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THE GENESIS OF A CURRICULUM IN BIOLOGICAL ENGINEERING

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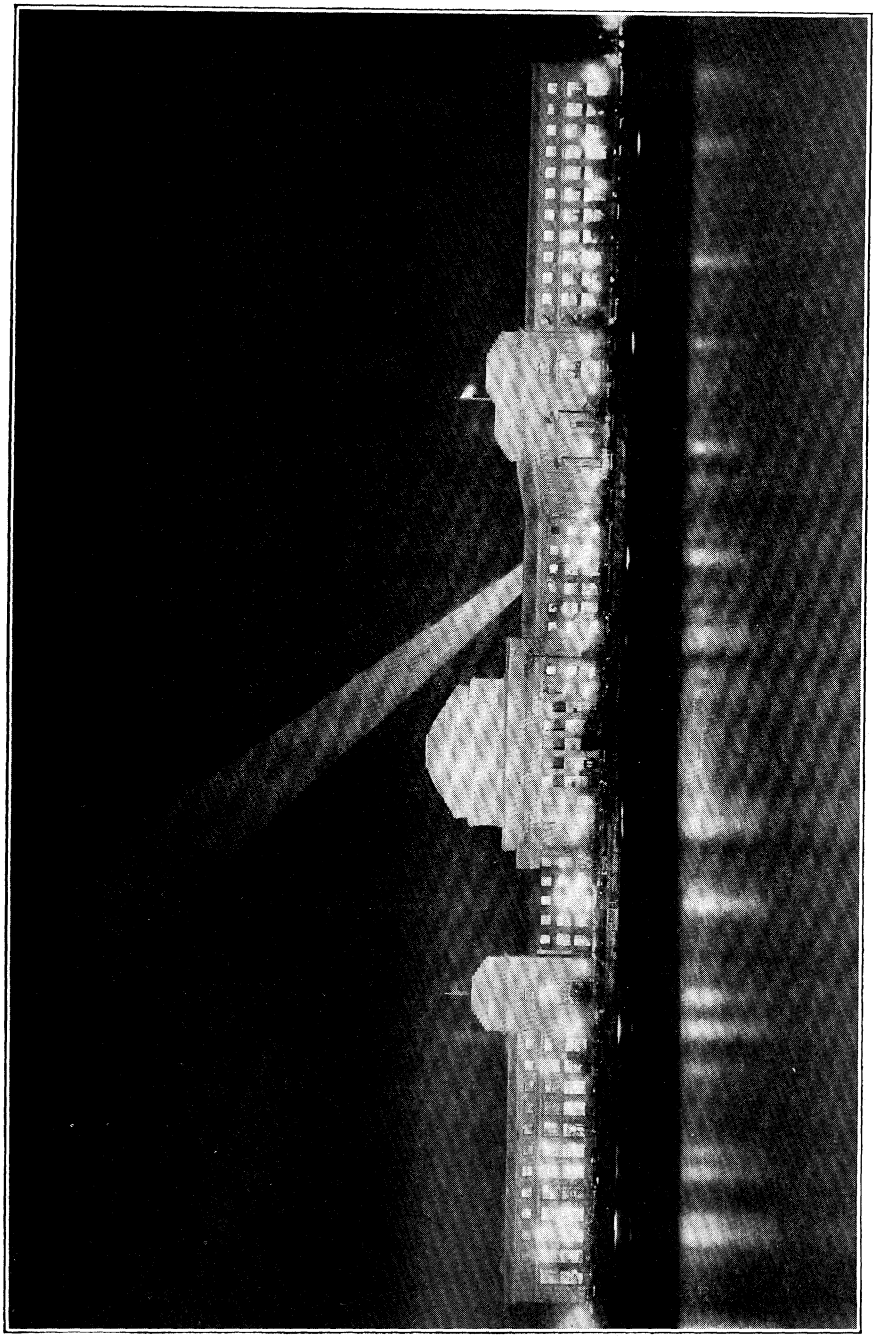
THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

ONE hundred years ago there were but two types of engineers, "military" engineers concerned with the operations of warfare and "civil" engineers whose activities were directed toward problems of civil life. Each utilized many identical techniques in mensuration over the surface of the earth but with different objectives; each was concerned with the building of roads and bridges for which the same scientific data and similar mathematical computations were employed. Neither exercised a monopoly on any particular applications of science; their objectives were different.

For a time, all engineering in civil life was civil engineering, but as some of these engineers became engaged in delving into the earth to secure mineral resources, adaptations of usual procedures in the matter of structures, methods of tunneling, bracing and the like led to the designation of these specialists as "mining" engineers. On the other hand, those engineers who specialized in the harnessing of mechanisms to manufacture, employing the principles of mechanics, came to be known as "mechanical" engineers, the first college curriculum in this field being established at Rensselaer Polytechnic Institute in 1862. Shortly thereafter the increasing applications of electricity in its manifold possibilities to aid the mechanical engineer called for specialization of training and practice in that branch of physics comprised in the field of electricity, as a result of which technical courses in electrical engineering were developed at M.I.T. in 1882.

Meanwhile, the sciences of chemistry and physics and, to a less spectacular degree, the science of biology had been accelerated in their development, and their so-called boundaries expanded until they overlapped. The service of chemistry to biology was obvious, and biochemistry existed at the interphase between the two long before formal recognition of this state came with its definite designation by name.

Chemistry was impressed also into the service of industry, and the utilization of chemistry with a judicious employment of physical and mechanical engineering principles in chemical manufacture was explored systematically and with encouraging results. Alert to the possibilities with which this merger of chemistry and engineering was potent, in 1888 President Francis J. Walker at the Massachusetts Institute of Technology included in its curriculum the first program of training in chemical engineering. Fifteen years later Professor William Walker, teacher of industrial chemistry at M.I.T., conceived the pedagogical plan of instruction in unit processes, such as distillation, dehydration, heat transfer and other processes which are common to many industries, replacing the plan of detailed description of particular processes of manufacture. The art of train-



THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY AS SEEN FROM THE CHARLES RIVER AT NIGHT.

ing chemical engineers therefore emerged by metamorphosis, as it were, after an incubation period of fifteen years and, having spread its wings, took off in strong flight, which is still successfully maintained.

The applications of these basic principles in the engineering manner was the logical sequence to such preliminary pedagogical training. By the application of this view-point of unit processes to industry itself, order arose from chaos; the problems of chemical industry became reduced to common terms; technical advances in one branch of industry were transferable to other branches. In the short space of thirty years chemical engineering has become one of the most vigorous and useful of all the applied sciences.

Biology is the name given to one subdivision of natural science and relates particularly to life and the products of living things. Originally a matter of observation, description and classification, "natural history" designated the scope of biology. Following the period of description and classification of forms, there developed a period of inquiry into the nature of these forms, the changes which they were observed to undergo and the accumulation of data concerning the analysis of life processes. Thus there was developed a body of facts within the broad field of biology which came to be designated as physiology. Great advances in physiology followed the demonstration that the functions of life are largely manifestations of chemical reactions. Utilization by the physiologist of the expanding knowledge in the field of science designated as that of organic chemistry brought about a corresponding expansion in our knowledge of the phenomena of life, and the accumulation of chemical data related to physiological happenings constitutes the basis of the subscience physiological chemistry or biochemistry.

A noteworthy advance in the study of all branches of chemistry has arisen from the demonstration of the essential unity of its subject-matters with those of pure physics. Chemist and physicist alike investigate the structure of matter and its behavior, and chemical secrets are being resolved by experimental and theoretical physics.

Living and non-living matter have in common a structure of matter, molecules, atoms and electrons, subject to the same laws of energetics. The very term "physician" and "physicist" are derived from the same root, φύσις, meaning nature as distinguished from the spiritual, mental or moral world. In the early days of science there was no sharp distinction between animate and inanimate phenomena. Pioneers in scientific observation concerned themselves with medicine, physics and alchemy.

Like pendulums swinging in opposite directions, so the history of science shows often a tendency toward expansion by specialization followed by convergence. As knowledge of natural sciences grew, specialization was a necessary phase of development in its major fields. Medicine and engineering emerged as combinations of art and applied science, medicine being based upon biology and engineering upon physics. Both medicine and engineering have taken unto themselves that which they may require from the richness of chemical knowledge, and each has become more efficient by such a merger.

Convergence of specialized fields comes about when some fundamental discovery discloses the underlying unity, the basic processes, of two branches of science which have developed apparently divergently on less fundamental and apparently unrelated bases. A generation ago it was easy to distinguish between a chemist and a physicist; the latter dealt with matter in bulk, the former with changes in molecular constitution. There still exists what might be called a plumbing type of physics and the culinary type of chemistry, but in their interpretative and many of their operational aspects the two sciences are now completely merged, to their very great mutual advantage. Every competent chemist is to some degree a physical chemist, and no observer of physical interactions can escape observation of chemical changes. It was only lack of information which compelled men to proceed along different lines based on imperfect conceptions of what appeared in our ignorance to be different sets of fundamental laws.

We now have learned a little more of truth, and perceive that the physical laws which formulate the relations of matter and energy in the lifeless world also apply to these relations in the world of the living. Biological science is one category of facts, relations and laws concerning matter and energy, just as chemistry and physics are other categories of the same broad classification. No boundaries exist to delimit sharply the fields of natural science; each merges into the other as the grass on the suburban lawn merges with that of the neighbor's yard. Names which are attached to centers of interest in each field are for convenience in description and reference and do not represent individual factual entities.

It is well recognized that man's achievement, all through the ages, has depended to a large degree upon the tools at his disposal. Already the techniques of experimental physics and chemistry have been applied in the study of biology with success, and the greater precision of measurement and of description of biological phenomena made possible thereby have changed the character of modern biology from descriptive to analytical. It is especially true in biology, due to the unpredictable idiosyncrasies of living specimens brought about by individual variations of environment or of heredity, that only by repetition can tests of theory establish truth. True repetition can be effected only when reproducible precision of essential measurement characterizes the tests. Chemical and physical measurements in biological investigation have supplied the precision necessary for successful experimentation.

As a result of the era of specialization in all fields of science, the biologist trained in the past finds himself to-day incompletely informed of the finest techniques of his brother specialists in physics, chemistry and mathematics. To acquire a comprehensive background of biological information, he has not had time to specialize in other sciences; the magnitude of the variety of experimental procedures in the various fields is beyond the comprehension and attainment of one mortal, it would require a superman.

Cooperation of specialists would seem to supply one answer to the dilemma which each faces. Cooperation means working together, it requires the ability to give and take mutually, and this give and take must not generate into "You give and I take." Cooperation requires adjustment of ideas when ideas are based upon imperfect premises. Cooperators must be able to reason logically and to yield to logic. They must be able to argue without acrimony, to convince or be convinced. If the answers were known in advance, there would be no need for search or research. Since the answers are not known, they must be sought by the formulation of hypotheses and the experimental testing thereof. This requires information and reasoning together with experimental skills.

Where there is a little knowledge but not enough, two heads should be better than one in gaining more. But man is a stubborn animal; and scientists are prone to be opinionated. The line between confidence and conceit is vague; the one quality is necessary for achievement, but the other is irritating to one's fellow man. Hence there are problems of human behavior and human reaction to be met with in cooperation. Without patience, differences of opinion are rarely resolvable. The very imperfection of words to convey the meaning intended by the user requires meticulous definition in discussion of scientific matters—and in other misunderstandings as well. To be specific, the biologist, chemist and physicist are conventionally trained in different terminologies and approach their problems with somewhat different attitudes. Cooperation does not come about like the amalgamation of mercury and other metal. It is something to be cultivated and nourished like a delicate organism until it acquires a sturdy habit of existence.

In 1931 one of us set about to study the technique of cooperation. Trained in biology, he formed a liaison with a fellow staff member of the research laboratories of organic chemistry, and later this was extended to calling in a physicist and various other experts. The results of some of these cooperative endeavors will be cited later in this chapter. The result of the first five years of this pleasant but at times turbulent experience proved several interesting things. One was that the art of cooperation can be learned and can be fostered. Another was the widespread interest held among scientists in matters which taxonomically belong in the field of another (perhaps analogous to the human interest we have in the business of other persons). A third was the demonstration that pooling of ideas and techniques is profitable in results.

Meanwhile, numerous sporadic inquiries from students in biology, physics and chemistry indicated some real interest in the question of preparation for professional work in biophysics or biochemistry. There is evidently an appreciation, by the thoughtful undergraduate, of the opportunities for useful work in the borderline fields between these sciences. The obvious answer to these inquiries seemed to be analogous to the reply of the modern dentist to the inquiry as to what one can do to insure teeth against decay, "See to it that your grandmother had a diet adequate in the basic nutritional elements, phosphorus, calcium and appropriate vitamins." The student who had specialized in physics without attention to biology had no means of acquiring a background of biological appreciation of natural phenomena without beginning all over again in biology; likewise, with the biologist who had spent his time on the various phases of his subject, exposing himself only to the conventionally required minimum of mathematics, chemistry and physics. As the result of experience and observation of the disadvantages of this procedure, and after consideration of the practical and pedagogical elements involved, we became convinced that the training of the biochemist or biophysicist could advantageously start simultaneously in biology and the sister sciences.

It is with satisfaction that one notes an agreement with this principle as indicated by the utterance of Dr. Detlev W. Bronk, director of the Eldridge Reeves Johnson Foundation, who, in addressing the Symposium on Biophysics sponsored in 1937 by the American Institute of Physics at Philadelphia, referred to the growth of biological research with the aid of the methods of physics and pointed out that too few students learn physics and biology together from the ground up.

Upon the above premises and with the objective of designing a curriculum in biophysics, two colleagues were called into conference, Professors Stockbarger and Warren. An analysis was made of the concepts, tools, techniques and opportunities involved in the proposed program, and it was agreed for a working premise that work in the proposed field will be largely concerned with experimental biology, and that the means of experimentation will include the application and the techniques of physical and chemical measurements of energy and reactions.

Among the types of energy likely to be usable there seemed to be the following: electromagnetic vibrations—infrared, visible, ultra-violet, radio frequencies, x-rays; radioactivity; electricity, electrons, neutrons, etc.; supersonics and ultrasonics; heat; chemical energy; magnetism.

Among the ways in which these and other types of energy are likely to be involved are the following: stimulation of protoplasms; chemical changes induced in organic materials once living or the products of the once living; effects on enzyme action; therapeutic effects in disease; abiotic effects on deleterious cells or parasites; effects on hormones or vitamins; electrokinetics of membranes; permeability of surface films and membranes; electrophoresis of cells; mutations; photochemical reactions; spectroscopy of biologic materials; explanations of metabolism in general.

There may be required the construction and operation of devices for securing objective measurements of changes induced as above, and also the measurement and recording of the following: temperature, pressure, humidity, air motion, gaseous relations; motion and time; amplification of feeble energies without distortion, by mechanical or photronic electrical devices; radiation measurements, x-ray dosages, other radiations, such as radioactivity, cosmic ray counting, mitogenetic radiation; hydrogen ion concentration; oxidation-reduction potentials; vapor pressures; heat flow, insulation thermodynamics; surface tension; conductance and impedance in protoplasms; diffusion and osmotic effects across membranes; molecular weights and isoelectric points; colloidal phenomena; agglutination and antibody reactions; electrical potentials; Donnan equilibria; Helmholtz double layer phenomena; axone potentials and action currents; reflex time and tropisms.

Among the technical skills which will be useful in constructing experimental and recording apparatus the following are suggested: design and construction of amplifier circuits, transformers, meters; machine tool work, welding, hard and soft soldering; wood-working, glass-working, glass metal seals; vacuum pumps, maintenance and measurements of high vacuums, manometry, use of McLeod gauge and other devices for measuring gas and/or vapor pressures; production and maintenance of uniform or varying temperatures, including cryoscopic work; thermionic, vacuum tube, thyratron circuits; scientific photography and photometry; optical measurements; radiation measurements; spectroscopy, absorption and emission spectra, extinction coefficients; spectroscopic analysis of biological materials; supersonic devices; radiation sources (electromagnetic, monochromatic, etc.); optical filters; use of the research microscope, transmitted and oblique illumination; the ultra microscope, dark field, quartz lens microscope, lithium-fluoride microscope; monochromators, quartz, lithium-fluoride; gaseous conditions for same; preparation and handling of pure gases.

Among the fields of usefulness in which a biophysicist may find employment is research in pure or applied biology, as in: medical schools; hospitals; medical and biological institutes; universities; institutes of biophysics; food companies, packers, canners, bakers, shippers, etc.; manufacturers of pharmaceuticals, chemicals or drugs; industrial hygiene; governmental laboratories, agriculture, food, health and standards; unforeseen outlets.

Fortunately for our purpose, an examination of the various curricula in the eighteen courses of study already available in our institution disclosed a wealth of material dealing with the basic sciences. A mosaic of selected courses of instruction in biology, chemistry, electrical engineering, organic, physical and colloidal chemistry, mathematics, theoretical and experimental physics was fitted together without serious conflicts of time schedules which gave a first approximation to the desired new curriculum.

It was judged that an educational program in four years could not be suffi-

VII-A. BIOPHYSICS AND BIOLOGICAL ENGINEERING

Course No.	First term Subject	Units	Course No.	Second term Subject	Units
		First Year			
5.01	Chemistry, General	7–4	5.02	Chemistry, General	7–4
8.01	Physics	6–5	8.02	Physics	6–5
D11	Engineering Drawing	6–0	D12	Descriptive Geometry	6–0
E11	English Composition	3–5	E12	English Composition	3–5
M11	Calculus	3–6	M12	Calculus	3–6
MS11	Military Science	3–0	MS12	Military Science	3–0
PT1	Physical Training	1–0	PT2	Physical Training	1–0
		Second Year			
5.11	Qual. Analysis	7–2	5.12	Quant. Analysis	7–2
7.01	Biology, Gen.	5–2	7.14	Comp. Anatomy	8–2
8.03	Physics	5–5	8.04	Physics	6–4
E21	Lit. & History	3–5	E22	Lit. & History	3–5
M21	Calculus	3–6	M22	Diff. Equations	3–6
MS21	Mil. Science	3–0	MS22	Mil. Science	3–0
	Gen. Study	2–2			30–19
		28–22			
		Summer			
5.41	Organic Chem. I	4–3			
5.428	Organic Chem. Lab. I	10–0			
		Third Year			
5.61	Phys. Chem. I	4–4	5.62	Phys. Chem. II	4–4
5.611	Phys. Chem. Lab. I	4–0	5.621	Phys. Chem. Lab. II	4–0
7.10T	Invert. Zool.	8–4	6.00	Elec. Eng. Prin.	4–4
7.301	Bacteriology	6–4	6.75	Elec. Eng. Lab.	2–2
Ec11	Political Economy	3–3	7.20	Physiology	6–4
	Language	3–5	Ec12	Political Econ.	3–3
		28–20		Language	3–5
					26–22
		Fourth Year			
6.01T	Elec. Eng. Prin.	5–7	7.84	Biophysics	6–3
6.761	Elec. Eng. Lab.	2–3	8.311	Atomic Struct.	3–5
7.80	Biochemistry	8–5	8.312	Atomic St. Lab.	3–2
8.09	Physical Meas.	3–2		General Study	2–2
8.161	Optics	3–6		Electives	20
8.162	Optical Meas.	3–2			49
		24–25			
		Fifth Year			
7.321	Adv. Bact.	3–4	7.82	Adv. Biochem.	6–3
7.81	Zymology	6–3	7.92	Biol. Eng. II	4–2
7.91	Biol. Eng. I	6–3	10.662	Colloid Chem.	2–4
10.661	Int. Colloid Chem.	2–4		Elective	9
	Elective	9		Thesis	20
	Thesis	10			50
		50			

ciently broad to give a fundamental grasp of the essential elements of biology, chemistry and physics here involved and at the same time go sufficiently into these fields to give power of using the concepts and techniques listed above. The proposed educational program must therefore be based upon a combination of undergraduate and graduate work. By extending the program through five years, the necessary minimum of training can be offered, including type applications of fundamentals to concrete biological problems.

This five-year program of study went into effect in September, 1936. Upon its satisfactory completion a student may be recommended for the degree of master of science in biological engineering and bachelor of science in biophysics (as of the preceding year).

The curriculum which is now in effect is presented herewith. The "unit" of class work or preparation consists of one hour per week for fifteen weeks; for instance, the symbols "7–4" mean seven hours of recitation, lecture or laboratory and the estimated preparation time of four hours per week.

The choice of the name "biological engineering" is the result of much thought and consultation, and it has been adopted in spite of its temporary abandonment when we were first searching for the precisely appropriate title to describe our objective. The name biophysics is not sufficiently definitive, and biochemistry is insufficiently inclusive. Such varied etymological combinations as biurgy, biodynamics and biotechnology were examined and discarded. The designation accepted was urged by Dr. Vannevar Bush as being appropriate because our objective so aptly conforms to the well-known definition of engineering as "the art of organizing and directing men and of controlling forces and materials of nature for the benefit of the human race." Within this conception lies ample scope for every activity from instrumentation to theory, including biophysics and biochemistry (which, in fact, contribute greatly to the meaning of physiology) so long as the major objective is the marshalling of all available resources to aid biology for the benefit of humanity. With clear vision, Dr. Bush stated, "I know you don't like the name now, but it will grow on you as you think it over." He was right.

A few concrete illustrations of the results which have been derived from the pooling of scientific resources to a common objective will be cited.

Seven years ago Dr. Nicholas A. Milas, of the Research Laboratory of Organic Chemistry at M.I.T., being interested in the broad subject of oxidations, discovered and reported the production of a peroxide of secondary butyl alcohol prepared by irradiating this reagent with ultraviolet light. The scientific interest of this finding was in itself sufficient justification for the planning and effort expended in its demonstration. In the course of conversations with a colleague in the department of biology, speculation arose as to whether or not this new compound, containing a source of active oxygen, might not have the property of killing bacteria. A test with the appropriate methods for determining germicidal property substantiated the hope. Clearly this chemical novelty had potential value of useful application in an unforeseen direction. Another colleague, impressed with the favorable surface tension property of the butanol solution and irritated by the discomfort of a foot infection which had remained with him from his days in college athletics, expressed curiosity as to whether this reagent could possibly be effective in combatting epidermophytosis of the type commonly called "athlete's foot." Cautiously applying the butanol peroxide to one infected foot, leaving the other untreated as a control, no one was more surprised than he at the speedy relief from discomfort which followed and at the definite healing process which ensued. This observation naturally led to systematic testing of the fungicidal properties of the new reagent by approved cup-plate tests with serum agar, and its fungicidal value as well as its penetrating properties was found to be superior to the usual medicinal agents available for therapeutic use in this ailment.

The stability of the peroxide solution under ordinary storage conditions being inadequate for practical medical use, a further series of investigations by Dr. Milas resulted in a method of chemical synthesis of an allied but different compound, namely, the hydroperoxide of tertiary butanol which, having been put through the same paces with encouraging results, has been tried clinically in hundreds of cases with such success that the material has been put into manufacture and is now available to the medical profession. As a further instance of how unpredictable results may come from the testing of hypotheses, it is pertinent to state that this medicinal preparation, already proved useful for fungus infections of the skin, has found new and promising uses in oral hygiene and in dental surgery.

A second instance of the profitable combination of science and engineering is the development of an instrument, the electrocardiotachometer, whose application has been in an unexpected direction. Based upon representations from European laboratories that in certain vitaminic deficiencies in the albino rat, the pulse rate of the animal is a useful diagnostic symptom, Professor R. S. Harris decided to investigate the pulse rate of some of his own white rats in the department of biology. There are at least two reasons why such a procedure is difficult. First, the albino rat, tame though it be, does not take kindly to having its wrist held; second, if by palpitation one endeavors to count the heart rate of the albino rat he finds himself in difficulty because that rate is normally between 450 and 500 beats per minute, which is too fast to count.

The dilemma was laid before Professor J. W. Horton, at that time attached to the electrical engineering department, and he called upon his recent experience in utilizing vacuum tube circuits for the purpose of counting cosmic ray impacts. By certain modifications, he devised equipment for picking up the minute voltages incident to each heart-beat through electrodes applied externally to the body of the rat, filtering out the bothersome muscle voltages, amplifying those desired, and fitting the impulses to an appropriate meter which, when calibrated, records instantaneously the desired rate of heart-beat. By the time that the kinks had been ironed out of this instrument its preliminary use had shown so great a variation in the pulse rate of a single animal during its waking and sleeping periods that the significance of the pulse rate as a diagnostic symptom was shown to be without value for the purpose intended. However, the application of this identical electrocardiotachometer to a patient under anesthesia during a surgical operation in a local hospital enabled the operating surgeon as well as the anesthetist to read the pulse rate of the patient at a glance and released one hand of the anesthetist, previously required for taking the pulse, for other useful purposes, and this application to human surgery has aroused much favorable and enthusiastic interest.

A third example of a contribution of physics to medicine arose independently of the development of cooperative effort in biophysics or biological engineering, but is a dramatic illustration of how science can be brought to the service of humanity. We refer to the work of Dr. Robley D. Evans, of our department of physics, who became interested in the unhappy condition which befell certain young women a few years ago while engaged in painting luminous dials on watches with radium paint who, by the careless practice of moistening their paint brushes on their lips to make a fine point, inoculated themselves unwittingly with radio-active material which is, of course, one of the most potent poisons known to man. In the hope of alleviating this condition of radium poisoning in the human being Dr. Evans secured the help of medical colleagues and with the active collaboration of Dr. Joseph C. Aub, of the Huntington Memorial Hospital in Boston, an expert on calcium metabolism, there was evolved the method of therapeutic treatment which has given the greatest relief to victims of radium poisoning. The medical part of this procedure involves the mobilization of calcium from bones into the blood stream and its elimination from the body. Radium, like calcium, when introduced anywhere into the body, migrates in part to the bones, where it is stored and where it may cause malignancy in the bones, resulting subsequently in death of the patient if even so small an amount as one millionth of a gram of radium is retained. But radium leaves the bones along with calcium when bone calcium is moved into blood and out of the body. Dr. Evans devised a most delicate Geiger counter and the ingenious method of using it to determine at any time with great precision not only the total amount of radium in the body, but also its anatomical position. This gave the physician a tool for gauging the success of his treatment. When the patient has been depleted of calcium as far as seems safe, the treatment is then reversed and a diet rich in calcium is supplied and new calcium free from radium tends to reform a healthy bone structure. Dr. Evans was given the Theobald Smith award in 1937 for his part in this very valuable work.

A fourth illustration of a useful result from collaboration between departments is the development of a new method for the production of vitamin D from appropriate sterol precursors by application of the energy of particles of high velocity excited in the electromagnetic field of a high frequency radio oscillator. This method was conceived by a chemist who was acquainted with the electrodeless discharge. Drawn into the development were also a biologist interested in the vitaminic potency of the product, an electrical engineer as designer of the electrical equipment and several physicists acquainted with the properties of electrically excited particles. This process is being used in industrial production.

The problems of importance to the welfare of mankind which should be susceptible of solution by the biological engineer are numerous and of great economic significance. He will be a pioneer on a new frontier with vast possibilities for useful endeavor spread before his ken. An explorer in ill-mapped territory, he may indeed lose his way at times, but so did Christopher Columbus, who (as pointed out by Clarence Francis in an address before the Industrial Research Conference at Ohio State University on November 4, 1938), through an error in navigation did not find India, whose spices he sought. "It was a golden error! For what Columbus did was to come upon a new world, change the existing trade routes, awaken mankind's curiosity, spur explorations, stimulate scientific research, improve the world's food supplies and point the way to health and long life by way of the balanced diet." Columbus as a navigator may have been no more adept than many of his peers, but he surpassed them all in confidence and perseverance, and he was alert to capitalize an unexpected observation, qualities necessary for the successful prosecution of useful scientific research.

The yearly destruction of food and of food crops by animal and plant parasites runs into millions of dollars. More efficient fungicides and insecticides are required, and rational methods for their efficient use are needed. Campaigns for the eradication of such parasites as those which cause the Dutch elm tree disease and the chestnut blight must be organized and carried through for public welfare with the methodical planning of the engineer.

Termite destruction of wooden structures is a menace against which more efficient methods of combat must be devised with due regard to the breeding and nutritional habits of the invader.

In our harbors the damage by shipworms and other biologic infestations is of far greater magnitude than landsmen realize. Within the last two years in Boston Harbor alone the cost of replacing piling, wharves and bulkheads ruined by marine borers is of the order of five million dollars. New York harbor with its piers and docks has been free from significant trouble of this sort. Test boards maintained in the North River and examined monthly by Wm. F. Clapp, lecturer in marine economics at M.I.T., have shown the first shipworm, a 35 millimeter teredo, on November 29, 1938. This has followed the diversion of substantially 20 per cent. of the pollution from that body of water through the meritorious efforts of the Sanitary Commission, which proposes to divert an additional 30 per cent. in 1939. Shipworms in their invasive stage can not withstand sewage pollution; as it is removed, they may be expected to invade, and once they are present one breeding season will result in their entry into unprotected wooden structures below salt water level. Once they have gained entry through minute holes which they bore, they tunnel as they grow until a porous shell of insufficient structural strength results and the piling fails to maintain its load. Means for combatting shipworms are known, but better, cheaper, more efficient methods must be devised and applied on a large scale to prevent tremendous economic loss from this menace.

Continued developments of physics and chemistry in the service of public health and of therapeutic medicine are to be expected, and these aspects of applied science must be not only developed but made applicable on a large scale for the good of all. Biology has already shown the way with aid of chemistry to combat malaria, diphtheria and many more of the communicable diseases; no one yet knows how to control infantile paralysis or the common cold. Pandemic diseases of the venereal group are still a scourge to mankind. We know relatively little of the transmission of virus diseases and not very much of the nature of viruses.

Recent biological byproducts of the new discoveries in atomic physics undoubtedly open up an enormous vista of opportunities for investigating the nature of biological processes in conditions of disease and health. A majority of the kinds of chemical atoms can now be produced in the radioactive state and used as "tracer elements" of prodigious sensitivity in the study of physiological processes. In some cases they can be used as therapeutic agents. Isotopes, also, can be used as biological or chemical tracers. Here are new tools, made available to the biologist by his colleagues in physics and chemistry, which may well rival the microscope and the x-ray in their ability to open up hitherto unexplored territory.

The human mechanism and the myriad forms of life which share its environment can be most intelligently controlled for the maintenance of health and the avoidance of ills only after man learns how these living mechanisms operate. The more complete his knowledge of the fundamental energy transformations and other chemical reactions of life in general and of human life in particular, the better can he expect to live and the more efficiently can he hope to promote the welfare of all.

Training in biological engineering is offered not as a mere intellectual invention but in recognition of an existing situation and a present need. The curriculum described above is designed to meet that need, and it was derived from a study of practical problems susceptible to cooperation between scientists each a master in his own field and sympathetically interested in the other's. Graduates with this new type of training should be equipped with technical skills and broad appreciation of fundamentals to a degree which, combined with moderation, zeal, persistence and ingenuity, should lead to success in research and in its applications.

A fresh field of useful endeavor lies before the young man of ability, imagination and courage. There are few if any ruts in this field into which the biological engineer may stumble. He must set his own course, for beaten paths are not there. No frontier of applied science has ever been presented to the scientific explorer more rich in possibilities of improving human welfare; no scientific explorer has been equipped with such diverse resources and instrumentation for useful research as are at the command of the biological engineer. Here is opportunity; how will it be met?