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# PROBLEMS OF THE ENGINEER

**By Dr. FRANK B. JEWETT**

BELL TELEPHONE LABORATORIES

AFTER a great many years of activity in one branch of the engineering profession, and through it having had some considerable contact with practically all the other branches of engineering, it seems to me that we are approaching an era—possibly we are already in that era—when the problems of the engineer, and particularly the problems of the engineering profession, are about to undergo some rather radical changes in their fundamental features. Whether we like it or not, and whether we would change the situation if we could, it seems clear not only that we are living in a highly mechanized age, but also that we and our children and their children are destined to continue to live in an even more highly mechanized environment. Periodically we hear or read statements and wails to the effect that it would be nice if we could return to a simpler mode of living. Any such possibility seems to be quite out of the question, however. The things of science which have been made useful to the people through the work of engineers have not only come to stay but are destined to increase in number. They have come in such large measure already, and they bid fair to come in such greater measure in the years ahead that many of the old controls which were developed through long ages of human activity no longer suffice for a proper ordering of them for the well-being of society.

We have about us everywhere the evidences of attempts to control a new scheme of living through the rules and regulations which grew up in an essentially agricultural and trading age. We are witness to all sorts of legislative action taken in an endeavor to control by statute things which can not be con-

[1] Address of the retiring vice-president of Section M—Engineering, American Association for the Advancement of Science, New Orleans, Louisiana, December 30, 1931.

trolled except in the light of a complete understanding of their scientific and engineering significance. Under the circumstances in which we find ourselves, it seems to me that if the people of the world are to live happily in the years ahead, and if their affairs are to be ordered in measurably decent fashion, a better general understanding of the things of science and engineering is imperative. Nor can this better understanding be confined to the limited few who make up the group of scientists and engineers. It must be an understanding which in some measure enters into our collective thinking and into our acts as a group of human beings bound together by what we commonly call political ties. If this premise is correct it would appear that the engineer must of necessity play an increasingly important part in the general scheme of things, since he is the only man who in general has that full understanding of the facts of science as applied to the affairs of everyday life which is necessary for a proper operation of the new controls.

As I look back to my own experience, and still farther back through history, particularly the history of these last one hundred years, it seems evident that we of the engineering profession have been in principal measure so largely concerned with and so interested in physical things, in the creating of new structures and of new applications of old and new science, that we have been content to let the social significance of our work rest wholly in the hands of non-scientific or non-technically trained people. It is true that, individually, in practically every activity in which we have engaged, we have had some influence in molding affairs. Nevertheless, acting as a group, we have not taken the same part in the evolution of society in this mechanized age that I think we are to and must take in the years ahead of us. If you grant this premise, then it seems to me obvious that there are two main problems—three main problems possibly—to which some thought must be given.

In the first place there are the problems of education for the young men who are to be our engineering successors. Up to the present time our scheme of engineering education has been essentially one which acquainted young men with the fundamentals of their profession and something of the groundwork of science, on which all engineering is based. It has been concerned in addition with the rules by which science is applied in the profession of engineering—rules which in the last analysis are nothing but the job of mixing fundamental science with dollars in an economic structure. Of course this aspect of engineering education is bound always to be a very large part in any scheme of technical training. There must always be a large number of men who are competent to take the facts of science and the rules of engineering and apply them for practical purposes. Further, no man is likely to achieve to real eminence in the broader aspects of a social service based on engineering unless he is himself competent to do and judge some at least of the things which are the hallmark of good professional engineering.

Beyond this basic requirement, if I am right in my picture of the years ahead, it may well be that in some at least of our engineering schools—possibly in most of them—more emphasis will come to be laid on the social side of the engineering profession. Where this is done the objective will be so to endow the young men who go out from the schools that they will be competent not only to do the kinds of things that you and I have been called upon to do in our active life, but more competent than we to take their places in the whole scheme of evolving society.

Then there are the problems which affect us in our professional association one with another, that is, in our technical societies. In the past our societies have been in large measure places of meeting where technicians could gather together for a general interchange of ideas, for a discussion of technical problems and for the taking of whatever group action seemed advantageous for the advancement of our profession. Possibly in the years ahead our engineering societies, either through modification of their present organizations or in their associations one with another in such things as the American Engineering Council, will find it expedient and necessary to equip themselves in better fashion to play the part which society has a right to demand of us, its experts in this particular field, in bringing to play on the problems which will confront our people the general consensus of understanding which we alone possess in the greatest measure.

Finally, there are the problems of a better education of the great rank and file of the population who have an interest in but no specific concern with the practical applications of science. I surmise that a large part of the things which we are prone to criticize in the acts of our political leaders, our political parties and our various social groups, are not so much due to any malicious desire to warp the situation as they are due to a fundamental ignorance of the factors which are involved. In a word, where these acts seem to play ducks and drakes with the facts of science and engineering they are, I think, in the main, the unintentional result of insufficient understanding.

We who are engaged in any field of science or its application know that the most dangerous thing we can do is to fool ourselves, or permit ourselves to be fooled, with regard to the facts of science or engineering. Old Dame Nature has a very unpleasant way of never fooling herself or allowing her votaries to be fooled with impunity. If we engineers either consciously or unconsciously misuse or misapply facts, we are pretty sure sooner or later to find ourselves in serious difficulties. For the engineer who finds himself in this kind of trouble there is in the main no extenuating alibi. This being so, and if I am right in my suspicion that a large part of the things we now criticize is due to ignorance on the part of the public generally, then, to such an extent as is possible with a great mass of human beings, we owe it to ourselves and to the society of which we are a part, to do what we can to bring about a better general understanding of the possibilities and limitations imposed by nature. In a word, where the facts of science and their application are really the controlling factors in any proposed legislative and administrative undertaking, general knowledge of the inherent possibilities and limitations is highly advantageous.

All of us have had numerous illustrations indicative of the abysmal ignorance of men and women of intelligence about things which seem to us the everyday commonplaces of life. We have equally, I think, all had the experience of seeing how easy it is to educate intelligent individuals or small groups of individuals, if we can only get them to listen to what we have to say. Educating the occasional individual or occasional small groups, as to some particular topic, is, however, quite a different problem from that of educating millions of people. Nevertheless, it seems to me that these millions of people must, in the years ahead, come to have a better understanding of the fundamentals of science and engineering than have their parents and grandparents. Moreover, we scientists and engineers must in some way or other take a real part in bringing about that education. Further, either individually or collectively, we must be prepared to play a real part not alone in our purely technical activities but as citizens of the community and of the nation in which we live.

So much for some of the reasons which lead me to believe that we are on the verge of a different kind of engineering life than we have experienced these last forty or fifty years. Now there are two things which seem to me to indicate a change in the point of view and, through it, in the activities of engineers as regards the more strictly professional side of their work.

One of these is that in many fields of engineering we seem to be reaching the ultimate of possibility in our applications of the things of science. I use the word "seem" advisedly, for frequently when I have thought that we were clearly at or near the end of our rope I have had brought to my attention something which caused me to wonder whether my conclusions were as sound as I thought they were.

Take, for example, the matter of dams. While I am not a civil engineer, I do know a little of civil engineering and am cognizant of the fact that dams to impound water are among the most ancient of man's engineering structures. I presume that the first dams were built untold centuries before there was any recorded history. This being so, one might easily think that in all the long period of human history men would have had experience with every conceivable element entering into the construction of dams, and so would know all there was to be known about them. Yet when one talks with one's civil engineering friends, and when one reads the more or less acrimonious discussion which goes on with regard to the stability of gravity dams, the cause of failure of such things as the St. Francis dam, and the probable stability of the great new Hoover dam, one begins to wonder just how much we really do know about them.

Despite such uncertainties there are nevertheless some fields where there seem to be fairly clear indications that our prsent applications have reached close to the limit of the possibilities permitted to us by the fundamental facts of science.

As an example, I can cite one illustration in my own field of engineering where we seem close to the limit. Not being clairvoyant, I am even here, however, uncertain as to what future science may have in store for us. What I do know is that in the present state of scientific knowledge we in the communication field have in some directions just about reached the point where we can not hope to go farther along lines which have been tremendously fruitful in the past. As an illustration of what I have in mind, let me cite a simple case involving the transmission to great distances, of electrical impulses. Fifteen years or so ago very great advances were made in extending the range of electrical communication through the development and introduction of distortionless amplifying devices. You are all acquainted with one form of such devices in the vacuum tubes of your household radio sets. As employed in the extension of electrical communication these devices are made to control relatively large amounts of fresh energy supplied to the transmission channel at points distant from the sending station, in such a way that the minute control impulses which reach them are magnified many fold without distortion of form. In a word, they are employed in such manner that they appear to a still more distant point as the relatively near-by primary origin of the impulses.

These devices of practical utility, which grew out of fundamental research in physics, opened the door to what appeared to be an almost illimitable amplification of very small amounts of energy without distortion. Initially it appeared as though one might go on practically ad infinitum in the multiplication of energy under the control of very weak impulses and so provide for spanning almost any terrestrial distance which might be involved in electrical communication. For a considerable number of years after their initial introduction this assumption seemed to be quite within the bounds of practical possibility. It still appears to be within those bounds wherever it is reasonably possible to provide intermediate amplifying equipment to the communication channel at suitable intervals.

Recently, however, in our attempts to span very great distances where we were deprived of the possibility of providing these revivifying agencies, as we can on land lines, we have come face to face with what appears to be the stone wall of a fundamental obstacle inherent in the nature of matter. Specifically, we have encountered this obstacle in our attempts to bridge great ocean distances, such as the Atlantic, with a telephone table. Here, because we are deprived of the possibility of installing intermediate amplifiers, we must, if the problem is to be solved, at all, depend, at the distant end of our circuit, on the minute remnant which remains of the energy imparted to that circuit at the sending end. This might not be a serious obstacle if we had to deal only with the fact that this remnant of energy was minute. All that might be required in such a case would be the introduction of a train of amplifying devices each adding its increment to the elevation of the energy level.

What we do encounter is, however, something quite different. We find the remnant of energy with which we have to deal is so minute that it is approaching the level of the electrical energies involved in the noises produced by thermal agitation within the material of the conductor itself. A short step further in this diminution, such as might easily be produced by an extension of distance, will bring us to the point where no amount of amplification can be of service, since any amplification will elevate equally both the desired impulses and their masking background of noise, and we know of no way of separating the two. Unless and until, therefore, some one finds either a metal which has a lower background of inherent noise, or a way by which that background of noise, which covers the entire spectrum, can be gotten rid of, there is a definite limit to what we can do.

Other examples might, I think, be cited to indicate that in certain other branches of engineering there are in the present state of our knowledge definite limits to what we can do in an engineering way. Where such fundamental obstacles are found to exist it is obvious that the past course of engineering development, on its more technical side, must be altered. In a word, we will have in such fields reached the frontiers and must consequently direct our energies to developments within those frontiers. Put another way, it means that in those particular sectors the engineering of the future must be directed to the problem of filling in gaps which now remain, in bettering the structures which we have already erected inside the frontier, in cheapening these structures, or in the thousand and one ways with which we settle up an already discovered country.

In other directions and in other branches of engineering it is quite obvious that we have not yet reached the point where such limits have begun to operate. In these fields progress can still be made along the old lines, although even in such areas I imagine that, relatively, we shall see much more attention given to the filling-in processes as we go along than may have been the case in times past.

There is another direction in which it seems to me that the engineering profession of the years ahead is likely to have a somewhat different point of view and a somewhat different method of approach from that which we have known in the past. Fundamental science has been bringing to us as raw material for our profession, these last three or four decades, a perfectly stupendous amount of new knowledge. New facts thoroughly proven in the research laboratory have been placed at our disposal to be applied as were the older facts which were their predecessors. In the main these new facts have had to do primarily with the ultimate structure of matter. They have placed and are placing in our hands smaller building bricks than we have had to deal with, and very much smaller building bricks than our engineering predecessors of a few decades ago had to deal with. All of us know that finer and more substantial structures can be made with finer ultimate elements than can be fashioned out of cruder things. To the extent therefore that this is so, it means both that our engineering structures of the future and the engineering attack which produces them must be concerned more with intimate details than has been the case in the past.

Further, in many branches of engineering, this added knowledge which the physicists and chemists are placing at our disposal is indicating quite clearly the basic causes of some of those failures which in the past we have guarded against by the rather crude processes of enlarged dimensions which we have come to designate as factors of safety. To me these so-called factors of safety should in fact, to a large extent, more properly be designated as factors of ignorance. Factors of safety will still be involved to insure against the unknown in the matter of maximum stresses, but they should in large measure be eliminated insofar as the inherent properties of the structural material itself is concerned.

Obviously, the more we can know with certainty about the things with which we deal, the farther we can go in refining our engineering in the design of our structures. This fact alone seems to be certain to have a very considerable influence on the type of education which we shall afford the young men who are to be the engineers of the future. Those among these young men who have in them the ability to reach the top of their profession, in whatever field of engineering, must be provided with a better knowledge of physics and chemistry and the underlying principles which guide their practical application than you and I were given when we were going through the rudiments of our technical education.

As an illustration of the necessity for this more intimate knowledge of basic things, it is easy to show in some branches of engineering that such knowledge is absolutely essential to progress and safety. For example, we have in recent years learned that in certain alloys and aggregates very minute admixtures of certain things produce effects which are out of all proportion to the amount of the extraneous material. Frequently these effects have been deleterious and the minute admixtures have been referred to as poisons. In other cases the effects have been beneficial.

Again, turning to the field with which I am best acquainted, I can cite you an example of what I have in mind.

Some years ago, in our quest for a magnetic material which would be more magnetic than the best irons and steels which were then available, and which, if produced, would open up wide avenues of progress, we evolved an alloy of nickel and iron. As I remember it, it was an alloy containing about 78 per cent. nickel and 22 per cent. iron. This alloy, when properly fabricated and properly heat-treated, had very remarkable magnetic properties. For the magnetizing forces with which we have to deal in communication circuits it was found to be many times more magnetic than the best irons and steels previously available and to have other desirable properties. It was consequently a very valuable addition to our store of structural materials. At the same time we learned, however, that very small admixtures of certain ingredients into the alloy had tremendous deleterious or poisoning effects on the magnetic properties of the alloy.

This discovery was a striking illustration not only of the effect of small things in upsetting the calculations which might otherwise have been made, but also of the dangers which one runs in proceeding too boldly to use some new discovery without the most complete and exhaustive investigation of the things which may result from slight deviations from absolute perfection. If I remember correctly, some rather disastrous consequences have followed attempts to use some of the newer steels or some of the newer forms of heat treatment of steel in mechanical structures. In all such cases which come to mind, the difficulty was either lack of complete understanding or failure to enforce rigorously the known controls in the factory.

Thus in many directions the engineer of the future, in my judgment, must of necessity deal with a much more certain and more intimate knowledge of the materials with which he works than we have been wont to deal with in the past. As a result of this more intimate knowledge his structures will be more refined and his factors of safety in many directions are bound to be less because the old elements of uncertainty will have in large measure disappeared. All in all he will be working on a sounder base of knowledge than has heretofore been possible. To the extent that this is possible, it must inevitably have a very considerable influence on the type of education given in our technical schools, at least to the men who have the inherent capacity to develop into the leaders of the engineering profession.

I would add just one word more about the changes which it seems to me are likely to come about in the relation of our successors to our profession. Whatever changes there may be in the intellectual or social phases of engineering, one can not escape a realization of the tremendous interest which resides in the purely physical. It is a type of interest which does not exist in any purely intellectual type of achievement. As one advances in years and experience the normal tendency of the engineer is to become more and more involved in phases of engineering which are essentially intellectual, and to a large extent lacking in personal contact with the purely physical. No matter how much satisfaction one may derive from the successful completion of a task of this kind, it is devoid of much of the thrill that accompanies the creation of a physical thing with one's own hands or through one's own efforts. I know this from my own experience, and while I derive a large amount of pleasure from the solution of the problems with which I now deal, they do not linger vividly in my memory as do the problems of my earlier years. As a matter of fact, I doubt if I derive as much personal enjoyment from the things of my business life as I do from the simple little structures which I make in my own shop merely as a matter of personal relaxation.

There is something stimulating in the creation of things which exist physically, which you can look at or feel, which does not exist in any purely intellectual achievement. This being so, I would not for a moment desire that the training of engineers for the future should so over-emphasize the purely intellectual side of our profession as to blot out the training which will enable men to produce things physically.

We must always have in mind that our engineers, in the last analysis, must be the creators of physical things if they are to be real producers, have a real understanding of their profession, and be able to play the enlarged part which I foresee to be the province of our successors.

As a telephone engineer I get a tremendous kick, whenever I go across the continent, merely in looking out of the car window and seeing such a simple thing as the pole line which carries the transcontinental circuits. Why? Because I realize that some of the best and happiest years of my life were spent in the creation of that very physical thing. At the present time I deal with similar problems almost wholly in an abstract way. I decide what sort of things should be done and I pass judgment on the work of others, but in the main I have no part in the construction of the things themselves. My life is given up almost entirely to paper-shuffling and various forms of intellectual gymnastics, which leave in me relatively little satisfaction.

# ON POSTULATES OF PROOF IN PROBLEMS OF THE BACTERIAL LIFE CYCLE

By Professor HANS ZINSSER, M. D.

DEPARTMENT OF BACTERIOLOGY AND IMMUNOLOGY, HARVARD MEDICAL SCHOOL

INTO many of the etiological questions of modern bacteriology there have been introduced problems of far-reaching biological consequences, which must be approached with the grim logic of the bacteriological forefathers unless we are to flounder in a bewildering confusion. These are the matters of the filterable stages of true bacteria and the suggested cyclic relationship between bacteria and the ultramicroscopic viruses. These two questions have often been confused with each other and there is a growing school of investigators from whose work it is often unclear whether they advocate one of these theories only or whether, in claiming the truth of one, they mean to imply that of the other as well. In regard to these developments, bacteriology is in much the same confusion with which it was threatened in the early etiological era, when countless false leads were laboriously followed out by investigators who attached etiological conclusions to the mere isolation of any organism from an animal or man suffering from a specific disease. And the formulation of his postulates by Koch was the warning of an uncompromising disciple of the truth against the dangers of allowing faulty reasoning to leap across experimental chasms. It is time for us to set up, in consultation, similar postulates in regard to the problems alluded to, if we are to avoid the obstructions to permanent progress which loose reasoning always produces. For there is no room for two schools of theory in any of these matters. Either a proposition is demonstrable by experiment, and confirmable, or it is not. And it can only delay the successful pursuit of the truth to claim, as established fact, conditions which have not been so established by observation. No one would be more delighted than the writer of these notes if most of the claims that have recently tended to establish a traceable cyclic relationship between invisible and visible forms of bacterial life could be substantiated. Such an achievement would enormously increase the capacity of bacteriologic methods to clarify important biological and medical problems. But we gain nothing in this direction unless we set down clearly the criteria of proof which alone can justify us in incorporating these new conceptions into the premises of our science. Regarding such criteria opinions may differ. It is with the purpose of clarifying this issue that these notes are written.

Let us consider first the question of the existence of filterable forms of true bacteria. The impulse for the present activity in this field was the great progress made in the knowledge of bacterial dissociation. And, in regard to this, it is gratifying to realize that the horizon of bacteriology and immunology has been infinitely enlarged by the studies of the so-called "mutations" in which cultural and colony studies and their immunological and chemical correlations constitute a series of discoveries achieved by the most rigid observance of that type of self-criticism in experiment which, it seems to us, is often lacking in the fields of inquiry which are the subject of this discussion. That all methods of bacterial filtration are complicated by a host of experimental irregularities is well known. And that there is no satisfactory method of appraising any of the ordinary