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CONTENTS

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SCIENTIFIC EDUCATION AND THE TEACHING OF PHYSICS[1]

THE real cause of the prevailing neglect of science, with all its pernicious results, is that almost all our political leaders have received the most favored and fashionable form of public school education, and are without any scientific education. An education in classics and dialectics, the education of a lawyer, may be a good thing—for lawyers; though even that is doubtful. For the training of men who are to govern a state whose very existence depends on applications of science, and on the proper utilization of available stores of energy, it is ludicrously unsuitable. We hear of the judicial frame of mind which lawyers bring to the discussion of matters of high policy, but in the majority of scientific cases it is the open mind of crass ignorance. The result is lamentable: I myself heard a very eminent counsel declare in a case of some importance, involving practical applications of science, that one of Newton's laws of motion was that "friction is the cause of oscillations"! And the helpfulness of some eminent counsel and judges in patent cases is a byword.

As things are, eminence in science is no qualification, it would even seem to be a positive disqualification, for any share in the conduct of the affairs of this great industrial country. The scientific sides of public questions are ignored, nay, in many cases our rulers are unconscious of their existence. Recently in a discussion on the Forestry Bill in the House of Lords a member of that illustrious body made the foolish assertion that forestry had nothing to do with science; all that was needed was to dig holes and stick young trees into them. Could fatuity go further?

[1] Concluding part of the address of the president to the Mathematical and Physical Science Section at the Bournemouth meeting of the British Association for the Advancement of Science.

This hereditary legislator who, as things are, has it in his power to manage, or mismanage, the conversion into available energy of the radiation beneficently showered on a certain area (his area) of this country of ours does not seem to be aware that the growing of trees is a highly scientific industry, that there are habits and diseases of trees which have been profoundly studied, that, in short, the whole subject of silviculture bristles with scientific problems, the solutions of which have by patient labor been to a considerable extent obtained.

Take also the case of the dyes industries. The publicists and the good business men—the supermen of the present age—who wish to control and foster an industry which owes its very existence to an English chemist, refuse to have on the committee which is to manage this important affair any man of scientific eminence, and no remonstrance has any effect. These great business men are as a rule not scientific at all. They are all very well for finance, in other respects their businesses are run by their works-managers, and, in general, they are not remarkable for paying handsomely their scientific assistants.

I myself once heard it suggested by an eminent statesman that an electrical efficiency of 98 per cent. might by the progress of electrical science be increased fourfold! This, I am afraid, is more or less typical of the highly educated classical man's appreciation of the law of conservation of energy; and he is, save the mark, to be our minister, or proconsul, and the conservator of our national resources. It is not surprising, therefore, that in connection with a subject which for several weeks occupied a great space in the newspapers, and is now agitating a large section of the community, the nationalization of our coal mines, there was not a single word, except perhaps a causal vague reference in the report of the chairman, to the question, which is intimately bound up with any solution of the problem which statesmen may adopt, I mean the question of the economic utilization, in the interests of the country at large, of this great inheritance which nature has bestowed upon us. In short, are Tom, Dick and Harry, if we may so refer to noble and other coalowners, and to our masters the miners, to remain free to waste or to conserve at their own sweet will, or to exploit as they please, this necessity of the country's existence?

The fact is that until scientific education has gone forward far beyond the point it has yet reached, until it has become a living force in the world of politics and statesmanship, we shall hardly escape the ruin of our country. The business men will not save us; as has been said with much truth, the products of modern business methods are to a great extent slums and millionaires. It lies to a great extent with scientific men themselves to see that reform is forthcoming; and more power to the guild of science and to any other agency which can help to bring about this much-needed result.

While scientifically educated men, whether doing special work or acting as officers, have been held of far slighter account in the services than they ought to have been, for physicists as such there has been little or no recognition, except, I believe, when they happened to be ranked as research chemists! How did this happen? Why, the various trades asserted themselves, and the result was a sufficiently long list of "reserved occupations," a list remarkable both for its inclusions and for its exclusions. There was, for example, a class of "opticians," many of whom have no knowledge of optics worth mentioning. They are merely traders. One of these, for example, the proprietor of a business, made a plaintive appeal to myself as to how he could determine the magnifying powers of certain field-glasses which he wished the Ministry of Munitions to purchase. But for a young scientific man, even if he were an eminent authority on theoretical and practical optics, but who was not in the trade, there was no place.

Research chemists received their recognition in consequence of the existence of the institute of chemistry. I am extremely glad to find that something is now being done to found an institute of physics. I hope this movement will be successful, and that it will be thoroughly practical and efficient. I hope its president and council, its members and its associates, will be jealous for science, and especially for physics. It ought to be a thoroughly hard-working body, without any frills, destitute of work value. They have an example in the General Medical Council, which has so effectively cared for the interests of the medical profession.

I am glad that something is being done at last for the organization of scientific research. This movement has started well in several, if not in all, respects, and I wish it all success. There are, however, one or two dangers to be avoided, and I am not sure—I may be much too timid and suspicious—that they are fully recognized, and that the result will not be too much of a bureaucracy. Somehow or other I am reminded by the papers I have seen of the remark of a poor man who, asking charity of some one in Glasgow, was referred to the Charity Organization Society of that city. "No, thank you," he said: "there is a good deal more organization than charity about that institution." So I hope that in the movement on foot the organization will not be more prominent than the science, and the organizers than the scientific workers.

There is to my mind too much centralization aimed at. Everything is to be done from London: a body sitting there is to decide the subjects of research and to allocate the grants. There may be a good deal to be said for that in the case of funds obtained in London. But apparently already existing local incentives to research work are to be transferred to London. The Carnegie Trust for the Universities of Scotland, soon after its work began, inaugurated a scheme for research work in connection with these universities. The beneficiaries of the trust, it is well known, must be students of Scottish nationality. The action of the trust has been most excellent, and much good work has been done. Now, so far as chemistry and physics are concerned, it has been proposed, if not decided, to hand over to the organization in London the making of the awards, a process of centralization that will probably not end with these subjects. I venture to protest against any such proceeding. The more incentives and endowments of research that exist and are administered in the provinces the better. Moreover, this is a benefaction to Scottish students which ought not to be withdrawn and merged in any provision made for the whole country, and administered in London by a bureau which may know little of the Scottish universities or of Scottish students. The bureau might, with equal justice or injustice, be given command of the special-research scholarships of all the universities both in England and Scotland, and administer them in the name of the fetish of unification of effort. I do not know, but can imagine, what Oxford and Cambridge and Manchester and Liverpool would say to that. But even Scotland, where of course we know little or nothing about education of any kind, may also have something to say before this ultra-centralization becomes an accomplished fact.

There is, it seems to me, another danger to be avoided besides that of undue centralization in London. In most of the statements I have seen regarding the promotion of research work the emphasis seems to be on industrial research, that is in applied science. This kind of research includes the investigation of physical and chemical products of various kinds which may be used in arts and manufactures, and its deliberate organized promotion ought to be a commercial affair. I observed, by the way, with some amusement, that according to the proposals of one committee for applied science, which is prepared to give grants and premiums for researches and results, the professor or head of a department, from whom will generally come what are most important, the ideas, is to have no payment. He is supposed to be so well paid by the institution he belongs to as to require no remuneration for his supervision of the committee's researches. And the results are to be the sole property of the committee!

There is in this delightfully calm proposal at least a suggestion of compulsion and of interference with institutions and their staffs, which ought to be well examined. Also some light is thrown on the ideas of such people as managing directors of limited liability companies, who are members of such a committee, as to what might reasonably be expected of men of high attainments and skill, whose emoluments taken all round are on the whole miserably insufficient.

I think that it is in danger of being forgotten that, after all, pure science is by far the most important thing. Most of the great applications of science have been the products of discoveries which were made without any notion of such an outcome. Witness the tremendous series of results in electricity of which the beginning was Faraday's and Henry's researches on induction of currents, and the conclusion was the work of Hertz on electric waves. From the first came the production and transmission of power by electricity, from the last the world has received the gift of wireless telegraphy. I am not at all sure whether the great men who worked in the sixty or seventy years which I have indicated would have always received grants for proposed researches, which to many of the good business directors and other supermen serving on a great bureau of investigation, had such then existed, would have appeared fantastic and visionary. In research, in pure science at least, control will inevitably defeat itself. The scientific discoverer hardly knows whither he is being led: by a path he knows not he comes to his own. He should be free as the wind. But I must not be misunderstood. Most certainly it is right to encourage research in applied science by all available and legitimate means. But beware of attempting to control or "capture" the laboratories of pure science in the universities and colleges of the country. Let there be also ample provision for the pursuit of science for its own sake; the return will in the future as in the past surpass all expectation.

I had intended to say something about scientific education as exemplified by the teaching of physics. I have left myself little time or space for this. I can not quite pass the matter over, but I shall compress my remarks. In the first place I regard dynamics, especially rotational dynamics, as the foundation of all physics, and it is axiomatic that the foundation of a great structure should be soundly and solidly laid. The implications of dynamics are at present undergoing a very strict and searching examination, and now we may say that a step in advance has been taken from the Newtonian standpoint, and that a new and important development of dynamics has come into being. I refer of course to the new theories of relativity, which are now attracting so much attention. I hope to learn from the discussions, which we may possibly have, something of the latest ideas on this very fundamental subject of research. It is a matter for congratulation that so many excellent accounts of relativity are now available in English. Some earlier discussions are so very general in their mathematical treatment and notation as to be exceedingly difficult to master completely. I have attacked Minkowski's paper more than once, but have felt repelled, not by the difficulties of his analysis, but by that of marshalling and keeping track of all his results. Einstein's papers I have not yet been able to obtain. Hence it is a source of gratification to have Professor Eddington's interesting Report to the Physical Society and the other excellent treatises which we have in English. But continual thought and envisaging of the subject is still required to give anything approaching to instinctive appreciation such as we have in ordinary Newtonian dynamics. I venture to say that the subject is preeminently one for physicists and physical mathematicians. In some ways the new ideas bring us back to Newton's standpoint as regards so-called absolute rotation, a subject on which I have never thought that discussions of the foundations of dynamics had said absolutely the last word.

The better the student of physics is grounded in the older dynamics, and especially in the dynamics of rotation, the sooner will he be able to place himself at the new point of view, and the sooner will his way of looking at things begin to become instructive.

With regard to the study of physics in our universities and colleges, I had written a good deal. I have put that aside for the present, and will content myself with only a few general observations. First, then, it would, I think, be conducive to progress if it were more generally recognized that dynamics is a physical subject, and only secondarily a mathematical one. Its study should be carried on in the departments of physics, not in those of mathematics or in separate departments of applied mathematics. It is, or ought to be, essentially a subject of the physical lecture-room and the physical laboratory. The student should be able to handle rotating bodies, to observe and test the laws of precession and nutation, to work himself, in a word, into an instinctive appreciation of at least the simpler results of rotational theory. He should learn to think in vectors, without necessarily referring either to Hamilton or to Grassmann. Some people appear to censure the use of vector ideas without the introduction at the same time of some form of vector notation. I do not feel drawn to any system of vectors in particular—all have their good points, and in some ways for three dimensional work the quaternion analysis is very attractive—but vector *ideas* are of the very utmost importance.

Hence I deprecate the teaching, however elementary, which as a beginning contents itself with rectilineal motion. The true meaning of rate of change of a directed quantity, even of velocity and acceleration, is missed, and instead of having laid a foundation for further progress the teacher, when he desires to go beyond the mere elements, has practically to relay his foundations, has in fact to extract imperfect ideas from his pupils' minds and substitute new ones, with the result that a great deal of avoidable perplexity and vexation is produced. The consideration of the manner of growth of vectors—the resultant vector or it may be component vectors, according to convenience—is the whole affair. As an illustration of what I mean, take this: A vector quantity has a certain direction, and also a magnitude L. It is turning in a certain plane with angular speed ω. This turning causes a rate of production of the vector quantity about a line in that plane and perpendicular to the former, and towards which the former is turning, of amount $L\omega$. Thus a particle moving in a curve with speed v has momentum mv forwards along the tangent at the position of the particle. The vector is turning towards the principal radius (length R) of curvature at the point at rate v/R. Hence towards the center of curvature momentum is growing up at time rate mv^2/R.

Dealt with in this way, with angular momentum instead of simple momentum, the motions of the principal axes of a rigid body give the equations of Euler instantly and intuitively, and all the mind-stupefying notions of centrifugal couples, and the like, are swept away.

With regard to mathematics, the more the physicist knows the better, and he should continually add to his store by making each physical subject he takes up a starting-point for further acquisition. Some very philistine notions as to mathematics prevail, and are very mischievous. For example, I once heard an eminent practical engineer declare that all the calculus an engineering student requires could be learned in an hour or two. This is simply not true, nor is it true, as some exponents of ultrasimplicity seem to suggest, that the professional mathematical teacher wilfully makes his subject difficult in order to preserve its esoteric character. Like the engineer or physicist himself, he is not always so simple as he might be; but the plain truth is that no good progressive mathematical study can be carried out without hard and continued application of the mind of the student to the subject. And why should he depend on the mathematical teacher? Let him be his own teacher! There are plenty of excellent books. If he has a determination to help himself he will, if he makes a practise of reserving difficulties and returning to them, find them vanish from his path.

As I have said, I am specially interested in rotational dynamics. In the course of the war I have been appalled by the want of appreciation of the principles of this subject, which, in spite of considerable acquaintance with the formal theory, seemed to prevail in some quarters. I don't refer to mistakes made by competent people—it is human to err—but to the want of appreciation of the true physical meaning of the results expressed by equations. A gyrostat as ordinarily considered is a closed system, and its dynamical theory is of a certain kind. But do away with the closedness, and the dynamical theory is quite a different affair. Take, as an example, the case of two interlinked systems which are separately unstable. This compound system can be made stable even in the presence of dissipative forces. A certain product of terms must be positive, so that the roots of a certain determinantal equation of the fourth degree may all be positive. The result shows that there must be angular acceleration, not retardation, of the gyrostat frame. This acceleration is a means of supplying energy from without to the system, the energy necessary to preserve in operation the functions of the system.

I have ventured to think this stabilizing action by acceleration of the compound motion very important. It is lost sight of by those who consider and criticize gyrostatic appliances from the usual and erroneous point of view. Also I believe that it is by analogy a guide to the explanation of more complicated systems in the presence of energy-dissipating influences, and that the breaking down of stability or *death* of the system is due to the fact that energy can no longer be supplied from without in the manner prescribed for the system by its constitution.

I had just concluded this somewhat fragmentary address when the number of *Nature* for July 24 came to hand, containing a report of Sir Ernest Rutherford's lecture at the Royal Institution on June 6. The general result of Sir Ernest's experiments on the collision of α-particles with atoms of small mass is, it seems to me, a discovery of great importance, whatever may be its final interpretation. The conclusion that "the long-range atoms arising from the collision of α-particles with nitrogen are not nitrogen atoms, but probably charged atoms of hydrogen or atoms of mass 2," is of the utmost possible interest. The α-particle (the helium atom, as Rutherford supposes it to be) is extraordinarily stable in its constitution, and probably consists of three helium nuclei each of mass 4, with two attached nuclei of hydrogen, or one attached nucleus of mass 2. The intensely violent convulsion of the nitrogen atom produced by the collision causes the attached nuclei, or nucleus, to part company with the helium nuclei, and the nitrogen is resolved into helium and hydrogen.

It seems that, in order that atoms may be broken down into some primordial constituents, it is only necessary to strike the more complex atom with the proper kind of hammer. Of course, we are already familiar with the fact that radio-active forces produce changes that are never produced by so-called *chemical* action; but we seem now to be beginning to get a clearer notion of the *rationale* of radio-action. It seems to me that it might be interesting to observe whether any, or what kind of, radiation is produced by the great tribulation of the disturbed atoms and continued during its dying away. If there is such radiation, determinations of wave lengths would be of much importance in many respects.

I may perhaps mention here that long ago, when the cause of X-rays was a subject of speculation, and the doctrine that mainly found acceptance was that they were not light waves at all, I suggested to the late Professor Viriamu Jones that radiation of extremely small wave length would be produced if atomic or molecular vibration, as distinguished from what in comparison might be called molar vibration, could be excited. An illustration that suggested itself was this: Take a vibrator composed of a series of small masses with spring connections. If these masses are of atomic or molecular dimensions any ordinary impulse or impact would leave them unaffected, while vibrations of groups of them, depending on the connections, would result. But the impact on one of the masses of a hammer of sufficiently small dimensions, and mass would give vibrations depending on the structure of the mass struck, and independent of the connections, just as the bars of a xylophone ring, while the suspended series of bars, if it swings at all, does so without emitting any audible sound. This is, I believe, in accordance with the theory now held as to X-rays. We now have some information as to the mode of producing a local excitement so intense as to cause not merely atomic disturbance, but actual disruption of the atomic structure. Further developments of Sir Ernest Rutherford's experiments and of his theory of their explanation will be eagerly awaited.

A. Gray

ENGINEERING SCIENCE BEFORE, DURING AND AFTER THE WAR. III

The nations which have exerted the most influence in the war have been those which have developed to the greatest extent their resources, their manufactures and their commerce. As in the war, so in the civilization of mankind. But, viewing the present trend of developments in harnessing water-power and using up the fuel resources of the world for the use and convenience of man, one can not but realize that, failing new and unexpected discoveries in science, such as the harnessing of the latent molecular and atomic energy in matter, as foreshadowed by Clerk Maxwell, Kelvin, Rutherford and others, the great position of England can not be maintained for an indefinite period. At some time more or less remote—long before the exhaustion of our coal—the population will gradually migrate to those countries where the natural sources of energy are the most abundant.

Water-power and Coal.—The amount of available water-power in the British Isles is very small as compared with the total in other countries. According to the latest estimates, the total in the British Isles is less than 1,500,000 h.p., whereas Canada alone possesses more than 20,000,000 h.p., of which more than 2,000,000 h.p. have already been harnessed. In the rest of the British Empire there are upwards of 30,000,000 h.p., and in the remainder of the world at least 150,000,000 h.p., so that England herself possesses less than 1 per cent. of the water-power of the world. Further, it has been estimated that she only possesses 2½ per cent. of the whole coal of the world. To this question I would wish to direct our attention for a few minutes.

I have said that England owes her modern greatness to the early development of her coal. Upon it she must continue to depend almost exclusively for her heat and source of power, including that required for propelling her vast mercantile marine. Nevertheless, she is using up her resources in coal much more rapidly than most other countries are consuming theirs, and long before any near approach to exhaustion is reached her richer seams will have become impoverished, and the cost of mining so much increased that, given cheap transport, it might pay her better to import coal from richer fields of almost limitless extent belonging to foreign countries, and workable at a much lower cost than her own.

Let us endeavor to arrive at some approximate estimate of the economic value of the principal sources of power. The present average value of the royalties on coal in England is about $6 per ton, but to this must be added the profit derived from mining operations after paying royalties and providing for interest on the capital expended and for its redemption as wasting capital. After consultation with several leading experts in these matters, I have come to the conclusion that about 1*s* per ton represents the pre-war market value of coal in the seams in England.

It must, however, be remembered that, in addition, coal has a considerable value as a national asset, for on it depends the prosperity of the great industrial interests of the country, which contribute a large