GENERAL DISCUSSION

MR. J. R. TOWNSEND.[1]—On October 4, 1957, the Soviets projected Sputnik I into orbit around the earth. In spite of the fact that the basic principles involved were Newtonian mechanics and 300 years old, the fact was greeted throughout the world as a great triumph of science, as indeed it was. The Cold War based on science and technology was upon us.

The singular fact of this event as related to our subject is that a new environment—that of outer space—had been entered and a prodigious new force had been placed in operation to break the gravitational ties that bind us to the earth. New materials are required to make this possible. A whole new science and technology must be explored and many people must be trained to labor on its detail. More important than this is that no longer are we in the position where we have a storehouse of scientific facts collected willy-nilly and available for our engineers to employ in the design of rocket engines, guidance, and communication. We must find new knowledge, relate it to what is now known and involved in the problem of new materials, and define steps to be taken to employ old and new materials in this new environment. There is a race involved. We must make new discoveries against time and we must shorten the time of their application.

What is the place of private industrial research and development in this race? To be sure, we must employ the talents of private industry wherever we can. But the knowledge we need to win the race is new—and not necessarily of immediate commercial value. We dare not leave to chance—or to private management decisions on research funding—the solution of questions of such great strategic necessity.

Let us take a look at the money involved. For convenience and clarity these will be given in round numbers. The gross national income is now about 350 billion dollars per year. The national budget is 77 billion. Of this, 40 billion is for defense in all of its forms. Research and engineering consumes about 6 billion dollars annually. As near as can be estimated, of this 6 billion, one-half billion is spent each year in the technology of materials. Much of this is buried in the shops and laboratories of the military contractors, but a considerable amount may be directly identified as research on engineering materials, and this amounts to 90 million dollars per year.

We are engaged in a Cold War contest based on technology, and success will attend the discovery of new scientific facts and their prompt application to end products, processes, procedures, and weapons.

This symposium has dealt largely with the education and training of engineers and scientific people at the undergraduate level. New facts in ma-

[1] Special Assistant to the Director of Defense Research and Engineering, Washington, D. C.

terials are needed and these can evolve only from scientific research. Because of the complexity of modern science, long years of training are now necessary for the practitioner to catch up with what has been previously learned in order that he may go on to discover and recognize new facts from nature. Two kinds of activity are generally required. One is the collection of data. This task can often be assigned to technologists representing a wide spectrum of training in detail, subject to the guidance of a professional scientist of top-level training. The second kind of activity is wholly new exploratory research which requires a combination of training and imagination. Obviously we need different kinds of people. The discussion at this meeting has emphasized the point that we should not leave engineering to one who would be an amateur engineer even though he may be a fine scientist. This is wrong on two counts. We would be employing the scientist in a way foreign to his training, and we need the art of the experienced engineer. A team effort is therefore presented to us as a necessity.

We estimate that there are graduated each year about 400 scientists at the Ph.D. level who have had training in the disciplines related to materials sciences: namely, metallurgy, ceramics, plastics, physics of the solid state, and physical chemistry, to mention a few. Over the last ten years or so, this number of people has remained about static. It is obvious that more are needed and it is equally obvious that we cannot use all of them to do research in materials since some must devote their time to teaching and the stimulation of the work of others. In order to fill the gap in the national picture we would estimate that the number of Ph.D.'s graduated each year in the physical sciences should be increased by at least 50 per cent.

It is a fact of experience that creative work is most often done in a culture or background of people associated in a broad enterprise. This is the purpose of a university. The Department of Defense, therefore, has proposed to place contracts for research in materials in certain universities to support research in new fields while at the same time accomplishing the training of additional people.

Several moves are required to bring this about. There must be a bringing together of the disciplines of knowledge applicable to materials sciences, housing for the laboratories, equipment and continuation funds. Our present estimate is that an annual expenditure of about $20,000,000 is required to cover fundamental research in materials and to produce 300 additional Ph.D's per year. It is estimated that an additional $35,000,000 will be required for buildings and equipment.

The Federal Council for Science and Technology has given its support to the proposed program, and several government agencies will participate. The Department of Defense is undertaking to support between 50 and 60 per cent of the total program indicated. We believe this allocation is reasonable. The number of professional and technical people employed by the government has grown to the point where 50 per cent of the present technical graduates are employed, either directly or indirectly, on government work.

MR. DANIEL ROSENTHAL.[2]—One gets the impression on reading the report of the ASEE Committee on Nature and Properties of Materials that the

[2] Professor of Engineering, University of California, Los Angeles, Calif.

only salvation from sin lies in the "unified group of concepts and principles . . .. now emerging as a result of the interchange of ideas among workers in fields such as chemistry, solid-state physics, metallurgy, and ceramics." This is not entirely correct.

To be sure, the discovery of a unified group of concepts and principles means no less to engineering than it does to other fields. But no special discovery is required to build an engineering course on science. If it were so a new discovery might easily undo what the old one did. Fortunately, nothing of the sort is likely to happen.

In the course on materials which we set up about ten years ago at UCLA we show how the properties are dependent on the internal structure, not because this is the most modern view of the matter, but because it is the most *general*, the most predictable, and therefore the most useful to the student and his future function. However, if this view were not available, we would still have been able to make the course meaningful, nonetheless, by using the macroscopic approach. In fact, the phase rule is still the most potent tool in our possession for the prediction of the behavior of metallic and ceramic multicomponent systems. In one form or another it will remain so, for it is based on the most general principles of nature—the principles of thermodynamics.

The same rule is applied in deciding which properties to include. By giving preference to the most *general* properties of matter (whether mechanical, thermal, or electrical) and by basing the selection of the course material on this criterion, we are sure to include information that is not only pertinent to all fields of engineering, but that is also lasting: that which the engineer uses and will use again, on which he depends to anticipate the behavior of engineering systems.

However, generality of topics is but one of the criteria in designing a course. The continuity of purpose, the unity of action—to borrow an expression from the playwright—is another. We cannot be sure of our selection unless it is not only necessary but also sufficient, unless it has neither left out too much nor too little. Without providing the ultimate proof, unity of action appears to be a reasonable criterion of our choices. A course carries a great deal more conviction if it has unity of action, if the topics succeed each other as inevitably as events in a well planned drama.

The materials course of the past—or is it already a past?—was anything but that. It moved from one topic to another almost by chance. Why did iron and iron alloys precede and not follow non-ferrous metals? What had rocks and stones in common with cement and concrete? There was no answer to these questions, for nothing in the aim of the course implied they were necessary. They became meaningful only when science cut out a path for the course.

Yet the signposts were there for all to read. The ancient Greeks suspected their existence, but modern science brought them into the open. Out of this background a spectacle has emerged, a spectacle of unity and order which did as much to the understanding of properties of materials as it did to the progess of science.

This is the unfolding sequence of events working its way from the elementary particles up to higher and more complex organizations of matter by a common process of repetition. The repetitive unit—the unit cell—may contain as little as one or several atoms (metals and many minerals) or as many as hundreds of thousands of them (large polymer molecules), and it may consist of several thousands of these molecules as in the case of tissues of living organisms. Yet in all these organizations the properties of the whole are determined uniquely by only two characteristics: the properties of the elementary particles composing the unit cell, and the variety of ways (entropy) they can be arranged in this cell.

To achieve unity of purpose the course at UCLA does not stop at the last landing in the mineral kingdom when ascending the staircase of evolution. Rather it makes a short, but decided, incursion into the realm of living organisms to bring out again continuity of physical properties.

Our past and present experience makes us feel that a course conceived along these broad lines is sufficiently flexible and versatile to comply with the changing demands of the times. One such demand is the increasing use of statistical inference.

To meet this requirement the course on properties of materials beginning next spring will be taught at UCLA in two parts. Part I, in the sophomore year, will emphasize the predominantly static behavior of elementary particles (as manifested, for example, by the elastic, plastic, and fatigue properties), while Part II, in the second half of the junior year, will concentrate on their kinematic behavior (viscosity, creep, conductivity). The latter will be preceded by a one-semester introduction to statistical mechanics in the recently reorganized course on thermodynamics based on information theory.

In this manner we expect to avoid the all too frequently employed device of "it can be shown," when dealing with energy levels and band theory, and make the course not only more meaningful to the student, but also more relevant to the aim of engineering.