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Published @ 2017 Trieste Publishing Pty Ltd

ISBN 9780649272679

On the Progress of Science as Exemplified in the Art of Weighing and Measuring: Being the Presidential address delivered before the Washington Philosophical Society, december 10, 1887, pp. XL-LXXXVI by Wm. Harkness

Edited by Trieste Publishing Pty Ltd.
Cover @ 2017

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Trieste

BULLETIN

OF THE

PHILOSOPHICAL SOCIETY OF WASHINGTON.

ANNUAL ADDRESS OF THE PRESIDENT.

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WILLIAM HARKNESS.

Delivered December 10, 1887.

THE PROGRESS OF SCIENCE AS EXEMPLIFIED IN THE ART OF WEIGHING AND MEASURING.

Two centuries ago the world was just beginning to awaken from an intellectual lethargy which had lasted a thousand years. During all that time the children had lived as their parents before them, the mechanical arts had been at a standstill, and the dicta of Aristotle had been the highest authority in science. But now the night of mediævalism was approaching its end, and the dawn of modern progress was at hand. Galileo had laid the foundation for accurate clocks by discovering the isochronism of the simple pendulum; had proved that under the action of gravity light bodies fall as rapidly as heavy ones; had invented the telescope and with it discovered the spots on the sun, the mountains on the moon, the satellites of Jupiter, and the so-called triple character of Saturn; and after rendering himself immortal by his advocacy of the Copernican system, had gone to his grave, aged, blind, and full of sorrows. His contemporary, Kepler, had discovered the laws which, while history endures, will associate his name with the theory of planetary motion, and he also had passed away. The first Cassini was still a young man, his son was a little child, and his grandson and great-grandson, all of whom were destined to be directors of the Paris Observatory, were yet unborn. The illustrious Huyghens, the discoverer of Saturn's rings and the father of the undulatory theory of light, was in the zenith of his powers. The ingenious Hooke was a little younger, and Newton, towering above them all, had recently invented fluxions, and on the 28th of April, 1686, had presented his Principia to the Royal Society of London and given the theory of gravitation to the world. Bradley, who discovered nutation and the aberration of light; Franklin, the statesman and philosopher, who first drew the lightning from the clouds; Dollond, the inventor of the achromatic telescope; Euler, the mathematician who was destined to accomplish so much in perfecting algebra, the calculus, and the lunar theory; Laplace, the author of the Mécanique Céleste; Rumford, who laid the foundation of the mechanical theory of heat; Dalton, the author of the atomic theory upon which all chemistry rests; and Bessel, the greatest of modern astronomers—these and others almost as illustrious, whom we cannot even name to-night, were still in the womb of time.

Pure science first felt the effects of the new intellectual life and it was more than a century later before the arts yielded to its influence. Then came Hargreaves, the inventor of the spinning-jenny; Arkwright, the inventor of the cotton-spinning frame; Watt, who gave us the condensing steam engine; Jacquard, the inventor of the loom for weaving figured stuffs; Murdock, the originator of gas lighting; Evans, the inventor of the high-pressure steam engine; Fulton, the father of steam navigation; Trevithick, who ranks very near Watt and Evans in perfecting the steam engine; and Stephenson, the father of railroads. If now we add the names of those who have given us the telegraph, to wit: Gauss, the eminent physicist and the greatest mathematician of the present century; Weber, Wheatstone, and Henry—all famous physicists—and Morse, the inventor and engineer; we have before us the demi-gods who have transformed the ancient into the modern world, given us machinery which has multiplied the productive power of the human race many fold, annihilated time and space, and bestowed upon toiling millions a degree of comfort and luxury which was unknown to kings and emperors of old.

The discoveries and inventions of the last two centuries have so far exceeded all others within historic times that we are amply justified in calling this an age of phenomenal progress, and under the circumstances a little self-glorification is pardonable—perhaps even natural. The weekly and monthly records of scientific events which appear in so many newspapers and magazines are the immediate result of this, and the great increase of ephemeral scientific literature has led multitudes of educated people to believe that such records represent actual progress. The multiplication of bricks facilitates the building of houses, but does not necessarily improve architecture. Similarly, the multiplication of minor investigations improves our knowledge of details, but rarely affects the great philosophic theories upon which science is founded. The importance of human actions is measured by the degree in which they affect human thought, and the only way of permanently affecting scientific thought is by modifying or extending scientific theories. The men who do that are neither numerous, nor do they require weekly paragraphs to record their deeds; but their names are honored by posterity. Even in this golden age the advance of science is not steady, but is made by spasmodic leaps and bounds. Mere scientific brick making, commonly called progress, is always the order of the day until some genius startles the world by a discovery affecting accepted theories. Then every effort is directed in the new line of thought until it is measurably worked out, and after that brick making again resumes its place. While the progress in two centuries has been immense, the progress in a week or a month is usually almost nil. Optimism has its uses in many departments of human affairs, but science should be cool and dispassionate, having regard only for the truth. To make a trustworthy estimate of the actual state of the whole vast realm of science would be a task beyond the powers of any one man; but perhaps it will not be amiss to spend the time at our disposal this evening in briefly reviewing the recent progress and present condition of the fundamental processes upon which the exact sciences rest—I allude to the methods of weighing and measuring.

Physical science deals with many quantities, but they are all so related to each other that almost every one of them can be expressed in terms of three fundamental units. As several systems of such units are possible, it is important to select the most convenient, and the considerations which guide us in that respect are the following:

1. The quantities selected should admit of very accurate comparison with other quantities of the same kind.

2. Such comparisons should be possible at all times, and in all places.

3. The processes necessary for making such comparisons should be easy and direct.

4. The fundamental units should be such as to admit of easy definitions and simple dimensions for the various derived units.

Scientific men have long agreed that these requirements are best fulfilled by adopting as the fundamental units, a definite length, a definite mass, and a definite interval of time. Length is an element which can be very accurately measured and copied, but it must be defined by reference to some concrete material standard, as for example, a bar of metal, and as all substances expand and contract with changes of temperature, it is necessary to state the temperature at which the standard is correct. A standard of mass, consisting of a piece of platinum, quartz, or other material not easily affected by atmospheric influences, probably fulfills the conditions set forth above better than any other kind of magnitude. Its comparison with other bodies of approximately equal mass is effected by weighing, and as that is among the most exact of all laboratory operations, very accurate copies of the standard can be made, and they can be carried from place to place with little risk of injury. Time is also an element which can be measured with extreme precision. The immediate instruments of measurement are clocks and chronometers, but their running is checked by astronomical observations and the ultimate standard is the rotation of the earth itself.

It is important to note that the use of three fundamental units is simply a matter of convenience and not a theoretical necessity, for the unit of mass might be defined as that which at unit distance would generate in a material point unit velocity in unit time; and thus we should have a perfectly general system of measurement based upon only two fundamental units—namely, those of space and time. Such a system is quite practicable in astronomy, but cannot yet be applied with accuracy to ordinary terrestrial purposes. According to the law of gravitation

$$\text{Mass} = \text{Acceleration} \times (\text{Distance})^2$$

and as in the case of the earth we can measure the quantities on the right-hand side of that equation with considerable accuracy, we can satisfactorily determine the earth's mass in terms of the supposed unit. That suffices for the needs of astronomy, but for other scientific and commercial purposes a standard of mass having a magnitude of about a pound is necessary, and as two such masses can be compared with each other from five to ten thousand times more accurately than either of them can be determined in terms of the supposed unit, three fundamental units are preferable to two.

The Chaldeans, Babylonians, Persians, Greeks, and Romans all seem to have had systems of weights and measures based upon tolerably definite standards, but after the decline of the Roman Empire these standards seem to have been forgotten, and in the beginning of the sixteenth century the human body had so far become the standard of measurement that the units in common use, as for example, the foot, palm, etc., were frequently taken directly from it. The complete table of measures of length was then as follows: the breadth (not the length) of four barley corns make a digit, or finger breadth; four digits make a palm, (measured across the middle joints of the fingers;) four palms are one foot; a foot and a half is a cubit; ten palms, or two feet and a half, are a step; two steps, or five feet, are a pace; ten feet are a perch; one hundred and twenty-five paces are an Italic stadium; eight stadia, or one thousand paces, are an Italic mile; four Italic miles, are a German mile; and five Italic miles are a Swiss mile. It was then the practice to furnish standards of length in books by printing in them lines a foot or a palm long, according to the size of the page, and from these and other data it appears that the foot then used on the continent of Europe had a length of about ten English inches.

In England the first attempts at scientific accuracy in matters of measurement date from the beginning of the seventeenth century, when John Greaves, who must be considered as the earliest of the scientific metrologists, directed attention to the difference between the Roman and English foot by tolerably accurate determinations of the former, and also attempted the investigation of the Roman weights. He was followed by Dr. Edward Bernard, who wrote a treatise on ancient weights and measures about 1685, and towards the end of the century the measurements of the length of a degree by Picard and J. D. Cassini awakened the attention of the French to the importance of rigorously exact standards. In considering the progress of science with respect to standards of length we may safely confine our inquiries to the English yard and the French toise and meter, for during the last two hundred years they have been almost the only standards adopted in scientific operations.

The English measures of length have come down from the Saxons, but the oldest standards now existing are the Exchequer yards of

Henry VII (1490)[1] and Elizabeth (1588).[2] These are both brass end measures, the former being an octagonal rod about half an inch in diameter, very coarsely made, and as rudely divided into inches on the right hand end and into sixteenths of a yard on the left hand end; the latter a square rod with sides about half an inch wide, also divided into sixteenths of a yard and provided with a brass bed having end pieces between which the yard fits. One end of the bed is divided into inches and half inches. Francis Baily, who saw this Elizabethan standard in 1836, speaks of it as "this curious instrument, of which it is impossible, at the present day, to speak too much in derision or contempt. A common kitchen poker, filed at the ends in the rudest manner by the most bungling workman, would make as good a standard. It has been broken asunder; and the two pieces have been dove-tailed together: but so badly that the joint is nearly as loose as that of a pair of tongs. The date of this fracture I could not ascertain, it having occurred beyond the memory or knowledge of any of the officers at the Exchequer. And yet, till within the last 10 years, to the disgrace of this country, copies of this measure have been circulated all over Europe and America, with a parchment document accompanying them (charged with a stamp that costs £3. 10s. exclusive of official fees) certifying that they are true copies of the English *standard*."[3]

In the year 1742 certain members of the Royal Society of London, and of the Royal Academy of Sciences of Paris, proposed that, in order to facilitate a comparison of the scientific operations carried on in the two countries, accurate standards of the measures and weights of both should be prepared and preserved in the archives of each of these societies. This proposition having been approved, Mr. George Graham at the instance of the Royal Society had two substantial brass rods made, upon which he laid off, with the greatest care, the length of three English feet from the standard yard kept at the Tower of London. These two rods, together with a set of troy weights, were then sent over to the Paris Academy, which body, in like manner, had the measure of a French half toise set off upon the rods, and keeping one, as previously agreed, returned the other, together with a standard weight of two marcs, to the Royal Society. In 1835, Baily declared this copy of the half

[1] 43, p. 34, and 44, pp. 51–2. (See Bibliography on page lxxix.)
[2] 43, p. 25.
[3] 34, p. 146.