SCIENCE

FRIDAY, NOVEMBER 1, 1918

CONTENTS

MSS. intended for publication and books, etc., intended for review should be sent to The Editor of Science, Garrison-on-Hudson, N. Y.

THE BALANCE, THE STEELYARD AND THE CONCEPT OF FORCE

THE primitive philosophy of *Animism,* "the doctrine that a great part, if not the whole, of the inanimate kingdom, as well as all animated beings, are endowed with reason, intelligence and volition, identical with that of man," still to a degree sticks in mechanics, in the concept of force. Schopenhauer is quoted as saying:

> That the essence of forces in inorganic nature is identical with the will in us, every one believes with full certainty and as a demonstrated truth, who seriously considers it.

R. Eisler says:

> Force is a concept which gets its content originally from the capacity of the ego in general by means of its will to bring about something, to overcome a resistance, and is then immediately superposed upon the objects of the external world. . . . Since the ego finds limits to its activity in the external world, feels itself hindered by objects, it inevitably interprets the hindrance as the expression and activity of a sort of will-power analogous to itself which things exert against it and by virtue of which they can or do influence other things. . . .

E. Mach says that the concept of force is a survival of fetishism; Kirchhoff, in the famous prefix to his Mechanics, acknowledges the value of the older view in the development of the science, and its usefulness in elementary teaching, but takes for himself this higher ground:

> I propose as the problem of mechanics, to describe the motions which occur in nature, and, forsooth, to describe them completely and in the simplest way. I will further add that it should deal only with this, to state what the phenomena are, not to determine their causes.

For him the term force "forms only a means of simplifying the forms of expression, *i. e.,* to express in brief phrases equations which without the use of this name could only with difficulty be expressed in words."

Believing that the history of a growing concept is sometimes an aid towards a teacher's understanding of his students' difficulties. I have been interested in forming a conjectural reconstruction of the history of this force concept, from the hidden days of pure animatism to the time when a distinct separation between matter and force concepts began to show itself; helping myself meanwhile with such facts as archeology scantily shows us about the most ancient tools, contrivances and ways of life.

To put the problem as a question: When and how was it learned that very different objects may have the same weight? That the same object may have different weights? To treat of force mainly in the weight form is no wrong, on account of the universality of gravitation and the fact that forces even to-day are measured mainly in terms of weight.

The second question is quickly answered; before Richer in 1673 returned to Paris from Cayenne with a report on the going of his clock in the two places, no one had suspected a variability of weight; Huygens concluded from this report that bodies in high latitudes fall faster, and are heavier, than in low; but even now this conclusion remains a deduction from refined instrumental observation; no mason's assistant can say from his personal experience that it is harder to lift a hod of bricks in Edinburgh than in Quito. To us all, the weight of a thing is constant.

That different objects may have the same weight is an extremely ancient idea, so familiar as to be a truism, I dare say, even to the pyramid builders and their forefathers. But I suppose that even truisms were once discoveries; this one, perhaps, became the property of man because he labored.

Assuming that sensations of effort are real, I would classify them, perhaps naïvely, in three groups: Sensations of

(*a*) Effort proper—central, which go with the sending of the nerve message from the central nervous system.

(*b*) Stress—the nerve message reaches the muscles, they contract, their changes in form affect the sensory endings of themselves and of neighboring parts, as the skin, the joints, etc., by virtue of arterial and venous compression, the circulation and the breathing also are affected, and, through them, distant parts of the body.

(*c*) Yielding—*changes* in stress occur when external bodies give way to the muscles and bones, or when the body itself is moved, as in jumping.

Normally (*a*) and (*b*) go together; in nightmare most of us have felt the will paralyzed, the body apparently not responding to the centers; in paralysis the separation may be permanent; I have read that the separation occurs in curare poisoning, when the motor nerves no longer actuate the muscles, but consciousness and sensation remain.

But (*c*) varies with the object dealt with, and also, for the same object, with bodily health and tone. It varies with the way the object is dealt with. Its variations, combined with the evidence of other sensations, enable us to distinguish between the self and the not-self, and between the parts of the not-self, of the external world. With (*a*) and (*b*) but without (c) we would know little of the mechanical qualities of bodies. With (*c*) we get notions of bodies differing not only in color, odor, etc., but also in weight; for to move objects, whether to lift, carry or throw them, requires effort, and the efforts for lifting, carrying and throwing a given body are of the same order of magnitude. Like bodies of about equal extent require like efforts; like bodies of unequal extent require unlike efforts; but equal extent does not condition equal efforts; *e. g.*, a block of wood and a boulder. So we can add to the differing qualities of bodies given by sensations of color, odor, etc., weight and specific heaviness. This effort-demanding quality, varying among bodies and with the condition of the person, would early be abstracted, and the concept weight would appear, in positive (heavy) and comparative (heavier, lighter) degrees. Weight was found to be a quality of solids and liquids universally; the sensations of effort have not yet made it apparent to us in the case of air, and Galileo first showed it there by experimental means—weighing compressed air—which appeal to other senses and to the reason. The savage laborer would have a rough idea of equality in his backloads, he might recognize this equality in backloads of venison or firewood, he might count backloads, bucks or arrows, and so attain crude notions of ratios, and in all things he would perceive the demand for effort, and so recognize the existence of *heavy matter* of all sorts; the sorts all being alike only in this effort-demanding quality.

Knowing effort only through the sensations of effort, which are subject to Weber's law, and through that form of hysteresis called memory, we can compare efforts, and the weights to which they correspond, only very crudely for equality, practically not at all for ratio, and with diminishing accuracy after longer intervening times. However, efforts being apparently equal, so are weights assumed to be, and, vice versa, bodies of like material and the same size are taken to have equal weights without "hefting them." One rabbit is about as big and so weighs about as much as another.

That two rabbits weigh twice as much as one, however, is not an experience, but a judgment. The effort sensation for two rabbits is not in any sense double that for one; if a man can lift a side of beef with great effort, is the effort required to lift two sides at once twice as great, when he perhaps can not lift the two sides at all? Is the effort made by a stronger man who lifts the two double that of the weaker lifting one?

A very ancient method of bearing loads, dating back to prehistoric times and portrayed in the most ancient records, is the carrying stick or yoke. Convenience and comfort in using this are greatest when the bearer is at the center, which is when equal numbers or volumes of like things swing from the two ends. This, I suppose, led to the invention of the balance with equal arms as a more refined and objective, more "honest," means for the inverse purpose of testing equality in respect to this effort-demanding quality, *weight* or *quantity of matter*. One Greek name for the balance is ζυγόν, yoke; but the implement itself dates to measureless antiquity. H. L. Roth,[1] quotes Mr. Ivan Chien, of the Chinese Legation in London, to the effect that Chinese history assigns the making of scales to the reign of the Emperor Fu Hi, B. C. 2956. Baumeister (Denkmäler) says it was known in Homeric times; excavations in Crete show that in the recently uncovered civilization of its people the balance was used; Egyptian hieroglyphics show it in ancient use. As the beam was commonly of wood it has not been preserved from those early days.

But why should people desire a more objective, more honest, means of comparing things than by "hefting" or counting? I take it, because of trade, whose routes were marked in Europe even in the Stone Age (as is known from the migration all over the continent of flints of identifiable origin). When the trade in metals grew up, accuracy and standards became of an importance hitherto unprecedented and with them arose the balance and calibrated weights. Lepsius[2] is referred to as figuring a sliding weight on a balance beam of ancient Egypt; I have not seen the figure; one would assume that such a sliding weight, serving perhaps as a handy tare, might have suggested the next improvement in weighing apparatus, the steelyard. Whether it did or not must remain for a while unknown; for the only authorities accessible to me are irreconcilably in contradiction as to the date earliest recorded of the Roman steelyard.

There are two forms of steelyard, the Danish and the Roman. The former seems once to have been very common. Sökeland[3] describes a large variety, from simple clubshaped sticks to elaborately worked metal pieces. It was slung by a cord; the unknown weight hung from another cord fixed near one end, and the more or less heavy knobbed or swelling end beyond the fulcrum balanced the unknown.

1 *Jour. Roy. Anthrop. Inst.*, 47, 1912.

2 Denkmäler, III., 39, No. 3.

3 Translated in Smithsonian Annual Report, 1900, p. 551.

In weighing the fulcrum was shifted from place to place, and there were notches for the suspending cord, determined, no doubt, with known weights, these having been calibrated with the balance. This Danish steelyard, desemer or bismar had, then, a graduated beam whose graduations followed no observable law and were wholly empirical. It is this that Aristotle discusses in his "Mechanical Problems," though without much success.

The Roman steelyard, "Statera Romana," familiar in modern form and but little improved since classical antiquity, appeared first perhaps in Egypt, perhaps in Campania. I can only quote authorities.

F. Müller:[4]

B.C. 1350. The steelyard with running weight is in use among the Egyptians.

L. Darmstaedter:[5]

B.C. 1400. The steelyard with running weight is in use at the time of the Egyptian king Amenophis IV.

F. M. Feldhaus:[6]

Unequal armed balance with running weight, usually called Roman steelyard. This balance has a short arm, on which the weighing pan hangs, and a long arm, bearing a graduation and notches for suspending a running weight. The steelyard is known to have been in use in Egypt about B.C. 1400.

Against these very definite statements must be set the authority of Sir J. G. Wilkinson[7] and of Dr. L. W. King and Flinders Petrie,[8] and of all others, as far as I know, who have published on the subject or answered my inquiries about it, to the effect that the Egyptians did not have the steelyard till the Roman period. Harper's "Book of Facts" (1905) says that it is mentioned B.C. 315—I do not know by whom.

Incidentally, I may say that I was not a little surprised to find this contradiction, and that so well known an instrument of trade should have so uncertain an origin.

I will assume that the Roman steelyard dates back to B.C. 400, and was then known through Mediterranean civilization. He who first graduated it may be called the true discoverer of the law of moment equilibrium, the law of the lever. With any pry or crowbar, or with the bismar, one would have to search for the law deliberately; but this improved weighing apparatus made for trade purposes displays its law to the eye. I imagine the inventor as using a bismar beam, but keeping the fulcrum fixed and sliding along a rider weight, calibrating the beam by means of known balance weights in the pan. The unaided eye could see that equal added weights in the pan corresponded to equal increments of length on the graduation; and so we may understand how Aristotle (B.C. 384–322), long before Archimedes (B.C. 287–212), was able to state the law thus "[9] . . . as the weight moved is to the weight moving it, so, inversely, is the length of the arm bearing the weight to the length of the arm nearer the power. . . ." This he attempts to demonstrate as a consequence of the properties of the circle, but with poor success.

Archimedes, knowing this law of the lever, wrote a book on the subject, unfortunately lost. Another book of his has come down to us, in which he discusses the subject of balanced bodies and the location of centers of gravity in certain plane figures. He does not define center of gravity, but from the use he makes of the term in his demonstrations it is clear that he means by it the point where a body balances when there suspended. This point he treats as representative of the body, and assuming this he attempts a demonstration of the law of the straight horizontal lever, or law of moment equilibrium. E. Mach[10] points out, however, that this demonstration, superficially convincing, is seen to be fallacious

[4] "Zeittafeln zur Geschichte der Mathematik," etc., p. 3 (1892).

[5] "Handbuch zur Geschichte der Naturwissenschaften," etc., p. 3 (1908).

[6] "Die Technik," p. 1251 (1914).

[7] "Manners and Customs of the Ancient Egyptians" (1878).

[8] Quoted by H. L. Roth, *l. c.*

[9] "Questiones Mechanicæ," E. S. Forster, trans. (1913).

[10] Science of Mechanics," McCormack trans., p. 18 (1902).

when one attempts to define more closely the concept *center of gravity*. For the law of the lever then appears as implicitly assumed in this concept, and hence not to be demonstrated by its use.

Our knowledge of Archimedes's attainments is limited to the scanty remnants which generations of militarists have allowed to survive. An examination of Aristotle's "Mechanical Problems" shows that even before Archimedes certain phenomena of the simplest machines were puzzling, that the effort-demanding quality of bodies presented itself in two aspects. Aristotle says (Ch. 10):

Why is it that a balance moves more easily without a weight upon it than with one? So too with a wheel or anything of that nature, the smaller and lighter is easier to move than the heavier and larger. Is it because that which is heavy is difficult to move not only vertically but also horizontally? For one can move a weight with difficulty contrary to its inclination, but easily in the direction of its inclination; and it does not incline in a horizontal direction.

Again (Ch. 19):

How is it that, if you place a heavy axe on a piece of wood and put a heavy weight on the top of it, it does not cleave the wood to any considerable extent; whereas, if you lift the axe and strike the wood with it, it does split it, although the axe when it strikes the blow has much less weight upon it than when it is placed on the wood and pressing on it? Is it because the effect is produced entirely by movement, and that which is heavy gets more movement from its weight when it is in motion than when it is at rest? So, when it is merely pressed on the wood, it does not move with the movement derived from its weight; but when it is put into motion, it moves with the movement derived from its weight and also with that imparted by the striker. Furthermore, the axe works like a wedge; and a wedge, though small, can split large masses, because it is made up of two levers working in opposite directions.

P. Duhem,[11] comparing the methods of the two great Greeks, says:

Admirable as a method of demonstration, the path followed by Archimedes in mechanics is not a method of invention; the certainty and the clarity of his principles stick on the whole where they are plucked, so to speak, on the surface of phenomena, and are not pulled up by the roots from the bottom of things; according to a remark which Descartes made less justly about Galileo, Archimedes "explains very well *what is* so, but not *why it is so*," therefore we shall observe the more striking forward steps in statics to start rather from the doctrine of Aristotle than from the theories of Archimedes.

But one should not look to the "Mechanical Problems" for demonstrations by an admirable method; they are but poor attempts at demonstration, from the hand of one of whom Duhem[12] writes:

Aristotle was not a geometer; from the principle which he had set up, he did not know how to draw with entire rigor all the consequences which can be deduced from it.

Attempts at demonstration, moreover which have doubtless suffered by transcription a hundredfold repeated, and at the hands of teachers and pupils who were merely Aristotelians. Unable successfully to solve his problems, he has yet the great merit, greater than that of a mere problem-solver, of perceiving the existence of the problems, and putting forward a statement showing the difficulty.

He for whom his most famous pupil, the conquering explorer Alexander, made collections of natural history, sending them far by the slow transport of those days to his master's school of science, was no pedant of the schools. He knew the mint, the market and the quarry; he saw the balance pans easily swinging when empty, but, loaded with metal or meat and balanced, hard to set in motion; he thought it odd that balanced weights, which, so to speak, lift each the other,[13] should be hard to move; he saw the cylindrical column sections rolled with labor up inclined planes out of the quarry, but rolling down again at a touch; why should they be hard to

11 "Les Origines de la Statique," p. 12 (1905).

12 *Loc. cit.*, p. 8.

13 "Q. M.," Ch. 26. "Why is it more difficult to carry a long plank of wood on the shoulder if one holds it at the end than if it is held in the middle? . . . The reason is, that if one lifts it in the middle, the two ends always lighten one another, and one side lifts the other up."

roll on a level, though then neither descending nor ascending? "Is it because that which is heavy is difficult to move not only vertically, but also horizontally?" Is it because things require an effort not only for lifting them, but also for setting them in motion?

He is evidently groping; his difficulty is, that he fails to analyze the meaning of the phrase, *easy to move*, or, *to move easily*. A thing is easy to move when with a slight effort in a short time we change its speed considerably, or give it a large acceleration; it is hard to move when we must exert a considerable effort to produce the same total change in speed, or a slighter effort for a longer time, then giving it only a small acceleration. He has not distinguished clearly the elements *inertia*, of which *mass* is the quantitative measure, and *acceleration*, or rate of change of speed; but he does see that there is a fundamental distinction between accelerating a body in the horizontal direction, the direction in which its motion is unaffected by weight, and accelerating it in the vertical direction, when the weight hindrance is superposed on and confused with the difficulty of acceleration. His observations being merely sensuous and qualitative, he could not know by measurement the constancy of gravitational acceleration, nor could he escape from the confusion of weight and mass which this same constancy made inevitable.

Again, watching the woodman and his axe, Aristotle knew that effort exerted as steady pressure would not cleave the block, though when swung through the air the blade split the wood instantly. It seemed odd to him that a continuing effort without motion should be unable to achieve an end so easily reached by an effort no greater used to produce motion of the axe.

> Is it because . . . that which is heavy gets more movement from its weight when it is in motion than when it is at rest?

For *movement* read here *momentum*, or use Newton's phrase, *quantity of motion*, and read *mass* for *weight*, and the query sounds much more modern, though not yet quite clear. He was again groping after distinctions later grasped by Newton. In his observation there was, of course, nothing new; upon such the arrow-maker's craft was built millennia before Aristotle; but he was perhaps the first to record a feeling of perplexity concerning them.

In another place (Ch. 31) Aristotle asks:

> Why is it that a body which is already in motion is easier to move than one which is at rest?

This evidently deals with running and starting friction. His answer is very unsatisfactory; but this query, as do one or two others, touches on the nature of friction, that other obstacle which for ages prevented the development of a science of mechanics.

I have no doubt that these two facts in terrestrial experience, the universality of friction and the practical constancy of gravitational acceleration, were not only the chief causes of the slow development of mechanics, but are also to-day among the main reasons why so many, perhaps most, of our athletically and mechanically wise students not only fail to comprehend the laws of motion—they simply do not believe they are so. They are confirmed Animists; to imagine a force acting, they must imagine themselves acting right there, or the agent feeling as they would in its place. They do not believe in a natural tendency of things to keep on going, and acceleration is to some of them a concept of inaccessible refinement. "To describe the motions which occur in nature, in the simplest way," or otherwise than in terms of their own effort sensations is a problem of small interest. And with the phenomena thus sensuously described, to them a body is hard to throw *because* it is heavy. From qualitative experiences, such as their predecessors since and before the Stagyrite have had in fulness, they will never gain conviction of the truth. Experiments must be devised and set before them to induce in them the perplexity Aristotle felt in presence of the loaded balance and the rolling cylinder; for this feeling of perplexity, and a revolt against it, are the beginning of science; then they must resolve this perplexity by experiments and study which will lead them along the path of Leonardo, Kepler, Galileo, Huygens and Newton.

Willard J. Fisher
Worcester Polytechnic Institute,

THE SCIENTIFIC MEMBERS OF THE BRITISH EDUCATIONAL MISSION

As has been noted in Science, the British government, on the invitation of the Council of National Defense, has sent to the United States a distinguished mission to inquire into the best means of procuring closer cooperation between British and American educational institutions, to the end, greatly desired on both sides, of making increasingly firm the bonds of sympathy and understanding that now unite the English-speaking world.

The members of the mission are:

Dr. Arthur Everett Shipley, vice-chancellor of the University of Cambridge, master of Christ's College and reader in zoology.

Sir Henry Miers, vice-chancellor of the University of Manchester and professor of crystallography.

The Rev. Edward Mewburn Walker, fellow, senior tutor and librarian of Queen's College, member of the Hebdomadal Council, Oxford University.

Sir Henry Jones, professor of moral philosophy, University of Glasgow.

Dr. John Joly, professor of geology and mineralogy, Trinity College, Dublin.

Miss Caroline Spurgeon, professor of English literature, Bedford College, University of London.

Miss Rose Sidgwick, lecturer on ancient history, University of Birmingham.

The proposed itinerary of the mission follows:

October	8–14	New York.
"	15–17	Washington (Mt. Vernon).
"	18	Baltimore.
"	19–21	Philadelphia (Bryn Mawr, Haverford).
"	22–23	Princeton.
"	24	New York (Vassar).
"	25–26	New Haven.
"	27	Amherst, Smith, Mt. Holyoke.
"	28–30	Boston and Cambridge (Wellesley).
"	31–	
November	2	Montreal (Ottawa).
"	3– 5	Toronto (Niagara Falls).
"	6	Ann Arbor.
"	7–12	Chicago (Urbana, Evanston).
"	13–14	Madison.
"	15–17	Minneapolis and St. Paul.
"	18	Des Moines (Ames).
"	19–20	St. Louis.
"	21	Cincinnati.
"	22	Lexington, Ky.
"	23	(Louisville).
"	24	Nashville.
"	25–28	New Orleans (Houston, Austin).
"	29–30	Tuskegee.
"	31	Chapel Hill.
December	1	Charlottesville.
"	2	Washington.
"	4– 7	Boston and Cambridge.

The British Bureau of Information has prepared a statement concerning the members of the mission, and we give the biographical sketches of the scientific members.

DR. ARTHUR EVERETT SHIPLEY

Arthur Everett Shipley, Sc.D., vice-chancellor of the University of Cambridge, is well known in the United States, in which he has on several occasions been an honored guest. He is an honorary D.Sc. of Princeton University, foreign member of the American Association of Economic Entomologists and of the Helminthological Society of Washington. Dr. Shipley is a member of the Central Medical War Committee of Great Britain. He holds many offices of great responsibility, being, for example, a trustee of the great collection of specimens illustrative of many branches of science which was made by John Hunter, purchased by the government after his death in 1793, and presented to the Royal College of Surgeons; a trustee of the Tancred Foundation established by Christopher Tancred (1689–1754) of Whixley Hall in the County of York, to provide studentships in divinity and in physic; a trustee of the Beit Memorial Fund for fellowships for medical research; chairman of the Council of the Marine Biological Association; vice-president of the Linnæan Society; member of the Royal Commission on the Civil Service. In 1887 he was sent to the Bermudas by the Colonial Office to investigate a plant disease. He was also commissioned by the