Stress—Its Definition.

THE important word *stress*, denoting a fundamental conception in dynamics, is one as to the meaning of which no haziness or doubt ought to be permitted by the scientific community.

In your review of Prof. Gray's "Physics," the reviewer criticises the use made of the word in question, and makes the statement: "Strictly a stress is measured by the force applied per unit of area; it has the dimensions of force divided by the square of a length. . . ."

No authority is quoted to justify this statement. Does such authority exist? On collating the statements regarding the meaning to be attached to the word in some of the most authoritative works in the language, I have found a considerable want of agreement.

Going back to Rankine, who is credited with having introduced the word *stress* as a technical term into mechanics, we find the following paragraph in his paper "On Axes of Elasticity and Crystalline Forms" (1855):

"In this paper the word *Strain* will be used to denote the change of volume and figure constituting the deviation of a molecule of a solid from that condition which it preserves when free from the action of external forces; and the word *Stress* will be used to denote the force, or combination of forces, which such a molecule exerts in tending to recover its free condition, and which, for a state of equilibrium, is equal and opposite to the combination of external forces applied to it."

Again, in his "Applied Mechanics" (1860), we find, in § 86:

"*Stress, its Nature and Intensity.*—The word STRESS has been adopted as a general term to comprehend various forces which are exerted between contiguous bodies, or parts of bodies, and which are distributed over the surface of contact of the masses between which they act. The INTENSITY of a stress is its amount in units of force, divided by the extent of the surface over which it acts, in units of area."

Then, in § 87, Rankine classifies three kinds of stress, (1) *Thrust or Pressure* (2) *Pull or Tension*, and (3) *Shear*, or *Tangential Stress*.

Further, in §§ 96: "*Internal Stress in General.*—If a body be conceived to be divided into two parts by an ideal plane traversing it in any direction, the force exerted between those two parts at the plane of division is an *internal stress*."

Clerk Maxwell, in "Matter and Motion," Art. 37, says: "The mutual action between two portions of matter receives different names according to the aspect under which it is studied, and this aspect depends on the extent of the material system which forms the subject of our attention.

"If we take into account the whole phenomenon of the action between two portions of matter, we call it Stress. This stress, according to the mode in which it acts, may be described as Attraction, Repulsion, Tension, Pressure, Shearing Stress, Torsion, &c."

Again, in Art. 101.—"Stress.

"The next step in the science of force is that in which we pass from the consideration of a force as acting on a body, to that of its being one aspect of that mutual action between two bodies, which is called by Newton Action and Reaction, and which is now more briefly expressed by the single word Stress."

Thomson and Tait's "Natural Philosophy" (1867), Art. 658 (referring to the theory of elastic solids). ". . . the forces called into play through the interior of a solid when brought into a condition of strain. We adopt, from Rankine, the term *stress* to designate such forces, as distinguished from strain defined to express the merely geometrical idea of a change of volume or figure."

Thomson (Kelvin) in the 9th edition of the "Encyclopædia Britannica," article "Elasticity": Mathematical Theory, Chap. i. "Def. A stress is an equilibrating application of force to a body."

Tait, in "Newton's Laws of Motion" (1899), Art. 45:

"A pair of equal and oppositely directed forces, acting in one line, is a particular case of what is now called a *Stress*. The stress along a stiff rod (necessarily the same across every transverse section) may be either a *Thrust* or a *Tension*, that along a string or chain can be a *Tension* only. [But the term stress, in its widest signification, means *any* system of equilibrating forces.]"

"In a fluid the stress at any point is generally what is called *Hydrostatic Pressure*, whose characteristic is that the stress is the same across a small given plane area. . . . In all these cases the stress is measured by the amount per unit area of the surface on which it is exerted."

Love, in "Theoretical Mechanics" (1897), Art. 122, defines the stress at a point A across a plane interface passing through A, as the force per unit area exerted across a small area whose centroid is A.

From the preceding quotations there would seem to be a double ambiguity in the present usage of the word *stress*.

Firstly, it may be used to denote the whole mutual action between two portions of matter, A and B, say, in which case it would be specified by stating the force or system of forces exerted either by A upon B, or by B upon A; or it may be used to denote the *force per unit area* exerted by A upon B. The latter is clearly less widely applicable (torsional stress, *e.g.*, cannot be reckoned per unit area), and corresponds to what Rankine calls *intensity of stress*, or what is by some teachers appropriately named *unital stress*.

Secondly, the term *stress* may be defined as in the "Elasticity" article in the Encyclopædia to be an "equilibrating application of forces," or, as by Maxwell, to be the complete phenomenon including the "Action and Reaction" of Newton's Third Law of Motion.

To my mind there can be no doubt as to the greater usefulness of the latter definition, even though the former may be more consistent with some of Rankine's statements on the subject. It will be noted that in my quotation from Prof. Tait's work there seems to be a vacillation between the two meanings (what is meant there by "stress across a transverse section," or "stress across a small plane area"?), though he explicitly adopts the former alternative; and in the paragraphs of "Thomson and Tait" immediately following that quoted above there seems to be a similar shifting of ground in applying the term, while Maxwell's use of the word is consistent with his clear definition. This in itself argues strongly for the Maxwellian use of the word. Besides, the "equilibrating application" definition would seem to leave us in the lurch when we wish to name the internal forces of bodies not in equilibrium. And all who have had much experience in teaching dynamics to beginners must appreciate the help which the word in its Maxwellian sense affords in getting the student to see the difference between reaction and equilibrant, and to stop asking one such conundrums as "If action and reaction are equal, why does a body move?" And of course it is precisely the beginner for whose benefit we should take the trouble to be consistent in the use of words.

Let me conclude by offering the following suggestions for what they are worth:—

(1) Let the word "stress" be defined and used as in Maxwell's "Matter and Motion."

(2) Let "unital stress" or "unital stress at a point across a plane" be used as defined in §122 of Love's "Theoretical Mechanics."

R. F. MUIRHEAD.

Glasgow, June 4.

I HAVE to thank the Editor for his courtesy in allowing me to see Mr. Muirhead's interesting letter. I quite agree that the meaning attached to the word "stress" by eminent writers during the fifty years from the time of Rankine to the present day has varied. At the same time, I observe that the only two definitions of the "measure of stress" which are quoted are of recent date, and both state clearly that a stress is measured by the force per unit area, though I find this same definition in Thomson and Tait, 1867 edition, Art. 661, a few lines below the quotation given by Mr. Muirhead. I think, then, I may claim sufficient authority for my statement, "Strictly a stress is measured by the force applied per unit of area," and for the doubt which I expressed as to the desirability of introducing the word "stress" as practically synonymous with "force" in a discussion of Newton's second law of motion.

While I share Mr. Muirhead's regret at the limitation thus imposed on the meaning of a general term "stress" as indicating the mutual action between two bodies, I hardly think his suggestion to distinguish between "stress" and "unital stress" will meet the case.

REVIEWER.

Hybrid Oochromy, with a Note on Xenia.

IN a note on "Telegony, Xenia and Hybrid Oology,"[1] which appeared in *Natural Science* (vol. xiv. p. 394, 1899), I introduced the last-mentioned term to denote a singular phenomenon

[1] At the request of the editor I have altered the term hybrid oology to hybrid *oochromy*, which I agree is in many ways better, except that it would seem to refer to the coloration of the egg to the exclusion of its microscopic structure.