The Contributions of Physics in the Rise of Industrial Superpowers - A Study

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Abstract

This paper discusses how physics can improve the lives of people in developing and developed nations to grow in to industrial superpowers. One measure of industry's stake in physics is to be found in the study summarized in the preceding article, which indicates that nearly half of the nation's physicists are employed by industrial firms. The applications of discoveries in physics, moreover, have given rise to new industries and to vast new areas of industrial progress and thus to products and processes and techniques which are becoming increasingly influential forces in the changing world of the twentieth century. These and other factors bearing upon the status of the physicist in industry are discussed in various frames of reference in this issue of Physics Today. The seven articles appearing in the pages that follow are based on invited addresses presented at a symposium on the role and training of the physicist in industry which was organized last fall by the American Institute of Physics as part of a meeting attended by more than one hundred individuals, including representatives of the Corporate Associates of the Institute, officers of the AIP Member Societies, and officers and staff members of the Institute. The symposium was held on October 1, 1959, at Columbia University's Arden House in Harriman, N.Y. C. Guy Suits, vice president and director of research of the General Electric Company and chairman of the Institute's Advisory Committee on Corporate Associates, presided at the meeting. In many cases a student has had little or now experience to show him whether his interests lie in an academic or industrial sphere. In both lines of endeavor there are fields of challenge and in both lines of endeavor there are certain necessary evils which must also be understood. But many erroneous conceptions of industrial problems have arisen and are likely to rise. There are misunderstandings of the aims of the industrial physicist and in the minds of some men a nervousness about these aims, which comes from contact with the unknown. Often there is an underestimation of the industrial physicist's abilities and importance. Like superstitious fear of any sort, many of these problems are conjured up by misunderstanding, and efforts to exorcise them must be made.

If it weren't for physicists, the modern world would be a very different place. The study of physics underlies many pivotal discoveries of the 20th century – including the laser, television, radio, computer technology, and nuclear weapons– and has played a vital role in the development of quantum theory, the theory of relativity, the big bang, and the splitting of the atom.

Key words: relativity, big bang, physics, splitting of the atom, applications, discoveries, industry

Introduction

The Industrial Revolution had one further important effect on the development of modern science. The prospect of applying science to the problems of industry served to stimulate public support for science. The first great scientific school of the modern world, the École Polytechnique in Paris, was founded in 1794 to put the results of science in the service of France. The founding of scores more technical schools in the 19th and 20th centuries encouraged the widespread diffusion of scientific knowledge and provided further opportunity for scientific advance. Governments, in varying degrees and at different rates, began supporting science even more directly, by making financial grants to scientists, by founding research institutes, and by bestowing honours and official posts on great scientists. By the end of the 19th century the natural philosopher following his private interests had given way to the professional scientist with a public role.Perhaps inevitably, the triumph of Newtonian mechanics elicited a reaction, one that had important implications for the further development of science. Its origins are many and complex, and it is possible here to focus on only one, that associated with the German philosopher Immanuel Kant. Kant challenged the Newtonian confidence that the scientist can deal directly with subsensible entities such as atoms, the corpuscles of light, or electricity. Instead, Kant insisted, all that the human mind can know is forces. This epistemological axiom freed Kantians from having to conceive of forces as embodied in specific and immutable particles. It also placed new emphasis on the space between particles; indeed, if one eliminated the particles entirely, there remained only space containing forces. From these two considerations were to come powerful arguments, first, for the transformations and conservation of forces and, second, for field theory as a representation of reality. What makes this point of view Romantic is that the idea of a network of forces in space tied the cosmos into a unity in which all forces were related to all others, so that the universe took on the aspect of a cosmic organism. The whole was greater than the sum of all its parts, and the way to truth was contemplation of the whole, not analysis.

What Romantics, or nature philosophers, as they called themselves, could see that was hidden from their Newtonian colleagues was demonstrated by Hans Christian Ørsted. He found it impossible to believe that there was no connection between the forces of nature. Chemical affinity, electricity, heat, magnetism, and light must, he argued, simply be different manifestations of the basic forces of attraction and repulsion. In 1820 he showed that electricity and magnetism were related, for the passage of an electrical current through a wire affected a nearby magnetic needle. This fundamental discovery was explored and exploited by Michael Faraday, who spent his whole scientific life converting one force into another. By concentrating on the patterns of forces produced by electric currents and magnets, Faraday laid the foundations for field theory, in which the energy of a system was held to be spread throughout the system and not localized in real or hypothetical particles.The transformations of force necessarily raised the question of the conservation of force. Is anything lost when electrical energy is turned into magnetic energy, or into heat or light or chemical affinity or mechanical power? Faraday, again, provided one of the early answers in his two laws of electrolysis, based on experimental observations that quite specific amounts of electrical “force” decomposed quite specific amounts of chemical substances. This work was followed by that of James Prescott Joule,

Robert Mayer, and Hermann von Helmholtz, each of whom arrived at a generalization of basic importance to all science, the principle of the conservation of energy.

The nature philosophers were primarily experimentalists who produced their transformations of forces by clever experimental manipulation. The exploration of the nature of elemental forces benefitted as well from the rapid development of mathematics. In the 19th century the study of heat was transformed into the science of thermodynamics, based firmly on mathematical analysis; the Newtonian corpuscular theory of light was replaced by Augustin-Jean Fresnel's mathematically sophisticated undulatory theory; and the phenomena of electricity and magnetism were distilled into succinct mathematical form by William Thomson (Lord Kelvin) and James Clerk Maxwell. By the end of the century, thanks to the principle of the conservation of energy and the second law of thermodynamics, the physical world appeared to be completely comprehensible in terms of complex but precise mathematical forms describing various mechanical transformations in some underlying ether.

Objective:

This paper intends to explore discusses how Physics attempts to describe the fundamental nature of the universe and how it works at industrial scale to grow into superpowers of most diverse behavior.

What IS an Industrial Physicist?

Arthur D. Little, in his memorable address to the Franklin Institute in September 1924, defined what he called a "Fifth Estate," According to Dr. Little, the fifth estate includes those having the simplicity to wonder, the ability to question, the power to generalize, and the capacity to apply. If one adds to the definition the phrase "willingness to expound," he will obtain a pretty good idea of a successful industrial physicist. It is not at all strange that this is the same definition which one would apply to a successful physicist of any description, or indeed to any successful worker in any of the natural sciences. The raw material must therefore be the same kind, since in America no distinction is made in educational circles between those who eventually go into industry and those who do not, the only thing which remains to differentiate the two is a difference in viewpoint.

The academic physicist is properly concerned with reducing phenomena of nature to terms of basic concepts; it has been generally believed in the past that the fewer these concepts are in number, the more powerful they are in action. This line of thought has resulted in the great simplifications inherent in such basic physical laws as the conservation of energy and the equivalence of energy and matter, as well as in the methods of mathematical physics.

The author, Harold A. Robinson, appears in this undated photo taken in the Karl Taylor Compton Memorial Room at MIT, his alma mater. Born in 1909 in Rotterdam, New York, Robinson was the chief physicist at Armstrong Cork Co. As Armstrong World Industries, the company continues to manufacture flooring materials. CREDIT: AIP Emilio Segre Visual Archives, Hutchisson Collection

The author, Harold A. Robinson, appears in this undated photo taken in the Karl Taylor Compton Memorial Room at MIT, his alma mater. Born in 1909 in Rotterdam, New York, Robinson was the chief physicist at Armstrong Cork Co. As Armstrong World Industries, the company continues to manufacture flooring materials. CREDIT: AIP Emilio Segrè Visual Archives, Hutchisson Collection

The industrial physicist is in an unusual position or, like the lawyer, he must be prepared to answer in a moment's notice a wide variety of specific questions in an almost unlimited number of fields. He must therefore be a person of exceptionally broad training and more than unusual abilities, for often the problems which come to him are not couched in physical terms. Industrial physics is complicated by constraints of a nonmathematical nature and one is forced to add intuition to training and knowledge of the successful methods of the past. Thus industrial physics in some ways covers a much broader field than does basic or academic physics, and often the industrial physicist finds himself measuring (after all, the science of physics is basically the science of measurement) many very unusual things, sometimes in very unusual places, and sometimes by non-traditional methods.

In addition, in industrial work, one is often struck by the necessity of cooperating with others trained in other scientific disciplines. Industrial physicists are constantly being exhorted to know more chemistry or to know more mechanical or electrical engineering. The specific discipline will vary from industry to industry but it is true that industrial work requires a breadth of viewpoint and a necessity for cooperation which his sometimes considered unnecessary in a university.

The submicroscopic world of material atoms became similarly comprehensible in the 19th century. Beginning with John Dalton's fundamental assumption that atomic species differ from one another solely in their weights, chemists were able to identify an increasing number of elements and to establish the laws describing their interactions. Order was established by arranging elements according to their atomic weights and their reactions. The result was the periodic table, devised by Dmitry Mendeleyev, which implied that some kind of subatomic structure underlay elemental qualities. That structure could give rise to qualities, thus fulfilling the prophecy of the 17th-century mechanical philosophers, was shown in the 1870s by Joseph-Achille Le Bel and Jacobus van 't Hoff, whose studies of organic chemicals showed the correlation between the arrangement of atoms or groups of atoms in space and

specific chemical and physical properties. Physics students need a very strong head for numbers, a good grasp of scientific principles and a keen interest in discoveries relating to the physical world.

Physics Problems in Industry

How can one measure the comfort of a floor? In years gone by this would not have been a proper question to ask a physicist, but in the past decade those physicists concerned with the measurement of color or with the measurement of acoustical properties have discovered, somewhat to their amazement, that these border-line problems in which an individual is part of the measuring system can sometimes be solved. Thus the broadening of physics to include physiological manifestations is now well established.

How can one measure the abrasion resistance of a material and yet have such measurements reproducible and from them derive a standard scale of abrasion resistance? How can one, from these measurements of abrasion resistance, construct the future with any confidence to show that one given material may be expected to outlast a number of the others? Is one justified in using a type of dimensional analysis in which time plays the role as length or volume in an ordinary scale model? How can one hope, by the standard methods of chemical physical research, to find an industrial process for oxidizing linseed oil, a natural product of variable composition, when purification to a single ester may destroy the oil's original, very desirable properties? What are the forces involved in holding a crown on a soft-drink bottle and what excess of force is necessary to prevent such as gasketed assembly from leaking?

These are problems which, in the academic sense, are not basic, and yet for the industry, which is build upon their successful solution, the problems are very basic indeed. In fact, the whole success of the industry, the financial well-being and happiness of the several thousand families thereby employed, as well as the health of physical welfare of the people who will use the product, all depend on a successful solution. The incorporation of these problems into the body of physics will go a long way toward satisfying the criticism of those who feel that physicists do not pay enough attention to the social results of their work. One is constantly struck, in industrial research, by the necessity of proceeding along two main lines. One group of scientists, even in a small laboratory, is properly concerned with extending the basic simplifications of physics into untapped fields, but if the greatest use and good are to come from these generalizations, another and often larger group of physicist or chemists must be in position to apply these or other ideas to problems of current interest. Often, in research on product development, teams using both approaches are necessary. Strangely enough the team using the quick approximate method usually succeeds first, and in many cases the fundamental approach must be reserved for the few problems of great complexity which are obviously not going to be solved immediately.

The Two Approaches

Physics itself has historically proceeded along these same two lines. We have had the great pioneers who established the structure of the atom, who discovered radioactivity, or who are engaged in understanding the nucleus. Almost without exception the minds able to make these great simplifications, and discover these underlying facts, have had to wait for masses of experimental data (of have had to develop such data themselves) before building a valid theory. In mathematics there is no such forced dependence on experimental data, and many physicists of late years have tended to misunderstand the teaching of history and have believed that it is possible to progress in physical knowledge by constructs of the mind only. While it of course true that this type of reasoning does and can lead to valuable results, it is extremely doubtful that it is the only type of reasoning applicable to the needs of a pragmatic civilization. In many cases, constructs of this type actually hamper further knowledge and under certain conditions this viewpoint can lead to sterility. The industrial physicist tends to minimize the value of many of these theoretical methods usually because they very often do not suffice to settle his problems.

The difference between physicists in general and doctors of medicine is most striking. Few doctors consider it other than part of their duty to cure a patient, even though the disease may not be recognized in medical textbooks; yet many physicists seem to resent the fact that they are called upon to use their intelligence in fields for which the textbooks have not been written. The industrial physicist cannot allow himself this luxury, and if he is given a problem of finding out why one material is slippery and another is not, he must be prepared to utilize his intellect and training to solve the problem.Thus academic freedom, superficially, constrains individual action less that does industrial physics, and in the sense that an academic physicist is free to pursue an isolated train of thought, this may be the case. But in the larger universities, the last few years show may cases where individuals group together in a mass attack on some given problem. The chances are that this trend may continue, particularly if the world remains too unsettled. Thus the division between the individual and a mass worker is tending to disappear even in those places where one would not expect it to.

As we have seen, though there may be a broader field of individual action for the academic physicist, the questions asked of the industrial physicist are apt to be broader in scope as well as being more varied in nature than those asked in college laboratories because they often cover unusual aspects of human endeavor. For this reason it is often much more difficult to solve such problems and, in many cases, it may be impossible at the present time with present resources. This impossibility can arise because of mathematical difficulties, but often one is not even allowed to consider these problems without the nonphysical constraints mentioned above. It has long been a commonsensical notion that the rise of modern science and the Industrial Revolution were closely connected. It is difficult to show any direct effect of scientific discoveries upon the rise of the textile or even the metallurgical industry in Great Britain, the home of the Industrial Revolution, but there certainly was a similarity in attitude to be found in science and nascent industry.

Generalization or Utilization?

We are thus led back to the problem of viewpoint. One has to decide whether the greatest contribution can be made in the traditional field of generalization or, in the manner of most physicians, in the field of utilization. The traditional field leads to analysis and the industrial field to synthesis. Clearly one can never be wholly in one or wholly in the other, and the successful attack on a complicated problem usually requires elements of both types of thinking. At this time in our society, the greater monetary awards usually follow the line of synthesis. Science has tended to make a virtue of its isolation, but in the present political complexion of the world it is unfortunately more than possible that this virtue will be legislated out of existence. It is important that the legislator understand that our traditional viewpoints have value, and one of the great tasks of the individual physicist will be to insist that the freedom of his academic brother be adequately protected. It is for this reason that we have added the "willingness to expound" to A. D. Little's definition of the "Fifth Estate."

Pure and applied physics.

Thus it appears that work in physics can be classified into two main groups. In the first lies work along traditional lines. Early physicists were interested in discovering the properties of matter en masse. As time went on they became more interested in the atom in an attempt to explain these mass properties. This led in turn to that study of the nucleus that is now proceeding so vigorously. It is, of course, imperative that problems in this category be pursued with full vigor and with the help and aid of as many people as possible. The results of this work are important to both pure and applied physics. Consider, for example, the discovery of radioactivity by Madame Curie. This work has led not only to a great broadening in our understanding of the structure of the nucleus, but also to important industrial and medical applications. In the second group lies work in physics utilizing present or past discoveries for future economies. This is the field in which the work of a majority of industrial physicists, particularly those in the smaller laboratories will lie. The results of this work are also important to both pure and applied physics. Edison's development of the carbon-filament incandescent lamp led to the invention at the General Electric Company of the tungsten lamp and the development of other types of lightning. But a byproduct of Edison's research (the Edison effect) was the first of several pieces of evidence which eventually led to the discovery and understanding of the properties of the electron. Often it has not been sufficiently recognized that either category of physical problem can stimulate and aid the other.

Many physicists are clearly confused on the relative importance of the two approaches but it has been shown that the impetus toward basic knowledge can come from economic demand as well as from an intellectual approach. Further, it must be borne in mind that neither aspect can be considered more important than the other. No less an authority than Sir James Jeans, in a presidential address to the British Association for the Advancement of Science, has remarked that the economic value of the work of one scientist alone (that is, Edison) has been estimated at three thousand million pounds. While one, of course, cannot hope or wish to assess the monetary value of the theory of relativity, it would seem, in view of the enormous amount of potential benefit involved in industrial work, that one

can obtain real satisfaction at being part of a group which clearly is able to add so much to the happiness and welfare of the peoples of the world.

Practical utilization and characteristic of both industrialists, experimentalists

It is perhaps unfortunate that the impetus for work on the nucleus, which occurred during the war, came from the desire for developing such a destructive weapon as an atomic bomb. The fact that such use was made of the work of nuclear physicists has led many of them into philosophical difficulties, and attempts are being made to rationalize their efforts by pointing out to the public the vast amount of potential knowledge which lies in store for the science of medicine or even for industrial applications in the field of atomic power. It would be very unfortunate if younger physicists should gain the idea that all types of applied research lead to such horrible results. It must be realized, in the larger scheme of things, that the value of knowledge comes with the application of that knowledge to new and useful properties for the benefit of society. The evil byproducts of such research unfortunately have to come along with the beneficial byproducts, and whichever aspect gains the most use is a matter of education among peoples coupled with their inner energy and their accepted ethics.

Close observation and careful generalization leading to practical utilization were characteristic of both industrialists and experimentalists alike in the 18th century. One point of direct contact is known: namely, James Watt's interest in the efficiency of the Newcomen steam engine, an interest that grew from his work as a scientific-instrument maker and that led to his development of the separate condenser that made the steam engine an effective industrial power source. But, in general, the Industrial Revolution proceeded without much direct scientific help. Yet the potential influence of science was to prove of fundamental importance.What science offered in the 18th century was the hope that careful observation and experimentation might improve industrial production significantly. In some areas, it did. The potter Josiah Wedgwood built his successful business on the basis of careful study of clays and glazes and by the invention of instruments like the pyrometer with which to gauge and control the processes he employed. It was not, however, until the second half of the 19th century that science was able to provide truly significant help to industry. It was then that the science of metallurgy permitted the tailoring of alloy steels to industrial specifications, that the science of chemistry permitted the creation of new substances, like the aniline dyes, of fundamental industrial importance, and that electricity and magnetism were harnessed in the electric dynamo and motor. Until that period science probably profited more from industry than the other way around. It was the steam engine that posed the problems that led, by way of a search for a theory of steam power, to the creation of thermodynamics. Most importantly, as industry required ever more complicated and intricate machinery, the machine tool industry developed to provide it and, in the process, made possible the construction of ever more delicate and refined instruments for science. As science turned from the everyday world to the worlds of atoms and molecules, electric currents and magnetic fields, microbes and viruses, and nebulae and galaxies, instruments increasingly provided the sole contact with phenomena. A large refracting telescope driven by intricate clockwork to observe nebulae was as much a product of 19th-century heavy industry as were the steam locomotive and the steamship.

Conclusion

Because physicists are a small group, they often suffer in many ways from psychoses similar to those found in political minorities. In an effort to keep their own individuality they feel it necessary to resist pressure from the outside and the result it, as has been pointed by Langmuir, that a group of physicists tends to behave like an amoeba. In this animal, a cautious arm goes out to find something of interest and pulls in the entire body behind it. As physicists increase in number this tendency of the whole body to follow the leader must become less marked and simultaneous exploration into several unknown or hitherto unallowed fields must become more prominent. It is the task of the industrial physicist of today to assist in and demand this broadening of our concepts. A physicist can do a variety of jobs in the industry, and when people say that they went corporate for better pay and hours, they usually mean that they're no longer doing physics per se, but indeed working as software developers or the like.

A lot of the jobs out there can be quite technical, where having a relatively mathematical background, such as a PhD in physics, can be helpful on the job and sometimes even a requirement to pass CV screening. A degree in physics is and is seen as one giving a good overview of a lot of things and as proof one can solve technical problems. That's why if you're not sure who to hire, you might go for a physicist. As the field becomes more standardized, specific degrees will often be crafted, like what happened in machine learning, data science and financial engineering.

Some of the more technical jobs remain close to academia in that you will be reading articles and maybe even publishing. Typically though what's different between academia and rhe industry is the robustness of the methodology: You often want something that can be trusted to be automated rather than the fanciest way of doing things where you sometimes need to guide things by hand to get best possible fit to some experimental data.

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