Plans have been drawn for the construction of four greenhouses, a heating plant, wells and windmills, and an underground piping system for irrigation purposes, on the new botanical garden for the department of botany of the University of Michigan. The old botanical garden east of the city with the 10,000 trees and shrubs which have been planted there, will be made into a tree and shrub park in about a year.

Dr. Henry C. Cowles, Dr. C. J. Chamberlain and Dr. O. W. Caldwell have been promoted to full professorships of botany at the University of Chicago.

Dr. Julius Stieglitz, professor of chemistry and director of analytical chemistry in the University of Chicago, has accepted an invitation to give courses in chemistry at the University of California during the summer term that begins June 21 and closes on August 1.

Professor Daniel Starch, of the University of Wisconsin, will give courses in educational psychology and educational measurements at the University of Washington, Seattle, during the coming summer session.

At the University of Birmingham Dr. Douglas Stanley has been appointed to the chair of therapeutics, and Dr. L. G. Parsons to a newly created lectureship in infant hygiene and diseases peculiar to children.

## *DISCUSSION AND CORRESPONDENCE*

### THE FUNDAMENTAL EQUATION OF DYNAMICS

The difference of opinion between Professor Huntington and myself is probably less than might be inferred from his recent communication.[1] I do not object to the use of the equation $F/F' = a/a'$, which indeed is a useful one. But it seems to me misleading to call this *the* fundamental equation of dynamics, because there is something equally fundamental that is quite independent of this equation—the fact that the *mass* of a body is one of the factors determining what acceleration it has under the action of a given force. The same fact is expressed by Professor Huntington in the words[2] "different bodies require different amounts of force to give them any specified acceleration," which he refers to as "this central fact of dynamics." My view is that this "central fact" should receive explicit and quantitative[3] statement in whatever equation or equations may be adopted for expressing the fundamental law of acceleration. The principle which such equations must express may be stated in different ways. In the review[4] which called forth Professor Huntington's comment I expressed the opinion that the method most intelligible to the beginner is to introduce at the outset the body-constant which was called by Newton *mass* or *quantity of matter,* and to make the fundamental principle a statement of the way in which the acceleration of a body depends quantitatively upon both the applied force and the mass of the body. The principle then takes the following form:

(*a*) *A force acting upon a body otherwise free would give it, at every instant, an acceleration proportional directly to the force and inversely to the mass of the body.*

The meaning is perhaps more clearly brought out by writing a definite proportion:

(*b*) *Forces $F$, $F'$, acting upon bodies whose masses are $m$, $m'$, cause accelerations $a$, $a'$ such that*

$$\frac{a}{a'} = \frac{F}{F'} \cdot \frac{m'}{m}. \qquad (1)$$

It is instructive to consider the following partial statements of the general principle:

(*c*) *If the same body is acted upon at different times by forces $F$, $F'$ and if $a$, $a'$ are the accelerations caused, then*

$$\frac{a}{a'} = \frac{F}{F'}. \qquad (2)$$

[1] Science, February 5, 1915.

[2] These words seem to be a very definite corroboration of the statement (quoted with disapproval by Professor Huntington) that "an equation which results from comparing the effects of different forces *upon the same body* can not be regarded as a complete expression of the fundamental law of motion; it is equally important to compare the effects of forces *acting upon any different bodies.*"

[3] The mere qualitative statement above quoted is no more satisfactory than the statement that "different forces acting at different times upon the same body cause different accelerations."

[4] Science, December 4, 1914.

(*d*) *If bodies whose masses are $m$, $m'$ are acted upon by equal forces, causing accelerations $a$, $a'$, then*

$$\frac{a}{a'} = \frac{m'}{m}. \tag{3}$$

(*e*) *If bodies whose masses are $m$, $m'$ are acted upon by forces $F$, $F'$ such that equal accelerations are caused, then*

$$\frac{F}{F'} = \frac{m}{m'}. \tag{4}$$

Equations (2), (3) and (4) are all particular cases of (1), but it requires two of them to express the whole import of (1), and there is no reason for regarding (2) as more fundamental or more important than (3) or (4). Any single equation which may properly be called *the* fundamental equation of dynamics must be equivalent in import to equation (1).

This does not mean that it is never allowable or advantageous to use the less general equations; on the contrary, problems and illustrations falling under these special cases are undoubtedly helpful to students. But the object should be to lead up to an understanding of the fully general principle expressed above in paragraphs (*a*) and (*b*) and in equation (1).

When this principle is fully understood, it is seen that equation (1) enables us to determine the acceleration of *any* body of known mass due to the action of *any* known force as soon as we know the acceleration of *one* body of known mass due to the action of *one* known force. For practical use it is advantageous to express the general equation in a more concise form. It is readily understood that (1) is equivalent to the equation

$$a = k\frac{F}{m}, \tag{5}$$

in which $k$ is a constant of which the value depends upon the units chosen for expressing acceleration, force and mass; and that the still more concise form

$$a = \frac{F}{m} \tag{6}$$

results if units are so chosen that *unit force acting upon unit mass causes unit acceleration.*

The foregoing is essentially the Newtonian explanation of the second law of motion as interpreted by Thomson and Tait and accepted by other high authorities. In essential meaning there is no difference between this and the method advocated by Professor Huntington. The word mass is, indeed, avoided in his statement; but in recognizing the importance of the fact "that different bodies require different amounts of force to give them any specified acceleration" he recognizes the reality and fundamental importance of the body-constant which is usually designated as mass. By whatever name this constant may be called, it must play a part in the theory equivalent to that taken by mass in the equations given above. In Professor Huntington's presentation this part is taken by "standard weight," defined as the force required to give the body the acceleration 32.1740 ft./sec.[2] This does not conflict with the theory outlined above; in fact since the forces required to give different bodies a specified acceleration are by equation (4) proportional to their masses, standard weight as above defined may serve as a valid measure of mass. In explaining this method, however, it is important to make perfectly clear the fact that the quantity called standard weight is in reality the measure of a body-constant and is quite independent of gravity, in spite of the fact that it is given a name which is almost always associated with gravity. If properly safeguarded in this respect, Professor Huntington's method of developing fundamental principles is, I believe, logically defensible. Whether it meets the needs of beginners as well as that based upon the Newtonian treatment of mass may, however, be questioned.

To start with the notion of mass defined provisionally as "quantity of matter" has the same kind of advantage as starting with the "spring-balance" definition of force. Both definitions have a sufficiently definite meaning, gained from ordinary experience, to be of service in a preliminary explanation of the laws of motion. In comparing the masses of bodies composed of one homogeneous substance the significance of the words "quantity of matter" is indeed readily recognized, and it is distinctly helpful to generalize this notion even though we must also recognize that any *general* method of comparing quantities of matter must employ either the laws of dynamics or some other physical law in which the same body-constant is significant.

Reflection upon what is really involved in the Newtonian laws soon shows, indeed, that the provisional definitions of force and mass are quite inadequate as a basis for a strictly logical explanation of the laws. It has long been recognized by writers who have attempted to formulate fundamental principles with full logical rigor that the definitions of both force and mass are implicitly involved in the laws of motion themselves.[5] An analysis of the strict logical import of the Newtonian system would, however, be quite unintelligible to beginners, and a recognition of the soundness of such an analysis is no reason for dispensing with the aid of the more tangible notions of *quantity of matter*[6] and *push or pull.*

While the method advocated by Professor Huntington is in my opinion sound in its essential features, the explanation of it in the paper[7] to which he refers seems to encourage the erroneous notion that the laws or facts of terrestrial gravity form a part of the principles of dynamics. Although the definition of standard weight quoted above is of course quite independent of gravity, in the paper it is given the form of a gravity definition: "The *standard weight* of a body is the force of gravity on that body in the standard locality." The reader is likely to miss the significance of the qualifying statement made elsewhere in the paper that the standard locality is any locality where $g$ has the value 32.1740 ft./sec.$^2$—a statement which makes the reference to locality and to the force of gravity wholly irrelevant as regards the real meaning of the quantity called *standard weight.*

It is to be feared, also, that the definition of "force of gravity" given in the paper encourages vagueness rather than definiteness in the force concept. The conception of force as a *push* or *pull,* exemplified by the pull which stretches a spring, is a very definite one. It loses its definiteness, however, unless the fact is kept in mind that *there is always some body that does the pushing or pulling.* When, therefore, it is said that a body is acted upon by a certain force, it is always pertinent to ask *by what body this force is exerted.* How is this question to be answered in the case of the "force of gravity" as defined in the paper? The definition is as follows:

> By the "force of gravity" on a body, we mean simply the unseen[8] force which gives the body, when allowed to fall freely from rest, in vacuo, in the given locality, the observed acceleration $g$. It is equal and opposite to the force required to support the body in that locality.

The question *by what body this force of gravity is exerted* is not answered in the paper, and an attempt to supply the answer leads to the conclusion that the definition is inconsistent with the conception of force as *a push or pull exerted upon a body by another body.* The "observed acceleration $g$" has a component that is not due to force at all, but to the fact that our base for estimating acceleration is the rotating earth. The body is not acted upon by a push or pull that is "equal and opposite to the force required to support the body"; if it were, a supported body would have no acceleration, while in fact it has an

[5] Probably the most adequate formulation of the Newtonian laws from the point of view of strict logic is that given by W. H. Macaulay (*Bull. Am. Math. Soc.*, July, 1897). Mr. Macaulay's analysis makes it clear not only that the definitions of mass and force are implicitly contained in the laws themselves, but that the law of acceleration and the law of action and reaction can not be treated as independent, and further that the question of a base for estimating acceleration is of fundamental importance, since the laws, if true for one rigid base, will not be true for another which has any motion except a uniform translation with respect to the first.

[6] Professor Huntington's statement that the mass concept is "a derived concept, both historically and practically" is hardly true in any sense in which it is not also true of force. At all events mass in the sense of quantity of matter has been treated as fundamental by many high authorities from Newton down. See the opening paragraph of the "Principia."

[7] *Bull. S. P. E. E.*, June, 1913.

[8] Is the word "unseen" here intended to imply that there are forces which are visible?

acceleration even though at rest relatively to the earth.

Professor Huntington objects to the definition "force of gravity = attraction of the earth" on account of "complications connected with the spheroidal shape of the earth, the influence of the earth's rotation, etc." From what has been said above it is quite evident, however, that if the complications[9] connected with the earth's rotation are evaded by his definition it is only by a sacrifice of clearness in the force concept.

Clear thinking about the concept of force would seem to be promoted by the more usual method of distinguishing between *true* and *apparent* force of gravity; the former being the actual earth-pull on a body, the latter the pull or push exerted by a body upon its support. Each of these is a true force (a pull or push exerted by a specified body); to assume them equal is a first approximation to the truth. The reason they are not exactly equal can be explained rigorously when the student is in a position to understand the dynamics of circular motion; before that stage is reached it is sufficient to stop with the explanation which neglects the effect of the earth's rotation.

L. M. HOSKINS

[9] The spheroidal shape of the earth introduces no complication whatever as regards the definition "force of gravity = attraction of the earth." It is not necessary to be able to compute the attraction in order to understand the definition.

### THE NATURE OF THE ULTIMATE MAGNETIC PARTICLE

FOR many years scientists have agreed in ascribing the magnetic properties of bodies to the action of exceedingly small elementary magnets, but the nature of these ultimate magnetic particles has been an open question. The influence of temperature, chemical composition and other factors has received the simplest explanation on the theory that molecules, or possibly groups of molecules, are the ultimate magnetic particles. On the other hand the electron theory of magnetism, developed by Langevin, Curie, Weiss and others, seems logically sound and is the only theory which has successfully accounted for diamagnetism.

The recently developed method of determining the positions of atoms within a crystal by X-ray photography and the ferromagnetic properties of magnetite, hematite and pyrrhotite crystals suggested a direct experimental method of eliminating one or the other of these two theories. By comparing photographs taken through these crystals while magnetized and unmagnetized it can be determined with certainty whether or not the atoms have moved from their positions of equilibrium during the process of magnetization. We have obtained experimental results with magnetite and hematite which indicate that the atoms do not leave their positions of equilibrium during magnetization. These results are consistent with the electron theory of magnetism and prove conclusively that magnetism is not a molecular phenomenon.

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### THE NEW GLACIER PARK

TO THE EDITOR OF SCIENCE: Referring to the pleasing intelligence communicated by Dr. John M. Clarke, in SCIENCE for March 12, relative to the new glacier park near Syracuse, a further note on the history of its investigation may well be added. It would seem that the earliest clear interpretation of the glacial stream channels about Jamesville came from a master of physiographic study who has strewn many seed thoughts by the way during the past forty years—Mr. G. K. Gilbert. The record is in "Old Tracks of Erian Drainage in Western New York," an abstract published in the *Bulletin* of the Geological Society of America, Vol. 8, 1897, pp. 285–286. Dr. Quereau's paper, which appeared in the *Bulletin* of the following year, cites Mr. Gilbert's interpretation by way of acknowledgment, and both papers have been followed by the full expositions of Professor Fairchild in the publications of the Geological Survey of New York.

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