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SOME PHYSICAL PROBLEMS IN THE FIELD OF MEDICINE[1]

IT is not so very many years ago that the well-educated physician, as a gentleman of broad culture, was expected to possess an easy familiarity with the entire field of natural science as well as a training in the disciplines of the ancient classics and the gems of modern literature. I need only remind you that one of the leading physicists of the preceding generation, Hermann von Helmholtz, was at the beginning of his career a physician. The famous essay on the "Erhaltung der Kraft" was published in 1847 while he was still on active duty in the German army as a military surgeon. After a brilliant career as a professor of physiology, he finally became professor of physics at the University of Berlin. His activities in that capacity and the record of the brilliant pupils whose work he stimulated are well known to all of you. I mention this example to indicate the magnitude of the change which less than half a century has wrought in the subject of physics. It is no longer possible for the medical man to be a master in the fundamental sciences, physics and chemistry. The very existence of the Optical Society evidences the increasing content of a single branch of physics. Moreover, the fact that in the meetings of the Physical Society we now have groups of papers on related subjects presented before sections of the society, emphasizes the difficulty of keeping up with the progress of the science. When the professional physicist is obliged to admit that he experiences difficulty in understanding the content of papers which deal with matters outside the particular field of his personal research activity, it will be readily appreciated that never again may we expect to see a physician possessed of such breadth of culture in this branch of science as Helmholtz had unless it may become possible through some trenchant generalization which shall bring back comparative simplicity. As a matter of fact I do not visualize the future of natural science as a labyrinth of ever-increasing complexity. Each new generation starts off with the best of what its predecessors possessed and does not hesitate either from habit or sentiment to discard what seems less fit to serve its purpose. We who are older have accumulated a miscellaneous lot of

[1] Read before a joint meeting of the American Physical Society and the Optical Society of America, at Columbia University, New York, February 23, 1929.

intellectual furniture which seems to increase the difficulty of finding room for new pieces, especially when they are of an entirely different "period" and do not harmonize with our previous accumulations. However, the fact remains that the rapid growth of theoretical and experimental physics presents a real difficulty to the cultivators of other branches of science who know that their own work will rest on insecure foundations unless they are familiar with the fundamental facts and concepts of this subject and who suspect that their productiveness may suffer if they fail to maintain some sort of contact with its progress and present state of thought.

From the standpoint of chronological development, chemistry may be looked upon as a younger brother of physics. For a long time medical men regarded chemistry mainly as an aid to the preparation of substances to be used for remedial purposes. A few of those better informed realized the possibilities of applying chemical methods to the study of physiology and pathology, and the rank and file of the profession rather suddenly woke up to the fact that chemistry offers powerful tools for attacking certain biological problems. I think this appreciation of the fundamental importance of chemistry and the rapid development of laboratories of biological chemistry may have been responsible for a tendency which was well marked about thirty years ago for medical students to emphasize the study of chemistry and to neglect the study of physics. Not that they have ever failed to study physics, but their attitude toward it was lukewarm. It was required as a cultural discipline not definitely related to their later work as chemistry then seemed to be. As a result a whole generation of physicians came into the profession with a comparatively meager command of physics at just about the time when physics was beginning to undergo that striking metamorphosis which began in the nineties of the last century. Perhaps the fact that chemistry as generally taught at that time was an almost entirely non-mathematical science was not without its influence in determining a willingness on the part of medical students to emphasize this subject in their preparation. Do not think that I undervalue sound preparation in chemistry as a basis for the study of medicine. It is fundamental and indispensable. The generation of doctors which began to come into the profession in the nineties were merely the victims of circumstance. Even the chemistry which they thought they were mastering has now become so involved with physics and mathematics that they find themselves unable to follow its developments.

In 1895 Roentgen discovered the X-rays. The fact that they penetrate the soft parts of the living body readily, casting well-defined shadows of the bones, led medical men to seize upon them immediately as an aid to diagnosis. A little later, at great cost in health and life, the destructive effects of these rays were discovered and suggested their use as a means of destroying or delaying the development of inoperable malignant growths. Also within a short time of Roentgen's discovery came Becquerel's discovery of radioactivity with the well-remembered sequence of important discoveries which followed. Again medical men found the radiations from radium effective in the palliative treatment of inoperable new growths. More recently it has been learned that the ultra-violet radiation of sunlight as well as similar radiation from artificial sources exerts a beneficial influence on certain of the vital processes of the animal body. With the desire to employ a powerful new agency for the control or alleviation of disease comes also a sense of responsibility, a realization that any form of energy capable of exerting beneficial effects is probably capable of producing undesirable ones also. Indeed, examples of these undesirable results were not slow in appearing. The intensity and quality of radiation can be measured. The physicist gladly explains the methods, but how many times the medical man has found the explanation to be in a strange language.

For many years there has been a group of physicians who have employed, and advocated the employment of, various means such as radiant heat and light, mechanical manipulation, electrical stimulation and the passage of electrical currents through diseased parts as curative procedures in addition to or as substitutes for drug therapy. Some of these men in their enthusiasm made claims so extravagant as to lead their more cautious confrères to look askance on the whole subject of physical therapy. Those who believed that good results were sometimes obtained were half inclined to attribute them to psychological effects on the patient. During the war, however, the serious and conservative student of physical therapy had an opportunity to practice his methods in the attempt to hasten the rehabilitation of sick and wounded soldiers, and the results were so striking as to convince the profession as a whole that the employment of physical measures in the treatment of certain disabilities should no longer be neglected. This important branch of medicine is still in its infancy, but is now recognized. Several years ago the American Medical Association established a Council on Physical Therapy, one of the duties of which is to see to it that manufacturers of equipment designed to be applied in the practice of this branch of medicine shall not deceive the less well-informed members of the profession by advertising apparatus with false or extravagant claims.

In the city of Syracuse, N. Y., there is a physical therapy clinic for the rehabilitation of injured workmen. The saving which has been effected in the few years during which this clinic has been in operation when expressed in the money value of workmen's time saved runs into figures which are most impressive.

A word now as to the effect of the general lack of adequate fundamental knowledge of physics on the part of physicians. For years most of the physicians who employed X-rays have purchased their apparatus on the recommendations of the salesmen. They have often received their instruction from the makers of the apparatus and the instruction has been of the cook-book type. When anything went wrong the doctor sent for a service man to try to set it right. Skill of a certain kind came with experience, but knowledge of the underlying phenomena was lacking. At the present time the manufacturers of apparatus for physical therapy print literature and even employ men to give instruction to physicians in the use of their equipment. Sometimes the information is reasonably correct and claims not altogether extravagant. Sometimes it is otherwise. Sometimes the "physics" taught by these high-pressure salesmen is a strange mixture of technical words and nonsense. They are able in this manner to impress the average medical man because he is quite at their mercy and can not question their statements.

As regards the physician who graduated a score or more of years ago, there is little to be done. Some of these men, not content to be mere pullers of handles, have undertaken to read physics and some have succeeded in a considerable measure, but the majority must rest content to do their work with the equipment they happen to have acquired and there will always be plenty for these men to do.

Our interest in this matter lies largely with the physicians of the coming generation. There was a time when the older men, not realizing that their own meager knowledge of the fundamental sciences had proved in any way a handicap to them, advised prospective students of medicine not to waste time in extensive study of physics or mathematics. I think there is now less tendency to decry such preparation. When the speaker first came to Columbia some eighteen years ago, it was the exception to find a medical student who remembered anything of his physics with sufficient definiteness to make practical application of it. Gradually there has developed a tradition which has spread from the medical school to the premedical students that physics has its place in the foundations of the medical sciences and even in the practice of medicine. In recent years there has been an increasing number of students who have studied physics with interest and who retain such a grasp of the principles as to be able to make immediate application of them. I have also noted with interest the increasing number of medical students whose preparation in mathematics includes the calculus and the elements of differential equations. They find this preparation useful not alone in physics but also in chemistry, and from time to time they find further applications in physiology. I have recently received from Professor A. V. Hill, in London, a reprint of a physiological paper on the diffusion of oxygen and lactic acid through tissues which is largely mathematical. Among the equations in this paper I noticed the Fourier equation of the form,

$$\frac{d^2u}{dx^2}+\frac{1}{x}\frac{du}{dx}+u=0,$$

the general solution of which is,

$$u=AJ_0(x)+BK_0(x),$$

where $J_0(x)$ is the Bessel's Function of zeroth order of the first kind and $K_0(x)$ is the Bessel's Function of zeroth order of the second kind.

From this it will appear that the prospective student of medicine may carry his mathematical training rather farther than such students usually do and still find applications without going outside the field of medical sciences for them.

I doubt if it is necessary to require of the prospective medical student more hours of work in physics than are now required. The principal consideration seems to be the awakening of the student's interest. He must be made to realize that for him the study of physics is of as great practical importance as it is for the student who is preparing for the study of engineering. The better college courses in physics seem adequate to prepare the student to undertake more advanced reading by himself if and when he finds that his work requires it, provided that his interest at the time he takes the course is such that he gives it his best attention, realizing that he will one day require it just as certainly as the surgeon requires anatomical knowledge. Any student knows that a surgeon's knowledge of anatomy must be such that it can be used at once for practical purposes. It is not sufficient to have acquired a smattering, to have understood the subject in a general way. If he will take the same serious view of his physics he will retain its important concepts as foundation stones for future use. He will, or should, require it before he ever reaches the medical school as an aid to the study of chemistry.

It may be asked why physicians confronted with problems requiring knowledge of physics have not more often consulted physicists. They have tried to do so. If any of you have ever tried to extract information in a foreign country from a native whose language you do not speak and who knows nothing of your own you will appreciate the position of the average doctor of the older generation who seeks aid from a professional physicist. He finds the greatest difficulty in stating his problem in language the physicist will comprehend and if he succeeds in doing this the assistance will come to him in terms which either mean little or nothing to him, or worse still in terms to which he attaches a meaning which is not the one the physicist intends. It has often been the speaker's lot to act as a sort of interpreter or go-between for physicians in this situation, since he has happened to know something of both languages. Twenty years ago he had not infrequently to explain to doctors why though it was perfectly proper to attach the ends of a power circuit to a voltmeter to determine the voltage of the circuit, it was not also in order to attach these same wires directly to an ammeter to determine whether the proper current would flow. All sorts of questions arise. In recent years the inquiries often pertain to sources of ultraviolet radiation, methods of measuring the intensity of such radiation, filters and the extent to which intensity is lost in limiting the range of wave-lengths, etc.

Really to get along with his problems the physician must be able to work on them and think about them himself. He may avail himself of advice and assistance, but he can hardly expect men who are busy with their own problems to turn aside long enough to solve all his when they enter the field of physics. Almost any good-natured physicist will listen to the statement of his problem and offer suggestions, but the medical man must know the language, he must have enough training to be able to read and go ahead with his own experiments.

In addition to the necessity for impressing upon the prospective student of medicine the importance of actually mastering the fundamentals of physics, there seems to be an urgent need for the inclusion in the staff of our medical colleges of at least one member whose training in physics has been as extensive as one would expect it to be in a young man who has just completed the work for a doctorate in philosophy in that subject. A young man with this training can, through association with men trained in present biological methods and familiar with the literature of the subject, readily become oriented in the new field and bring his own intellectual armamentarium to bear on its problems. He should not be expected to teach physics in the medical school. Rather he should be primarily an investigator. His teaching activities may properly include some supervision of the work of graduate students. It might well include some work with undergraduates in medicine on subjects which can not be included in their preparatory work in physics through lack at that time of the biological background. There are many such subjects. The effects of radiation on the various life processes would alone furnish material for several exercises. Such work could not be introduced without deleting something from an already topheavy curriculum, but I think this might well be done if a proper instructor were available to give the new material. It is the research aspect, however, which is the most important and pressing. There is an actual demand for qualified young men for a few positions of this kind at the present moment and I am certain this demand will grow. As instances that the selection of a man trained primarily in a fundamental science rather than in biology is not without precedent I may mention that Professor A. V. Hill, whose work I have already referred to, trained primarily as a mathematical physicist, has been most successful in physiology as is attested by the award to him a few years ago of the Nobel prize in physiology.

Columbia University has recently called to the chair of biochemistry in the medical faculty an organic chemist, Professor H. T. Clarke, who had no previous biological experience. This was done because it was regarded as of the first importance that the work of this department should be based on sound knowledge of the fundamental science. The same principle should guide in biophysics. It would be useless for a physicist to undertake work in the biological field without availing himself of the advice of biologists and of such sound biological information as is available in the literature. On the other hand much time and effort has been wasted by biologists who have tried to avail themselves of physical methods without a sound training in its theory and practice.

As an example of one of the physical problems which confronts the student of medicine I may cite the difficulty he has in learning anything about the physics of the conduction of electricity through gases, thermionic emission, the phenomena of X-ray tubes, the measurement of intensity and quality of X-rays, the measurement of high voltages, the principle on which the various kinds of electrical vacuum valve tubes operate, the construction and adjustment of apparatus for the production of a high tension pulsating direct current and various other subjects which are fundamental to sound knowledge of the application of Roentgen rays in medicine. These subjects are not treated in the elementary course which is open to premedical students. They are usually covered in advanced courses, prerequisites for which are courses in mathematics which only a few premedical students elect.

To meet this need the speaker conducted for a number of years a course of lectures illustrated with experiments and presented in such a manner as to avoid the use of mathematics beyond algebra and trigonometry. These courses were well attended, and not infrequently in addition to the medical students, graduate physicians who were making use of X-rays in their practice requested permission to attend. It is conceivable that a professor of biophysics in a medical college might develop a much better course of this kind dealing with the biological effects of X-rays and perhaps including also the effects of other radiation and means for its production and measurement.

By far the most important need is for the close cooperation of the physicist, the chemist, the physiologist, pathologist and others in an attempt to evolve rational theories to coordinate and explain the immense amount of curious and interesting experimental data which workers in the various fields of biology have accumulated.

The medical sciences already owe a large debt to physics. They have had at various times the services of more than one eminent investigator in that field. There remains a wealth of problems still unsolved and with the powerful aids which recent advances in physics make available it should be possible to secure results with greater ease than ever before. May I leave with you first of all the suggestion that students about to enter upon their premedical work should be impressed with the importance of making the utmost use of the opportunity which is afforded them in their course in college physics. In addition may I suggest that occasionally an advanced student of physics who has developed an interest in its biological applications may find in biophysics a field of activity where there is an abundance of interesting problems to tax his ingenuity and where he may, if fortunate and industrious, achieve results whose importance can hardly be estimated.

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THE MECHANISM OF SPARK DISCHARGE IN AIR AT ATMOSPHERIC PRESSURE

SOME fifteen years ago the mechanism of the electric spark in air was considered as quite satisfactorily described by the classical theory of Townsend.[1] In recent years this theory has been seriously called into question by the researches of Holst and Oosterhuis,[2] and James Taylor.[3] As shown by the writer in a recent article[4] the serious difficulty with the original theory of Townsend lay in the fact that the mechanism of spark discharge proposed assumes ionization by the positive ions of the gas through collision with gas molecules in such a manner and measure as to produce enough electrons in the neighborhood of the cathode as to make the discharge self-maintaining. This means that the positive ions must gain enough energy in moving through several free paths in the field to enable them to ionize neutral gas molecules by impact. Now in recent years the ability of the positive ions to ionize molecules by impact has been seriously questioned.[5] Furthermore Taylor and Holst and Oosterhuis believed to have shown in inert gases at low pressures that the nature of the cathode surface plays an important rôle in the mechanism of the spark as the alkali metals like Na and K gave distinctly lower sparking potentials under these conditions than more inert metals. The possibility that at low pressures in spark discharge the generation of electrons from the electrode surface occurs through positive ion impact (an effect characteristic of the metal as their results indicate) was also scouted by these authors as unlikely for two reasons. The first one was that electron emission by positive ion bombardment on an outgassed surface is a phenomenon requiring high potentials as shown recently by Jackson.[6] The second reason is that in the fields assumed the positive ions could only extremely rarely (one in 10^{-17}) acquire the ionizing energy over a mean free path in the gas.

Now the writer[4] pointed out that metal surfaces even in inert gases were not "outgassed" so that positive ions of 20 or less volts equivalent energy could remove electrons.[7] He further stated that the assumptions as to the values of the fields occurring near the cathode just at sparking (which gave the low values for the energy of impact of positive ions) were both gratuitous and probably contrary to fact. In his original deductions Townsend assumed that the fields were uniform and that the sparking potential gradient was merely the sparking potential divided by the distance. This assumption was probably made for simplicity only, and Townsend[1] himself provided the possibility of non-uniform fields at breakdown in

[1] J. S. Townsend, "Electricity in Gases," Clarendon Press, Oxford, 1915. pp. 322, 330 and 429.

[2] *Phil. Mag.*, 46: 1117, 1923.

[3] *Phil. Mag.*, 3: 753, 1927; *Proc. Roy. Soc.*, 114A: 73, 1927.

[4] *Jour. Franklin Inst.*, 205: 305, 1928.

[5] L. B. Loeb, SCIENCE, 1928.

[6] W. I. Jackson, *Phys. Rev.*, 28: 524, 1926; 30: 473, 1927.

[7] H. Baerwald, *Ann. der Physik*, 41: 643, 1913.