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THE RÔLE OF PHYSICS IN MODERN INDUSTRY

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IN speaking of the rôle of physics in industry, I shall dwell on its accomplishments in the way of making itself useful to the engineer, to the factory operator and to the public generally. As I shall point out incidentally, the service is not one-sided, and an interesting chapter could be written on the service of industry to physics and to other sciences. It is hoped that this will be remembered if at some times I appear to get enthusiastic and to claim too much for the science which is my hobby. To give a glimpse of the other side of the picture, I shall first proceed to make an acknowledgment of the great debt that physics owes to industry and which was incurred before either industry or the science was organized.

Physics originated in the arts and crafts of prehistoric and early historic times. The students and philosophers of those days played no part in the beginnings of the science since they thought of their activities as being on a different plane from the activities of those who labored with material things and were not inclined to interest themselves in anything of a physical nature except philosophically. They attempted to arrive at an understanding of nature by speculation. This attitude made it impossible for them to learn of the characteristics of things from experience. Soldiers, sailors, shepherds, craftsmen, builders and others who had to do with physical things were the ones who not only developed an acquaintance with physical characteristics, but who also learned to apply principles that were not formulated, but were useful, and that later became the foundation of physics.

These workmen learned how to do many things that have been the bane of the existence of young students ever since physics became a part of the curriculum. They learned to use the lever or the inclined plane to raise their weights, to use the wedge when they wanted to split a piece of timber and to make use of kinetic energy when swinging the axe or the hammer. They knew how to use fire, and not only that, but they learned how to transform mechanical energy into heat enough to start a fire before any one had ever suggested that heat had a mechanical equivalent. They had found out that by building a craft which could be used to displace water it was possible to float over the lakes and the rivers and the oceans. They knew how to make use of action and reaction in their oars and the rudders of their boats and how to use the composition of forces and the analysis of forces to make their sails effective. They used compasses before there was ever written a chapter in regard to magnetism. They were acquainted with the practical value of capillary action, which they made use of in the wicks of their lamps. Centrifugal force was known and applied in the use of the sling. The bow and arrow is a good illustration of the transformation of potential into kinetic energy. They used heat insulation in their clothes and in their houses. They used mirrors, and lenses in the form of burning glasses, before refraction was understood, and so on. The list could be extended very much farther and I have given all these illustrations only to emphasize the fact that a great deal of physics was known long before there was ever a book written on the subject and long before there was ever a man who could be called a physicist. This illustrates how closely physics is related to many human activities and shows that it had its origin in this very practical fact. The first physics was applied physics, and applied physics has existed ever since human beings began to exercise their ingenuity with mechanical things, although it is only recently that the physicist as such has entered the practical field.

A striking illustration of the fact that physics was originally practical is to be found in that well-known experiment of Archimedes which became the basis of what is known as Archimedes' principle in regard to buoyancy. Archimedes performed that experiment in order to answer a practical question. The story goes that his king had bought what he was told was a gold crown. Being of a suspicious nature, he wanted to determine whether the crown was all gold or whether it had been loaded with lead on the inside. He wanted to determine this without spoiling the crown and gave the problem to Archimedes. After some thought Archimedes decided that by weighing the crown in air and in water and also by weighing pieces of gold and pieces of lead in air and in water he could determine how much was gold and how much was lead in the construction of the crown. Archimedes' principle is, therefore, the outcome of a very clever solution of a practical problem. While Archimedes is known as a philosopher and a physicist, he was also responsible for many inventions. He evidently gave a good bit of thought to the solution of practical problems. He devised a complicated system of pulleys for moving ships up on the beach and is said by some to have been the inventor of the screw as an instrument for raising heavy weights.

It was not until the sixteenth century that science and especially physics began to become organized. This organization began with such work as that of Galileo and Newton and so had its origin partly in astronomy, and since then it has grown on the foundations that had been laid by the artizans, until at the present time we have a rather elaborate set of facts and principles known as the science of physics.

This science consists of the known facts in regard to matter and energy and the generalizations based on these facts. These generalizations enable us to classify many physical phenomena and to describe them in such simple terms that we can work with them, show how they are related to one another and develop new and useful combinations, without having to cut and try quite as much as did the men who discovered and developed the first useful physical devices. Much of the rapid growth of new industries which has taken place in recent years is due to this possibility of making new combinations. Of course, this possibility increases very rapidly with the number of facts and principles that are available. From this some of the service that physics can bestow upon industry is at once apparent.

During the last few decades, there have sprung up a great number of branches of physics which have separated from the parent science and acquired new names. They are practical applications of physics, and most of the branches of engineering have originated in this way. All the physical branches of engineering are really applied physics, so that every civil, mechanical, electrical, illuminating or telephone engineer is a physicist who has specialized in one particular branch of the subject, and in that branch especially in its practical applications. Many of these branches of engineering originated as appendages of departments of physics. You all know that in various institutions in the country, departments of mechanical engineering, of electrical engineering or of illuminating engineering have originated as special courses in physics. Gradually, as the demand for the work increased and the work was expanded, more of the practical subjects were added and they grew away from the physicist. The engineer had to learn to draw and to make designs and to do many other things that the physicist had not learned. In these developments of designs and of practical apparatus, the engineer encountered many questions that the physicist was unable to answer. The physicist was not only unable to answer them, but was inclined not to spend time on them because they were too specialized. The engineer performed his own experiments and found his own answers and in this way he gradually built up these several branches of physics which appeared more and more different from the parent science. It became necessary then to separate these groups of subjects from the departments of physics and they became the corresponding engineering departments.

The engineering branches gradually grow away from physics especially in that they formulate the principles that they use in their own way and the connection is soon more or less obscured. The principles become narrower because they are used in special practical applications. The equations of physics are rewritten to serve special purposes and to give the values of quantities in which the physicist as such is not so often interested. The broad statements used in the general subject of physics are no longer necessary. In fact, in many cases, the broad statements are not as valuable as the more specific statements which answer more specific questions brought out in the designing, testing or using of practical equipment.

In spite of the transformation which the various special branches of physics underwent at the hands of the engineer it was nevertheless physics that he took with him into industry and that he used as the basis of his practical work. He took the laws of statics and dynamics and the laws of thermodynamics and built the vast specialized fields of civil and mechanical engineering. He took the laws of electrodynamics and built electromagnetic machinery and developed the science and art of electrical engineering and the enormous electrical industry. He took the principles of optics and built illuminating engineering and the corresponding industry. In the beginning, it was possible to carry on in each of these fields with very simple principles, simply stated. As industry grew and more complicated devices were developed, it became necessary to apply more and more of the principles of physics, the engineering branches began to overlap, the electrical engineer began to need the assistance of the mechanical engineer and others and *vice versa.* It became more and more essential for the engineer to be a general physicist. What more natural, then, than to invite the physicist to come with his science. So it happens that not only physics, but also the physicist is back in the industries where he had his origin. Physics and industry are inextricably interwoven with one another and have been mutually stimulating and helpful.

Parenthetically it may be remarked that all sciences seem to have had their origins more or less in a real or an imagined practical need. Astronomy developed from the requirements of navigation and the requirements of astrology. Medicine grew from the obvious need to cure diseases. Mathematics developed from the necessity of using numbers and of making measurements, and so on.

The industrial physicist is usually, but not always, found in a portion of the plant that is known as the research department. There it is his function to transmit to the rest of the plant the benefits that may be derived from the study of his subject.

In 1927, $217,000,000 was spent for research in the United States. Of this, $200,000,000 was spent in industrial research in approximately one thousand laboratories. It may be assumed that more than one half of this money was spent in physical research. This great interest in research as well as the great interest that industry has taken in physics developed during and immediately after the war. It developed as a result of the fact that during the war the whole nation became practically one industry and it became necessary to expend every possible effort to do more, and to do more that was new, than was ever required during the same length of time under peace conditions. This high-pressure industry, which in this country *was* the war, made it necessary to get every help possible, and while the industrialist in the beginning was not convinced that the laboratory man from the university could do him much good, he was convinced that it was necessary for him to do everything that could be done, and since it was *possible* that the scientist could help, he took a chance and gave the scientist his opportunity. The scientists, principally the physicist and the chemist, were equal to the occasion and their ability to produce was so striking that they have had an important place in industry ever since. New things had to be done and it was demonstrated that there were many possibilities of new results in the knowledge and the experience of the university laboratory men.

In addition to having served as the basis of nearly all the branches of engineering, physics is serving industry in a great number of more direct ways, some of which I shall now try to enumerate. Physics is primarily a quantitative science, and it is a quantitative science that deals with physical phenomena and physical characteristics. Physical phenomena and characteristics are the materials used in the industries, and it becomes at once the natural thing to look to physics for the methods of measurement that are used to determine characteristics and to measure physical changes. Physicists have developed methods of measuring almost everything with which they are acquainted. In fact, some say that physicists do not profess to know what they can not measure. The methods of measurement, which some years ago were known to be useful only in the theoretical laboratory, are gradually being taken to industry and it becomes the physicist's task not only to teach them, but also to show how they can be used to get the data that the engineer uses in his designs and developments. It is evident at once that physics in the person of the industrial physicist becomes a supplement to the engineer. His understanding of methods and principles of measurement makes it natural to depend on the physicist for standardization of processes, materials, methods of measurement and instruments that are used in the measurements. Accordingly, some industries assign to the physics laboratories the writing of materials and process specifications. In fact, any materials and process department is in reality a laboratory of physics and chemistry, although it does not always carry the name.

A good illustration of such service in connection with measurements and shop problems may be seen in the recent history of the paint industry. A few years ago, the hardness of a paint or a varnish surface was determined by scratching it with a fingernail; colors were known by name and were compared with standard colors which changed with time. There was no adequate standard "white" and no satisfactory measure of hiding power. One physicist, Dr. A. H. Pfund, of the Johns Hopkins University, in a few years found solutions for all these problems by the applications of fundamental principles and of the ingenuity which he had developed in a long laboratory experience. His hardness tester consists in a small piece of apparatus in which hardness can be read directly in terms of the diameter of a small circular area seen in a microscope. He has shown how the comparison of colors can be made with high precision and how the question whether a body is or is not white can be determined without using a standard of comparison. In both the latter problems he made use of the fact that the color of the reflected light from an object is accentuated by multiple reflections. The hiding power of a paint was measured by the clever use of a wedge-shaped body of paint pressed between two pieces of glass.

In a similar way many shop and production problems call for the assistance of the industrial physicist. Take, for instance, as a problem the study of the behavior of a paint or a varnish that is used for insulating purposes. It becomes necessary to study its electrical resistance through the film and over the surface, its dielectric strength, its absorption of water and the effect of this absorption on the electrical properties, its resistance to the action of ultra-violet light and to weathering influences generally, its hardness, brittleness, flexibility and other characteristics, all of which require physical measurements and the application of well-established physical principles, and are best carried out in a physics laboratory.

Physics as represented by the industrial physicist should take an important part not only in the standardizing of methods of measurement but also in the choice of characteristics to be measured and in the making of definitions of the units to be used in the measurements. In many cases the characteristics that need to be measured are still not chosen. That has to be done before the method of measurement and the units can be decided upon. A national society of applied physics such as has been proposed by the Akron Society of Applied Physics could certainly be helpful in promoting such standardization.

Constant and intimate contact with the products of scientific work develops in the individual an appreciation of scientific method. It does not necessarily result in acquiring the scientific method of thinking or of investigating. It is one of the functions of physics and of other sciences in industry to lead the way in the use of the most effective method. In practical questions it is often not possible to use it fully. Results have to be got in a hurry since the answer may have commercial value and its postponement is expensive. When time is available, the method of physics is to gather all pertinent data carefully and impartially, to subject them to thorough and unprejudiced examination and analysis, to check the conclusions experimentally and then to give the answer, unless, as often happens, analysis of the first set of data reveals the necessity of repeating the whole process before a conclusion can be reached. While the process usually can not be followed in its entirety, the principle can be kept in the foreground even when its application is imperfect. If the physicist is the right sort, his own attitude and his own methods will sell the idea of the importance of the scientific attitude to those with whom he comes in contact. Thus, he and his science should be a sort of leaven in the industrial organization. Their influence should be to develop a frank, honest and thorough consideration of all problems, an openness to suggestions of whatever kind and from whatever source, a conservatism toward untried devices and ideas and at the same time an optimism towards the possibility of making improvements which should stimulate every one in the organization to his best efforts. It should become a habit to obtain as far as possible all available facts in regard to any problem, to weigh them carefully and to direct the efforts of the organization in accordance with the results.

One usually looks to chemistry to supply new materials, but it is the rôle of physics sometimes to discover and to demonstrate new uses of materials that are already known or of combinations of such materials. The gas-filled lamp is an illustration of a discovery that has been of enormous commercial and human value. It is the result of the discovery that it is not necessary to mount a lamp filament in a vacuum and that, as a matter of fact, the filament deteriorates less rapidly and can be used at a higher temperature and, therefore, more efficiently if it is surrounded by a gas at a considerable pressure. The new material in this case was the inert gas used as an essential part of an incandescent lamp.

Another illustration of a valuable discovery in materials is the result of the work of the laboratory of the Eastman Kodak Company on films for moving pictures. Physics and chemistry cooperated in this result. The remarkable conclusion was reached that in order that the gelatin made from their hides should be useful for fast moving picture films, it was necessary for cows to eat mustard. The mustard oil is the important ingredient.

It is often said that industry needs more fundamental scientific principles in order to solve its problems. This is doubtless true and every one will agree that the more thoroughly we know nature the better. However, I think it is also true that the science that is already known has only begun to be exploited.

A very interesting case of a new use of known facts is that of the Kodacolor process of making colored moving pictures. It is really a very surprising use of well-known optical properties. The process is based entirely on physics and has for one of its essential elements the formation of a great number of very narrow cylindrical lenses on the surface of the film, 559 to the inch, to be exact. These lenses are a part of the optical system and when the film is exposed they project against the sensitive layer of the film, which is on the other side, three parallel strips of light which have passed respectively through the red, green and blue portions of a color filter placed in front of the lens. Under each of the cylindrical lenses there are then three strips of exposed film, each exposed to the light of one of the primary colors. The exposed film is just like any black and white picture and it looks like magic when the placing of a screen of three colors between the film and the lens of the projector causes the picture to be shown on the screen in its natural colors.

Another illustration may be taken from optics. The use of goggles to protect workmen from ultraviolet and from infra-red radiations in various industrial processes interested Dr. Pfund. Being acquainted with the optical characteristics of gold in thin layers and knowing that it could be applied to glass by sputtering from a cathode in a vacuum-tube, he suggested the use of a glass for goggles which should consist of a thin layer of gold protected by glass on both sides. As you know, thin layers of gold as seen by transmitted light are green. Every one has seen that in gilded glassware. So gold transmits energy in the green portion of the visible spectrum and is opaque to the radiations of longer or shorter wave-lengths. That is, the blue, the red, the infra-red and the ultra-violet are all reflected or absorbed. A thin layer of gold thus affords vision in green and provides protection at the same time. This may be taken as a new and unlooked-for application of an old material, or it may be thought of as a new material to be used as the transparent part of a pair of goggles. In any event, it is the product of an idea born of a thorough knowledge of the characteristics of the substance in question.

These are all illustrations of the combinations of well-known facts and principles in new and useful arrangements. A physicist with a vivid imagination can make these combinations more easily than any one else because he knows the facts and has the principles at his command. If he keeps in touch with new work in his science, he is also prepared to make immediate use of new discoveries.

As an illustration of how new physical facts point to new processes, there is probably nothing more striking than the discovery and the early use of atomic hydrogen in a torch for welding. Atomic hydrogen was discovered and its characteristics were studied in a vacuum-tube. It was found to persist for a certain length of time after forming, and knowledge of its great energy of combination into molecular hydrogen made it evident that it would be possible to get high temperatures without the addition of oxygen and that, therefore, it would be possible to make welds that would be free of oxides and slag. This process is now in practical use. One would not be surprised to learn that many valuable processes lie hidden in known physical principles which have never found application in industry.

On the other hand, there are many illustrations of the effect of practical needs in stimulating new discoveries. In the recent work on television, for instance, there developed a very urgent need of a more sensitive photoelectric cell and one that would be sensitive not only in the ultra-violet end of the spectrum, but that would also have comparable sensitivity in the whole visible spectrum. This requirement led to experiments with various materials in photoelectric cells and recent reports present the very surprising result that a layer of sulphur superposed on a photoelectric material, such as an alkali metal, enormously increases the sensitivity and extends it into all parts of the visible spectrum. The increased sensitivity makes television possible when applied to actual objects under ordinary conditions of illumination and also makes it possible to get more nearly correct shades in the picture.

This result grew out of the need coupled with the physicist's understanding of what that need implied. He knew that if certain characteristics could be developed in photoelectric cells, the desired result could be accomplished. He knew how to determine experimentally to what degree he had found the required characteristic. It remained to try the "hunches" that followed from the experience that had been accumulated by all the men working in this and in related fields. In all these respects the physicist had the equipment and, in this case, the result soon followed.

Many developments and much progress in industry as well as in science are due to combinations of facts and ideas. The way in which the two work together to produce new, unexpected and valuable results is well illustrated in many of the scientific and industrial events of the last few years. One of the most interesting illustrations to my mind is that of the discovery of radium and of X-rays. In the nineties of the last century, Geissler tubes were very interesting laboratory curiosities and many physicists played with them, both because they were interested in the phenomenon itself and because the tubes were beautiful to look at and interesting to demonstrate to their audiences.

Roentgen was experimenting with such a tube and happened to have a photographic plate lying in the neighborhood of it, the plate being protected as usual with black paper. When the plate was used, it was found to have been light-struck, so that the picture was a failure. Most men would have thought either that the plate was too old or that it was imperfect from the factory or else that, in one way or another, it had become light-struck in the camera. Roentgen, however, was not the type of man to be satisfied with such an explanation. He investigated and put another plate through the same history as the plate that was injured. He found again that the plate was light-struck. After some more experiments he came to the conclusion that some radiation from the tube was able to penetrate the opaque paper and to affect the photographic plate. This was the beginning of X-rays—the combination of a physical fact which most men would have overlooked with an idea born of the imagination of the experimenter that here was a radiation that was able to produce actinic effects and was also able to pass through opaque objects. Nothing like this had been known before, and when one remembers how difficult it is for us to believe the existence of something new it is realized that it was a real act of imagination when Roentgen came to the conclusion that here was a new type of ray.

Becquerel became interested in this phenomenon and noted that the operation of the Geissler tubes produced fluorescence. He knew also that various minerals displayed fluorescence and hit upon the idea that there might be some relation between the two phenomena. He, therefore, took some uranium minerals that were fluorescent and exposed to them a photographic plate which was protected with opaque paper. The plate was affected just as it had been by the radiations from the Geissler tube.

He then began an exploration of these minerals, which consisted first in making analyses and testing the various parts separated out to determine whether the activity was associated with any particular constituent of the mineral. It was found that these minerals were active whether they did or did not show fluorescence, and it was also found that some parts separated out were more active than other parts. Monsieur and Madam Curie undertook the task of separating out the active element and by following the activity through a most complicated analysis, which required not only great technical skill but also the use of a vivid imagination, they succeeded in separating out the most active part of the uranium mineral, and when you remember that the material that was found was not only exceedingly minute in quantity, but was, moreover, a new element, the characteristics of which were learned during the process, you realize that it was a very noteworthy accomplishment.

You may say that this work on radium was chemistry, and it is true that the analysis was of course partly chemical, but it was nevertheless an accomplishment of physics because physical methods were necessary for the detection of the material that was being sought in the analysis. Ordinary chemistry alone could not have found radium. Spectroscopy or the use of the electroscope were essential to the detection of the minute quantities of material that were present.

In this discovery of radium, ideas and facts were combined step by step. The effect of the radiation from the Geissler tube on a photographic plate was combined with the idea that it was due to a new penetrating radiation and the further idea that it might have something to do with fluorescence and that it might be present where fluorescence was present under other conditions. This idea led to experiments which discovered other facts in regard to the characteristics of uranium minerals. Of these facts was born another idea that there is something present in the uranium mineral which is the principal cause of the activity, and this idea led to the very complicated series of experiments carried out by the Curies and the discovery of radium itself.

There are two other illustrations with which you are all familiar but which are so to the point that I wish to give them. Radio was born when Clerk Maxwell wrote his equations of electromagnetic radiation, or rather we should say that its birth dates back to the experiments of Faraday, which had stimulated Maxwell. He had the insight to see that a displacement current in a dielectric may have the same effect as a conduction current. A few years later, Hertz took the next step by making laboratory experiments in which he demonstrated that Clerk Maxwell's supposition was correct and showed that displacement currents in some respects were the equivalent of conduction currents. From this point radio grew by leaps and bounds through Marconi and others and you are all familiar with that story.

The vacuum tube amplifier is another striking illustration of the same kind of thing. From the Geissler tube, which was simply a glass tube from which most of the air had been pumped out and which had been provided with two electrodes, was born the X-ray tube, and with the X-ray tube it became increasingly important that a good vacuum should be produced. Edison, experimenting with his lamps, discovered the conduction through gas of the partial vacuum from one end of the filament to the other and this served as another starting-point. This led to the construction of valves which were unidirectionally conducting on account of the fact that the source of electrons existed only in the hot electrode. It was found that the amount of current that could be passed through such a valve was limited, and the space charge became apparent. The realization that the effect of a space charge is an electrostatic phenomenon led to the introduction of a grid to neutralize it, and when that is done you have a radio detector or a radio amplifier tube. Step by step the facts generate ideas and the ideas lead to experiments which uncover new facts which stimulate thought to produce new ideas, and so on in a continuous progression of intellectual and physical product.

The injection of new ideas to react with the knowledge of needs and the practical experience of the engineer and the shop man is probably one of the most important *direct* services that can be given to industry by physics. The more completely the physicist can assimilate the facts and principles of his science and the more thoroughly he can lay them bare and show to the engineer their bearing on practical problems, the more valuable is his assistance. Just as the number of possible permutations and combinations of a number of objects increases very rapidly with that number, so the number of practical combinations of physical facts and principles increases with the number and variety of the latter. If you consider the accomplishments that are possible with static electricity or with magnetic bodies or with current electricity, each used without the assistance of either of the others, you find that the number of possible instruments or processes is comparatively small. If you combine the three and use them in combination in your instruments, the number of possible devices and accomplishments is enormously increased. It probably increases as some higher power of the number of fundamental principles that are involved. It is the function of physics not only to teach facts and principles already known and to show their applications but also to add to that knowledge new facts and principles at an increasing rate. Therein lies the practical importance of pure science laboratories.

One of the great values of a thorough acquaintance with fundamental facts and principles is of a negative nature. It prevents persons who have original minds and imaginations from spending time on hopeless projects. Such proposals, for instance, as tide motors of certain types can usually be shown by a little calculation to be impractical. Recently there has been a great deal of enthusiasm about the power of the light from neon lamps to penetrate fog. In some minds there seems to be no appreciation of the fact that a given amount of energy in a given portion of the red part of the spectrum has the same ability to pierce fog whether it comes from a neon lamp or from some other source of light. Experiment shows too that the difference in transmission of light of different colors through fog is like the report of Mark Twain's death. It has been grossly exaggerated.

Another popular fancy of the present day is that subatomic energy will some day be used as a source of power. The probability is very remote, since the breaking up of all but the heaviest atoms must be accompanied by absorption and not by the emission of energy. Although this principle has been announced on what seems to be a sound scientific basis we shall probably hear the suggestion for a long time to come, just as we still have perpetual-motion cranks. It is one of the duties of science to prevent the waste of energy on such projects.

It is very difficult to distinguish between what is fundamental and what is of purely practical value, as is seen from some of the illustrations that I have already given. Consider, for instance, the early work in radium and the early work in vacuum tubes and the most recent practical developments that have resulted. Edison's work is usually eminently practical. Still he sometimes does things that are of fundamental importance. His discovery, for instance, of the Edison effect has been the basis of the vast development of amplifier tubes and may be classed as of fundamental importance. Rutherford, on the other hand, is a man whose work has been devoted entirely to the study of scientific facts and principles, but nevertheless, some of his work on vacuum tubes, discharges in gases and the electrical constitution of matter has had enormous practical importance. Take as another extreme case Einstein's equation derived from the principle of relativity $mc^2=E$ representing the relation between mass and energy. This may save industry untold effort and expense by discouraging attempts to make subatomic phenomena into a practical source of power. Taken together with knowledge of atomic weights, it leads to the conclusion mentioned above that atomic energy is generally not available.

In our every-day consideration of the accomplishments of science, we are often tempted to overlook the fundamental work that is at the basis of a new device and to give the man who contributed the final practical application the full credit. This has been the case in radio. The work of Maxwell and Hertz does not usually receive the notice that is given to the work of Marconi, and yet the former was at least as important as the latter.

It would undoubtedly be true that if some one to-day should produce an internal combustion engine that is very much more efficient and very much smoother in its operation than our present gasoline engines he would be hailed as having done something entirely new, while, as a matter of fact, he might be applying old and well-known principles in a new way. Certainly, the discoverer of the fundamental principle that is involved did as much toward the final result as did the man who made the practical application.

Physics is the source of practically all the general scientific principles on which the industries are built, and these principles constitute its greatest contribution toward material accomplishments. The laws of dynamics, known as Newton's laws, and their corollaries are used in every mechanical design, and without them we should probably have had neither modern physics nor modern industry. The laws of thermodynamics are of universal application and directly useful in the study of all kinds of energy transformations, especially in heat engines. The equations of Maxwell at the basis of the development of radio, and the laws of electrodynamics have led to many results that need not be recounted, and as a simpler and still a very important illustration may be mentioned Ohm's law. These constitute the foundation on which physics and engineering, and therefore also modern industry, are built.

There is a still more important service that physics can give to industry and to society in general. This is connected with the philosophical principles on which all the developments of which I have spoken are and must be based. Consider, for instance, the principle of order which we believe applies at least to all macroscopic phenomena of nature. Primitive man did not understand the things that went on around him in the way that we do, and in his efforts to explain to his own satisfaction the things with which he was confronted he peopled nature with a variety of conscious beings, some good and some bad, some friendly and some inimical to his interests. The phenomena of weather, of sickness and of health, of prosperity and of poverty, were all thought to be willed and caused by gods or evil spirits. Primitive man thought himself entirely helpless in all these matters and was governed in many of his actions and many of his thoughts by fear of these supernatural beings and supernatural occurrences.

Science has taught and we believe that all the phenomena of nature including even sickness and health take place according to definite laws that are either known or capable of being known by man. When the laws are known, it becomes possible for man to adjust himself to his surroundings in such a way that the elements that were formerly considered dangerous and evil become his servants. His fear of something capricious and something that he was unable to understand and in the nature of things never could understand has disappeared, and in its place is his faith in the orderliness of nature and in his own ability to understand and to regulate the phenomena of nature to his own advantage.

Physics has done a great deal to bring about this state of mind, and it is of immediate and direct practical advantage in industry. The industrialist, whether he is the financier, the engineer or the shop man, has faith that nature is orderly and that he can control the processes in which he is interested. He is certain that if a process which was satisfactory yesterday goes wrong to-day, it is because conditions have changed. He has no fear that some evil-minded person's curse or the influence of an evil spirit has caused the trouble, so, calmly and without fear, he goes about determining by observation and experimentation what it is that has gone wrong. We usually call this process "shooting trouble," and just imagine, if you can, the state of mind of a shop man who believes the cause of shop trouble is to be sought in the supernatural influence of his enemies or of evil spirits. When things go wrong, he has to close down until some one who was doing the damage recovers from his indigestion or otherwise acquires a better humor.

Not such a great length of time has passed since we labored under these handicaps. There are parts of the world to-day where evil spirits and witches are real in men's minds and where they accomplish such unfortunate results as the drying up of a cow when she should be giving milk, and other rural calamities.

Our manifold contacts with machinery, mechanical and electrical, has taught every one that at least in such matters a result always has an understandable relation to other circumstances and that the only requisite for satisfactory control of machine and process is sufficient knowledge. So the industrialist has his course of action plainly marked out and he seeks knowledge and more knowledge. The fact that this understanding is a recent acquisition and still not thoroughly a part of us is perhaps illustrated by the fact that when it comes to a matter of our individual physical beings where the machine is not so well understood we are not entirely convinced. At least we are willing to do things to ourselves in the way of eating, drinking or exposure that we know are harmful. It is probably too much to say that we know, since somehow we have a feeling that we shall escape the consequences of our indiscretions. I think it is John Dewey who says that "knowledge is knowledge only when it is translated into habits of action." We should probably say that we know more about our mechanical and electrical machinery than we know about ourselves. One of the functions of physics in industry is to strengthen our conviction of the orderliness of nature.

It is undoubtedly a fact that the teaching of such fundamental principles is the most important contribution of science even when we remember all the physical conveniences and comforts that have resulted. The value of understanding is unbounded. We are just beginning to realize the possibilities in accomplishment that are inherent in an understanding of the physical universe. The aim of physics as a science is to learn to understand fully the nature and the interrelation of physical phenomena, and this at once singles it out as the natural helpmeet of industry.

The characteristics of modern civilization and our mode of living are largely determined by the products of applied science. Land, water and air transportation; telegraph, telephone and radio; the internal combustion engine that made automobiles and aeroplanes possible; the electrical industry, from heavy traction and electrically driven ocean liners to the smallest incandescent lamp, are all so much a part of our lives that it is difficult to imagine what it would be like without them. They are all based largely on physics as are also the machines and processes by which they are produced. Industry is busy in the production and maintenance of these and similar devices. It follows that for the future development of industry, physics must take a great if not the principal part in showing the way. By revealing facts of nature, propounding principles and teaching method, physics must show what can be done and how, and the engineer, who is also a physicist, will work out the details. That, in a word, is the rôle that physics must play in the industry of the present and of the future.

OBITUARY

CAPTAIN CHARLES FREDERICK SILVESTER

The older anatomists in this country will recall their associate, the late Charles Frederick Silvester, preparator in anatomy and curator of the Biological Museum in Princeton University, whose skill was often evidenced at meetings of the American Association of Anatomists by the anatomical preparations he exhibited.

A descendant, through his mother, of General Putnam, of the Colonial Army, he was born near Princeton, New Jersey, on December 21, 1876, and attended the rural schools in the neighborhood of Princeton. The lure of natural history, which had interested him from boyhood, brought him to my laboratory, where in 1895 he applied for the position of general laboratory assistant. Soon he gave evidence of having a great natural aptitude in the preparation of anatomical material. Within a short time after he entered the laboratory he mounted the disarticulated skull of a young dog in such a manner that it was clear he should train himself to be a professional preparator. He had unusual mechanical ability, and was most ingenious in inventing methods of dissecting and mounting his material; the fact that he was ambidextrous greatly added to his facility. During a period of twenty-two years he developed under my direction the extensive collection of comparative anatomical preparations that constitutes a large part of the present Princeton University Morphological Museum.

Throughout his life Silvester sought opportunities to increase his efficiency in whatever work he was engaged. He attended my courses in comparative anatomy and the development of vertebrates and thus