

Geometry, Algebra and Trigonometry the basis of the work of our intermediate classes.

This arrangement of classes, however, is not justified by the mere fact of its being desirable that men in both the above stages of mathematical study should have the advantage of a study of Physics. It must further be shewn that with the mathematical equipment assumed the work of our classes can be adequately accomplished. That it can, seems to be the opinion of a large body of teachers. For there are many text-books available for both classes, which are quite suitable in scope and in the amount of Mathematics assumed. And these books have not only been written by men who presumably believed in them, but shew by their extensive sale that they meet a felt want. This opinion, however, is not universally held; and the immediate occasion of this address is the publication (in *Nature*, vol. XL, p. 126) of a paper on "The vices of our scientific education," in which the opposite opinion is maintained. Its author, Prof. G. M. Minchin, is so deservedly eminent as a teacher in the department of Mathematical Physics, that the severe strictures which he makes on some portions of the work which I have sketched out for our classes here, have led me to reconsider the whole matter, and lead me now to bring before you the reasons why, notwithstanding his criticism, the maintenance of the present organisation of our classes seems to me to be justified.

Prof. Minchin's criticism of the work which we propose to do in our intermediate classes has reference to that part, in which we employ the methods of the Calculus without using its symbols and without requiring students to have previously obtained a knowledge of that branch of mathematics. "It may perhaps be best described," he says, "as Calculus dodging. For some curious reason, which I have never discovered, it has been generally assumed that a student can possess a very extensive knowledge of the results and principles of Dynamics,—of the composition and resolution of forces and couples in three dimensions, of the principle of work and energy, of the nature and properties of tubes of force, potential, etc.,—without any knowledge of the Differential or Integral Calculus. This is surely a piece of self-deception." If so, there can be no justification for a considerable portion of the work of our intermediate classes; and it is necessary therefore to enquire into the validity of this criticism.

But let me note first that the Calculus dodgers are a most respectable body of men. The most artful dodger of them all is Clerk Maxwell, whose book on the Theory of Heat, just because he obtains in it important thermodynam results, usually establish-

ed by the aid of the Calculus, in such a way that readers who have no knowledge of the Calculus can follow him, has obtained a wide popularity and is very extensively used. In Electricity, Cumming dodges, more laboriously it is true, but still to good purpose. In Optics Glaucbrook takes the same course, and to men of small mathematical equipment throws a flood of light on a region that was cloudy and dark before. In Dynamics, Clifford was a dodger of great power; and even Thomson and Tait do not disdain to employ the process when they can do so with elegance and grace, though they despise the laborious dodging which involves the use of unwieldy formulæ. May we not rank even Newton himself as a dodger though he had no Calculus to dodge? At any rate all those teachers who in these latter days encourage their pupils to study Newton, must be held to be guilty of aiding and abetting in the practice of this educational sin. And, indeed, we may increase the number of our allies to an almost unlimited extent by noting that whosoever establishes, without formal integration, the familiar laws of the motion of uniformly accelerated bodies, must be considered to be one of the noble army of dodgers.

We cannot settle a question of this kind, however, by authority. Prof. Minchin's hand may be against every man, but it may, nevertheless, have grasped the truth. Hence we must look into this charge of self-deception. Prof. Minchin merely makes the charge. He does not shew where the deception of self comes in. But I think one or two considerations will shew it to be unfounded. For what after all is it that the dodger does? He finds himself under the necessity of treating certain special variable quantities, without being able to make use of the knowledge which mathematicians have acquired of variable quantities generally, because his pupils do not possess it. Hence he treats the special quantity, if he can hit upon no better plan, and if the process is not altogether too cumbrous, in the same way as the mathematician has treated the general variable, and thus attains the same result as if he had applied to the special case the general results of the Calculus. There can thus be no more self-deception in dodging the Calculus than in obtaining the same result by applying it, provided always the dodging is properly done. It may, of course, be bungled; and I think it must be admitted that the dodging is more liable to be bungled than the applying, as it is a much more difficult process. But this should lead us rather to look carefully into each particular instance of the method than to indulge in general condemnation.

The next point in Prof. Minchin's indictment against Calculus dodging must to a large extent be