The Status and Development of Biophysics

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IN THE PAST HUNDRED YEARS a number of text and reference books have been written on "biophysics." Each has contained that material which the author considered as biophysics, and each has differed from all the others. Some have been complete in one field, deficient in others; some have been inadequate in every field; and some have been so comprehensive that they have included much information rightly belonging to other disciplines. The definition of the field has varied from author to author, and it still varies. This lack of agreement on a definition has thus far hampered the development of biophysics as a field.

At present there are numerous agencies desirous of seeing such development proceed, and the near future should see a definition emerge. There are many excellent reasons for the currently surging interest in biophysics. Man now travels faster and farther, higher in the air, and deeper in the ocean, than ever before. He is exposed to new physical influences by virtue of the invention of new weapons and machines. We must learn the effects of these physical influences on living matter. Research in many biological areas has progressed to the point where physical analysis is imperative. The biologist is not equipped to perform complex physical analyses, and the physicist usually is not aware of the need for his ability, or he considers the problems unworthy of his attention. Physical instrumentation is becoming a discrete phase of biological experimentation, and the biologist alone cannot supply the needed apparatus. Therefore, a definite need for a significant number of well-trained biophysicists is indicated.

Modern physics is awe-inspiring to the general public, and perhaps to the biologist. It is even becoming common practice to frighten graduate students of the biological sciences by threatening to require advanced work in physics. There is an aura of mystery about the physicist, his apparatus, and his mathematical formulae. This mystery is a myth and is dispelled by familiarity. More and more biologists are learning physics because they are driven to it through specific needs. As they learn physics, they become thrilled by its prospects in biology. Like a new religion, biophysics is passed from one person to another, gathering converts in its progress. These converts are important to its continued existence.

Unfortunately, there is no uniformity in the approach of biologists interested in biophysics. Indeed, we do not even know what a biophysicist is! It is not a new science, for it has existed as long as the scientific method, though never as a separate science. Helmholtz, the greatest of all biophysicists, worked more than a hundred years ago, and no one will dispute his classification of his own work as biophysics. In the past, however, biophysics as a separate science has ventured timidly into the world, but has retreated into latency to await a more favorable opportunity. Now the stage seems to be set for its appearance. There is a growing demand for biophysicists; there are many excellent scientists interested in the subject, and the conditions existing in other biological sciences almost require its development into a special subfield. Laboratories of biophysics already exist in many of our leading universities and research institutions; some universities have new departments of biophysics, and courses in biophysics are being offered to biology and medical students.

Heretofore, the functions ascribed to biophysics have been performed by physiologists, bacteriologists, botanists, zoologists, physicians and, rarely, by physicists. To remove biophysics from these fields is a major amputation, for it constitutes a significant portion of some of them and, if it were severed from the rest of biology, it would lose its usefulness.

The heterogeneity among biophysicists does not admit of a uniform program of development for the field. There is almost a total lack of precedent in the training of biophysicists, for this has been haphazardly accomplished by many devious routes in the past. It is not surprising, then, that those concerned with the development of biophysics as a field of endeavor are beset with problems. Some of these problems have seemed almost insurmountable and have been responsible for the failure of the field to emerge in previous times. Among the major questions are the following:

1. What should be the scope of biophysics?
2. Should the subject be organized as a separate field, or as a subdivision of biology or physics?
3. From what personnel sources should students be recruited?
4. What constitutes an adequate curriculum?
5. How can biophysicists be most useful to society?

These questions cannot be answered singly, for each has a bearing on the others. This discussion will present possible solutions. The thoughts set down herein are of necessity preliminary, for actual practice may indicate the need for appreciable revision. It is the purpose of this paper to precipitate interest by supplying a definition of biophysics and proposing a detailed program for the training of biophysicists. It is hoped that other, more profound and practical analyses of the situation will be born of this beginning.

Current Views of Biophysics

Loofbourow (1950), in a calm and objective analysis of biophysics, has subdivided the field into three main divisions; namely, the physics of biological systems, the biologic effects of physical agents, and the use of physical methods in the study of biologic problems. This is a correct definition in that it is sufficiently broad to encompass whatever one might wish to include in it, but it is not specific enough to be of use in planning the development of the field.

The greatest of the printed works on biophysics is the magnificent reference edited by Otto Glasser (1944, 1950). Its two volumes, some 3,000 pages in length, contain authoritative articles on virtually every subject that might be considered biophysics. Glasser belongs to a school of thought (with which I agree) that includes in biophysics the thorough study of all the physical phenomena used by the biologist to study or explain the behavior of living matter. (This concept will be discussed in detail later.)

To a very large number of scientists, biophysics means the application of nuclear physics to biology. The *Advances in Medical Physics* (1948) and *Symposium on Applied Biophysics* (1949) are devoted almost entirely to this type of information, although this viewpoint is not adequate from the long-range standpoint.

A third group would limit biophysics to the study of the physical nature of protoplasm and cells, including such phenomena as viscosity; coagulation, gelation, and thixotropy; elasticity of protoplasm, permeability of membranes, and so on. They call these the "fundamentals" of biology, and in their eyes biophysics should be limited to such studies.

We may recognize a fourth (and unfortunately large) group that looks on biophysics as the process of furnishing instruments for use by biologists and on the biophysicist as a gadgeteer. This is sheer sacrilege to a true lover of the subject, and the danger of this attitude cannot be overemphasized.

A fifth group, with fewer disciples than most fields (for obvious reasons), embraces the mathematical approach to solutions of biological problems. It has been stated, facetiously, to be sure, that young and eager scientists often take courses in the calculus and from that time on consider themselves "biophysicists." This is not so deplorable as it may seem, for these young specialists have become aware of a gap in their training and are striving to fill it. Admittedly, they are rushing the issue, for they have only a glimpse of a vast and complex vista of work to be done.

Still other groups lay greater or less claim to biophysics but, obviously, no concerted effort toward development of the field can be made until there is widespread agreement as to what shall constitute the field. Each of the schools of thought listed above seems to be somewhat intolerant of the others' claims, and one of the cardinal needs for the future of biophysics is general agreement on a definition of the field.

I believe that the principal aims of the biophysicist must embrace the study of the physical analysis of biologic behavior, the determination of the effects of physical agents on biological material, and the application of physical techniques to biological measurement. Confining biophysics to one of the narrower fields of endeavor listed above would be like limiting biochemistry to the study of carbohydrates alone, or proteins, or lipids. Separation and development as a distinct field would not be appropriate within these narrower concepts, but with a broad definition of scope such separation is needed.

The Broad Concept of Biophysics

There is an impressive volume of material on living matter at the microscopic, submicroscopic, and molecular levels. This material is, of necessity, included in the broad definition of biophysics. The worker interested in this phase of biophysics would study tissue ultrastructure, especially with the aid of physical instruments, such as the electron microscope, the x-ray diffraction camera, the microscope centrifuge, and others. He would investigate the viscosity, elasticity, optical activity, surface activity, and numerous other facets of the behavior of protoplasm. He would look carefully at the physical nature of the environments in which living matter exists, and would study plant and animal material as a physical conglomerate in the midst of other physical systems.

The biophysicist must apply himself to the theoretical and experimental determination of the role of molecular and atomic structure in the production of physiological events. In spite of the increasing difficulty of application of theoretical physics (in view of the departure from classical Newtonian mechanics), the essential analyses will eventually be made, and the biophysicist will probably make them. In this respect, the biophysicist invades the domain of the physical chemist, but some such overlapping is inevitable. Biologists have, for the most part, ignored this fruitful field of research, but the future should see many profitable man-years spent in its pursuit.

With this introduction to the nature of physical biological existence, the biophysicist might proceed with the mechanics of living matter on a larger scale. He could analyze the motion of various parts of the body relative to each other, with special reference to force-torque relations of musculoskeletal systems. He could observe the effects of motion of the body through space, the effects of accelerations, such interesting factors as the mechanical impedance of living material, and the coefficients of elasticity and strength of materials making up biological matter. Such studies involve most of the fields of statics and mechanics and can, in fact, be used as an approach to the study of the physics involved. It is the author's understanding that a textbook of physics, designed expressly for premedical students and using this approach to the study of physics, is now in preparation.

The biophysicist must also turn to the applications of heat physics to biology. He must know thermometry and calorimetry, and be able to analyze with precision phenomena involved in loss of heat from the body. He should scrutinize carefully the work of A. V. Hill, W. O. Fenn, and other famous biophysicists, on the production of heat in living matter, and he should carry further the investigations of the physical energetics of life. The thermodynamics of living matter constitutes a fundamental field of research that is rich in interesting and exciting biophysical problems.

The most obvious application of wave mechanics to biology is in the study of light and sound receptors. Here extreme care must be taken in the definition of the extent to which biophysics may go. One concept includes in biophysics all the physical phenomena occurring in the chain of receptive events up to and including the absorption of radiant and sonic energies, and their conversion to conducted disturbances. This seems a reasonable dividing point. This phase of biophysics also embraces the study of the effects of vibratory and radiant energies other than those of nuclear disintegration (which deserve separate consideration) on living material.

There are still many gaps in the understanding of electromagnetic spectra, from both physical and biological standpoints. The basic principles of particle analysis by spectroscopy have scarcely been applied to biology. Spectrophotometric analysis of biological materials, now limited almost entirely within or near the visible wavelength range, may constitute a real contribution to our knowledge of the primary nature of life. It is the biophysicist who will carry these analyses into the infrared, ultraviolet, short and long radio wave, x-ray, gamma, and cosmic regions. It is the biophysicist who will ultimately determine the pattern of molecular orientation that gives protoplasm the faculties of life, and he will do so through the fuller understanding made possible by new physical techniques.

There is no doubt that the electrical physics of living matter is of primary biophysical importance. The instrumentation necessary to measure bioelectric phenomena is essentially physical in nature, and analysis of the experiments performed in bioelectricity requires a thorough knowledge of the characteristics of the instruments used. Likewise, the production of potentials observed in living matter is at least partly physical and must be analyzed thoroughly with a view to physical interpretation, as has been done in the work of Kenneth Cole, Otto Schmitt, R. C. Beutner, and others. Only recently has there been consideration of the dynamic electrical characteristics of living tissues. The effects of passage of electric currents through animal and plant tissues invite investigation, and the application of electronics in instrumentation for study of phenomena other than bioelectric must be continued and enlarged.

The physics of gases has already been used in the development of protective devices for the aviator, in the diagnosis and treatment of respiratory diseases, and in increasing the ability of man to descend to great depths under the sea; and it may ultimately be considered in the development of space travel. At present, a full understanding of the dynamics of the respiratory system is rapidly becoming more attainable, thanks to the application of physics both in instrumentation and in theory.

Essentially the same is true of the application of fluid statics and kinetics to biology. For the most part, this application has been concerned with the study of circulation of blood in large animals, under the names "hemostatics" and "hemodynamics." The biophysics of circulation includes the study of pressure-flow relations, the energy content of the blood under different conditions of pressure, velocity, and position. It involves the analysis of factors contributing to the resistance of blood flow through tissues, the occurrence of turbulence, and the application of Poiseuelli's equations, Bernoulli's theorem, etc.

The biophysicist should devote himself to physical measurement of the three basic phenomena of circulation: pressure, volume of flow, and velocity of flow. Instruments like the ballistocardiograph, electrokymograph, capacitance cardiometer, and electromagnetic flowmeter are physical in nature and need further study for their successful application. Already, the diagnosis and treatment of cardiovascular disease are benefiting from the application of physical instrumentation and theory to circulatory problems.

Obviously, the position of nuclear physics in biology is an important one. It includes the study of nuclear radiations for tracer isotope investigations, the effects of nuclear radiations on living matter, and a thorough treatment of the hazards involved in handling radioactive materials. The physical nature of this body of information is sufficiently clear to make further exposition superfluous. In the program currently being developed at the Ohio State University a separate course equivalent to that embracing all the other subfields of biophysics is devoted to radiation.

Another facet of biophysics is the study of the mathematical analysis of biological phenomena, which is the major thesis of the group headed by Rashevsky (1948). Unfortunately, research in this area requires more training in mathematics than most biologists have had. However, the amount of training necessary for an understanding of the material need not go much beyond the calculus; and as soon as biology students are aware of their need in this respect, the existing deficiency may be corrected.

Physical instrumentation forms a major portion of the projected activity of the biophysicist. In the past two decades electronics has assumed the dimensions of a complete science, and many measurements are now possible that previously awaited development of physical methods for transduction, amplification, and recording. The design of apparatus with correct frequency response and recordable output, with sufficient linearity for accuracy and without instrumental hysteresis or other apparatus artifact, requires intimate knowledge of a large number of available types of equipment. To learn of the existence and application of this equipment, and to keep abreast of the prolific output of the instrument makers, will require a significant portion of the biophysicist's time. Further, the latter must learn how to pass on to the biologist the theory of coupling mechanisms, damping, conversion of energies, properties and parameters of physical systems, and other information relating to instrumentation and applicable to the analysis of life.

Collectively, the body of information in these several fields is "biophysics." There are, of course, other directions in which the categorization might proceed, and in no case is the list of material in any group complete. With this definition as a beginning, however, a working concept of the scope of biophysics can and will be evolved.

The biophysicist should know all these fields well enough to teach them to students without omitting either the physics or biology. He should be able to discern places where application of physical thought and techniques is indicated. He should know reasonably well both the physical and biological literature on each subject, and he should keep abreast of the developments in both fields. In the specific field in which he does research, he must be capable of bringing about a union of biological and physical thought. These are rigid standards, of course. However, as the training of biophysicists becomes coherent and more uniform, and the literature is collected, the maintenance of standards will become less difficult.

Biophysics as a Separate Science

It is easy to see that biophysics covers a very large quantity of information. Most of the material is included in the literature of other fields, and the effect of this intellectual obesity is reflected in the tremendous size of reference books in the biological sciences. No graduate student of biology even attempts to learn thoroughly all the information thus presented to him and, in fact, the biophysical information is often made easy to skip by being printed in small type. Exceptions to the contrary, most graduate curricula in biology simply ignore or pass over lightly the detailed study of physical phenomena.

Of equal importance is the fact that physics is also growing rapidly and has reached immense proportions. The normal three- or four-year curriculum of the graduate course in biology does not allow time for the study of physics, and the physics student has no time to devote to biological studies. For the biology student to acquire the physics necessary to apply physical thought and techniques intelligently to biology would require two or three years of additional training. No one relishes the idea of a long extension of his educational period. Therefore, irrespective of the feelings of the observer, he must conclude that the only solution to this problem is the establishment of a separate discipline for the pursuit of biophysics. The training program should be designed to provide a working knowledge of both biology and physics, and it should stress those aspects of biophysics that are peculiar to neither biology nor physics.

This idea will bring forth howls of protest from many quarters, for there are those who claim (and rightly so) that there is already too much specialization in science. There are many who think that, if one is sufficiently interested in the application of physics to biology, he will get the training he needs, even though it is not immediately available to him. There will be a few such persons, but the production of biophysicists will not be sufficient to meet the demand for them if one relies on such haphazard means. There would be no control of the quality of training of persons who enter the field in this way. To put the issue bluntly, if the opponents of specialization can produce adequate numbers of biophysicists to meet the standards we have set without resorting to specialization, let them do so. Such a demonstration would decide the matter.

People who recognize the need for specialization in this respect must work for it in the face of opposition. In five or fifty years, biophysics will become a mature, separate science, and it will flourish because it is needed. The danger of separation of biophysics from biology is that of loss of liaison between the two fields. This must not occur, for the biophysicist can function well only so long as he retains his knowledge of biological thinking and methodology. There are also hazards in the administrative details of a complete severance of biophysics from the other disciplines of biology. It is wise, therefore, to present an alternative to the unequivocal separation of biophysics from biology. One possibility is the incorporation of biophysics in departments of physiology, zoology, or botany.

In schools of medicine, where biophysics is likely to grow most rapidly, the physiology departments are the logical homes for biophysics. There is little doubt that, in the future, the field of biophysics will grow to such proportions that the creation of a separate department will be imperative, and in some institutions it may even now be desirable. For those institutions in which the position of biophysics is tenuous, however, a more or less brief period as a subdivision of a physiology department is likely to be valuable. It must be emphasized that, if biophysics does develop under the auspices of another department, the people concerned must retain the authority to ascertain the direction of their researches, to train others in biophysics, and to call themselves "biophysicists." They must have sufficient autonomy to decide on biophysics curricula and training programs. Their background must, of necessity, differ from that of other biologists, and this will make mutual understanding difficult; but I believe it is important that a person engaged in the activities of either a department of biophysics or a subdivision of biophysics in another department should have the title "Professor (or Assistant or Associate) of Biophysics," so that he may perform his tasks without danger of confusing his duties with those of other persons. The original recipients of the title may not have the training to warrant it, but careful selection of these people for their interest in the field and their background should partially solve this problem. Eventually they will pass on and leave true biophysicists in their wake.

Sources of Biophysics Students

The training of a biophysicist will be no easy task, especially as there is now no pattern set for his training. Before instruction can even begin, there is one question which must be answered—namely, whether biophysicists should be sought among students in the biological sciences or in physics. In a symposium on biophysics held at the Johnson Foundation for Biophysics, University of Pennsylvania (1938), Detlev Bronk presented a very good case for the training of biophysicists from persons already educated in physics. A. C. Burton (1949) also feels that such individuals are better equipped for biophysical training than are biologists, and A. V. Hill is a notable advocate of this idea.

Unfortunately, physicists who work in fields other than their own do not acquire a name for themselves among their fellows, and that name is important to their advancement. Young physicists will not be interested in a field that is merely an application of the "meat" of their training, but will wish to pursue activities leading to fame and fortune in physics. Furthermore, the salary scale in physics is higher than that in the biological sciences, because of the active demand for physicists, and the discrepancy is not likely to disappear in the near future. Moreover, the physicist does not ordinarily acquire a "biological turn of mind." He is accustomed to experiments with a reasonably narrow range of variation, and he is trained in the design of experiments with few variables. To work in biophysics, he must first learn the techniques used in controlling many variables, and this involves special biological training, which takes time. The one or two or three years of training in addition to that he has already received will deter many a young scientist, who will want to begin professional activity as early as possible.

Biologists, also, usually lack the necessary background for training in biophysics. Whether we like it or not, there is a difference in the approaches that physicists and biologists take in tackling problems, and the student of biology is acquainted only with the biological way of thinking. We must recognize this difference in evaluating the advisability of training either physics or biology students in biophysics. As with the physics student, the biology student would require some years of special training, and biologists have the same objections to extra training that the physicists have.

The fact remains that biophysics involves the application of the physical way of thinking and the techniques to biology. Unless a biophysicist is trained accordingly, he will not be successful in the field. Therefore, adequate training in both physics and biology is essential, but which of the disciplines is followed first is not important. Students may be drawn from either field. The problem is not one of choice of students, but one of making students of either field sufficiently interested to pursue the extra studies and labors required to wed the disciplines. Ideally, this fusion would begin early, and special curricula should be designed for undergraduate students who propose to enter graduate work in biophysics. Naturally, demand for such students must be created before their training is practical. This is another problem in the evolution of biophysics that must await further development for a satisfactory answer, but for which temporary expedients may suffice quite well.

A Suggested Graduate Curriculum in Biophysics

The successful training of biophysicists obviously depends on the development of an acceptable curriculum for the student to follow. This curriculum must be sufficiently broad in scope to produce the desired result, but must also be practical from the standpoint of time and facilities. The discussion that follows presents only one of several possible curricula which would give proper training to biophysics students, and it is intended only as a suggestion. It has never been tested. It is designed to give the maximum education in biology and physics, in what is considered a reasonable length of time for graduate study (four years).

Ideally, the decision to become a biophysicist should be made in early undergraduate work, so that training in elementary physics and biology can be directed intelligently. If this is possible, the basic training in physics, zoology, botany, chemistry, mathematics, and anatomy can be acquired before graduate work is begun. Thus, emphasis is placed on the need for propaganda at the undergraduate level, by deans and advisers in arts and sciences colleges, and by instructors in physics and biology. At present it is not evident that an undergraduate degree in biophysics will do anyone any good, but in the future there may be a demand for workers with an orientation knowledge of biophysics. Such persons might be useful in instrument design, manufacture, and sales.

For much of the routine work in laboratories of biophysics, a level of training equivalent to the master's degree would be adequate. In the one or two years usually devoted to earning the master's degree, the student could not be expected to absorb enough biology and physics to pursue independent research on his own, but he can become thoroughly enough acquainted with biophysical techniques to apply them under direction. In the radiological defense program of the Armed Forces, students at Ohio State University do acquire a reasonable knowledge of the field. However, these students have had special preparation for the work, and they must spend some time in the Atomic Energy Commission laboratories, besides the two years they spend in didactic work and research at the university. At the end of their training periods, they receive a joint master's degree in physics and physiology.

Unfortunately, it is rare that one becomes interested in a field like biophysics before graduate work is begun. Therefore, deficiencies in preliminary training usually exist, and the program of graduate study must first make up these deficiencies before providing the more advanced training required for qualified biophysicists.

In the graduate program of training a compromise between the desirable courses and practical time limitation is obviously in order. The first year must be at least partially used in making up existing deficiencies. By the end of this first year, the student would ideally have finished successfully courses in differential equations, statistics, engineering physics on a higher level than the usual elementary physics, physical chemistry, biochemistry, and physiology. The biochemistry and physiology should be on a level at least comparable with courses offered in the medical schools. This is a formidable list of subjects, and in some schools it may not be practical from the standpoint of course offerings. Actual curricula may vary with respect to individual courses but should not deviate appreciably in the over-all content of the first year's work.

During the second year, the student might receive course instruction in general physiology (with special emphasis on the application of physical chemistry to biology), classical biophysics, and radiation biophysics in the biological sciences; and nuclear physics, wave theory, mechanics, and any other advanced physics courses he can work in. If possible, courses in neurology and histology should be taken. The student should by this time be regularly attending seminars in physiology and special seminars in biophysics. His contact with the biophysics teaching staff will have developed to the point where work on a dissertation problem may begin.

The third year should be spent on research, for the most part, although special courses in instrumentation and electronics are desirable at this time. A regularly assigned reading program should be designed to help the student acquire supplementary information of biophysical nature, and he should become thoroughly acquainted with the literature of biophysics. Toward the end of this third year, examinations might take up the majority of the student's attention, for he will be about ready for the preliminary orals at this time. Any language requirements should have been worked off by the end of this year.

In the fourth year, the procedure would be the same as in any of the sciences, and the time would be largely devoted to finishing the dissertation and taking final examinations.

With such a program as this, the student will have obtained the course work usually required for a master's degree in biology, and about the same in physics. In addition, he will have put considerable emphasis on the problems peculiar to the field of biophysics and, if his dissertation is acceptable and his understanding of the field is adequate, he will be entitled to the degree Doctor of Philosophy in Biophysics.

It should be reemphasized at this point that this is only a suggested approach to the graduate study of biophysics, and there may be many other programs with equal or greater practicability. In any suggested curriculum such as this, there will be corrections and revisions to make and, of course, the curriculum will be modified according to the courses available to the student. The actual success of any graduate program in biophysics will depend on the men who direct the graduate work. Slipshod advising, ignorance of what is needed by the student, lack of interest in teaching biophysics, or poor organization of the program will all spell failure, and failure cannot be tolerated in a field that is not yet fully established. Therefore, before any program for graduate training is set up, the faculty should be scrutinized carefully for the necessary qualifications. If possible, the students should initially be selected with more than ordinary care, and their training should be conscientiously supervised, for these students will go on to train others and the future of the field may depend on them.

Even when graduate training of biophysicists is undertaken in physiology departments, the degree given should be in biophysics, so that the world will know the nature of the training of the individual. This will be important to his future, for selection of biophysicists will eventually be based upon training and the volume and nature of published research, and not upon unsubstantiated claims of being a biophysicist.

The Usefulness of the Biophysicist

The biophysicist will have plenty to do. In the medical professions few people (especially those who use physical equipment) are adequately trained in physics. Indeed, it is the expressed opinion of many who are in the business of designing instruments for the medical profession that it is fatal to leave a hole in the apparatus large enough for the user to stick his finger into, for, if it is there, the finger or the apparatus will suffer. Another way of stating this sentiment is that, in designing a medical instrument, one makes it foolproof, then goes further to make it nurse-proof. It is difficult to make the instrument doctor-proof, for doctors carry screwdrivers in their pockets.

If amusing, the situation is also serious, for it means that educators in the basic sciences have failed to emphasize this important facet in the training of medical students. It is not only in instrumentation that these students are lacking, for frequently a promising line of medical research will be dropped when the investigator reaches the limits of his inadequate physical knowledge. The basic ethics of medicine demand that a physician, in treating a patient, shall know when he needs a consultation and whom to consult. This precept is scrupulously followed. In planning research, however, the physician or surgeon may not realize that he needs a consultation, or he may consult the wrong person. Physicians need not be biophysicists, but they do need an introduction to biophysics sufficiently extensive to tell what is possible, and to know where they need to go to learn what they do not know. The medical curriculum is already overcrowded, but sufficient time for such an important phase of training in all specialties of medicine will certainly be found when medical educators become aware of the need, and when the biophysicists are available.

Although they are not often aware of it, physicists also have a gap in their training. They set out to study in detail the physical phenomena of the world about them, but do not take into account man himself, who is the ultimate observing instrument for all physics. Physicists should receive some training in biology, and it would strike home more effectively if such training were of immediate interest in their own field.

The most important task of the biophysicist is that of teaching graduate students in biophysics. The developments in the philosophy of biophysics in the next few years will determine the type of training these students will receive, and we can rest assured that, with the large number of competent scientists now becoming interested in training biophysicists, training will move in the direction calculated to make biophysicists most valuable to society. In the teaching of graduate students in physiology, zoology, botany, and bacteriology, biophysics is assuming a more and more important role. Such students already get adequate training in chemistry, but their physics training is often neglected. In general, their only contact with physics is a single sophomore course, taken because it is required. Any physiologist will concur in the idea that his field embraces the physics and chemistry of living matter. The physical portion of such studies certainly should not be slighted.

There are thus at least four major groups who need training in biophysics. Who is to give them such training? Obviously, there must be especially trained personnel prepared to teach biophysics, perform biophysical experiments, guide the biologist and physicist in their work, and teach others, that the field may continue in its usefulness.

Dr. Burton (1949) has placed considerable emphasis on the role of the biophysicist in performing purely administrative duties, such as consultation on problems of measurement, furnishing special physical materials, administration of shop procedure, and maintenance of an electronic construction and repair service. Such duties are certainly a part of the biophysicist's job. However, extreme caution must be exercised that these service functions do not take up more than their fair share of the biophysicist's time, to the exclusion of other duties. To conceive and execute the construction of an instrument for measurement of a biological phenomenon is a worthy undertaking. Much of the work involved is purely routine manual labor, however. The wiring of circuits, the machining of parts for instruments, and their testing on completion can well be placed in the hands of competent technicians. The biophysicist will be most useful as a consultant on instrumentation problems, not as a mechanic to build the instruments. Give the biophysicist control of machine shop and electronic construction facilities, and he can turn out the required instruments and still perform many more useful and significant functions.

The duties I have listed are those performed in academic positions in biophysics. These academic jobs will be in medical schools, liberal arts schools where graduate physicists and biologists are trained, and in technological schools where engineers are given broad education. In addition, as departments and university laboratories of biophysics become better financed, there will be many research jobs associated with university activities. These jobs should be filled by competent, hence specially trained, biophysicists.

The military laboratories likewise offer excellent opportunities. I can imagine openings for such persons in laboratories like the Aero Medical Laboratory at Wright Field; The School of Aviation Medicine at Randolph Field; the Naval Research Laboratories at Pensacola, New London, Bethesda, and elsewhere; Army laboratories concerned with problems of chemical and biological warfare, soldier welfare, cold and hot weather operations, and many others. There will also be positions in purely research organizations such as the Rockefeller Institute, National Institutes of Health, and so on.

The industrial field will be a fruitful one for biophysicists in the future, especially in industries manufacturing apparatus to be used by biologists and physicians. There will be administrative jobs with organizations like the Office of Naval Research, or the National Science Foundation when it becomes activated. The laboratories concerned with atomic energy (such as those at Oak Ridge, Brookhaven, Argonne, Hanford, and Los Alamos) may use many well-trained biophysicists when they become available.

The list of potential uses for biophysicists could go on and on, of course. Those given here will strengthen one of the essential points this article desires to make, to wit: The specially trained biophysicist is sorely needed, and he probably will never starve.

Bibliography

BRONK, D. W. *J. App. Physics*, **9**, 3, 139 (1938).
BURTON, A. C. *J. Assoc. Am. Med. Coll.* (July 1949).
GLASSER, O. (Ed.) *Medical Physics*. Chicago: Year Book Pub., Vol. I (1944); Vol. II (1950).
HOWARD-JONES, N. (Ed.) *Applied Biophysics—Symposium*. Brooklyn, N. Y.: Chemical Pub. (1949).
LAURENCE, J. H., and HAMILTON, J. G. (Eds.) *Advances in Biological and Medical Physics*. New York: Academic Press (1948).
LOOFBOUROW, J. R. *Biophysics*. In Glasser, O. (Ed.) *Op. cit.*, (1950).
RASHEVSKY, N. *Mathematical Biophysics*. Chicago: Univ. Chicago Press (1948).