eight credits of prerequisite course work; this generally involves physiology and chemistry for engineering students and mathematics and systems courses for non-engineering students.

3. Research Training Staff - Research dealing with analytic, chemical or computer investigations are generally supervised by faculty with strong engineering backgrounds. Animal laboratory projects and related work are generally handled by faculty with strong life science backgrounds. Most projects include a combination of these. The faculty members listed below constitute a representative sampling of available full-time training staff.

   Jesse Crump, M.D. 1956, B.S. 1950, U. of Neb.; Assoc. Prof.; (Bioengineering); Cardiovascular studies, instrumentation, tonometric measurements.
   Shirley Motzkin, Ph.D. 1958, N.Y.U.; Assoc. Prof. (Biology); Artificially induced abnormality through use of drugs and x-rays.

Joseph W. Neidinger, Ph.D. 1965, U. of Ill., M.S. Physics 1954, Stevens Institute; Assoc. Prof. (Bioengineering); Electronarcosis and related effects.
William B. Blesser, M.E.E. 1958, Polytechnic Inst. of Brooklyn; B.M.E. 1950, Rensselaer Polytechnic Inst.; Prof. (Mechanical and Electrical Engineering); Pulmonary function studies and simulation of physiological systems.
Sid Deutsch, Ph.D. 1955, Polytechnic Inst. of Brooklyn; Prof. (Electrical Engineering); Electronarcosis, nerve simulations and electrical properties of the nervous system.
Irving F. Miller, Ph.D. 1960, Univ. of Mich.; Assoc. Prof. (Chemical Engineering); Materials and artificial membranes.

In addition to the above named staff members, the Polytechnic enjoys the continued cooperative assistance of medical personnel at various local hospitals such as Long Island College Hospital, Downstate Medical Center, Mount Sinai Hospital, etc.

4. Research Equipment and Facilities - Most live animal experimental work and related research efforts are performed at the Long Island College Hospital where Drs. Neidinger and Crump have offices and laboratory space. These laboratories include animal operating facilities and associated equipment as well as a biomedical electronics laboratory and together comprise about 1000 sq. ft. of space. Polytechnic students have also been welcome to do research at other neighboring institutions such as the Pulmonary Function Laboratory at the Downstate Medical Center and the animal laboratory in the Department of Medicine at Mount Sinai Hospital. In addition, approximately 2500 sq. ft. of teaching and research laboratory space within the Polytechnic proper is used for biomedical work and includes space in the newly constructed biology laboratory, the Wunsch Center, the Bio-chemical Systems Laboratory and the Psycho-Physiology Laboratory.

Finally, Polytechnic students can use the digital and analog computing facilities for project work as necessary. The institute maintains a 360-50 digital unit and has also time-sharing access to the GE 265. A small unit (PDP-8) is also readily accessible. There are eight TR-20 analog computer units available for analog simulation studies and related work. An electronic microscope is available if research requires the use of such a facility. In addition to the Spicer Library at the Polytechnic Institute, the bioengineering students also have access to the superb library facility at Downstate Medical Center.

5. Departmental Graduate Body - There are approximately 55 graduate students in the program, of whom 15 are full time. Present students in the program have backgrounds in electrical engineering, mechanical engineering, chemical engineering, chemistry, biology, medicine and dentistry.

6. Sources of Additional Information - For additional information, write to:

Professor Irving F. Miller
Polytechnic Institute of
Brooklyn
333 Jay Street
Brooklyn, New York 11201

OR

Professor William B. Blesser
Polytechnic Institute of
Brooklyn
333 Jay Street
Brooklyn, New York 11201

COLLEGE OF ENGINEERING AND APPLIED SCIENCE
UNIVERSITY OF ROCHESTER
Rochester, New York 14627

1. Program of Research Training under GM-540 - The College offers a program leading to the Ph.D. in Biomedical Engineering. This program is centered in the Department of Electrical Engineering. Courses and research opportunities are offered cooperatively with the School of Medicine and Dentistry, the Center for Brain Research and the Center for Visual Studies of the University. It is expected that entering students will be well grounded in basic engineering or physics at the undergraduate level. Students are expected to select an area of engineering which has important applications of a biological nature and to develop their understanding in this area to the degree expected of Ph.D. candidates. In addition, they are expected to acquire basic knowledge in the biological area to which they expect to apply their engineering skills. Possible areas of specialization are:

   a. Control systems in engineering with application to physiological controls such as regulatory mechanism in living organisms, eye movement control, physiological reflexes, etc.

   b. Communications in engineering with applications to studies of the brain and neurological mechanisms, information processing, etc.

   c. Materials science with application to the electrical and acoustical properties of biological materials.

   d. Various special problems, such as problems in psychoacoustics and communications, blood flow and cardiac output monitoring, biological mathematical studies in population growth, etc.

   Other units of the University which cooperate in this program are all adjacent to one another and are provided with well-equipped laboratories, animal facilities, computer facilities, etc. to make this type of research feasible.

   The Ph.D. program requires a minimum of three years, but more realistically four to five years beyond the B.S. degree are required. This is especially true of the joint degree program in Electrical Engineering and Neurobiology that is offered with the Center for Brain Research.

2. Entrance Requirements - Students normally are expected to have B.S. degrees in engineering or physics and to have graduated from accredited institutions with a record of .B or better. There are no firm requirements of a biological nature, but students are encouraged in preparation to take chemistry through organic chemistry and some elementary biology courses.

3. Research Training Staff

Gerald Cohen, Ph.D. 1950, Univ. of Wisc., Professor (Electrical Engineering); Biological control systems.
Edwin L. Carstensen, Ph.D. 1955, Univ. of Penna.; Assoc. Prof. (Electrical Engineering); Biological materials.
Edwin Kinnen, Ph.D. 1958, Purdue Univ.; Assoc. Prof. (Electrical Engineering); Biological controls.
Herbert Voelcker, Ph.D. 1961, Univ. of London; Assoc. Prof.; (Electrical Engineering); Psychoacoustics, communications.
Daniel W. Healy, Jr., Ph.D. 1951, Harvard U.; Prof. (Electrical Engineering); Director of the Program in Biomedical Engineering.

In addition, many other members of the University faculty (primarily in the life sciences) cooperate with this program and provide research guidance.

Faculty presently working with our students include: Professor Robert Boynton, Center for Visual Studies; Professor Paul Yu, Medical School.

4. Research Equipment and Facilities - In addition to the large and specialized facilities of the School of Medicine and Dentistry, Center for Brain Research, and Center for Visual Studies, the Department of Electrical Engineering has a hybrid computation laboratory especially designed for on-line real time simulation of control systems and control biological experiments (1040 sq. ft.) and a well-equipped laboratory for studies of the electrical and acoustical properties of biological materials. Library computer facilities, graduate student research space, animal facilities and biological laboratories of many kinds all are available to students within a convenient walking distance.

5. Departmental Graduate Body - The Department of Electrical Engineering limits the number of predoctoral students in this program to about 15 to 20. At present there are 17 students enrolled. There is no formal postdoctoral program.

6. Sources of Additional Information - For additional information, write to:

Daniel W. Healy, Jr., Program Director
Biomedical Engineering Program
University of Rochester
Rochester, New York 14627

OR

Dr. Edwin L. Carstensen
Co-Director, Biomedical
Engineering Program
University of Rochester
Rochester, New York 14627

ELECTRICAL ENGINEERING DEPARTMENT
UNIVERSITY OF SOUTHERN CALIFORNIA
Los Angeles, California 90007

1. Program of Research Training under GM-1724 - A predoctoral training program, leading to a Ph.D. in Electrical Engineering (Biomedical Engineering option) or a Ph.D. in Biomedical Engineering which is to be initiated in 1970. Approximately one-third of the students' course work is in life sciences and special courses, with the remainder in Electrical Engineering and mathematics. The following special courses are offered: (1) BME 486, Bioinstrumentation and Hospital Systems; (2) BME 487, Introduction to Biological Systems; (3) BME 586 ab, Mathematical Models of Biological Systems; (4) BME 686 ab, Introduction to Biomedical Research; (5) BME 687 ab, Mathematical Models of Neuronal Signals and Systems; (6) BME 688 ab, Mathematical Models of Cardio-Pulmonary Systems; (7) BME 689 ab, Mathematical Models of Fluid-Electrolyte and Renal Systems; (8) BME 692 ab, Mathematical Models of Endocrine Systems. The emphasis of the program is in the study of biological regulation and control, as well as information flow in biological systems. Advanced seminars now center around mathematical descriptions of neuronal interactions and other neurophysiological problems, regulation and control in respiratory and cardiovascular systems, fluid and electrolyte balance, artificial kidneys and electrical stimulation of muscle. It is expected that a student entering the program with a B.S.E.E. can complete the work for the Ph.D. in approximately four years. A student with an M.S.E.E. degree may require two to three additional years, depending on his life science background.

2. Entrance Requirements - Admission to the program requires a B.S. or M.S. in Electrical Engineering or a related field. Students with degrees in other fields are admitted with undergraduate deficiences and are evaluated by the Biomedical Engineering Committee. The preferred trainee's background is in electrical engineering, but with some undergraduate work in biology.

3. Research Training Staff

Fred S. Grodins, M.D. 1942, Northwestern Univ. Med. School, Ph.D. 1944, Northwestern Univ.; Professor (Electrical Engineering and Physiology); Regulation and control in biological systems, cardiovascular and respiratory control, mathematical modeling and computer simulation of biological systems.
F. Eugene Yates, M.D. 1951, Stanford University; Professor (Electrical Engineering and Physiology); Biological control systems, mathematical modeling of bio-systems and endocrine systems.
George A. Bekey, B.S. 1950, Univ. Calif. (Berkeley), M.S. 1952, U.C.L.A., Ph.D. 1961, U.C.L.A.; Professor (Electrical Engineering and Computer Sciences); Identification and modeling of cardiovascular and neuromuscular systems, biological control systems, control theory and applications, hybrid computation.

George P. Moore, B.A. 1954, U.C.L.A., M.A. 1957, Ph.D. 1961, U.C.L.A. Associate Professor (Electrical Engineering and Physiology); Timing of neuronal events, statistical properties of neurophysiological signals, models of the neuromuscular system.
Matthew B. Wolf, B.S. 1957, U.C.L.A., M.S. 1962, U.C.L.A., Ph.D. 1967, U.C.L.A.; Asst. Prof. (Electrical Engineering and Physiology); Mathematical modeling of fluid and electrolyte balance, use of radioisotopes in study of fluid and electrolyte distribution, control of artificial kidneys, math modeling of patient-artificial kidney system.
John P. Meehan, B.S. 1945, Cal. Tech., M.D. 1948, Univ. of Southern Calif.; Chairman and Professor (Department of Physiology); Effects of stresses on the cardiovascular system.
Morton D. Schwartz, B.S. 1958, U.C.L.A., M.S. 1960, U.C.L.A., Ph.D. 1964, U.C.L.A., Adjunct Asst. Prof. (Electrical Engineering); Bioinstrumentation and hospital systems.

4. Research Equipment and Facilities - Laboratories used in this training program located in the Engineering Building include: (a) Neurophysiological Systems Laboratory, approximately 250 sq. ft.; (b) Respiratory and Cardiovascular Systems Laboratory, approximately 350 sq. ft.; (c) Biomedical Engineering Computer Laboratory (containing PDP-8-EAI 580 Hybrid Computer), approximately 200 sq. ft.; (d) Body Fluid and Electrolyte Laboratory, approximately 350 sq. ft.; (e) Endocrine Systems Laboratory, approximately 350 sq. ft.; and (f) System Simulation Laboratory, including hybrid computer facilities, magnetic tape recording, analog to digital conversion, etc. approximately 400 sq. ft. The main campus also provides animal storage and care, an Engineering-Mathematics Library and a Science Library. Extensive laboratory facilities are also used in the Medical School buildings. In addition, laboratory space is available at Los Angeles County Hospital pharmacology ward, shock research unit, dialysis ward and other laboratories, as well as Rancho Los Amigos Hospital in Los Angeles.

5. Departmental Graduate Body - At present there are twenty-two Ph.D. students in Biomedical Engineering. Sixteen of these are supported by the NIGMS Training Grant. One has a Hughes Aircraft Co. Doctoral Fellowship and two have NIH Special Fellowships and three have support from research grants. Two students have been awarded Ph.D. degrees, and three additional students are expected to complete their work in 1969-70.

6. Sources of Additional Information - For additional information, write to:

Dr. George A. Bekey
Professor of Electrical Engineering and Computer Sciences
University of Southern California
University Park
Los Angeles, California 90007

OR

Dr. Fred S. Grodins
Professor of Electrical Engineering and Physiology
University of Southern California
University Park
Los Angeles, California 90007

DIVISION OF BIOMEDICAL ENGINEERING
UNIVERSITY OF VIRGINIA
Charlottesville, Virginia 22901

1. Program of Research and Training under GM-01919 - The principal objective consists of producing professional scientists who are qualified to teach and to conduct research and development in various areas of Biomedical Engineering. The primary emphasis of the program stresses the application of physico-chemical principles to the analysis of biomatter and the integration of this knowledge toward a better understanding of the function and control of biological systems. A special effort is made to provide a strong background in the life sciences throughout the program. (The first year is usually devoted entirely to courses in the life sciences.)

We believe that a properly conceived Biomedical Engineering program can and should serve as the cornerstone for the solution of a large number of problems of utmost importance of society. Staff participation in the program therefore encompasses many areas not usually considered as a component of Biomedical Engineering--such as, social sciences, economics, political sciences, etc.

An integral part of the Schools of Engineering and Applied Science and of Medicine, the graduate program at Virginia involves courses in both schools--in the basic medical sciences and in aerospace, chemical, electrical, mechanical, and nuclear engineering, applied mathematics, and materials science as well as in the graduate school of Arts and Sciences--chosen according to the student's background and interests. Within the Division, course offerings cover instrumentation and measurement, computer applications, biological systems analysis, biomechanics, biomaterials, and biomathematics. The Ph.D. in biomedical engineering is normally sought by students entering with engineering undergraduate preparation, while the Ph.D. in biophysics is available through the biophysics program for those with biology or medicine as their background. For exceptional students a double degree program is available leading to a Ph.D. in biomedical engineering and an M.D. in a minimum of six years.

Ongoing research programs involve the development of methods for the analysis of large systems, applications of computers to medicine and biology, the development of prosthetic and assistive devices, continuous monitoring of critically ill patients, dynamics of oxygen transport, its optimization and control, the development of novel and improved sensors, processors, and display systems for physiological variables, and selected aspects of neurophysiology and cardiovascular and cardiopulmonary physiology.

2. Entrance Requirements -

a. Ph.D. in Biomedical Engineering: A bachelor's degree in one of the engineering or physical sciences provides a suitable base. A course

in organic chemistry is a prerequisite and preparatory courses in biology and physical chemistry are recommended.

b. Ph.D. in Biophysics: Students with a bachelor's degree--science or engineering--will be considered for admission. Prerequisites are similar to (a).

c. M.D. and Ph.D.: In addition to the requirements listed under (a), the prospective candidate has to fulfill the entrance requirements of the Medical School.

3. Research Training Staff

Allison, James L., Ph.D., Physiology and Biophysics, University of Mississippi; Instructor in Biomedical Engineering. Cardiovascular biophysics and biological control systems.
Annè, Antharvedi, Ph.D., Electrical Engineering, University of Pennsylvania; Associate Professor of Biomedical Engineering. Computer applications in medicine and biology and biological systems analysis.
Attinger, Ernst O., M.D., University of Zurich; Ph.D., Biomedical Engineering, University of Pennsylvania; Chairman, Division of Biomedical Engineering and Professor of Biomedical Engineering and of Physiology. Systems analysis and biological control mechanisms.
Dammann, Frank J., M.D., Cincinnati University Medical School; Professor of Cardiac Pediatrics and of Biomedical Engineering. Intensive care unit, patient monitoring.
Lee, Jen-shih, Ph.D., Aerospace, California Institute of Technology; Assistant Professor of Biomedical Engineering. Biomechanics.
Lewis, David, Ph.D., Northwestern University; Associate Professor of Mechanical Engineering and of Biomedical Engineering. Prosthetics.
Kenner, Thomas, M.D., University of Vienna; Associate Professor of Biomedical Engineering. Cardiovascular biophysics.
McCartney, Michael, Ph.D., Biomedical Engineering, University of Virginia; Assistant Professor of Biomedical Engineering. Biomedical instrumentation.
Stegemann, Jürgen, M.D., University of Erlangen, Visiting Research Professor of Biomedical Engineering; Cardiovascular Control.
Updike, Otis L., Ph.D., Chemical Engineering, University of Illinois; Professor of Biomedical and of Chemical Engineering. Measurements and interpretation of biological system parameters.
Wright, Donald J., M.D., Medical College of South Carolina; Assistant Professor of Biomedical Engineering and of Preventive Medicine. Biocommunications, computer applications.
Wilkins, Michael G., Ph.D., Biophysics, University of Illinois (Urbana); Models of neurons and neuronal networks. Assistant Professor of Biomedical Engineering.

4. Research Equipment and Facilities - The recently renovated facilities of the Division (approximately 8,000 square feet) are situated adjacent to the audiovisual studios and the computer facilities of the Medical School in Cobb Hall and comprise student laboratories, animal laboratories, electronic laboratories, shop facilities, a computer laboratory, a library, and office space. Some laboratories and the library are directly connected

with the audiovisual studios of the Medical School for teaching and research purposes. Available instrumentation includes an expanded LINC computer with A-D and D-A conversion facilities, an Ambilog 200 hybrid signal processor, EAI TR-48 and TR-10 analog computers, multichannel analog and digital tape recorders, and sensors for a variety of biological variables, as well as specialized equipment for construction as well as for static and dynamic characterization of transducers. Since most of the research projects in biomedical engineering are multidisciplinary, facilities and equipment of most departments of the participating schools may on occasion be used. University facilities such as the Burroughs B-5500 digital computer, the EAI hybrid system, the nuclear reactor and accelerator facilities, a number of electron microscopes, spectrometers, etc., may support particular projects.

5. Departmental Graduate Body - The current enrollment consists of 22 predoctoral students (two of which are candidates for the double degree) and three postdoctoral fellows.

6. Sources of Additional Information - For additional information, write to:

Dr. Ernst O. Attinger, Chairman
Division of Biomedical Engineering
Box 224, Medical Center
University of Virginia
Charlottesville, Virginia 22901

DEPARTMENT OF ELECTRICAL ENGINEERING
SCHOOL OF ENGINEERING AND APPLIED SCIENCE
WASHINGTON UNIVERSITY
St. Louis, Missouri 63130

1. Program of Research Training under GM-1827 - A comprehensive predoctoral program for engineering biophysics has been formed for graduate students in the Department of Electrical Engineering with the aim to develop their backgrounds in both the physical and the life sciences such that they can become effective workers in the biologically and medically oriented phases of engineering. Both M.S. and Ph.D. degrees are awarded. The programs are from 1½ to 2 years and from 4 to 6 years in duration respectively. Postdoctoral opportunities are also available, helping to augment and broaden the exposure of the predoctoral students. Both groups can seek specialization in: computer technology as applied to both clinical and basic problems in biology and medicine; theoretical and experimental cardiac studies, including applications to intensive patient monitoring; studies of electrically excitable membranes; bio-acoustics; the application to biological signals of detection and estimation theory; studies of sensory systems with emphasis on electrophysiology and mathematical modeling of phenomena; theoretical studies of molecular control mechanisms; biological control mechanisms; and problems in preventive medicine and therapeutics. Other departments of the university augment this program with areas such as biological fluid dynamics, blood rheology, artificial organ research, biostatistics, radiation physics and bio-mathematics. The minimum predoctoral requirements are: (1) Nine units of fundamental subjects in the electrical sciences; (2) Six units of advanced mathematics; (3) Nine units of engineering biophysics offered by the Department of Electrical Engineering; e.g., Electrobiology, Biological Control Mechanisms, Sensory Communications, etc., or from the Engineering School Bio-Medical Engineering Interdepartmental Program, such as Mathematical Methods in Physiology, Experimental Surgery for Biomedical Applications, etc.; (4) Twelve units of life science courses from outside the Department of Electrical Engineering; (5) A working knowledge of biochemistry; (6) A thesis appropriate to the field. Masters degree candidates require 30 units of work, six of which may be thesis credit.

2. Entrance Requirements - The university requires that applicants have a bachelor's degree (accredited) in engineering, science or mathematics and a B average for work beyond the sophomore year. The department prefers that engineering biophysics students have done some work in biology or biochemistry. For postdoctorals--completion of a doctoral degree appropriate to the department's research interests.

3. Research Training Staff

Jerome R. Cox, Jr., Sc.D. (E.E.) 1954, M.I.T.; Prof.; Applications of digital computers to problems in biology and medicine.

Robert O. Gregory, Sc.D. (E.E.) 1964, Washington Univ.; Prof.; Electronic instrumentations.
Charles E. Molnar, Sc.D. (E.E.) 1966, M.I.T.; Assoc. Prof.; Design application of computers for biology; theoretical studies of neuron properties.
Gordon M. Schoepfle, Ph.D. (Biology) 1941, Princeton Univ.; Prof.; neurophysiology--effect of metabolic inhibitors on excitable membranes.
Arthur F. Niemoeller, Sc.D. (E.E.) 1961, Washington Univ.; Assoc. Prof.; Physical acoustics.
Russell R. Pfeiffer, Ph.D. (E.E.) 1963, M.I.T.; Assoc. Prof.; Sensory communications; biomedical engineering; bioacoustics.
William F. Pickard, Ph.D. (Applied Physics) 1962, Harvard Univ.; Assoc. Prof.; membrane phenomena.
Gerald R. Little, Ph.D. (Physiology and Biophysics) 1967, Washington Univ.; Asst. Prof.; Mammalian cardiac physiology.
Kwang B. Woo, Ph.D. (E.E.) 1965, Oregon State Univ.; Asst. Prof.; Biological control mechanisms at molecular and cellular levels.

4. Research Facilities and Equipment - The following facilities are available to pre- and postdoctoral graduate students for research activities. Some are in the Department of Electrical Engineering, others are in affiliated laboratories (1) Biomedical Computer Laboratory (School of Medicine)--several LINC computers and an inventory of electronic equipment; (2) Computer Systems Laboratory (Washington Univ.)--several LINC computers, macromodular computer design, equipment for studies of computer controlled microscope, applications to x-ray diffraction molecular structure, clinical information processing, etc.; (3) Sensory Biophysics Laboratory--complete acoustic calibration facilities, complete stimulus generation, signal monitoring and data processing equipment (LINC), anesthesia control equipment, facilities for studies of single neuron and single nerve fiber electrical activity; (4) Membrane study laboratory--designed for study of single nodes of Ranvier; (5) Cardiac muscle study facility; (6) A Biomedical Engineering Laboratory of the Department of Electrical Engineering to be ready September 1969; (7) Fluid Dynamics Laboratory of the Departments of Chemical Engineering and Mechanical and Aerospace Engineering.

   Affiliation with: The Center for the Biology of Natural Systems, Central Institute for the Deaf, Department of Physiology and Biophysics, Department of Biochemistry, Department of Radiology, Department of Medicine, Department of Psychology.

   Students enjoy a large central library, the use of several departmental as well as Medical School libraries, study carrels, machine and electronics shops.

5. Departmental Graduate Body - The department has fifty parttime graduate students who are employed in local industry. The department has 62 full-time graduate students and two postdoctoral fellows. They are distributed by interests as follows: computers, 25; engineering

biophysics, 10; applied physics and electronics, 26; electrical and electronic systems, 3. One postdoctoral fellow is working in computers, the other in engineering biophysics.

6. Sources of Additional Information - For additional information, write to:

Professor Russell R. Pfeiffer
Department of Electrical Engineering
Box 1127
Washington University
St. Louis, Missouri 63130

OR

Richard L. Hopkins
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Box 1127
Washington University
St. Louis, Missouri 63130

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