METALLURGY
and METAL PHYSICS

To the manuscript of his talk, presented as an after-dinner address at the banquet of the American Physical Society meeting in Philadelphia on March 22, 1957, the author attached the following admonition: "The reader will kindly note the circumstances under which this was prepared, and preferably read it only after consuming three cocktails and his least favorite dinner menu."

By ***Cyril Stanley Smith***

HAVING spent most of my life working at the borderline between physical metallurgy and metal physics, I wish to discuss some of the characteristics of these two fields of science, and particularly the manner of their interaction: If tonight I seem more critical of physicists than of metallurgists, please remember that this talk is addressed to the former and that metallurgists would be exposed to very different arguments.

Human activities tend to crystallize into well-formed patterns, for reasons that are not entirely unrelated to the segregation of alloys into two phases. This segregation is extremely strong in a university, for university departments have to decide what is and what is not formally part of a teachable discipline. Most of the important activity in both metal physics and physical metallurgy has had its origin not in universities but rather in government and industrial laboratories, and only in the last generation has it become part of the accepted discipline.

There are many cases in the history of science where parallel development in two fields has occurred painfully and slowly, when even a little interaction between them would have accelerated an approach to the truth. Solid-state physics developed very late in history, not because many useful concepts were beyond the basic knowledge of the time but simply because eighteenth century physics became excessively mathematical. Mathematical statements are fine if they exactly relate to phenomena, but they tend to exclude an interest in the real world. It seems to me that a physicist should supplement his mathematical ingenuity with an almost aesthetic feeling of enjoyment for materials. Such a feeling will temper his annoyance when some equations he has cooked up on the simplified model fail to fit in with his predictions.

The great physicist Robert Hooke worked when solid-state physics was a real part of physics in a way that it ceased to be for two centuries after him. He talked with artisans and was interested in the quenching of steel, the hardening of all metals by cold working, and he speculated on the building up of spherical units into crystals. A sense of structure was very much in the air in the seventeenth century as the new mechanical philosophy was being born from a combination of ancient atomism and Cartesianism. A French physicist, Jacques Rohault, in his *Traité de Physique* (Paris, 1671) developed Descartes' ideas into a fine outline of solid-state physics for he showed how the properties of matter could be explained in terms of the interaction of parts. The sliding or parting of them, their alignment into preferred orientation on working, and the effects of hardening, alloying, transformation, and diffusion were all explained well though qualitatively. His compatriot, Réaumur, in 1722, basing his work to a large degree on Rohault's ideas, made a greater contribution to the practice in the iron and steel industry than any one man had previously done, and in turn, from his practical observations on the quenching of steel, called attention for the first time to the differences of specific heats of materials and continued to develop the field of thermometry in general. As perhaps the first applied scientist of the modern type he consciously studied and developed theory for its guidance toward practical objectives, and conversely he used observations on labora-

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tory experiments and industrial operations to suggest new theories.*

Newton, in the Queries appended to the second edition of his *Opticks,* talked of particles, of the kinds of forces between them, of elastic deflection, and of plasticity due to the sliding of parts over each other. Though he made hypotheses profusely and sensitively, the rigorous mathematical method of his *Principia* came to be accepted as the only method of science and the approach suggested by his optical Queries was abandoned. Newton's superb gravitational cosmology rightly displaced Descartes' misleading vortices, yet it was a tragedy for physics that Cartesian interest in real matter was also discarded. The magnificent advances in physics that came from the adoption of the Newtonian mathematical method were obtained at a price, and nowhere, I think, is the price greater than in the field of solid-state physics. There were, after all, relatively few areas of science that would yield to a rigorous approach in the eighteenth century. The flourishing beginning of solid-state physics in terms of some kinds of units building together into successively bigger ones with certain structures and interrelationships at each stage of the hierarchy was disregarded by physicists, and instead of solid-state physics there arose that curious body of knowledge known as "Elasticity and Strength of Materials" which provided wonderful exercises for mathematical ingenuity but, having preassumed homogeneous isotropic material, it discouraged interest in crystalline matter and focused even the engineers' attention on design instead of suggesting the possibilities of better materials. Physical crystallography became a branch of mathematics, with emphasis on space groups and symmetry elements, with a minimum of consideration of local groupings of atoms and the forces which produced them. The chemists did better, for to them the atom was a useful concept in the first decade of the nineteenth century.

One would think that a spectacular change in the properties of matter such as the hardening of steel would attract considerable attention from physicists. Actually, after Réaumur, the field was left entirely to practical men until well after the middle of the nineteenth century, and then it was reopened by a man who was a dilettante geologist. Even as late as this, cast iron and platinum were practically the only materials in common use not known or used by the Romans.

The way to discovery is usually not through mathematics. Almost all of the phenomena now being studied by a physical metallurgist as well as those of concern in the broader field of solid-state physics were discovered centuries, indeed millennia, ago by practical artisans. Cold working, solid-solution hardening, and transformations, to mention but three, were effectively utilized long before dislocations or free energy changes were conceived. Microcrystalline grains were first observed on fracture and used to control composition and heat treatment, though I am glad to concede that the first realization that they were not like grains of wheat with a skin but differed only in orientation did come as a by-product of the work of a physicist who was interested in elastic anisotropy.

On the whole, I think practical men see the significance of theory more quickly than theoretikers learn from practice. A practical man sees things integrally. A piece of metal under fire and forge is a fine analogue computer, and has the advantage over the typical *Physical Review* paper that it does not omit the insertion of a single one of the myriad pertinent variables. Although it is the strength of the physicist's method to simplify problems by excluding the extraneous, he should not forget that he has chosen to wear blinkers like a horse, and once in a while he should remove them to see and enjoy the sweep of scenery.

Robert Hooke, in his *Micrographia* (1665), was well aware of the twin difficulties: "Lest by seeking to enlarge our knowledge we should render it weak and uncertain; or by being too scrupulous or exact about every circumstance we confine and straighten it too much." Metallurgists and metal physicists approach problems each with a bias toward a partial aspect of the whole. They should, however, learn to appreciate the other's point of view—and both will realize how much they still have to learn about materials if they will spend some time studying works of art made by great craftsmen wherein the properties and qualities of metals, stones, and ceramics are aesthetically used.

* The University of Chicago Press has just published a new English translation by A. G. Sisco, entitled *Réaumur's Memoirs on Steel and Iron.*