THE FOUNDATIONS OF MECHANICS

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BY

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FOUNDATIONS OF MECHANICS.

1. It cannot, I believe, be denied that amongst those who have to apply science to practice, and especially therefore amongst engineers, there exists considerable confusion as to the meaning of the fundamental definitions and fundamental principles on which the science of Mechanics is built. These definitions and principles are explained, it is true, in the various works written upon the science; but the explanations are not always as full and as clear as would seem requisite to prevent confusion; nor is it always easy to reconcile, at least at first sight, the definitions and explanations given in one work with those given in another. There would thus appear to be a want of some treatise which shall apply itself specially to the task of setting forth those fundamental definitions and principles in the fullest and clearest manner; using the accounts of them, given in the works above mentioned, as a guide, but supplementing or explaining these where necessary, and taking care to show how they harmonise with the actual facts, as to which, it may be stated at the outset, there is among scientific men little or no dispute. This want was, in fact, strongly insisted upon in a leading article of The Engineer, February 25, 1881; and it is in the hope of supplying it, at least in some measure, that the following pages have been written. They are not addressed to actual beginners in mechanics, but rather to those who have studied the subject in the ordinary way, but who still feel that they need a firmer and surer grasp of the principles, especially in order to be able to apply them with confidence in practice. It will be assumed, therefore, that the reader is familiar with the leading facts and propositions, both of mechanics and of engineering, and free reference will be made to these whenever necessary. For the same reason no attempt will be made to divide the subject sharply into

the three branches of statics, dynamics, and kinematics—a division which is convenient for the purpose of elementary instruction, but is in some ways unfortunate as regards the study of fundamental principles. On the other hand, the treatise is still less intended for advanced students of higher dynamics, whose perfect familiarity with, and agreement in, the symbolic form of the science, renders them comparatively indifferent to the names employed for its elementary conceptions. Their business is to rear and to ornament the building; mine is the humbler one of attempting to give an accurate plan of the foundations—a part of the structure which architects and householders are both somewhat inclined to neglect, but an acquaintance with which is necessary alike for the stability of the building and for the security and comfort of its inhabitants.

2. Before beginning to consider the definitions of mechanics, it will be well to make one or two remarks about definitions in general. It is necessary, in the first place, to draw a distinction, very important but often overlooked, between definitions of terms and definitions of things.* The nature of this distinction is well illustrated by the definitions used in algebra and in Euclid. When we proceed to prove a theorem or solve a problem by algebraical methods—for instance, a problem as to the number of acres in a field which is reaped under certain conditions—we begin by saying, "Let x = the number of acres in the field." We have then defined the term x for the purpose of that particular problem; from henceforward it stands merely as a convenient symbol for the words by which it is defined, and if we take care to preserve its meaning unaltered, we shall solve the problem much more easily and clearly by its aid. And this will not prevent us from defining the same term as something quite different—say the number of gallons in a particular tank—for the purposes of the next problem we may wish to attack. In both cases we are merely defining a term, and have only to take care

* This difference, which is, of course, an old one, is objected to by J. S. Mill—Logic, p. 296—but its reality and utility will be established, I believe, at least as far as mechanics are concerned, by the present treatise.

that we keep the term to its definition. But when Euclid defines a square as a quadrilateral figure, of which all the sides are equal, and all the angles right angles, he is not telling us in what sense he is going to use a particular *word*, but is giving a sufficiently accurate description of a particular *thing*, namely, a geometrical figure of which everybody has a general knowledge, and the exact properties of which it is his purpose to investigate. And all his other definitions will be found to be of a similar character.

3. From the distinction thus drawn several consequences follow. It is evident, for instance, that the same word may properly have several different definitions; different, that is, not merely in the exact words used, but in the conception which those words convey. But of these various definitions one only can be the definition of a thing—omitting the case of synonymous words, such as "race," as to which there is practically very little confusion: the others must only be definitions of terms. Thus, as we have just seen, the letter x, taking it as a word, may be defined as a term in innumerable different ways; but as a thing it can have but one definition, which would be somewhat as follows:—A letter in the English alphabet expressing a particular sound, which sound can of course be only spoken, not written. If a word is used indiscriminately of two things which are not, like the two meanings of "race," entirely different, but yet which cannot be brought under the same definition, confusion is nearly certain to result; and if the practice exists, and has gone too far to be stopped, the only remedy is to banish the word from precise and scientific language altogether. To give a single instance, the word "nature" has been used so widely and loosely, that it would almost certainly be impossible to construct a definition which should cover the whole of its applications; and accordingly it should never be used where accurate writing is intended.

4. It should, however, be noted that in giving several successive definitions to the same word, care should in general be taken to preserve some connection between them. Thus the connection between the innumerable definitions given to

x in algebraical problems, is that in every case it expresses the unknown quantity which is the subject of inquiry. Similarly in Co-ordinate Geometry, x expresses the co-ordinate of a point as measured not up but across the paper. If in any particular case we were to reverse this, and call x the co-ordinate measured up the paper, we should be extremely likely to get our work into confusion. Similarly, in giving a scientific definition, as a term, to a word which is used in ordinary speech, it is most desirable that the scientific should not be inconsistent with the ordinary acceptation. If it is, confusion is sure to follow, from the natural error of sometimes mixing up the meaning of the scientific term with that of the ordinary word—a fallacy than which none is more common in argumentative writings of all kinds. Thus, if we were to define nature as "the totality of all phenomena"—a definition actually proposed—we should certainly run into confusion when arguing with ordinary people, who recognise the possibility at least of phenomena which are supernatural, or beyond nature.

5. Further, it will be evident that the definition of a term will generally be much more meagre, but at the same time more complete, than the definition of a thing. A term may be used, and used correctly, of a number of things, which perhaps have no property whatever in common, except that to which the term applies; and in that case the definition can express nothing beyond that property. Thus, if we define an explosive as "a substance having the property, under the influence of heat or impact, of suddenly generating a large quantity of gas," that definition cannot be objected to on the ground that it does not really tell us what an explosive is; in other words, does not give us tests by which we may recognise an explosive as soon as we see it. The fact is that no such definition is possible. Under the term explosives are combined a large number of chemical substances, which, except as to this particular property, have little or nothing in common; and as long as we deal with the theory of explosion alone, the definition given above is quite sufficient for our purposes, and indeed the only one, probably, which could be used with satisfaction.

6. Lastly, we may draw from what has been said the

obvious conclusion that there must be some things which cannot be defined. For every definition must be in words, and each of those words may be challenged for its own definition; and if this is persisted in without limit, we must either come round in a circle or consent to an endless retrogression. We must therefore take our stand upon certain simple words, representing things so familiar that they can be no further elucidated; and these must form the elements, out of which all other definitions are made. Thus, if I am asked in the last result to define existence, I simply reply, "Existence is that which I mean when I say that I myself exist;" and I refuse to be driven further than that elementary fact. It may seem a pity that, in all the past ages of learned disputation, no attempt has been made to settle what these elementary things shall be taken to be, and by framing a list of them to establish a common basis of argument; but since no such attempt has been made, each man must frame his own list in the best way that he can.

7. In the above remarks on definitions in general, we have avoided, as far as possible, illustrations taken from mechanics —the science under consideration. Their application to that science will become clear in the course of our investigation, to which we may now proceed.

8. *Definition of Mechanics.*—Since our business is exclusively with definitions and first principles, we must begin by defining the science itself of which we treat. For this purpose we shall adopt the definition of Rankine ("Applied Mechanics," Introduction, Art. 1), which is as follows:— Mechanics is the science of rest, motion, and force.

9. To this definition Whewell ("Mechanics," p. 3) practically adds another clause, defining mechanics as "the science which treats of the motion of bodies—or which treats of forces—so far as they are governed by discoverable laws." And this clause he justifies by the following weighty words: —"In many chemical, electrical, and magnetical phenomena the motions of bodies occur; but in those cases the circumstances and laws of the motion are not considered; if they were, that part of the reasoning would belong to mechanics. It is probable that almost all the phenomena, in the different departments of natural philosophy, consist in the insensibly