



J. Herbert Hollomon is manager of the Metallurgy and Ceramics Research Department at the General Electric Research Laboratory in Schenectady. He has served as adviser for metallurgy activities at GE's Knolls Atomic Power Laboratory, and since 1953 has been a member of the NSF High-Temperature Panel.

The Role of Physicists in Materials

By J. Herbert Hollomon

SPEED is characteristic of our age. Speed is important not only to our lives and to our space-ships, but to our ability to bring to social use the important, significant discoveries of science. Physics and the physicist must not only play the traditional role of discovering the secrets of nature, but must increasingly, with all other men, appreciate sooner the requirements, characteristics, and limitations of the application of this discovery to modern living. In no area is the need for speed so clear and important as in the development and improvement of materials upon which our industrial economy is based and on which the defense technology depends. A look at materials development might, therefore, illustrate the vital significance of the physicist in this new accelerating world.

The most important engineering materials can be classified as metals, ceramics, semiconductors, and polymers. The technology, art, and practice of metallurgy is old. It is, in fact, one of the oldest activities of man. The discovery of the techniques for refining metals was the mainspring for civilization. It made possible the "first accumulation of capital" by producing the tools for more efficient agriculture. Man's attempt to transmute one metal to another and his desire to improve the art of refining led to the science of chemistry and stimulated chemical engineering. Ceramics—formerly the art and science of pottery and brickmaking—is antique and has only recently been influenced by the principles deriving from physics and the tools of modern science and technology. While semiconductors (selenium and other special materials) have been used for years in photosensitive and other devices, only after the World War II development of the germanium diode for radar and the subsequent invention of the transistor did the need for semi-

conductor materials and processes to produce them become important. Polymer science and the technology of the production of complicated synthetic, organic, structural materials is only a very recent development. It derived from the application of physical-chemical principles to organic chemistry.

During the development of metallurgy and of the technologies related to ceramics, semiconductors, and polymers, physics contributed greatly through the techniques by which the understanding of the behavior of these materials was accomplished. Physics did not contribute directly to the invention, improvement, or development of engineering materials but was effective only through the slow diffuse process of changing the underlying technology. The professor of metallurgy, for example, had first to appreciate, apply, and teach the new learning before it could be practiced by anyone directly in industry. Modern industry has attempted to arrange for the more direct application of science by creating the industrial, scientific research laboratory; but there has been little change in either the general method of the teaching of physics or its codification for others' use.

Spectroscopy, an experimental technique of physics, had a very large influence on materials development and led to the accurate determination of composition and made possible vast improvements in refining practices. The use of the optical microscope, so important to the study of all crystalline materials, initiated the science of metallurgy at the turn of the century and led to the rapid development of the controlled heat treatment of steels and to the development of age hardenable and other special, light, nonferrous alloys. The understanding of the nature and origin of microstructures of ceramics is a recent development. X-ray

and electron diffraction techniques derived from the understanding of the quantum nature of energy made possible the description of the regular arrangements of atoms in solids. The electron microscope permitted a more detailed look at structures than did the optical microscope. Physics contributed new techniques for measuring magnetic, electrical, thermal, and optical properties of materials. These experimental techniques embodied the applications of the knowledge and were the vehicles for its translation to use. The metallurgist didn't have to understand the basic principles of optics to use the microscope to examine materials.

Physicists concerned with materials ask about their relatively simple and obvious characteristics. The questions of the physicists are: Why are materials so much weaker than would be predicted from the forces between regularly arranged atoms? What is the nature and origin of ferromagnetism? What governs thermal conductivity? Why are some materials superconducting? Further, the physicist studies these questions using highly refined and specially characterized materials in order that the questions may be examined with the least influence of other uncontrolled variables. When answers to these questions are obtained, the physicist often leaves the problem to others—metallurgists, ceramists, and mechanical engineers—to apply the new understanding without any real effort on his part to interpret it. All too often, those who must use the information do not speak the new language of the physicist, are not prepared to accept the knowledge, and resist its use. The first application of any new information is a most difficult task. The materials man comes from the other side of the tracks.

On the other hand, physical chemists are directly involved in studying the kinetics of reactions in metallic systems. Inorganic chemists synthesize special ceramic materials. Organic chemists produce whole new classes of compounds. Statistical mechanics and kinetic theory are directly applied to the understanding of the behavior of complex polymers. The physicist's study of simple systems to the exclusion of the complex and the belief of the physicist that somehow his analysis of the simple can and will automatically be synthesized to permit the understanding of the complex have sort of removed him from the natural world of real materials.

In order to obtain a rough idea of the role of physicists in metallurgical research (as an example of the materials field), I have examined the publications in the two leading journals reporting metallurgical science. As indicated in Fig. 1, the proportion of trained physicists among the authors of articles appearing in *Acta Metallurgica* and the *Transactions of the Metallurgical Society* is very small, less than 10%.

Another way of looking at the role of physics in the materials industry (using again metallurgy as an example) is by determining the number of physicists employed in the basic metallurgical industries that contribute the most metallurgical research. In a recent study, we have examined the papers published in a little over one hundred of the leading scientific and

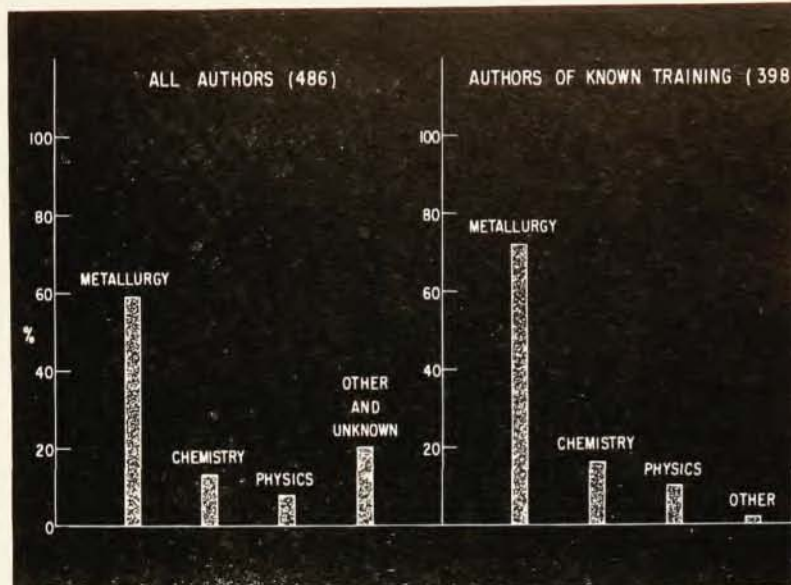


Fig. 1. Proportion of authors in two leading metallurgical journals with physics training (*Transactions of the Metallurgical Society* and *Acta Metallurgica*, 1958).

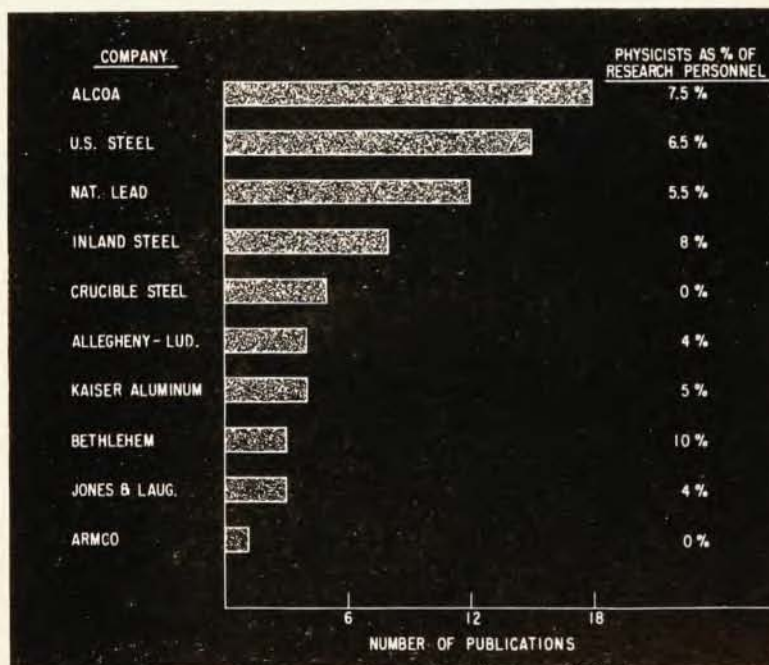


Fig. 2. Total technical publications and research personnel trained in physics for the primary metals industry. (Technical publications are taken from 101 selected scientific and engineering journals for the year 1957. Training of research personnel taken from *Industrial Research Laboratories of the United States*, Publication 379, NAS-NRC, 1956.)

technical journals. From this tabulation, the institutions performing the technical work in various fields as indicated by their publication activities can be determined. The technical publication effort of the ten primary metals industries that lead in publishing activity is compared in Fig. 2. The percentage of physicists employed by these companies is less than 10% of the total research personnel.¹ I conclude that physics and

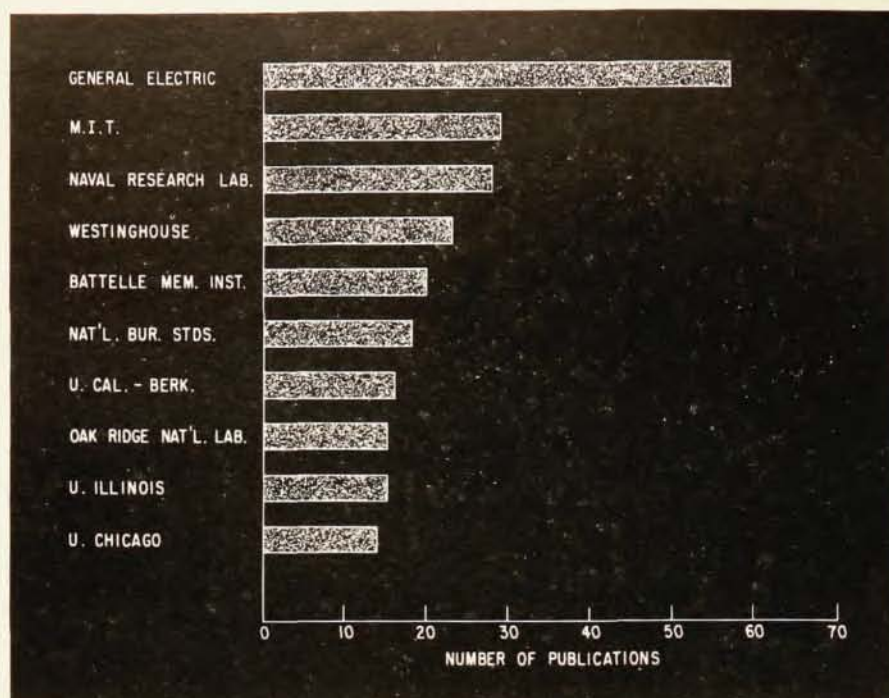


Fig. 3. Technical publications of the ten institutions with the most activity in metallurgy, 1957. (Same 101 selected journals.)

physicists play a minor role in the basic research and development having to do with metals and alloys, at least that performed by the primary metals industry. The results would be the same, I am sure, in the fields of ceramics and polymers and, if the work on devices were excluded, in semiconductor materials research.

A much larger amount of materials research and development, at least as indicated by publication activity, is carried on by those institutions which are engaged in the most advanced technology, such as in electronics and nucleonics. Here, the materials requirements are crucial and the limitations of materials to the advancing technology are obvious. Fig. 3 compares the publication activity having to do with metals and alloys of the ten institutions that do the most work in this field. Since these institutions do not separate their work by field of research in reporting the make-up of their research staff, I cannot report the proportion of physicists except at General Electric where in the metals, ceramics, and glass research about one quarter of the staff is trained in physics.

Another way of examining the role of physicists is to determine how innovations in materials and processes arise and the role of physics and physicists in accomplishing them. A number of the leading people in industry, government, and academic institutions are being asked to list the important materials and process innovations that have occurred in the decade or so that has followed World War II. A preliminary and incomplete tabulation based on early replies indicates that few of these innovations were dependent directly upon advances in solid-state physics or involved any

physics that was not "classical". It is true that in the development of fine-particle magnets, the history of which I will discuss a little later, the understanding of the nature of the coercive force of fine particles was contributed by Néel and appreciated by Stoner, Kittel, and others—all physicists. Further, there was also a close connection between the development of zone refining and the advances in solid-state physics by Shockley, Bardeen, and Brattain that led to the transistor as an electronic device. The transistor, however, was not a materials development but rather required zone refining based upon physical-chemical principles and the ingenious inventiveness of Pfann.

The case of fine-particle magnets illustrates, I think, some of the facts about materials research and development, and the attitude and role of physicists. The general principles leading to the understanding of the origin of the coercivity of magnetic materials indicated that a material consisting of small particles of a ferromagnetic substance oriented and imbedded in a matrix would have a larger energy of demagnetization than the best commercial magnets. These principles were enunciated in the early 1930's and were justified experimentally prior to 1945. In a sense, the physics was done and the problem was only one of applying the information. On the other hand, the physicist was not able to translate this understanding to those capable of applying it to useful commercial production. Complex problems of process development, economic analysis, and evaluation of the magnets for applications remained and nearly twenty-five years had to pass before the knowledge and vision were in the minds of those who could apply it. The steps in translating this knowledge to a practical, social use are illustrated in Fig. 4. The crucial inventions were based on a knowledge of nuclea-

¹ *Industrial Research Laboratories of the United States*, National Academy of Sciences—National Research Council, Tenth Edition, Publication 379 (1956).

tion and growth and the techniques of electrodeposition and on a knowledge of physics available for twenty-five years.

In some organizations such as the Bell Telephone Laboratories, Westinghouse, RCA, and General Electric, physicists are becoming involved in research with complicated real materials, and are contacting those who recognize the problems of making new discovery of nature useful and appreciate the great skills required in doing it. In these institutions engaged in work at the forefront of advancing technology, it is recognized that the improvement of old materials and the development of new ones might be affected by the knowledge now being gained from solid-state physics, and that the innovations must be accomplished without waiting the quarter century necessary for the slow diffusion of the knowledge by learning it in schools.

The understanding of dislocations and their role in governing mechanical properties, the physics of many-body systems and the quantum mechanical description of the nature of cohesion will certainly provide understanding that will lead to radical improvement in materials if the physics can be translated to those who can use it in an understandable form. If physics and the principles and viewpoints of physicists are to become directly and quickly used in the materials business, the traditional role of the physicist in understanding the behavior of matter must be enlarged to include the responsibility of making it available to those who can use it for developing and improving materials. Nowadays, the physicist insists that the advance of society (and the national security) is critically dependent upon "basic research" without fully accepting the necessity of helping to translate the results of the research to use and of supporting the institutions and people who accomplish the translations.

What are some of the limitations in fulfilling this most demanding new role of the physicist? He must learn to appreciate that his knowledge of simple systems cannot be directly used to describe the complex behavior of complicated real materials. As the physicist has approached the problem of the understanding of the behavior of materials by regarding the simpler and more highly specified systems, in a sense he holds himself removed from the real world in which that understanding would be of practical consequence. The

behavior of metals or alloys containing precipitates of one sort or another with grain boundaries and miscellaneous impurities is often a dirty problem to the solid-state physicist. Sometimes, the physicist looks down on those who worry about such materials. Pierce,² in a recent article on the freedom of research, described the situation by saying the mathematician looks down on the physicist, the physicist on the chemist, the chemist on the biologist, the biologist on the psychologist, and sometimes, I think, metallurgists are at the bottom of the totem pole. There is insufficient contact in educational institutions between physicists, chemists, metallurgists, polymer chemists, and semiconductor technologists. The physicist needs an increasing awareness of the stimulation and thrill of relating his physics to these other disciplines.

What seems to me to be needed is an education that emphasizes the broad range of science, the types of problems to which science has made a contribution both from the practical as well as from the cultural point of view. It should also emphasize the evident generalities of physics and should in every way resist the tendencies that lead to specialization. As in engineering education, there needs to be a renaissance of the general as contrasted with the special. There is needed a recognition of the world of complicated systems and a science to treat complicated systems of materials and complex arrangements of individuals—such as in a society. New physics leads to a new applied science and can be used promptly without waiting for the infusion into an old technology if physicists appreciate the process of development and the economics of innovation. The codification and translation of physics for us poor beggars at the bottom of the totem pole would let us apply the principles and the new discoveries of physics promptly and effectively.

I hope that physicists will, in the future, concentrate less in narrow disciplines and on highly specialized problems, and will become interested in other related fields. I hope they will come to appreciate the role of applied science and the importance of the contributions of the industrial institutions that support it in our economy without detracting from the great excitement of physics and its role in man's quest to understand his world.

² J. R. Pierce, "Freedom in Research", *Science*, #3375, 130, 540 (September 4, 1959).

Fig. 4. History of the development of fine-particle magnets.

