Research Work and its Applications.¹

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RESEARCH is a word that is much used nowadays : especially, we may perhaps say, in consequence of the tremendous applications of science during the years of the War. There is a conviction that we ought as a nation to take more trouble about our research work and put it on a stronger foundation. The very existence of a Department of Scientific and Industrial Research, with power to allot large sums of money to the encouragement of research in promising directions, is a witness to the firmness with which that conviction is held on the part of Government. The various Industrial Research Associations which have been formed are breaking new ground, and some at least are going to reap a harvest. The fighting services have each of them, Army, Navy, and Air Force, well-established research departments, doing fine work. Medical research is eagerly promoted, though, of course, the possibilities seem so great that it is easy to be impatient with the money and time devoted to it. In British Universities and Technical Schools the capacity for research is, as we all know, a test of constant application to candidates for teaching positions and to students seeking the better classes of degree. It is all good healthy movement. Let me try to show what we are doing and to bring our main aims into focus. In what way do we hope to benefit by research ?

Let us begin with the work done by teachers and students in Technical Institutes. Why do we encourage the student to do research work at all ? To put a very practical question, why does a student stand a better chance of preferment if he has read a paper before some scientific society ? We should answer, I think, that his research work is a guarantee that he possesses something more than the capacity to learn from books : a something which is of urgent importance to himself and to others. It implies a training of a special character. Research work brings out a man's self-reliance and proves his capacity to march by himself.

A good research student is like a fire which needs but the match to start it. It is a discipline to put the text-book to one side and to get out further knowledge by one's own effort. It teaches the student how to value evidence ; how to read with discretion, since he must weigh what others have done before he uses the previous knowledge as a foundation for his own advances. He learns to meet disappointment, to realise how little he can do in a day, and that weeks or months may go by without obvious progress. It is strange to discover that he must spend so much time on small things, that he must wait a week before he has succeeded in stopping a small leak, or go himself to buy some trivial thing, or spend weary hours in the adjustment of an instrument which in the end he learns to put straight in a moment. There is so much little work to be done before the good observations come ; it may be that weeks are spent in preparation and five minutes in making the actual measurement. It is all very humiliating ; and the blunders one makes

are very foolish ; and the one redeeming feature is that in its apparent perversity it is like every other piece of real work. Research is rather like playing against bogey at golf : Nature never has any weakness of which advantage may be taken ; there is no hole to be won by bad play because our opponent plays worse. Yet research is very human, for the researcher finds himself one of a company who have in their turn striven and denied themselves, very happily ; and have handed on their experience to those who take up the quest where they have left it.

It is, as I have said, a great discipline ; and there is always the hope before every student that he may contribute something to the total of human knowledge. Perhaps the hope is not so often reached as it might be, but that does not mean that the work has been done in vain : a thousand times, no. It is a remarkable fact that if a man tries to set down on paper, in line or in colour, that which he sees in Nature, his own vision of what is beautiful is quickened. The pencil teaches him the beauty of line, and the brush opens his eyes to all sorts of delicate colour schemes which he never saw before. It does not matter if his efforts are a bitter disappointment to himself, and he need not show them to any one else. Similarly, the man who strives to understand the workings of Nature by experiment which may make him feel very feeble and stupid, is paid by his discovery of a richer world. There is a fellowship between all who have tried to understand, which enables the worker in one field to have a welcome power of appreciation of the work of others. He gains not only in the richness of appreciation of what is beautiful and interesting, but also in the power of making friends.

But we may well say these are not the things which we have most in mind when we devote the national funds to research. We expect results which will be of benefit to us all. We realise that activities of to-day are the consequence of discoveries of the past : that, for example, Faraday's discovery of electro-magnetic induction laid the foundation of all the electric development of our time ; that Pasteur's researches in bacteriology gave us new insight into the meaning of disease and new powers to fight it ; and that the work of the organic chemist has given us a host of new colours for our pleasure. We know that in a thousand ways the results of research have added to our riches, removed our disabilities and eased our pain.

If science has also been turned to sad purposes, as in the poison gas, we can say justly that for one life it has been made to take by evil use, it has saved a hundred in the hands of those fit to employ it. We cannot escape from the need to defend our country and establish her in the world : it is true, however sad it may be, that if we do not develop research among us so that we may improve our fighting capacity, then other nations can bring us to defeat and shame. Further, if we fail to bring the efforts of research to the help of our industries, we run the deadly risk of losing our means of livelihood. Willy-nilly, we must research, and with all our energy.

¹ From an address delivered at the Sir John Cass Technical Institute on January 30.

Here are various reasons for the encouragement of research: the benefit of the student, the addition to human knowledge, power and riches, and the needs of defence, military and industrial. But I think we still have failed to include the most important reason of all, the real reason of which the others are only derivatives. It is that the spirit of research is like the movement of running water, and the absence of it like the stagnation of a pool. Scientific research, in its widest sense, implies, of course, far more than exploring the questions of physics and chemistry and biology. It is not a religion; but it is the act of one. It is the outcome of a belief that in all things which we try to do we may by careful seeking and by a better understanding do them better; that the world, far beyond what we can see of it on the surface, is full of things which it would be well for us to know. It is our duty and our gain to explore: we have always grown by doing so, and we believe that the health of our souls depends on doing so. Shall we sit still when

there are difficult questions to solve; and when the answers may give us new insight and new power? There is a hesitation which would beg us not to push forward lest we come to think less of the world. As against this, research is an act of faith in the immensity of things. There is no end to the search: it is a poor thought that there might be.

The spirit of research would drive us all to work to the utmost of our power, believing that the more we do and the better we do it, the better for the work and lives of others. It is vigorous, hopeful, trustful and friendly; it adds always new interest and new life. It is a spirit which should run through all our activities, and not be found in laboratories only. It is, in fact, a spirit which is essential to us as a nation trying to rise above ourselves to better things. All our efforts to encourage research have before them not only one or other such immediate object like that to which I have already referred, but also this great ideal.

Lightning and High-Voltage Phenomena.

MANY estimates have been made of the voltage required to produce a lightning flash. It is now possible to give a rough estimate. The very high pressures at present used in the everyday transmission of electric power by engineers have led to researches in high-voltage phenomena, and results have been obtained which prove that the average voltage before a lightning flash occurs is of the order of 100 million volts. The General Electric Co. of America has built a million-volt (1.4 million maximum) transformer for testing the strings of insulators which are used to suspend the power lines in California where the pressures between neighbouring wires are 220,000 volts. It is also necessary to test the lightning protective devices used, and so a two-million-volt "impulse" generator has been built for this purpose.

Mr. F. W. Peek, the consulting and research engineer of the General Electric Co., describes in the January number of the Journal of the Franklin Institute some interesting experiments he has made with these machines and deduces important results. He finds that up to two million volts, the maximum highest voltage obtained, the ordinary formulæ for the sparking distances between spherical electrodes are true. Consequently, with very large electrodes at considerable distances apart, an average voltage of 150,000 per foot is required to produce a spark. Estimates of the voltage required for a lightning flash can therefore reasonably be made.

Mr. Peek has found that the laws for disruptive discharge between needle gaps, between spherical electrodes and for visual coronas found at low voltages, still apply at high voltages. He proves experimentally that the curve connecting the disruptive voltage for a needle gap with its length is a straight line at least up to two million volts. The curve for a spherical electrode gap is in accordance with the assumption that the disruptive discharge takes place when the maximum value of the potential gradient in the gap attains a definite well-known value depending on the size of the spheres. It was found by experiment that the "impulse" spark-over voltage of the needle gap varies

with the wave shape of the impulse, but the sphere gap disruptive voltage is practically unaffected by the wave shape.

The experiments prove that the wet and dry spark-over voltages for strings of insulators are practically the same whatever the applied pressure. The voltages used in these experiments were of the same order as the "lightning voltages" which appear on power transmission lines. It is known that a definite amount of energy is required to rupture gaseous, liquid, and solid insulating materials. For example, when a voltage is applied at a very rapid rate, as by an impulse generator, breakdown does not occur at the same pressure as that required by a continuously applied voltage. In air with spherical electrodes the time lag is practically negligible, but with needle points it is easily measurable. Hence this can be used to measure the rapidity of the impulse.

Photographs are shown of a spark-over on a string of porcelain insulators protected by two large rings at each end. The discharge is seen taking place between the rings, the insulators being completely shielded. Lightning voltages cause coronas on the wires. It was found that a corona produced by a "lightning" voltage which lasted less than the millionth of a second could be easily seen. The fact that coronas are caused by these sudden voltages explains why lightning discharge rushes are so rapidly damped on transmission lines.

Mr. Peek calls lightning an "electrical explosion," and states that time periods of less than the millionth of a second are required for the discharge in model "lightning" generators in order to get trustworthy results. He uses a generator giving two million volts, and it sometimes produces a current of the order of ten thousand amperes. A photograph is shown of a large wooden post split and blown apart by the discharge. After the explosion the wood had the odour of the gases produced by destructive distillation, but there was no sign of burning. A plate of glass coated with metal was perforated at this pressure.

When lightning strikes the earth where the soil is