EARLY MEASUREMENTS AND UNITS OF MEASUREMENT, AND HOW WE OBTAINED THE SYSTEMS WE USE TO-DAY

Part I. British Units of Length and Time

PHYSICS is a science of observation. A proper appreciation of our observations requires the making of measurements; so that physics teaches us not only the habit of observing, but also of making definite *quantitative* observations.

From the earliest periods of man, the observer, comparisons have been made between natural objects. At first these comparisons were merely qualitative—big people and little people, animals that you slung over your prehistoric shoulders and scarcely noticed, and animals that were so heavy that you staggered and eventually devised other means of carrying. There were periods of "light-time" and periods of "dark-time." Early units of length measurement, such as we still see amongst uncivilised peoples, included the combined ideas of length and time—for instance, "as far as one could travel whilst it was light," or a "day's journey." We have come back to one such a combined unit for length to-day—the "light-year" is a distance, the distance light will travel during the period of one year, and we employ it in astrophysics and astronomy.

You will understand that the distance one could travel in a day would not be very definite—it would depend on the individual, the reason for travelling, and the nature of the country. Also, it would be quite useless for measuring short distances. Our ancestors cast around for other comparisons, and found them on their own bodies. We use some of these to-day to make rough measurements—the span of the open hand from thumb tip to farthest finger tip is about nine inches. Girls hold the end of a piece of material between a finger and thumb, extend the arm at full length, turn their heads in the opposite direction, and with the material held in the other hand touch it ceremoniously to their lips. The distance from extended finger tips to lips is about a yard.

There is no doubt that when our forbears began to find it necessary to make measurements of distance, they turned to the lengths of their feet, and of their forearms; to the breadth of their fingers and of their palms; and to the length of their paces in walking or marching. We also find them using the width and length of grains such as barley.

Communications between different settlements were not of the intricate nature of to-day, so the fact that the comparisons of measurement of length varied from country to country was relatively unimportant; but in any one community it would soon be observed that there were very big differences between the length of the foot of one man and of another. Whilst one person might have a slim hand, another would have one very much wider. That would cause immediate concern once it became important to measure lengths in any way accurately, and hence sticks were cut to represent the accepted and intended length. These were the earliest standards of length, and were purely local to the small community. Thus, for example, Athens and Sparta would have different standards, based on the same ideas.

Let us examine, first, the derivation of that unit of length, the foot, based on the length of a human foot. The Egyptians had such a unit of measurement, and it was equivalent to 12·4 of our modern inches. In Greece, back in the vicinity of 300 B.C., we know of three different accepted lengths for the foot—none of which were rigorously fixed. The Attic foot was 11·6 modern inches, the Olympic foot was 12·8 inches, and the Aeginetan foot was 13·0 inches—a variation of ten per cent.

The Roman pes, or foot, was nearly the same as the Grecian Attic foot, namely, 11·6 of our modern inches, though they also had a "pes drusianus" of 13·1 inches. The foot was not a very common unit of measurement until about 280 B.C.

The Roman scale of measurement was based on their foot, or pes. Five pedes equalled one passus, or double stride. One hundred and twenty-five passus equalled one stadium, and eight stadia were a mile, or mille passus, being a thousand of their big double strides. It was 5,000 of their pes, and consequently 5000 × 11·6 of our modern inches; that makes it about eight per cent. shorter than our present mile.

The old cubit, from the Latin *Cubitum*, elbow, is derived from the length of the forearm, or *Ulna*. I want you to remember this word ulna, because it is directly connected with our present standard of length, the yard, though very different in length. The English ell, which you meet in the old saying, "Give him an inch and he'll take an ell," and which was originally a unit of length amongst tailors, is also derived from the ulna.

This forearm unit of length was used by the ancient Babylonians, the length varying with them from 20·6 to 20·8 of our modern inches. It was known quite early in Egyptian history, and numerous specimens are still in existence. The early Egyptians called it the mahi, three of which made a xylon, which was the usual length of their walking staffs—about 61½ inches.

The Roman cubit was 17·4 inches.

So that, in modern inches, the unit of length derived from the forearm, Cubit or Ulna or Mahi or whatever it may have been named, was about 17·4 inches with the Romans, and 20·6 inches with both Babylonians and Egyptians.

The finger breadth was used both by the Greeks and Romans, the latter of whom called it the "digitus." The width of the palm also provided a unit of measurement amongst both of those nations. The Romans linked these units with the cubit and the foot, thus: four digitus equal one palmus; six palmus equal one cubitus. The Roman foot was thirteen and a half digits. You will remember that I mentioned before that the Roman foot was equivalent to 11·6 of our inches, so that you have all your approximations there.

Another obvious basis of measurement was the fully extended arms. The name of this unit amongst the Romans was derived from the Latin, "tensum," stretched. We have it perpetuated in the English fathom, from the Anglo-Saxon "fœthm," to embrace. It is six feet.

The thumb was also employed, and helped to fix our somewhat variable earliest "inches." The Latin "pollex" gave rise to the French "pouce," an inch.

With all countries and all races establishing their own units of measurements, with no fixed standards of comparison, conditions may have been "good enough" before trade and science developed. England was provided with a variety of different units by her different invaders. It was not until we had the good fortune to be invaded by William the Conqueror (1066) that we started to have any uniformity in our standards. The thumb, the span, the cubit, ell, foot and pace were in use, also the mile, fathom and furlong, but not fixed, and varying throughout the country.

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For example, the Scotch inch was averaged from the thumbs of three men. We read, "That is to say, a mekill man, and a man of messurabill size, and of a lytill man."

The span was of the open hand, thumb to little finger. It was taken as being nine inches.

The ell, also now obsolete except in arithmetic books, has varied greatly. In England, before it ceased to be a legal unit, it was 45 inches. The old Scotch ell was 37·2 modern inches, and the Flemish ell 27 modern inches.

The fathom, or "embrace," we have already discussed, and recognise the mile as the Roman mille passus. In England, for longer distances than the pace, it was usual to employ "time-labour" units—the furlong, one-eighth of a mile, is probably from the Anglo-Saxon word "furlang," meaning furrow long, or length of a furrow. So also for length we had "a day's journey," and "a morning's ploughing."

This latter, the "morning's ploughing," gave us our acre as a unit of area, from the Anglo-Saxon "œcer," meaning a morning's ploughing. The area of a morning's ploughing was taken rather than the area of a whole day's ploughing, apparently because the cattle used for ploughing in the morning were put out to pasture in the afternoon.

I have left the yard till last, as the most important. The word is from the middle English "yerd," meaning a stick or rod. The unit of length is based on the old Saxon yard, the derivation of which I do not know. Henry I, according to an old chronicle, established a standard yard. We read: "That there might be no abuse in measures, he ordained a measure made by the length of his own arm, which is called a yard." This is quite probable, though not substantiated; at any rate, Henry I was only *fixing* an earlier unit, and endeavouring to create a *standard length*.

It is sometimes suggested as being the waistline measurement of an earlier Saxon king.

Although laws had been passed by different kings, right back into Saxon times, to *fix* standards of length, it was left to Edward I* to correlate and unify the earlier laws so that the relationship between different commonly employed units of length should be definite throughout

* Uncertain. The act may have been due to Edward III. See "Statutes at Large," Vol. I, "Composito Ulnarum et Perticarum."

his realm. The essential part of his law reads: "It is ordained that three grains of barley, dry and round, make one inch. Twelve inches make a foot. Three feet make an Ulna. Five and a half Ulna make a perch; and forty perches in length and four perches in breadth make an acre." "And it is to be remembered that the Iron Ulna of our Lord the King contains three feet and no more; and the foot must contain twelve inches, measured by the correct measure of this kind of Ulna; that is to say, one thirty-sixth part of the said Ulna makes one inch, neither more nor less . . . . in accordance with the above described Ulna of our Lord the King."

You will see that Edward had established a standard, the Ulna, which is our modern yard in length, though it came originally in name from an Ulna, or forearm length, of some 18 modern inches. In terms of that bar of iron, he had defined the foot and the inch. It was unfortunate that he also defined the inch, as a preliminary, in terms of the width of grains of barley. In effect, Edward was thus commanding the barley to grow in accordance with his law—each grain of barley was instructed to be 1/108th of the length of his bar. It is more probable that the width of the grains of barley were merely put in the Act to show how he derived his yard, or iron Ulna, which then became the legal standard.

We frequently see "grain" units employed; in early Indian measures, the "finger" is defined as eight breadths of a barley corn. The length, or in some cases breadth, of a barley grain was in use right up to the 17th century, in spite of coexisting standards.

This standard Iron Bar of Edward I is lost. The earliest standard now possessed is that made by Henry VII, a brass yard. But we know them all to be founded on the Ulna of Edward I, and hence originally fixed in terms of the width of grains of barley, although the name suggests the old "forearm" standard.

Queen Elizabeth caused a standard bar of brass to be made in 1587. This differs from our present standard yard by only 1-100th of an inch; the Henry VII standard differs by about 1-30th of an inch. None of them were wrong—a standard cannot be wrong, because it is right whilst it is the legal standard. An Act of Parliament is passed saying that the length of this bar, or the distance between fine scratches on it, is the standard yard. It is certainly annoying if changes are made, because all other measures based on obsolete standards automatically become wrong. The old "standard," ci-divant, becomes an historical relic.

In 1758 a Parliamentary Committee constructed another brass yard, based on that of Queen Elizabeth. This new standard became such by law in 1824, and was the First Imperial Standard. It was burnt in the fire at Parliament House, London, ten years later, in 1834. All available copies of the lost standards which could be trusted were compared, when a commission was appointed four years later, in 1838, to consider steps to restore the standards. The commission reported three years later, in 1841; as a result of their report a new committee was appointed two years later, in 1843; this committee reported eleven years later, in 1854. The new standard length, the Imperial standard yard, was then made under the direction of this committee, and that Imperial standard they made became the standard by law in 1855 by Act of Parliament. Knowing something of committees and commissions, we are not really surprised that it took 21 years after the fire to replace the standard of reference.

This is really, then, a very interesting lump of bronze (not brass, as frequently stated) when we consider how it has replaced all earlier "standards," right back through history. And how that particular length has grown to be adopted as a convenient unit of reference, so that the standard length is a yard. All the older "standards" are replaced by this new one—they become merely lumps of metal of great historical interest.

This present Imperial standard yard is in the custody of the Warden of Standards in London. It is a bar of square cross section, each side being 1 inch, and is 38 inches long over all. Two little circular wells are drilled in it, of $\frac{1}{2}''$ diameter, so placed that their centres are $1''$ from each end. These little wells go $\frac{1}{2}''$ deep into the bar, so that they are half way through it. In the bottom of each hole and level with the bottom is let in a little gold plug. Each gold plug is 1-10th inch in diameter, and on each are drawn lines. When this bronze bar is properly supported so that it is not strained, and when the temperature is exactly 62° F., then the distance between the centres of the lines on the one gold plug and on the other *is* one yard. Four "Parliamentary copies" were made, at the same time, of the Imperial standard yard. One is walled up in the Houses of Parliament, Westminster, one is deposited at the Royal Observatory, Greenwich, one at the Royal Mint, and one with the Royal Society, London. These are the secondary standards, and are not correct, because it would be merely an accident if the copies reproduced the length of the standard absolutely exactly to the sixth decimal place of an inch, say. But they have been compared with the standard, and their minute errors are known. By law, these secondary standards have to be compared with one another once every ten years (except the Parliamentary one walled up in the "New Palace" at Westminster), and they have to be compared with *the standard* once every 20 years. Remember, the standard cannot be wrong. Even if by some unimagined happening during the 20 years it should slightly alter the length between the centres of the systems of lines on its gold plugs, that distance is still, by law, the Imperial yard.

Personally, I find this bronze bar, sixteen parts copper, two and a half parts tin, and one part of zinc by weight, with its all historical associations right back into the unrecorded past when men first began to measure things, far more fascinating than any diamond valued at thousands of pounds. If you had the money, you could go and buy the diamond. You could not buy the Imperial yard. The Imperial yard fixes the units of length in British units throughout the world; the diamond also would generally spend its time in safe deposit vaults, but would serve no useful purpose.

Let us arouse the interest of our students, so that they will read for themselves. A good encyclopædia, such as the *British Encyclopædia,* will give them an interesting article on metrology, as the science of units and standards of measurement is called. It will also give them references to other books which they may find in the libraries.

[As an appeal to students themselves: That is one thing I *do* want to ask of you—don't merely be *taught.* Learn to read and think for yourselves; discover how to seek out extra information on subjects which interest you. I am not asking you to neglect your ordinary routine work, but to read and think outside that on any aspects of your work that interest you. Don't tell me you haven't time—I know far too much about boys and girls from nought to twenty-one to believe that; the time is there if you use it properly. Spend profitably, in reading that interests you, some of the time you waste sitting back on your tails and gazing into vacancy whilst you think how you hate work but had better get on with it. Once you get interested in a subject as something besides stuff to be prepared for an examination, it is no longer work, but an occupation.]

TIME.

We will next consider the idea of time, and our standard of time, briefly. Our whole idea of time depends on things happening—depends on events. This event occurred *before* that event, we say; or that happened *after* that other event. Our ideas of time are linked up with *changes* in the universe. If *no* event ever occurred, if no change ever occurred in the universe, the idea of time vanishes. Think over that later. So the whole idea of time is dependent on things happening, and our methods of measuring time are based on relative motion of bodies, that is, on movement.

Our method of recording "after" and "before" events is by the relative motion of a position on earth to the sun or to the stars; and we have several different "seconds," depending on what comparison we make. In physics, as you know, we use the mean solar second as our standard of time.

We can imagine our early ancestors noting the events of the sun rise and sun set. The first main division of time would be into daylight and dark. The next observation would be that the "event" of the sun being at its highest point, or casting the shortest shadow of an object that day, appeared to occur regularly. It was a very long time before it was appreciated that this time interval was not *quite* uniform, because the discrepancy between the time taken on the shortest and on the longest day for the return of the sun to the "meridian" is only 51 of our seconds. This day, the time for the sun to go from highest point to highest point, that is the time interval between its crossing the meridian, is a true solar day.

Coming on to historical periods, we find that the Babylonians commenced their day at sunrise. The Athenians and certain ancient tribes at sunset; the Umbrians at noon; and the Roman and Egyptian priests at midnight. We find in our earliest records that solar day as arbitrarily divided up into twenty-four periods.

The Babylonians and the Chaldeans were early astronomers. Aristotle tells us that before 2200 B.C. they were attempting scientific astronomy. They divided the "natural day" and "natural night" into twelve hours each, employing the sundial by day and the water clock by night. The water clock was merely a device by which water dripped from an upper into a lower vessel, thus marking the "hours" of the night by the volume or weight transferred. For astronomical purposes, they divided the solar day into twenty-four hours. The "day hours" were, of course, longer than the "night hours" in the summer time, and shorter in the winter time. Why the 24 was chosen, which has been handed on until to-day, we do not know. It may have been because 12 provided easy fractional parts—$\frac{1}{2}$-day, $\frac{1}{3}$-day, $\frac{1}{4}$-day—but that is purely a speculation; 12 was always a popular number, on account of its divisibility. The division does not seem to have been given a name—even the Greeks of the time of Plato or of Aristotle did not use the word "hora" for that idea, but for a "season." It was applied to the "hour" much later.

The *first* division of the hour was into 60 equal parts, making minute fractions of the day. The *second* division of the hour was into 3,600 parts, each 1/60th of a minute. This was the same division that was made by the Greeks in angular measurements.

The introduction of the "60" division is supposed to be due to the Babylonians or Chaldeans. Using the water clock, and the balances for weighing, which they undoubtedly had, they carefully collected and weighed the water coming over between the time the first tip of the sun appeared above the horizon until it was completely above the horizon. The time also from sunrise to sunset was then "weighed" in collected water. And thus the relative diameter of the disc of the sun to the length of its path in the sky was calculated. The relationship was about 1:720. The true solar day being divided into twelve double hours, or twelve day hours and twelve night hours, the obvious smaller division was into one-twelfth of 720, which is 60—so the minute is approximately the time taken for the sun to move on in the sky a distance equal to the apparent radius of its disc—it moves on a distance equal to its own diameter in a time, very approximately, of two minutes.

Having made this "minute" portion of the hour 1/60th of it, the second division into 1/60th of that again was probably purely a logical one. Our hour, minute and second by unit and name were passed on to us through the Romans—the "events" of sun rise and sun set, and of sun at highest point for the day were such as could be observed everywhere.

It was not until clocks came into use that we were able to calculate the *average* time taken for the sun to pass from meridian to meridian, which constitutes what we now employ as our mean solar day, and thus dodge the variation of 51 seconds which otherwise occurs between the length of the longest and shortest true solar day throughout the year. Remember, a true solar day is time of the sun from its highest point in the sky one day to its highest point the next day, and *not* the period of the "natural day," which is the time it is above the horizon.

The length of a "natural day" varies by many hours between summer and winter. The length of a "true solar day" varies by 51 seconds; a mean solar day is the averaged time over a whole year; we then divide that into 24 equal parts called mean solar hours; and each hour into 60 parts called mean solar minutes; and each minute into 60 equal parts called mean solar seconds, and they are our standard.

Unfortunately, we know that our "world sun" clock is slowing down! Each of our mean solar years is shorter than the preceding one, as we slow in our rotation about our axis—but the error is scarcely measurable, and does not exceed 1/100th of a second change in the length of the mean solar day in 100 years.

We have no difficulty in determining the time, with a good transit telescope, to within a few hundredths of a second. Greenwich is satisfied to send out absolute time by its radio signals correct to 1/20th of a second, though they confess that sometimes after long spells of dull weather they may make a mistake which amounts to nearly 1/10th of a second.

It is quite possible to measure time intervals correctly to 1/1000th of a second with suitable equipment, and this is quite frequently done. So we are depressed by the fact that our so-called standard of time, the mean solar second, is altering, although the change is only about one part in ten million over every hundred years. It may be left to you to give us the absolute time standard, which at present is being sought within the atom of matter.

In the next article will be considered the derivation of British units of mass.

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