OUTLINES OF THE
EVOLUTION OF WEIGHTS AND MEASURES
AND THE METRIC SYSTEM

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PREFACE.

In the following pages it has been the aim of the authors to present in simple and non-technical language, so far as possible, a comprehensive view of the evolution of the science of metrology as it is now understood. Inasmuch as the introduction of the Metric System into the United States and Great Britain is a topic of more or less general interest at the present time, it has seemed that a work designed both for the student of science and for the general reader, in which this system is discussed in its relation to other systems of weights and measures past and present, would fill a certain need. While there are many works on metrology that treat at considerable length the historic and scientific sides of the subject, as well as the economic and archaeological questions involved, and a large number of books and pamphlets dealing with the teaching of the Metric System, besides those supplying tables and formulas for converting from one system to the other, yet there is apparently a distinct lack of works, which in small compass discuss the subject comprehensively from its many points of view. Indeed, the student of metrology is apt to be embarrassed by an extensive literature rather than by any deficiency in the amount of collected material, though much of the latter, to be sure, is included in various Reports and Proceedings of learned societies and official documents rather than in single works. A large amount of this literature devoted to metrology represents a minute specialization and critical analysis often discussing either a certain epoch, or a single system or group of weights and measures, where the treatment is from the standpoint of either archaeology, economics, or physical or mathematical science, and but rarely combining the three points of view. In addition, much of this literature is of an argumentative nature, and debate and discussion rather than definite conclusions compelling universal acceptance seem to be characteristic of metrological writing.

It has been the intention of the authors to consider briefly and systematically the general history of weights and measures, the scientific methods by which units and standards have been determined, the concrete standards by which the units are represented, and the present aspect of modern systems of weights and measures, together with the difficulties and advantages involved in any proposed changes. Experience derived while giving instruction in physics to students in applied science has suggested the general plan of treatment, and it has seemed desirable to present from an American standpoint the most essential facts in as logical relation as is possible in a science that is often marked by conditions quite illogical. From the copious notes and bibliographical references, which it is hoped will be appreciated by advanced students and those specially interested in the subject, it will be seen that at the outset any claims to striking originality must be dismissed, and the obligations of the authors to the various authorities mentioned in the notes are ungrudgingly acknowledged.

The authors hope that their work will serve two useful ends: first, as an introduction to metrological science designed especially for the student entering on the study of physics to whom a knowledge of units and standards is most necessary; and second, as preparatory to an intelligent understanding of the discussions involved in the proposed adoption of the Metric System by English-speaking peoples, especially by those to whom Metric and Anti-Metric arguments are being addressed with such frequency and persistence. It has been the intention of the authors to avoid as far as possible all controversy for several reasons; the first and most important of which is that this side of the question has been and is being abundantly covered elsewhere, so that it has seemed preferable in this work to include a mere statement of facts rather than to repeat or even add to the arguments. Such has been their intention, but they are also compelled to admit that they are supporters of the Metric propaganda, and they must ask indulgence for any departures from the plan determined on. However that may be, they have endeavored to give a fair and concise history of the Metric System so that its logical development and characteristics will be apparent, and this, together with the experience of European nations as briefly described, will supply sufficient data on which may be formed an intelligent opinion as to the desirability of adopting in America and Great Britain at an early date the International System of weights and measures.

In view of the fact that such a work has involved the use of a vast number of authorities, it is manifestly impossible to specify in detail other than in the notes the great indebtedness on the part of the authors to the labors of many famous metrologists. Naturally they have consulted freely the classic work of Méchain and Delambre, *Base du système Métrique*; General Morin's *Notice historique sur le système Métrique*; Bigourdan's *Le système Métrique*; Guillaume's *La Convention du Mètre*; and his excellent little treatise on *Unités et Étalons*, as well as Benoit's Report on Standards of Length to the International Physical Congress of 1903. In addition they have used the various publications of the International Bureau of Weights and Measures. For ancient weights and measures many sources have been consulted, while for English standards and metrology the works of Chisholm and Chaney have been found most helpful, but they have been supplemented by various papers of Parliamentary commissions and the Proceedings of scientific societies. In the United States the Reports and other papers of the Coast and Geodetic Survey, the recently established National Bureau of Standards, and the Committees on Coinage, Weights and Measures, of the House of Representatives have formed a nucleus that has been supplemented by extensive reference to other scientific literature.

In conclusion the authors would gratefully acknowledge their obligations to M. Ch. Ed. Guillaume, Assistant Director of the International Bureau of Weights and Measures, and Professor S. W. Stratton, Director of the U.S. Bureau of Standards, who most kindly consented to look over the proofs and have rendered assistance in many substantial ways.

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CHAPTER I.

ORIGIN AND DEVELOPMENT OF THE SCIENCE OF METROLOGY.

FEW questions concern the human race more directly and universally than the subject of weights and measures. In fact, so intimate is this connection that the common weights and measures of a people bear much the same relation to it as does the language of ordinary speech, being assumed and applied in their daily occupations without active thought, and resisting changes and reforms, even when brought about by the most strenuous efforts and with convincing proof of their desirability or necessity. For the origin of weights and measures it is necessary to go back to the earliest days of the human race and deal with the elementary mental processes of primitive man. The idea of measuring must have been closely akin to that of number, which, of course, implied the perception that certain objects could be grouped together either actually or at least ideally. The next step would be the comparison of the various objects of such a group, and this would involve a simple ratio in terms of one of the members of the group. When the comparison was extended to other groups, there was need of a standard, and, when various classes of objects were compared, a standard had to be selected which would answer in common. Such standards would readily suggest themselves. If it took a certain number of days and nights to make a journey, the distance travelled in one day, that is from one sunrise or sunset to the next, would straightway be considered as a natural measure of journeys of considerable duration, while, for shorter distances, the pace as a regularly recurring interval would be adopted for measuring the total distance, and the single pace would be taken as a unit.

For measuring still smaller distances the primitive man would take, say the length of his foot or the breadth of his hand, as it would be most convenient for him to employ as units in his measurements the objects usually at hand, and it was but natural that the dimensions of the body would furnish such units. Thus for linear measures there would be employed the breadth of the first joint of the forefinger, the breadth of the hand, the span of the extended fingers of one hand, the length of the foot, the length of the forearm, the step or single pace, the double pace, and the distance between the tips of the fingers when the arms were outstretched. All of these distances figured in the early systems of linear measures of the ancients, and, in fact, great diversity of measures was a characteristic of early civilization, due to the fact that originally only the convenience of the individual had to be consulted. With the growth of society the tendency was toward uniformity, and this tendency, with but occasional retrogressions, has been maintained. When several persons were concerned in the comparison of the size of an object or some other kind of measurement, it was necessary to consult the convenience of the group rather than that of the individual, while with the development of trade there was also added the idea of equity.

Along with the general tendency of progress from diversity to uniformity of measures in the evolution of society, must also be considered the securing of uniformity of single measures. Thus, if a pace or length of a forearm was a convenient unit for a number of individuals, it would soon become necessary to specify the class of individuals, or, better still, the single individual whose pace or forearm was to be the standard; was it to be that of a man six feet in height or one considerably shorter? Such a discussion could not but lead to the actual measuring of the pace or forearm which would by common consent serve as the measure, and then by laying off the distance on some surface a standard or concrete reproduction of the unit would be constructed which would answer for the family or small group. Just as it was necessary for the family to come to some understanding as to what measures would be standard for their household, so it was soon realized that the interests of all would best be subserved if a single system should be employed throughout the tribe, either by a gradual adoption of a common mean, or by having some standard imposed by authority emanating from the ruler or headmen of the tribe. This latter practice was the more prevalent, and, remarkable to say, has persisted to modern times. So late as the time of Henry I. the length of the English yard, according to tradition, was fixed by the length of the sovereign's arm, while even in the United States in nearly all cases the national standards of weights and measures have been determined by executive order rather than by legislative action.

While the foregoing observations would also hold true in the case of weights, yet in connection with the latter there are certain additional matters to be considered. When the primitive man had advanced in civilization to a point where he looked beyond his immediate needs, he would doubtless own a certain number of slaves and domestic cattle, and his life being spent in an habitation or home more or less permanent, it would be natural for him to accumulate stores of grain and other substances both for his future wants and to barter for other commodities. Now, it seems that the earliest unit of wealth and basis of exchange was the ox or cow, and this soon found an equivalent in a certain amount of gold, a substance which, on account of its practically universal distribution and its uniform scarcity, could readily be given a fixed value in terms of cows or oxen.[1] This would involve some rude form of measurement, such as a goose-quill for the measurement of gold dust by capacity, or a linear measurement if the gold was in the form of wire or strips, and eventually the use of a primitive balance with the natural seeds of plants for weights. These seeds indisputably were the first weights, as can be proved by studying the habits of primitive peoples past and present, where such use of seeds has been and is practically universal, and this custom, furthermore, has survived in the grains of the Anglo-Saxon weights and the carat (from the Arab *carob* or bean) of the dealers in precious stones. But this early weighing was

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[1] Ridgeway, *Origin of Metallic Money and Weights* (Cambridge, Eng., 1892).

confined to gold for purposes of trade, and to other metals, such as silver and copper, when they were subsequently used for a similar purpose; and this is amply demonstrated by early Egyptian records where mention is made of weighing only gold, silver, and copper, and lapis lazuli, until the time of the seventeenth dynasty. As it was not until the seventh century B.C. that coined money was used, this weighing of metals was universal, and the use of the balance was required in practically all transactions, as when "Abraham weighed to Ephron the silver which he had named in the audience of the sons of Heth, four hundred shekels of silver, current money with the merchant" (Gen. xxiii. 16).

It followed naturally from such universal weighing that certain units should be formed, made up of a certain number of seeds and reproduced by stone or metal standards. Though we may agree with Ridgeway that the earliest weighings were empirical, and were carried on by seeds and natural standards "before ever the sages of Thebes or Chaldaea had dreamed of applying to metrology the results of their first gropings in Geometry or Astronomy,"[1] yet we must admit that some sort of a mathematical system of units of weight was bound to come where weighing was so widespread. Then with the development of civilization, especially as regards science and commerce, it was but natural that these weights should be defined either by royal decree or by common consent, and be based upon a standard which, according to some metrologists, was scientifically determined, or in the opinion of others was merely an arbitrary weight or weights. At all events it must be borne in mind in considering questions of metrology from the earliest times down to within the last two centuries that accuracy in weights and measures was neither demanded nor possible, and that attempts of archaeologists accurately to weigh the weights or measure the linear scales from old ruins, and to use small differences in forming their theories, are in most cases quite unwarranted. There is, however, indisputably a certain amount of correspondence among the weights and measures of antiquity due to commercial intercourse which took place both by sea and by caravan, and which was much greater than we would be apt to

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[1] Ridgeway, p. 232.

suspect, and this should of course receive due weight in all discussions of the metrology of the ancients.

For the measure of capacity i~~t is quite obvious that~~ the earliest units were natural objects such as eggs or gourds, and ~~that~~ a basket or jar would be constructed by a certain tribe which would be of a convenient capacity for the purposes for which it was used, such as carrying grain or water. Such natural or arbitrary units would straightway find application and would doubtless fill all needs, as capacity measurements would be of the simplest nature possible. In~~ fact, with certain primitive peoples, as is now the case among some Asiatic tribes, units of measure of capacity were quite unknown, and it is the general tendency for units of capacity to come after units of weight.~~ If we are to follow the theories of some metrologists we must assume that the ancients derived their units of capacity from a cube one of whose sides was the linear unit, and that the unit of weight was this, or a proportionate cube, which was filled with pure water. In fact, such a process would give a unit of area by taking a square whose side was a linear unit, and a cubical measure formed by a unit cube whose edge was a linear unit. Whether or not the ancients followed such a process of reasoning it is impossible to say, but on both sides of the question there are many arguments which will briefly be referred to a few pages further on.

While the development of weights and measures is a gradual evolution, yet it is a complex matter to which so many influences have contributed that it is difficult to trace any clear course or logical development. Ethnic conditions, the whims and caprices of rulers, imposition and fraud, conquest, and methods and habits of thought and life, all in turn have had their effect. Nevertheless the growth of scientific knowledge and its application, the influence of the market-place, as well as that of a broader commerce and laws and customs, in every nation have tended to bring together into something more or less resembling a system all matters connected with weighing and measuring built up on such units as the tribe or nation had selected for their interchange of commodities and ideas.

For the units or bases of such systems it is possible to select two different classes of quantities, arbitrary and natural, and to use them in their development. By an arbitrary quantity is meant one that is selected without reference to its occurrence in any natural object or condition, but merely a certain distance, mass, etc., which will furnish a convenient basis both in its original state and by its multiples and submultiples, for the measurements to which it will be applied. In actual practice the result has been, in spite of many attempts to construct systems based on natural units, that the fundamental units are arbitrary, and where interrelated are based upon actual standards of length rather than distances found in nature. As examples of natural units might be cited the measures derived from the human body already mentioned, which readily connect themselves one with another by certain relations. Thus:

The Digit, - - - - -	equals	1	part
Palm or handbreadth, - -	„	4	„
Span, - - - - -	„	12	„
Foot, - - - - -	„	16	„
Cubit, - - - - -	„	24	„
Step or single pace, - - -	„	40	„
Double pace, - - - -	„	80	„
Fathom, or distance between extended arms, - - -	„	96	„

This ratio we find observed in early systems of measurement, and it must be borne in mind in considering them.

As typical of early natural measures as found in the Orient, the following passage from the writings of Hiuen Tsiang (Yuan Chwang), 603-668 A.D., a Chinese traveller and author, of Ho-ran, written in A.D. 629 in regard to the measures of India, may be cited:[1]

"In point of measurements, there is first of all the yôjana (yu-shen-na); this from the time of the holy kings of old has been regarded as a day's march for an army. The old accounts say it is equal to 40 li; according to the common reckoning in India it is 30 li, but in the sacred book (*of Buddha*) the yôjana is only 16 li. In the subdivision of distances a yôjana is equal to eight krôśas (keu-lu-she): a krôśa is divided into 500 bows (dhanus): a bow is divided into four cubits (hastas): a cubit is divided into 24 fingers (angulis): a finger is divided into 7 barley-

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[1] Beal, *Buddhist Records of the Western World* (London, 1884), vol. i. p. 70.

corns (yavas): and so on to a louse (yûka), a nit (likshâ), a dust grain, a cow's hair, a sheep's hair, a hare's down, a copper water,[1] and so on for seven divisions, till we come to a small grain of dust: this is divided sevenfold till we come to an excessively small grain of dust (anu): this cannot be divided further without arriving at nothingness, and so it is called the infinitely small (paramânu)."

Leaving out of consideration the source or antiquity of these particular measures, they may be considered as exemplifying the use of natural circumstances or objects as units and their connection into a system. However, as is mentioned in the case of the yôjana, and the same may be found in numerous other instances in early measures not only in the Orient but throughout the civilized world, the ancient systems may have contained units varying in value and in their relation to other units. It may be said in passing that it is fair to assume that these particular measures were much older than would at first glance appear from the date of the work quoted, as India and the adjoining countries boasted a civilization that was nothing if not conservative, and traced its traditions to a remote past.

Another example of a natural unit, according to some of the older authorities on metrology, including Paucton,[2] though the theory is now regarded as entirely erroneous, was the base of the Great Pyramid, which was constructed equal to the five hundredth part of a "degree," and was divided into 600 Ptolemaic feet or 400 Ptolemaic cubits. Likewise in the determination of the meter an attempt was made to measure the ten-millionth part of a quadrant of a great circle of the earth, but it was subsequently found that the meter thus obtained did not represent this fraction with sufficient accuracy, and it was concluded to retain such a meter as an arbitrary standard and as the basis of the metric system rather than attempt to secure a new natural unit which might require subsequent changing with future scientific developments.

Even after the metric system had been developed, Sir John Herschel, the British astronomer, proposed as a standard the

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[1] Possibly the size of the small hole in the tamri or copper cup for the admission of water.

[2] Paucton, *Métrologie, ou Traité des Mesures, Poids et Monnoies* (Paris, 1780), chap. i. p. 109 *et seq.*

length of the polar axis of the earth, as $\frac{1}{500,000,000}$ part of this quantity would give the present British inch very closely.[1]

Another class of natural units that were employed as the basis of systems of weights and measures consisted of the dimensions or weight of grains of barley or corn, a number of such grains being placed in a row to form such a unit as the English inch, or collected to a certain number to form by their weight an English pound.

Whether the units be natural or arbitrary there must be some that are fundamental, and on them can be based and developed others as civilization, commerce, and science need additional units to express the magnitudes with which they are forced to deal. For example, in the eighteenth century it was not possible to make any measurements of electricity, nor indeed were such demanded, yet one hundred years later a complete system of electrical measurements was developed based on measures and units previously used.[2]

For fundamental units it is possible and most convenient to start with the unit of length and develop from it units of weight and capacity by taking a volume equal to that of a cube, each side of which is equal to the selected unit of length, and then filling it with water, as was done with the modern metric system, and is a feature claimed for the weights and measures of the ancient Babylonians. Similarly, units of area could be developed by taking a square whose side is the linear unit, and with the addition of a unit of time, units of velocity, acceleration, etc., could readily be derived. By the time that these and other required units were obtained, they naturally would become associated into a system of more or less logical relation and arrangement. In such a system there necessarily would be a number of different units for different classes of quantities, and these would be multiples and sub-multiples of each other. Such arrangements and systems would reflect the methods of thought of the people by whom they were developed. Accordingly in ancient Egypt and also in China we find a decimal system employed as in their system of numerical notation, while among the Babylonians, Chaldaeans, Assyrians, and the Egyptians of certain later dynasties

[1] See chapter vi., p. 164.

[2] See chapter ix.—Electrical Units.

the basis of division was sexagesimal, as is retained in our modern notation of time. The Romans used the duodecimal system, where the foot, *sextarius* (measure of capacity), *libra* (pound), etc., were divided into twelve equal parts. With the Hindus there was the binary subdivision which was also followed by the Germanic and Teutonic peoples, and also by the Arabs, despite their decimal system of notation. These examples show how national or racial conditions affect the development of a system of weights and measures, and of course as the political, commercial, or intellectual influence of a nation extended it was but natural that with it would go its weights and measures, which, if not supplanting those of other countries, at least in many cases would have a corrupting and disintegrating influence.

In any attempt at a brief historical survey of the origin and history of weights and measures there are many matters to be taken into consideration which prevent a complete and comprehensive sketch of the subject. For over two centuries there has been much attention devoted to ancient metrology, and many and contradictory theories have been advanced. They are for the most part founded on data or hypotheses by no means satisfactory; though in nearly all instances plausible cases which often show the greatest study and ingenuity have been made out by workers whose sincerity and industry cannot be questioned. In certain of these systems and theories the ancients are credited with a knowledge of mathematics, both theoretical and applied, which some scholars do not think at all warranted, while other systems have been built up on limited data, often text allusions in ancient literature and inscriptions, which though harmonious to a greater or less extent do not absolutely convince one that the harmony is not quite as much the result of chance as of design.

Assuming that the parts of the body were employed by many ancient races as the basis of measures of length, it is desirable to ascertain how these were united into a system and how such a system spread. It is usual to credit the origin of systems of weights and measures to Babylon or Egypt, the systems of both countries showing a common source, and there being various remains, literary and archaeological, on which have been based explanations of the origin of all ancient measures. Thus the great pyramid of Ghizeh, dating from about 4000 B.C., by some has been thought to have an important bearing on metrology, and has figured in many discussions and theories, since by its dimensions and inscriptions it supplies data which are susceptible of various interpretations. Thus Paucton and Jomard,[1] two distinguished metrologists of the eighteenth century, assumed that the side of the pyramid represented a fraction of a degree of the earth just as the French scientists based the meter on a fraction of the earth's quadrant; while later Prof. Piazzi Smyth[2] and Lieut. C. A. L. Totten[3] derived the Anglo-Saxon weights and measures directly from its dimensions. These theories, as well as the idea that the great pyramids played an important part in ancient astronomy, have been amply controverted, and according to the opinion of Lieut.-Gen. Sir Chas. Warren[4] in the light of the most recent investigations, "The Pyramid is simply a record of the measures, linear, capacity, and weight, which were in use in former days." There is nothing astronomical about it except its orientation and the direction of its great gallery to a point in the northern sky.

There were, however, other great structures in Egypt and Babylonia in which stone and brick[5] of regular dimensions were used, and even in the earliest times of which we have record it seems conclusive that there must have existed fairly complete systems of weights and measures.

According to the Jewish tradition given in Josephus, we are informed in the quaint language of Dr. Arbuthnot, "that Cain was the first monied man, that he taught his band luxury and rapine, and broke the public tranquillity by introducing the use of weights and measures."[6] What happened in the land of Nod,

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[1] Paucton, *Métrologie, ou Traité des Mesures, Poids et Monnoies* (Paris, 1780); Jomard, *Mémoire sur le Système Métrique des Anciens Egyptiens* (Paris, 1817).

[2] C. Piazzi Smyth, *Life and Work at the great Pyramid* (Edinburgh, 1867); *Our Inheritance in the great Pyramid* (London, 1864). These works and Professor Smyth's theories are discussed by Dr. F. A. P. Barnard in *Proceedings Am. Metrological Society* (New York), vol. iv., 1884, pp. 197-219.

[3] Charles A. L. Totten, *An Important Question in Metrology* (New York, 1884).

[4] Warren, "The Ancient Standards of Measure in the East," p. 222, *Palestine Exploration Fund Quarterly*, 1899.

[5] In Babylonia square bricks were used which measure 13 inches on each edge, or $\frac{1}{3}$ of the double cubit as given by the Gudea Scale (see p. 14).

[6] Arbuthnot, p. 1, *Tables of Ancient Coins* (London, 1754).

whither Cain had wandered with his band and where he founded his city (Genesis iv. 16 and 17), soon must have become universal, for we find the dimensions of the ark as Noah was told to construct it given in cubits (Genesis vi. 15).

Apart from such traditions and scriptural legends we know from brick tablets and other remains that weights and measures in some form or other flourished in Babylonia and Egypt, and that the systems of the two countries doubtless had a common origin. Although it cannot be definitely proved it is likely that this origin was Babylonian, and much that has been written on ancient metrology is based on this view. Hommel, in speaking of the Babylonian metrology,[1] states that from it "admittedly all the ancient metrological systems (that of ancient Egypt included) were derived." This is also the opinion of Dr. Brandis.[2] Assuming such to be the case, we are brought at once face to face with a great diversity of opinion on the point as to whether a well-developed and scientific system of weights and measures existed in Babylonia, from which were derived the weights and measures of the adjoining nations, and which, through trade and commerce, spread over the then civilized earth, or whether various systems of weights and measures came into existence separately in different countries and gradually, with the development of civilization and under similar conditions, spread abroad and became more or less assimilated. The first is the point of view of Boeckh[3] and the members of a distinguished school of Continental archaeologists and metrologists, and from available monumental and literary remains with endless patience and ingenuity they have evolved theories so scientifically constructed that they excite admiration if they do not convince. On the other hand there are a number of students of archaeology who dispute the scientific basis on which such systems are constructed, and deny that requisite knowledge and mental ability for such scientific reasoning and construction was possessed by these early

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[1] See article "Babylonia," Hastings' *Dictionary of the Bible* (New York, 1903), vol. i. p. 218.

[2] See J. Brandis, *Das Münz- Maass- und Gewichtswesen in Vorderasien bis auf Alexander den Grossen* (Berlin, 1866).

[3] Boeckh, *Metrologische Untersuchungen über Gewichte, Münzfüsse und Masse des Alterthums* (Berlin, 1838).

peoples. They claim that weights and measures from some early body measures and natural standards developed according to the needs of the people and depended on widely understood ratios and rules of exchange rather than on any scientific basis.

In considering the first point of view it is necessary to assume that considerable mathematical and astronomical knowledge was possessed by the ancient Babylonians and was used by them in standardizing their weights and measures. In other words, from ancient and arbitrary measures, doubtless of the body, they developed such a system as was early required by the demands of their scientific work in astronomy and their active building operations. As measuring is essential to all scientific work, it is not to be doubted that its importance was thus early recognized, and in conjunction with their system of numerical notation a permanent system was arranged. This was also brought into direct relation with their astronomical work, which was by no means inconsiderable for these early times. In the course of their observations it was ascertained that at the equinox the apparent diameter of the sun on the horizon was $\frac{1}{360}$ of the half circle. Furthermore, by using a water clock, where water was allowed to flow through a small orifice from one jar into another, it was found that the amount received in the twelve hours between sunrise and sunset was 360 times as much as when the sun was traversing a distance equal to its own diameter or two minutes of time.[1] This afforded an accurate method of measuring time, and formed the foundation of the sexagesimal system which was the underlying principle of all Babylonian metrology and harmonized perfectly with their system of numeration. This idea naturally involved the division of the circle into 360 degrees, or rather 720 parts, which has continued to the present day, and the important geometrical fact that the radius is equal the chord of one-sixth the circumference was also well known at this time.[2]

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[1] L. Ideler, "Ueber die Sternkunde der Chaldaeer," *Abhandl. der k. Akad. Wissenschaft in Berlin*, 1814-1815, p. 214. Referring to Cleomedes *Cyclom.* (On the Circular Theory of the Heavenly Bodies), 1. 11. p. 75 ed. Balfor; Proclus *Hypotyp.* p. 41 (ed. Basil. 1540-4); Pappus, especially in his *Commentary on the Fifth Book of the Almagest of Ptolemy.*

[2] Hommel, article "Babylonia," Hastings' *Dictionary of the Bible* (New York, 1903), vol. i. p. 219.

By some authorities it was believed that the water jar referred to above was also used as a measure of capacity, and that it was divided on a duodecimal basis corresponding to the hour division. It was then assumed that from a cube equal to such a volume the unit of length was derived by taking the length of one of its edges, which was the Babylonian foot, and bore a natural relation to the cubit. This unit of volume when filled with water gave the Babylonian talent, from which other units of the same name were derived. This theory, however, which was supported for many years, has been abandoned, and it is believed that the unit of weight was derived from the unit of length, just as is done in the modern metric system.

The relation of numbers and linear distances in Babylonian measures is best derived from a study of the Senkereh Tablet, which dates back to about 2500 B.C., and was discovered in 1850 in a small Arab village on the site of the ancient city of Larsam or Larsa. It is now in the British Museum, and affords considerable information as to the Babylonian measures and the methods of computation. It is a clay tablet, on one side of which are the fractions and multiples of the ell or cubit, and on the other are the squares and cubes of the cubit from 1 to 40.[1] This tablet has received the attention of a number of scholars, including the late Professor Rawlinson, and the sexagesimal character of the measures has been clearly demonstrated. In connection with the scale of Gudea, to be described a few lines below, it has been examined by the Rev. W. Shaw-Caldecott, who concludes that "The breadth of the hand-palm conventionalized was the fundamental of all length measures," and "That there were three ell (cubit) lengths in simultaneous use, each probably in a different kind of trade like our own Troy and avoirdupois weights."[2]

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[1] Hommel, article "Babylonia," Hastings' *Dictionary of the Bible* (New York, 1903), vol. i. p. 218.

[2] Shaw-Caldecott, "Linear Measures of Babylonia about 2500," p. 263, *Journal Royal Asiatic Society*, 1903, London. In this article the characters on the tablet are reproduced. See also R. Lepsius, "Der Babylonisch-Assyrischen Längenmasse nach der Tafel von Senkereh," in the *Abhandlungen der Königlichen Akademie der Wissenschaften zu Berlin*, 1877. With this article is printed a photographic reproduction of the tablet, together with a reconstruction.

Accordingly from the tablet Mr. Shaw-Caldecott derives the following units and proportions:

Line - - - = $\frac{1}{180}$ of a palm.
Sossus - - - = $\frac{1}{60}$ „
Twentieth of a palm - = $\frac{1}{20}$ „
Twelfth of a palm - = $\frac{1}{12}$ „
Third of a palm, or digit = $\frac{1}{3}$ „
Palm.
Small ell (cubit) - = 3 palms.
Medium ell (cubit) - = 4 palms.
Large ell (cubit) - = 5 palms.
Small reed - - = 4 small ells (cubits).
Medium reed - - = 6 medium ells (cubits).
Large reed - - = 6 large ells (cubits).

While the Senkereh Tablet establishes the ratios between the various units yet it does not afford any information as to their absolute value, and for this recourse is had to a tablet forming part of a statue discovered in 1881 at Telloh in southern Babylonia, not far from Senkereh, by M. E. de Sarzec, and now in the Louvre.[1] It dates from about the same period as the Senkereh Tablet, and represents King Gudea in a position of prayer, and holding on his knees a slab of stone on which is engraved the ground plan of a palace, a graving tool, and a double line, the latter being cut near the outer edge and being crossed by a number of indentations or cuts. This unmistakably is a scale, and, furthermore, it is the oldest scale that has been discovered up to the present time. By assuming that it is the same size as the scale of linear measures then in use, and by applying the proportions obtained from the Senkereh Tablet, it is possible to obtain the lengths of the various units in terms of modern equivalents, preserving the decimal and duodecimal division characteristic of the Babylonian arithmetical system. Thus we have the handbreadth or palm equal to 99-99·6 mm. (3·9-4·1 inches), and the cubit composed of five handbreadths

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[1] E. de Sarzec, *Découvertes en Chaldée*, 1884-1889, Pl. 15. See also Shaw-Caldecott, *loc. cit.* See also Toy, "The Book of the Prophet Ezekiel" (Part 12, *Sacred Books of the Old Testament*, "Polychrome Bible") (New York, 1889), Notes, pp. 179-180 for illustrations and description.

equal to 495 mm. (19·483 inches), and also in early and widespread use a double cubit twice this length or 990 mm. (38·976 inches). This latter unit is of interest on account of its close approximation to the modern meter of 1000 mm., and also on account of the fact, first discovered by Lehmann, that it is almost exactly the length of the second's pendulum for the latitude of Babylon (31 degrees north, at which point the theoretical length of a second's pendulum would be 992·35 mm.). Consequently he argues that the theory of the pendulum must have been known to the early Babylonians, who doubtless derived it from the plumb-line, which must have been employed in their building operations.[1] This fact, however, cannot be regarded as more than a mere coincidence, and while it is most interesting it is not considered possible that such an important physical principle should have been known at so early a day and then allowed to lapse from human knowledge until the time of Galileo.

Multiplying the great cubit by 6 the "reed" was obtained, and by taking 12 great cubits the *gar*. To form the *ush* or stadion 60 *gar* were required, and 30 *ush* made a parasang or *kasbu*, which was equivalent to about 21 kilometers. These longer linear measures are again connected with the measure of time, as 360 great cubits represented the distance an average walker could accomplish in four minutes, while the great *kasbu* of 21,600 cubits was the distance traversed during a night watch of four hours or $\frac{1}{6}$ of a day, and the small kasbu would be one half of this distance.

Measures of area constructed by squaring the linear measures are also claimed for the Babylonians, and here again the sexagesimal ratio was preserved; thus 180 *she* made a *gin*, which was possibly equal to a square cubit. A "garden" (*sar*) was composed of 60 *gin*, and 1800 gardens formed a "field" (*gan*). But the Babylonians, in common with other Asiatic nations, also employed for measuring land the amount of seed required to

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[1] Lehmann, p. 89, "Ueber das babylonische metrische System und dessen Verbreitung," *Verh. der Physikalischen Gesellschaft zu Berlin* (Berlin, 1890), vol. viii. pp. 81-101; also in abstract, pp. 167-168, vol. lxi., *Nature* (London, 1889). In this connection a paper by the same author, "Alt-babylonisches Maass und Gewicht und deren Wanderung," *Zeitschrift für Ethnologie* (Berlin, 1889), pp. 245-328, may also be consulted with profit.

sow a field, and statements based on this idea are found in many old Assyrian documents.[1]

The Babylonian capacity measures started with a cube whose edge was a handbreadth in length (99-99·6 mm.), and which when filled with water gave the unit of weight, the great mina, which, occupying as it does almost the volume of a cubic decimeter, would correspond quite closely with the modern kilogram. Such a capacity measure was known as the *ka*, and was nearly the equivalent of the modern liter. As multiples of the *ka* there was the *gur*, which was composed of either 360 or 300 of the smaller units, there being not only two such *gurs* but a third divided into 180 parts and based on a double *ka*, from which the Hebrews probably obtained their *kor*, which they divided into 180 *kab*. Likewise in the subdivision of the Babylonian measures there was the *gin* or $\frac{1}{60}$ of a *ka*, which in the Hebrew system was paralleled by the *hin*.

The relation between the capacity and weight we have already seen in the case of the great mina, which weighing, as it did, between 982·4 and 985·8 grams gives a noticeably close approximation to the modern kilogram. This great or heavy mina was composed of 60 shekels, each of 360 *she* or grains of corn, thus combining in a system of weights two classes of natural units. The greater weight was the talent composed of 60 minas. Such a system would have been simplicity itself, were it not for the fact that several systems of weights, just as of linear measures, are found employed at the same time. There was a light mina which weighed one half of the heavy mina, and in fact whole light and heavy systems standing to each other in the ratio of 1 : 2 are believed to have existed, of which representative weights have been found. Furthermore, as gold and silver, whose values were in the ratio of 40 : 3, were used as currency, other systems designed to accommodate both weight and value arose, and there was a mina of gold which was composed of 50 units, each a shekel or $\frac{1}{60}$ of the weight mina. Then there was a silver mina which weighed about $\frac{1}{9}$ more than the Babylonian mina of weight, while there was a Phoenician mina which was also divided into 50 units, which made the whole equal to $\frac{100}{135}$ of the original weight mina.

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[1] C. H. W. Johns, *Assyrian Deeds and Documents* (London, 1902), vol. ii. pp. 219-220.

The subject of Babylonian units of weight is one of considerable complexity on account of the fact that weight and currency had so intimate a relation and that gold and silver were both standards. Furthermore, there was doubtless legislation standardizing certain other weights so that discrepancies would be found on that score.

Having considered such a carefully erected structure we must now discuss briefly the position of those that would demolish utterly any such scientific arrangement and basis for ancient weights and measures, and more particularly any connection between the two. We are called upon to proceed further along the lines indicated in the beginning of this chapter, and to observe that the use of weights and measures accompanied the gradual development of civilization, and that exactness in either the determination of units of measure or in the preservation of standards was no more characteristic of the twentieth or thirtieth century B.C. than it was of the second or third. Although the early Babylonians may have known how to divide time on a sexagesimal basis and to observe eclipses, yet so simple a mathematical process as obtaining area by multiplying length and breadth together seems to have been unknown according to a study of their literary remains, since for the measurements of land areas the unit was not a square, but a strip of uniform width.[1] Furthermore, the extensive use of the amount of seed required superficial measures. The most strenuous objection has been made to any systematic relation and connection between weights and measures, and this feeling on the part of continental scholars is considered due to their intimate knowledge and use of the metric system, which acquired by them so readily would doubtless suggest the possibility of the employment of its fundamental features by the ancients. Why several thousand years should intervene before the mind of man would return to such devices, it is difficult if not impossible to explain, and like many other phenomena considered now so simple, it is most natural to assume that it was known to the ancients, yet at the same time it is impossible to prove it. Thus any such relations must be entirely hypothetical, and the only arguments to be advanced in

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[1] C. H. W. Johns, *Assyrian Deeds and Documents* (London, 1902), vol. ii. pp. 219-220.

their support must be founded on circumstances which are probably mere coincidences, and doubtless most delusive. Professor Flinders Petrie, in speaking of this subject, says:[1] "All that can be said therefore to the many theories connecting weights and measures is that they are possible, but our knowledge at present does not admit of proving or disproving their exactitude." Though this was written some years ago, nevertheless it is fair to say that there has been no discovery or research that would warrant any different expression from one holding Mr. Flinders Petrie's views. According to another leading authority, the Rev. C. H. W. Johns, who has carefully examined many literary remains of the old Babylonians, there is not afforded by these documents any ground for believing in any connection between Babylonian measures of length and weight, while to him Lehmann's idea of the double cubit derived from the second's pendulum seems quite ridiculous. According to Ridgeway,[2] considering the Hindus as an ancient people of culture, with whose literature we have some acquaintance, we find that "though they were clever mathematicians, yet they fixed their standards of weights by natural seeds in the good old primitive fashion, and did not make the slightest attempt to find a mathematical basis for their metrological work."

In short, from this point of view the situation for the Babylonians, and indeed for any other nation whose claim for a similar priority should be advanced, may be summarized as follows: The Babylonians in common with other nations from body measures and seeds of grain or other plants developed such systems of measurements as sufficed for their wants; their standards were arbitrary and changing, but since they were the leading people of this part of the world as regards culture, their measures were impressed on their neighbors, and especially on the Phoenicians, by whom as the chief traders of this period of antiquity they were spread abroad. There is no reason to believe that the weights were preserved in any kind of purity, nor is there any reason to see why this should have occurred, and when we consider the variation in weights and measures

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[1] W. M. Flinders Petrie, article "Weights and Measures," *Encyclopaedia Britannica*, 9th ed. vol. xxiv. p. 482.

[2] Ridgeway, *Origin of Metallic Coinage and Weights*, Cambridge, 1892, p. 178.

during more recent centuries with their scientific men and methods, their mints and their standards, not to mention government regulation, as exampled, say, in Great Britain, it is not natural to believe that those ancient units could have been fixed to any basis with scientific exactness. Such mere coincidences as that a cubic foot of water weighs 1000 ounces, and that a British imperial gallon of water at temperature of maximum density weighs ten pounds, if put back into the past would form a far better basis upon which to form decimal and other systems than many of the facts that have been employed by scientific metrologists.[1]

As an argument of this kind depends largely upon quoting authorities, and dealing in detail with apparent and actual inconsistencies, it is manifestly impossible to do justice to it in these few paragraphs; but reference to Johns and Ridgeway in the volumes quoted will amply repay the student interested in this phase of archaeology and metrology, as by both authors the case is stated most ably and critically.

The Jews, unlike their neighbors in Babylonia and Assyria, were not a people of scientific tastes, and their weights and measures were derived largely from the nations whose territory they adjoined, consequently it is not natural to expect much uniformity of weights and measures among them. Indeed, there are indications that there were at a single time among the Israelites as many as three different and distinct units of weight, Babylonian, Syrian, and Phoenician, and in each case there was both a heavy and a light system standing towards each other as two to one. Undeniably there were Egyptian influences on the Hebrew weights and measures, but far more is due to Babylon, as the civilization of that country was predominant in Canaan up to the fifteenth century B.C. according to records in the Tel-el-Amarna correspondence, and this predominance carried with it undoubtedly the Babylonian weights and measures. By the eighth century B.C., however, the Israelites had a legal system of weights and measures, but long before this they were accustomed to their use, as when Abraham bought the field of Ephron he "weighed to Ephron the silver" (Gen. xxiii. 16).

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[1] Flinders Petrie, article "Weights and Measures," *Encyclopaedia Britannica*, 9th ed. vol. xxiv. p. 482.

In fact, the Israelites became so accustomed to the use of the balance and of measures that they began to employ false weights and wrong measures, with the result that not once but many times[1] their prophets and teachers are forced to emphasize honest dealing in matters of measurements and the weighings of daily life. The chief unit of length of the Hebrews was the cubit, and with it were employed the usual body measures, such as finger breadths or digits, palms, spans, and fathoms and reeds. For these measures we have practically no data for determining their equivalents, and Professor A. R. S. Kennedy expresses the opinion "that reliable data for the exact evaluation of the Hebrew cubit do not exist."[2] In fact, values from 16 to 25·2 inches have been proposed for this unit, and by many it is believed that there were two cubits, one the "cubit of man" of six handbreadths, and also "a cubit and an handbreadth" or seven handbreadths, which was used in the construction of the temple (Ezekiel xl. 5). This would correspond to similar cubits of the Egyptians, and there is reason for believing that the weights and measures of the two nations were intimately connected, if not quite similar at the time of the Exodus, but like many other points in metrology it is not possible to bring forward absolute proof. For the measurement of area the Hebrews employed generally the amount of seed required to sow the land, or the amount of ground that could be ploughed by a yoke of oxen, the latter unit being the *zemed*, which in the Old Testament is translated by acre.[3] This is thought to be an area equivalent to the Egyptian *aroura*, which was a square 100 cubits on each side.

The capacity measures of the Hebrews for both wet and dry commodities were arranged upon a systematic basis which has in not a few cases been obscured by imperfect translation in the English Bible. The relation of the different measures is expressly stated in Ezekiel (xlv. 11 *et seq.*), where we learn that the *ephah* and *bath* were one and the same unit, the former being used for

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[1] Leviticus xix. 35 *et seq.* Deuteronomy xxv. 13-16. Ezekiel xlv. 9-14. Amos viii. 5. Hosea xii. 7. Micah vi. 10. Proverbs xi. 1, xvi. 11, xx. 10.

[2] Kennedy, article "Weights and Measures," Hastings' *Dictionary of the Bible* (New York, 1903), vol. v. p. 907.

[3] 1 Samuel xiv. 14 and Isaiah v. 10.

dry measure and the latter for liquids. This unit was one-tenth of the *homer*, a dry measure, and its liquid equivalent was the *kor.* One-third of the *ephah* gave the *seah*, which was divided in half and formed a dry measure equivalent to the liquid *hin.* One-tenth of the *ephah* gave a dry measure known as the *oner*, while the next smaller unit, used for both dry and liquid measure, was the *kab*, which was $\frac{1}{180}$ of the *homer* or *kor.* The fourth of the *kab* gave the *log*, the smallest liquid measure. By taking the *ephah-bath* as equal to 36·92 liters, or 65 (British) imperial pints, a value derived from a study of Greek and Hebrew literature, the modern equivalents can be approximated, though this equivalent is variously stated from 36·37 liters to 40·5 liters.

In considering the Hebrew units of weight we must bear in mind what has been stated about the Babylonian units and their fundamental proportions, where the talent was equal to 60 minas, each composed of 60 shekels, or in the case of the gold mina of 50 shekels. There was the heavy and the light systems, standing in the ratio of 2 : 1, and, as we have said above, systems based on Babylonian, Syrian, and Phoenician standards. Here of course it must be remembered that the units of weight were also units of currency, and to this fact is due in no small degree much of the variation in the standards. The shekel was for the Hebrews the principal unit, and in the three different systems mentioned from literary evidence and actual weights the following values have been assigned:

Babylonian unit, - - -	252 grains.
Syrian unit, - - - -	320 „
Phoenician unit, - - -	224 „

The Hebrews' weights without doubt were not preserved in anything like purity, and besides showing the effect of their Babylonian origin, in later times there are evidences of Persian, Greek, and Roman influences, so that our only means of identifying them consists largely in the connections established by the later Hebrew and the Greek and Latin authors. The weights of the Bible have received considerable study, and the only warrant for dismissing the subject here so summarily is that each separate phase demands detailed treatment and a critical examination of authorities. Furthermore, the absence of positive conclusions which can be stated definitely relieves us of the necessity for fuller discussion in this brief historical sketch.[1]

In the study of Egyptian measures there is considerable data for the metrologist, which is in the form of literary remains, such as papyri, monuments of one form or other from the Great Pyramid of Ghizeh to wall carvings, and actual wooden and stone scales. In the main there is little variation from the measures of Babylonia and many points of similarity both in the weights and measures and in the etymology of the words expressing them are seen, which indicate a common origin for the weights and measures of both nations, and aid in substantiating any theory based on the assumption that there was a definite parent system. There is a correspondence between the royal or building cubit of seven palms and 28 digits which has been constructed from the measurements of temples and other buildings in Egypt and the so-called sacred or building cubit of the Babylonians. Actual representatives of the former have been found in the nilometer cubit of Elephantis, and the wooden scale of Amenoemopht from the necropolis at Memphis, and other scales both wooden and stone.[2] A mean value obtained from actual scales and measurement gives for the modern equivalent of the cubit 525 mm. or 20·63 inches.

With this royal cubit was also used a natural or common (short) cubit which was of the length of six palms, and corresponded to the Greek cubit. The Egyptians employed the various subdivisions on the basis of the body measures, but they do not seem to have used either the foot or the fathom. All of these can be found expressed in their hieroglyphics, and are found in many of the ancient papyri. For long measure there was the

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[1] For further information and detailed references the following authorities may be consulted: Kennedy, article "Weights and Measures," in Hastings' *Dictionary of the Bible* (New York, 1902), vol. v. p. 901 *et seq.*; G. F. Hill, article "Weights and Measures," in *Encyclopaedia Biblica* (New York, 1903), vol. iv. p. 5292 *et seq.* These and allied articles contain full and detailed bibliography. See also C. R. Conder, "Hebrew Weights and Measures," *Palestine Exploration Fund Quarterly Statement*, 1902.

[2] For description and illustrations, see Lepsius, *Ueber die alt-aegyptische Elle und ihre Eintheilung* (Berlin, 1865).

khet, which was equal to 100 cubits, and was represented by a hieroglyphic of a coil of cord, as undoubtedly a line and reel were used for such measurements, just as Ezekiel (xl. 3) speaks of a "flaxen line" and "measuring rod" being used in measuring the new temple, and Jeremiah (xxxi. 32) mentions the use of the "measuring line" in surveying land. For very long distances the Egyptians had a measure, the *ater*, equal to from 30 to 60 or more stades and known to the Greeks as a *schoenus*, but it is expressly stated by Strabo that it varied in different parts of the country. It is of some importance, however, as it figures in geographical descriptions of Egypt, and has been actually found marked on the Memphis-Faium road.[1] The Egyptians had a series of square measures with a chief unit in the *set* equal to the Greek aroura and comprising a square, a *khet*, or 100 royal cubits on each side, the latter unit forming the basis of land measurement. For capacity the principal measure was the *hekt*, which was equal to $\frac{1}{30}$ of the cubit cubed, while for corn there was employed the *khar* ("sack") of 20 hekt until superseded by the sack of 16 *hekt* or the Greek *medimnus*, at or before the XVIII. dynasty. After ④ the Macedonian conquest the latter measure was halved to form the *artaba*, doubtless to conform with a measure introduced from Persia. Then there was the *henu* or $\frac{1}{16}$ of the *hekt*, used both for solids and liquids, as well as numerous other measures. According to Griffiths, whom we have followed in this description of Egyptian weights and measures,[2] the Egyptian measures were not derived from a cubit or fraction of a cubit cubed, but it is probable that the cubic idea was introduced a considerable time after the measures had been quite definitely fixed by custom.

In striking contrast to the many allusions to measures that are found in the early papyri there is a lack of information as regards weights. That weights existed and were used is known from a large number of weights that have been discovered, and from the

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[1] Flinders Petrie in *Encyclopaedia Britannica*, 9th ed. vol. xxiv., article "Weights and Measures," p. 483. Also *id.*, *Season in Egypt*, pl. xxvi. (London, 1888).

[2] F. L. Griffiths, "Notes on Egyptian Weights and Measures," *Proceedings Society of Biblical Archaeology* (London), vol. xiv. p. 403 *et seq.*, 1892. In this paper will be found the various hieroglyphics and a full explanation of their use. See also a continuation of this paper by the same author in same *Proceedings*, vol. xv. p. 301, 1893.

fact that balances are shown in the decorations of the tombs of the V., XI., XII., and XVIII. dynasties. In fact, the earliest known weight is inscribed with the cartouche of Chufu (IV. dynasty), the builder of the Great Pyramid at Ghizeh, whose date was approximately 4000 B.C.

The use of the balance in the earliest times was probably confined to exchange of gold and silver, and it doubtless was invented for this purpose. But one reference is found to weights before the XVII. dynasty, and only gold, silver, copper, and lapis lazuli were weighed even at that time, as no mention of weight is made in the so-called medical papyri, where it would be natural to find such an allusion were weights in current use. Their application increased slowly, and by the time of the Ptolemies, incense, honey, and drugs, as well as metals and precious stones, were weighed. About the time of the XVII. dynasty the *deben* or *uten*, a weight of 1400-1500 grains, and its tenth part, the *kiti* (also called *kat*) are found to be the only recognized units of weight in the various documents, but there have been found a wide variety of actual weights, which it is quite impossible to identify either with any system or among themselves, and which serve to embarrass the investigator.[1]

Later the units of weight in widespread use were the talent, the mina, and the shekel, as in other ancient nations, but considerable diversity is shown, though in general plan much the same division was followed as for the weights of the Babylonians and Hebrews already described. By some authorities the basis of the Egyptian unit of weight is considered to be a cubic volume (the cubic foot or cubit) of water, but at all events there were also various foreign influences, such as Greek and Asiatic units of weight, which produced a certain amount of confusion, and prevented any universal and single system. Under Ptolemy Lagos (d. 283 B.C.), however, certain reforms of weights and measures were effected that resulted in perpetuating the old Egyptian system, and the talent weights thus defined were known subsequently as the Alexandrian talents. These were

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[1] Flinders Petrie, article "Weights and Measures," *Encyclopaedia Britannica*, 9th ed. vol. xxiv. p. 486. Griffiths, *loc. cit.* p. 435, and vol. xv. p. 307. A. E. Weigall, "Some Egyptian Weights in Professor Petrie's Collection," *Proceedings Society Biblical Archaeology* (London), vol. xxiii. p. 378, 1901.

of two classes, each of which were divided into 60 minas of 50 shekels or 100 didrachms each, but the greater Alexandrian talent of copper or brass weighed just twice as much as the smaller or lesser Alexandrian talent of silver. The former was divided into 125 pounds by the Romans when they occupied Egypt, while the mina derived from the lesser talent was divided into 12 ounces (*unciae*), and weighing as it did 5460 grains, it became the predecessor of the series of European pounds of which the Troy pound is a type. From one of these ounces, if we may believe a Syrian authority, Anania de Schiraz, who wrote in the sixth century, by taking the $\frac{1}{144}$ part the carat or diamond weight was originally formed.[1]

In Greece the fundamental unit of length was the foot, and while we find the cubit, yet it is the foot that plays the principal part. The same unit, namely, the Olympian foot, was found throughout Greece, though, of course, there was necessarily considerable divergence from any one value at different times and different places. A clue to the actual length, however, is found in the ruins of the Parthenon, where the main hall of the Temple of Athena is called, according to Plutarch,[2] Hekatompedos (one hundred feet), and measurements show that it was 100 Attic feet in breadth by 225 in length, these numbers being derived from the ratio of the breadth to the length, and giving an Attic foot equal to ·30828 meter or 12·1375 inches. One hundred times the foot gave the plethron, which was squared and used as a measure of area. The Greek cubit, or 1½ times the foot, closely resembles the natural cubit rather than the sacred or building cubit of the Babylonians and Egyptians, and four of them made the *orguia* or fathom, that is the distance between the tips of the fingers when the arms were extended. This multiplied by 100 gave the stadion, originally the distance that a strong man could run without stopping for breath, and then fixed as the length of the Olympian stadion or athletic track, which was 600 feet in length.[3] This stadion was

[1] H. W. Chisholm, *The Art of Weighing and Measuring* (London, 1877), p. 42.

[2] Plutarch, *Pericles*, 13.

[3] Hultsch, *Griechische und Römische Metrologie*, 2nd ed. (Berlin, 1882), p. 33. This will be found a standard authority in classical measures, and will give text references to all authorities. On it are based most of the statements in the pages devoted to Greek and Roman metrology.

about one eighth of the Roman mile, and this ratio, as well as $8\frac{1}{3}$, is used by Strabo and Polybius.

It was most natural that the measures of Greece should pass to Rome, and we find between the two a close connection. The principle of subdivision was duodecimal, and we find the Greek foot introduced as a unit of length. It, as well as the *as*, or unit of weight, was divided into twelve *unciae*, whence our English words inch and ounce. Among the other measures of length employed by the Romans was the *palmipes*, or foot and hand-breadth; and the *cubitus* (cubit), or, as it was also known, the *ulna*, from which is derived the French word *aulne* and the English *ell*. The *passus* or unit of itinerary measure was equivalent to 5 Roman feet, and when multiplied by 1000 gave the *millia passuum*, from which was derived the mile as subsequently used in Britain and elsewhere. The *passus* was a double step or *gradus*, and was the distance covered from the time when one foot was taken from the ground until it was placed down again. For architects and surveyors there was a unit ten feet in length known as a *pertica* or *decempeda*, and the square of this distance gave the unit of area employed in surveying, twelve times which gave the *actus* or distance that a plow would encompass in a single course, while the *actus* multiplied by two would give the *jugerum* or Roman acre (·6229 English acre).

Perhaps the foot is the most important of the Roman measures, as it not only extended throughout Europe as a fundamental unit, but in some form it has survived almost everywhere until supplanted by the meter. True, there were marked variations, and the standards employed were most arbitrary, but the supremacy of the foot as the unit of length was maintained in Europe until the nineteenth century. The connection of the Roman foot to that of Greece has already been shown, but attention should be called to the fact that it gradually become shorter, and in the time of Pliny it bore the relation to the Greek foot of 25 : 24. There was also a foot of Drusus which was used outside of Italy for measuring land, and became permanent in the countries along the Rhine and Lower Germany. This foot contained $13\frac{1}{2}$ Roman inches or 13·1058 English inches, 332·6 mm., and doubtless came to Europe in some way from Asia Minor. It is worthy of note that, besides persisting in the Rhine countries, it was adopted by the Belgic tribes, and by them introduced into Britain, where it endured, as will subsequently be shown, until the fifteenth century.[1]

Greece originally had as its standard of weight the heavier Babylonian talent, or, speaking more exactly, this was in use in Aegina, and thence extended into the Spartan States and to Corinth, whose inhabitants being actively engaged in commerce did much to spread its use. This talent was considered equal to the weight of a cube of water whose edge was an Olympic cubit, or $1\frac{1}{2}$ times a Greek or Olympic foot. By diminishing the Babylonian talent one-sixth, was obtained the Euboic talent which flourished in Greece and especially in Athens before the time of Solon. This latter ruler in order to release the people from the usurers established by decree (c. 592 B.C.) a smaller talent which amounted to $\frac{3}{5}$ of the Babylonian talent, and weights were derived from it which alone were lawful in Athens. The close connection between money and weight then existing must be appreciated, and we find in ancient writings that the material of the talent when used as currency is mentioned, as a talent of silver (the standard) or a talent of gold. The Athenian talent was divided into 60 *minas*, each composed of 100 *drachmas* containing each 6 *obols* or 48 *chalkus*. There was a half *mina* and a double *drachma* or *didrachm*, and also a *gramma* equal to one third of a *drachma* or 2 *obols*, one third of which was a *lupine* whose half in turn was a *siliqua*. The unit of liquid measure in the Athenian system was the *metretes* (39·39 liters), which was subdivided into 12 *chus* or *amphora*, and so on on a duodecimal basis. The *metretes* was $\frac{9}{10}$ of a Babylonian cubic foot. The Attic unit of dry measure was the *medimnos*, which corresponded to $1\frac{1}{3}$ *metretes* or in modern equivalents to 52·53 ⑦
liters. It was divided into six *hekteus* or *modius*, each of which was composed of two *hemiekton* or eight *choinix*. The *choinix* was made up of two *xestes*, and two *kotule* formed a *xestes*.

The Roman unit of weight was the *libra*, or pound which corresponded in money to the *as*, and was divided on the duodecimal basis characteristic of the Romans. Thus the pound (327·45 grams) was composed of 12 *unciae*, each of 4 *sicilii*, each of 2 *drachmas*, each of 33 *scripula*, each of 2 *obola*, and each of

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[1] See p. 31.

3 *siliquae*, these names surviving in modern apothecaries' measure. Its connection by water with the amphora and thus with the Greek measures will be given below, and may be further explained by stating that while the Attic talent of Solon was divided into 60 minas, the same weight of water contained in the amphora was divided into 80 pounds, thus making 3 Attic minas equal to 4 Roman pounds. Originally the Roman pound was established on the basis of the Aeginetan weight, and was equal to $\frac{9}{10}$ of the Aeginetan half mina, this basis being used in the Roman coinage.

As a measure of liquid capacity the Romans had the *amphora*, which was equal to a cubic foot and contained 80 *librae* (pounds) of water. This was divided into 8 *congii*, each composed of 6 *sextarii* with further subdivisions. For dry measure one third of the *amphora* or *modius* served as the unit, and was made up of 16 *sextarii*. These measures harmonized with those of Greece, inasmuch as the amphora was two thirds of the Attic metretes, and the modius was one sixth of the medimnos. In passing, mention might be made of the fact that a foot derived theoretically from the amphora would not give a cube equal to the amphora, but differing by as much as a twentieth part and in some cases by as much as one twelfth, depending, of course, upon the cubical contents of surviving examples, of which there are several.[1]

The Roman weights, measures, and coinage, by virtue of the conquests and influence of the empire, found their way all over Western Asia and Europe; and with the decline of the imperial power formed the foundation for local systems, but with the lack of interest in science which soon began to characterize the age and the general decline of culture, weights and measures were no longer maintained in conformity with any system or with any due regard to primary standards. Consequently there was a distinct corruption of measures, and until the revival of experimental science in the middle ages but little attention was paid to the subject. Indeed, all standards and systems were practically neglected, and by the sixteenth century there was virtually a return to the body measures throughout Europe.

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[1] Flinders Petrie, article "Weights and Measures," *Encyclopaedia Britannica*, 9th ed. vol. xxiv. p. 486.

Previous to the beginnings of European scientific investigation[1] there was, however, important work done by the Arabs, and as measurement is an essential of all experimental science, it was natural that they should have devoted much attention to the subject, and included the discussion of measures in their writings. It is quite certain that the measures of the Arabs owe their origin to the old Babylonian measures, especially as their philosophers were careful students of antiquity; but it is evident that while the measures were maintained they lost sight of the underlying principles, and when it became necessary to define them or refer them to standards, entirely new methods were employed. In these an attempt was made to secure a natural basis, and such fundamental units as a degree of the earth, hairs of horses or mules, and grains of barley were used. Then, too, the contact between the Arabs and the Egyptians had its effect, and old and new measures were blended so that the absolute value of the weights and measures is quite impossible to determine, though by references to ancient authorities relative values can be obtained in many cases.[2] It was from the Arabs that the Yusdruman pound of Charlemagne, for so many years the standard of France, was obtained, and the idea of using barleycorns for the measure of length, as was done subsequently in England by statute.

In this connection mention might be made of a unit of length, namely, the "black cubit," which figured in an important measurement of a degree of the earth's surface executed in 830 A.D. by the astronomers of the Caliph Al-Mamun (713-833). This measurement, made on the plains of Mesopotamia, is generally spoken of in connection with similar measurements made by Eratosthenes (c. 276—c. 196 B.C.), the Alexandrian, as they were the forerunners of later geodetic work, on which in part the modern metric system was founded, it being of course unnecessary to say that this and other ancient astronomers believed in the spheroidal form of the earth. The "black cubit,"

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[1] About the earliest systematic works in Metrology in England are *A Discourse on the Roman Foot and Denarius* and *Origin and Antiquity of our English Weights and Measures* (London, 1745), by John Greaves (1602-1652), and *De Mensuris et Ponderibus Antiquis* (Oxford, 1699), by Edward Bernard (1636-1696[7]).

[2] See Boeckh, *Metrologische Untersuchungen* (Berlin, 1838), pp. 246 *et seq.*

however scientific the use to which it was put, was not due to any particular metrological study, but, according to tradition, was the length of the arm of a favorite black slave of the Caliph, and has been said by Jomard to have been equal to 519·16 mm.[1]

The source from which the Anglo-Saxons derived their weights and measures is not particularly certain, yet they early endeavoured to secure uniformity by enacting good laws,[2] and in this they were so successful that they were enabled to maintain these weights and measures in their integrity despite the Norman conquest.[3] In fact, they were specially recognized and preserved by a decree of William the Conqueror, which stated that "the measures and weights shall be true and stamped in all parts of the country, as had before been ordained by law." The standards of the Saxon kings which had been preserved at Winchester were, however, removed to London, where they were deposited in the crypt chapel of Edward the Confessor in Westminster Abbey, which later became known as the Pyx Chapel, as here were also preserved the standard trial plates for gold and silver coin used at the trials of the pyx, or formal official assay of the coin of the realm.[4] With Winchester are associated the earliest Anglo-Saxon weights and measures, and their authority as standards is said to date back to King Edgar (reigned 958-975), who decreed that "the measures of Winchester shall be the standard." The unit of length was the yard or gird, which was identical with the

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[1] See Boeckh, *Metrologische Untersuchungen* (Berlin, 1838), pp. 246, 250-3.

[2] Greaves, *Origin and Antiquity of our English Weights and Measures* (London, 1745), p. 68.

[3] Bishop Fleetwood's *Chronicon Preciosum* (London, 1745), p. 27: "It was a good law of King Edgar that there should be the same money, the same weight, and the same measures, throughout the kingdom, but it was never well observed. What can be more vexatious and unprofitable both to men of reading and practice, than to find that when they go out of one country into another, they must learn a new language or cannot buy or sell anything. An acre is not an acre; nor a bushel a bushel if you but travel ten miles. A pound is not a pound if you go from a goldsmith to a grocer, nor a gallon a gallon if you go from the alehouse to the tavern. What purpose does this variety serve, or what necessity is there, which the difference of price would not better answer and supply?"

[4] See H. J. Chaney, *Our Weights and Measures* (London, 1897), pp. 120-121. An interesting account of the Pyx Chamber together with a description of the Jewel Tower, now the Office of the Standards, will be found in "The Story of a Tower," *The Art Journal* (London, 1900), pp. 200-203 and 244-247.

ell, and as late as the reign of Richard II. (1377-1399) the words *virga* or *verge* (yard) and *ulna* or *aulne* (ell) are found in the laws and official documents in Latin or Norman French, as the case may be, to denote the same unit of length. In addition to the purely Saxon measures there were those which had been brought by the Roman, and which, though incommensurable with Saxon measures, had survived and become assimilated with the older measures. Among these were the mile, corresponding to the Roman *millia passuum*, the inch and the foot, which soon became recognized as purely English measures and to have their own fixed values. Then, in addition, when the Belgic tribes migrated to Britain, they brought the Belgic foot of the Tungri, which was $\frac{1}{8}$ longer than the Roman foot, and was used until the fifteenth century.[1] The average length of this foot was 13·22 inches, and a yard formed by three such feet would be 39·66 inches, which would correspond most closely with the meter of to-day, which is equivalent to 39·37 inches. Such a yard existed and was known as the yard and the full hand, and eventually was suppressed by law in 1439. This was extremely unfortunate, as had this yard been retained it would have ensured a correspondence with the French metric system without the slightest difficulty. Furthermore, we are informed that the old English system was largely decimal, and had these features been preserved a vast improvement would have been worked in the wretched system, or lack of system, with which the English-speaking people have been afflicted for centuries.

In the Domesday Book (1086) we find the Saxon yard used as a unit of measure, and land thus measured is referred to as *terra virgata*, and shortly afterwards, from the reign of Henry I. (reigned 1100-1135), the tradition is current that the legal yard was established from the length of that monarch's arm. In the reign of Richard I. (reigned 1189-1199) there were laws enacted providing for standards of length constructed of iron and for measures of capacity whose brims should be of this material also, suitable standard measures to be kept by sheriffs and magistrates.[2]

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[1] Flinders Petrie, article "Weights and Measures," *Encyclopaedia Britannica*, 9th ed. vol. xxiv. p. 484.

[2] See Kelly, *Metrology* (London, 1816), p. 336. A brief and interesting account of early history of British Weights and Measures, with summary of legislation.

The most important early English legislation was contained in Magna Charta (1215), and laid stress on the principle of uniformity by providing that there should be throughout the realm, one measure of wine, one of ale, and one of corn, viz., the quarter of London: and that it should be of weights as of measures. This declaration of uniformity was considered so fundamental that it was subsequently repeated in numerous statutes in essentially its original form, and we find many acts passed as occasion demanded to carry out its manifest intention. This naturally involved the definition of the standards and measures, and from time to time statutes are found which supply us with more or less complete information about the measures of the period. Thus, while we know that the unit of monetary weight was a pound used from the times of the Saxon kings, yet we do not find it defined until the time of Henry III. (51 Henry III., stat. I. 1266), when the relation of the various weights and measures are given by the following law, forming a part of the well known statute of the Assize of Bread and Ale, where it is stated, "that by the consent of the whole realm of England, the measure of our Lord the king was made, viz., an English penny called a sterling, round and without any clipping, shall weigh thirty-two wheatcorns in the midst of the ear;[1] and twenty pence do make an ounce, and twelve ounces a pound: and eight pounds do make a gallon of wine, and eight gallons of wine do make a bushel, which is the eighth part of a quarter." Thus we have defined the ancient Tower Pound, which, having the same weight as the old German medicinal or apothecaries pound, is believed to have been derived from the mina of Ptolemy or one-sixtieth part of the Lesser Alexandrian Talent of silver, as it was but 63 grains lighter than that weight. This was the earliest form of the British sterling pound, and the division into 20 shillings of 12 pence each was the same as is now practised, and in fact was the same as the division of the *livre esterlin* of Charlemagne, which was slightly heavier (5666 Troy grains as compared with 5400, see p. 38). In addition, the English monetary weights were connected with those of Germany, based on the Cologne mark, by a mint weight

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[1] "This pennyweight was equal to 22½ Troy grains, which is found to be the average weight of existing coined silver pennies of the Saxon Norman Kings" (Chisholm, *Weighing and Measuring*, London, 1877).

substantially equivalent to the latter and equal to two-thirds of the Tower pound. This was known as a mark, and was used for denoting both the weight and value of silver under the Norman kings.[1] While the Tower pound was defined in terms of grains of wheat, nevertheless it did not originally depend upon them, and their inclusion in the English system of weights was doubtless due to French influences subsequent to the Norman Conquest, as the French had doubtless derived this idea from Oriental sources. With the Tower pound used for mint purposes, and for the derivation of measures of capacity, as well as for precious metals in general and drugs, there must be considered the commercial pound (*libra mercatoria*), which is of almost as great antiquity and of far more general use. It also is defined in a statute of Henry III. (54 Henry III.) and was the weight of 25 shillings, or in other words equivalent to 15 ounces of the Tower pound. Commercial pounds were used also on the continent of Europe along with the Troy pound, and it is to one of these, namely the French commercial pound of 16 ounces, that we have to look for the source of the English avoirdupois pound which soon supplanted the commercial pound in that country.

The early English Tower and commercial pounds were forced to give way before the French weights, the Troy pound and the avoirdupois pound, whose use the more intimate contact following the English victories in France at Poitiers and on other fields had doubtless spread through the English realm. As to the source of the Troy pound there is a difference of authorities, but it is usual to credit it to the city of Troyes in France, and in support of this view it is stated that associated with this city, a town of some commercial importance, were a *livre de Troyes* and a *marc de Troyes*, whose weights were comparable with the modern Troy pound. Going back still further, it is possible to derive the Troy pound from the Roman weight of 5759·2 grains, which was the $\frac{1}{125}$ of the large Alexandrian talent. This weight, after the fashion of the Romans, was divided into 12 ounces, and the original unit and its division may possibly have survived. At all events the Troy pound slowly made its way in England, and from as early as the first year of the reign of Henry IV., when it was employed

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[1] H. W. Chisholm, *The Art of Weighing and Measuring* (London, 1877), p. 55.

in an inventory of the Royal plate, it was increasingly used. In 1495, in defining the bushel and the gallon, Henry VII. made use of the Troy pound, and in 1527 the Tower pound was formally abolished as the legal standard at the Mint by an Ordinance (18 Henry VIII.) enacting that "the Pounde Towre shall be no more used and occupied, but al maner of golde and sylver shall be wayed by the Pounde Troye, which maketh xii oz. Troye, which excedith the Pounde Towre in weight iii quarters of the oz." Likewise, as we have indicated, the avoirdupois pound was adopted as a commercial pound, and formed of 16 avoirdupois ounces, and composed of 7000 Troy grains, it is mentioned in a statute (*Tractatus Ponderibus et Mensuris*) of Edward I. (31 Edward I. 1303). From these origins the English Troy and avoirdupois pound have descended in substantial integrity to the present time, and such changes as have been made have been due to the restoration of standards, and have been of a minute and unavoidable character.

Many standards of weight were constructed based on these fundamental definitions, and a number of them are still in existence, having been used on numerous occasions for deriving other standards. In fact, one bell-shaped avoirdupois pound of the Exchequer of the reign of Queen Elizabeth was continuously used for this purpose from 1588 to 1825. This weight, which at the time of its construction in 1588 was supposed to be equal to 7002 Troy grains, was found in 1873 to weigh 6999 grains of the imperial standard pound.[1]

In 1758 a standard Troy pound was constructed and standardized by Harris under authorization of an Act of Parliament, but it was not legalized until 1824 (5 Geo. IV. c. 74). It was then specified (§ 5) that in the event of the loss or destruction of this standard, that it should be reconstructed by considering that a cubic inch of distilled water at 62 degrees Fahrenheit, weighed in air with brass weights, and at 30 inches pressure of the mercurial barometer, should weigh 252·458 grains, of which the Troy pound contained 5760.[2] This standard was destroyed together with

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[1] H. W. Chisholm, *The Art of Weighing and Measuring* (London, 1877), pp. 62 and 63.

[2] This definition bound the unit of weight to the unit of length, which was then considered fixed by its reference to the second's pendulum.

the standard yard by the fire of October 16, 1834, when the Houses of Parliament were burnt. To construct new standards a Standards Commission was appointed in 1843, and for the unit of weight the avoirdupois pound was taken as the basis. The new standard was defined in terms of the lost Troy pound as given by various existing standards, and was duly legalized in 1855 (18 and 19 Vict. c. 72). This standard pound will be more specifically described when we come to discuss the subject of Standards in a subsequent chapter.[1]

From the definition of the measures of capacity, given in the Statute of the Assize of Bread and Ale referred to above, the gallon and the bushel were obtained from the pound, using wine as the measuring medium. This class of measures was one that greatly concerned the government on account of the collection of the excise duties, and there are numerous statutes defining or regulating in one way or another the capacity and use of these measures. On the basis of the early legal definition, however, Henry VII. caused to be constructed a standard corn gallon and a standard corn bushel, the former having a capacity of $274\frac{1}{4}$ cubic inches and the latter $2150\frac{1}{2}$ cubic inches. ~~These standards date from 1495, and are now in actual existence.~~ The Winchester corn gallon, as the measure is known, was employed until it was supplanted in 1824 by the imperial gallon, while its companion, the Winchester bushel, which was similarly outlawed in 1824 in favour of the imperial bushel in Great Britain, has survived in the United States. In 1601 we find the British ale gallon with a capacity of 282 cubic inches duly recognized by Queen Elizabeth, and there is extant an Exchequer standard quart which bears this date and the royal initials and crown. 4

In the reign of Queen Anne the standard wine gallon was defined by statute (5 Ann. cap. 27, 17) as "any cylinder 7 inches in diameter, and 6 inches deep, or any vessel containing 231 cubical inches and no more shall be a lawful wine gallon." Such a standard of the Exchequer dated 1707 is still extant. On the reorganization of the weights and measures in 1824 the wine gallon was abolished, but it was never supplanted in the United

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[1] Chas. Ed. Guillaume, *Unités et Étalons* (Paris, 1893), p. 96. H. W. Chisholm, *The Art of Weighing and Measuring* (London, 1877), pp. 69-81. W. H. Miller, *Philosophical Transactions* (London, 1856), part iii.

States, and remains as the legal gallon. The British imperial gallon, legalized in 1824 (5 Geo. IV. c. 74) to the exclusion of the three former gallon measures, and which forms the basis of the present British measures of capacity, instead of being based on a given number of cubic inches, was taken as the volume of ten pounds of pure distilled water at 62 degrees Fahrenheit. This corresponds to 277·274 cubic inches. With the gallon as the unit of capacity for liquid measures, it was determined to derive the imperial standard bushel or unit of capacity by taking a volume equal to eight imperial gallons, or a volume corresponding to 2218·192 cubic inches.

Unlike the measures of weight and capacity, there have been few changes in those of length from the times of the Saxons, and the earliest surviving standards of length, those of Henry VII. (about 1490), and Elizabeth (about 1588), vary scarcely more than a hundredth of an inch from the present imperial yard.[1] With the second of these standards there is also an ell rod of 45 inches, and a bar with a bed or matrix for both the yard and the ell rods, but such an ell, which doubtless corresponded to the French measure of cloth, does not appear in any statute or in the records of the standards of this time. In fact, we find the Anglo-Saxon measures of length perpetuated on the same basis as is given in the statute of Edward II. (17 Edward II. 1324), where there is a restatement in statutory form of what has since become the well-known rule that three barley-corns, round and dry, make an inch, twelve inches a foot, three feet a yard (ulna), five and a half yards a perch, and forty perches in length and four in breadth an acre.[2]

Consequently the general discussion that has been devoted to

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[1] See chapter x. on Standards, pp. 243-244.

[2] See H. W. Chisholm, *Seventh Annual Report of the Warden of the Standards*, 1872-3 (London), pp. 25 and 34, English Parliamentary Papers, *Reports from Commissioners*, 1873, vol. xxxviii. Id., *Weighing and Measuring* (London, 1877), pp. 51-53. George Graham, "Description of Standards and Use of Beam Compasses," *Philosophical Transactions* (London, 1742-3), vol. xlii. pp. 541-556. Francis Baily, *Memoirs Royal Astronomical Society* (London), vol. ix. 1836, pp. 35-184. William Harkness, "The Progress of Science as Exemplified in the Art of Weighing and Measuring," vol. x. *Bulletin Philosophical Society of* Washington, D.C., published as vol. xxx. *Smithsonian Miscellaneous Collections.* The latter contains a good resumé of British weights and measures as well as a useful bibliography.

the British measures of length has been mainly towards securing standards of greater accuracy, or with the object of obtaining either a decimal division or the adoption of the metric system. With the exception of the act of 1824, which defined the yard in terms of the second's pendulum, and provided in case of its loss or destruction that it should be replaced on that basis, little has been done in the way of legislative enactment save to recognize and establish legally new standards of length. The determination and construction of such standards, however, has been of extreme importance, and has involved most careful and accurate scientific work, so that for this reason the various British standards and their development can best be treated in that portion of the present volume devoted to this subject.[1]

While there have been for well over a century many and earnest advocates of a decimal division of British weights and currency, yet the net results of their labors and agitation have been practically nothing other than to strengthen the cause of the metric partisans. In fact, decimalization never has progressed to the same point as in the United States, and it is probable that the old weights, measures, and methods will remain until supplanted by the metric system.[2]

Although the preservation of the French standards of measure in the royal palace is recorded from the time of Dagobert (650),[3] yet it is usual to trace back such measures as might properly be considered as forming the national system to the time of Charlemagne (768-814), since during his reign there was a uniformity of weights and measures, and reproductions of the royal standards were widely distributed over the realm.[4] The unit of length in this system was the *pied de Roi*, or royal foot, representing, according to tradition, the length of the foot of the monarch, and which, following the duodecimal

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[1] See chapter x.—Standards and Comparison.

[2] For progress of Metric System in Great Britain, see chapter iii. pp. 98 *et seq.* It is of course impossible in the present space to describe the various measures of Scotland, Ireland, and other local systems. These will be found quite fully described in Kelly, *Metrology* (London, 1816), and also in Chaney, *Our Weights and Measures* (London, 1897), the latter containing also a description of the various standards.

[3] Paucton, *Métrologie ou Traité des Mesures, Poids et Monnoies* (Paris, 1780), p. 8.

[4] *Ibid.* p. 13.

division derived from the Romans, was divided into 12 inches (*pouce*) of 12 lines, which in turn were composed of 12 points. The French foot was longer than the English foot, being equal to 12·79 inches of the latter, and considerably longer than the ancient Roman foot, which was 11·65 English inches in length. In the French system there was also the *toise* or fathom of six feet, and the earliest record of a standard of length dates back to the Toise du Grand Châtelet, constructed in 1668, and based (though five lignes shorter) on the ancient *toise de maçons* of Paris, which was doubtless as old as the times of Charlemagne.[1] It is said by La Condamine[2] to represent one half the distance (12 feet) between the walls of the inner gate of the Louvre. Subsequently, copies of this were made, and the toise was used as the basis for standards of linear measures, such as the *Toise de Perou.*[3] There was also the aune or ell, which, originally a double cubit, became adopted as a unit of linear measure for cloth, and survived until displaced by the meter. A standard Aune des Marchands, Merciers et Grossiers, 1554, divided into halves, quarters, thirds, sixths, etc., was preserved by that guild, and was the basis of this unit. The aune of Paris corresponded to $46\frac{17}{20}$ Eng. inches, but it was never adopted in the latter country to any considerable extent or authorized by law, though a cloth aune or ell of 45 in. is found marked on the standard yard of Queen Elizabeth.[4]

For the origin of standards of weight in France we have to go back to the Arabs, as the basis of the ancient French system is reputed to be an Arab yusdruma, which was sent by Caliph Al Mamun (786-833) to Charlemagne. This yusdruma, or later Arab pound, was the monetary pound or *livre esterlin* of Charlemagne, and amounted to $5666\frac{1}{4}$ grains, or 367·128 grams.[5] It was divided into 12 ounces, or 20 sols, of 12 deniers, of 2 oboles of 12 grains, or 5760 grains in the aggregate, each grain weighing ·063738 grams.

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[1] La Hire, *Mém. de l'Acad. Roy. des Sciences*, 1714, pp. 394-400 (Paris, 1717).

[2] La Condamine, *Mémoires de l'Acad. Roy. des Sciences*, 1772, 2nd part, pp. 482-501 (Paris, 1776).

[3] See chapter x. on Standards.

[4] See chapter on Standards, p. 243. Also *ante*, p. 31.

[5] The name "esterlin" was employed at one time in the French language to signify "true," being equivalent to the modern Fr. word "veritable." It has, however, disappeared from use, but has been retained in English, with the same signification, in the form of "sterling," as, for example, "pounds sterling."

The livre esterlin of Charlemagne was one and a half times the weight of the marc of the monetary system which was established between 1076 and 1093 by Philip I., who used 8 of the 12 ounces of the former system for this purpose. This marc was doubled, and made to consist of 16 ounces, by King John the Good, in 1350, and it was adjusted according to the weights of Charlemagne. The weights of King John were known as the "pile de Charlemagne," and were the French standards of weight until the adoption of the Metric System in 1789.[1] In this system the *livre poid de marc*, or pound, consisted of two marcs or half-pounds, 4 quarterons, 8 half-quarterons, 16 ounces, 32 half-ounces, 128 gros (drachme) or grams, 384 scruples, or deniers, 9216 grains. There were also in France four other marcs duly and legally recognized, viz., that of Rochelle, which was called English, equal to 13 sols, 4 deniers, in terms of the livre esterlin; that of Limoges, equivalent to 13 sols, 3 oboles; that of Tours, equal to 12 sols, 11 deniers, 1 obole; and that of Troyes and Paris, equivalent to 14 sols, 2 deniers.[2]

We have referred specifically to early measures only in Great Britain and France, as throughout the rest of Europe there was such great diversity until well into the nineteenth century that little would be gained for our purpose by considering the dozens of kingdoms, principalities, free cities, etc., each with their separate systems. Local conditions and traditions everywhere governed, and not only in different countries in the same region would there be different values for the same weights and measures, but also in different towns of the same state.[3] While the names feet, pounds, etc., were quite universally employed, yet they designated different quantities, and save for arbitrary standards, possibly in many cases not even duly legalized, there was no attempt at securing uniformity. A foot might be divided

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[1] Guillaume, p. 94, *Les Unités et Étalons* (Paris, 1893).

[2] Quoted by Guillaume, p. 95, *Les Unités et Étalons*, from *Chronique de 1329 environ.*

[3] "At the close of the last (eighteenth) century, in different parts of the world, the word pound was applied to 391 different units of weight and the word foot to 282 different units of length." T. C. Mendenhall, *Measurements of Precision.* Such a list with British and metric equivalents may be found in Barnard, *The Metric System* (Boston, 1879), pp. 348-360. The kilogram has superseded over 370 of the different pounds.

duodecimally, as was done by the Romans, or, on the other hand, it might be divided into nine, ten, eleven, or thirteen inches. Then again the actual distance represented by a foot varied from 9 to 18 inches, and equivalents are now known for many different European feet.

As to the sources of these measures, we have to look to the Romans and to the East, as the former nation in its conquests overran a great part of Europe, and implanted its weights and measures with more or less permanence, while the effects of trade with the Orient and the intellectual influence of the Arabs doubtless served to introduce new measures or to corrupt old ones. Several mark weights soon became known as standards for coinage and precious metals, notably that at Cologne, while the Rhine foot enjoyed a pre-eminence in the neighboring countries.[1] As practically no scientific work of a quantitative character was done for many centuries, the influence of science in systematizing and demanding exact standards of measure was not felt, so that only the needs of trade, often of a most restricted character, which could be satisfied by crude and imperfect systems, had to be provided for. The lineage of many of the old European weights and measures has been traced more or less satisfactorily back to ancient times, but the subject presents little scientific attraction, save to the historian or archaeologist and the student of metrology.[2] Lack of system prevailed, and apparently was quite satisfactory, but gradually the minds of scientists and statesmen became aroused to the importance of the subject and the need of fundamental changes, and a rational systematization was urged, which found its first substantial fruit in the development in France of the metric system.

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[1] This Rhine foot defined in Prussia by law in 1816 was standardized by Bessel in 1835-1838, and survived in that kingdom until the adoption of the metric system. It is still (1906) the standard of length in Denmark.

[2] An interesting summary of ancient and modern measures, which, however, must be modified in many aspects, and considered in the light of modern researches and theories, is contained with a wealth of bibliographical material in Karsten, *Allgemeine Encyklopädie der Physik*, vol i. "Maass und Messen" (Leipsic, 1869).

CHAPTER II.

ORIGIN AND DEVELOPMENT OF THE METRIC SYSTEM.[1]

WHILE the inconveniences and difficulties attending arbitrary systems of weights and measures were appreciated, nevertheless philosopher and peasant alike submitted, and it took many years for a feeling in favour of a rational and fixed system to develop. Such a system at its best, as we have seen, would involve an invariable unit derived from nature itself, which not only could be reproduced readily, but was capable of being measured with a

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[1] In this chapter detailed references have been given to authorities for particular statements for the benefit of those who desire to pursue the subject further. The history of the Metric System has been well summed up in a treatise by M. Bigourdan (*Le Système Métrique*, Paris, 1901), in which will be found usually the text of all French legislation and the salient features of discussion by lawmakers and scientists, as well as a complete bibliography. There is also an excellent historical sketch, "Notice historique sur le Système Métrique, sur ses developpements et sur sa propagation," contained in the *Annales du Conservatoire* (*Imperial*) *des Arts et Metiers*, by General A. Morin (Paris, 1870), vol. ix. pp. 573-640. This is a brief but excellent description of the origin and development of the system by a member of the Committee of Verification, director of the Conservatoire des Arts et Metiers, and a member of the first International Commission. "A Historical Sketch of the Foundation of the Metric System," by Général Bassot, was published in the *Annuaire pour l'an* 1901, of the Bureau of Longitude, Paris (translated into English by Miss F. E. Harpham of the Astronomical Department of Columbia University, and published in the *School of Mines Quarterly*, vol. xxiii. No. 1, November, 1901. First and foremost, however, is the classical work of Méchain and Delambre, *Base du Système Métrique*, 3 vols. (Paris, 1806-1810), which is the primary source of information for the early work in establishing the Metric System. It is, of course, unnecessary to say that in the following pages these works have been most freely used, and can be recommended for those desiring additional information on the subject.

high degree of precision. Obviously such standards as barleycorns and human feet did not possess the slightest claim to invariability, and as soon as the subject began to be considered seriously and earnestly by scientific men, the choice for the fundamental unit of linear distance became narrowed to two classes of lengths, and around them most of the subsequent discussion centred. One was the length of a fraction of a great circle of the earth, while the other was the length or a fraction of the length of a pendulum, vibrating in intervals of one second or some other chosen unit of time. For the first, proceeding on the assumption that the earth was a spheroid (or very nearly so), it was possible to measure the arc of a great circle even in the seventeenth century without any great difficulty. Such a measurement involved the determination with considerable accuracy of the geographical position, or in other words the latitude and longitude, of two points, and then a geodetic or trigonometrical survey which took into consideration the curvature of the earth's surface, measuring the actual distance between them in terms of a unit of length selected for that purpose and represented by a standard which was employed in the measurement of a base-line. The distance, as found by the triangulation, could then be compared with the difference in latitude between the two points, and thus the actual distance in degrees could be obtained in terms of the selected linear standard. The other invariable standard of length was that of a pendulum, which in a given place executed its vibrations always in the same time. By the law of the pendulum, the time of vibration is inversely proportional to the square root of the acceleration due to gravity, and directly as the square root of the length. Consequently, being able to measure time, and, assuming that the acceleration of gravity at a given point is constant, it is possible to determine or reproduce accurately a given length by this instrumentality.

After considering the invariability of the original standard, the next important matter to bear in mind is the symmetry and convenience in actual use of any system of measures which is based thereon. In the light of the development of the science of arithmetic and of the popular methods of reckoning, it can be safely said that the decimal system for money, weights, and measures, must stand as the most simple and useful. Therefore in considering the genesis of the modern metric system, as a universal system founded on an invariable standard and symmetrically and conveniently developed, it is necessary to go back to Gabriel Mouton, Vicar of St. Paul's Church, Lyons, who first proposed in 1670 a comprehensive decimal system having as a basis the length of an arc of one minute of a great circle of the earth. One minute of arc would give the length of a *milliare* or *mille*, which would be subdivided decimally into *centuria*, *decuria*, *virga*, *virgula*, *decima*, *centesima*, *millesima*.[1] The *virga* and *virgula* would be the chief units of the system corresponding to the toise and the foot then in use. This geometric foot (*virgula geometrica*) was further defined by Mouton as corresponding to the length of a pendulum making 3,959·2 vibrations in a half hour at Lyons.[2] This proposition contained essentially the germ of the modern metric system and Mouton's suggestion of the pendulum was soon repeated by Picard (1671), and by Huygens[3] (1673). The former said[4] "The length of a pendulum beating seconds of mean time would be called the astronomical radius (*Rayon Astronomique*), of which the one-third would be the universal foot: the double of the astronomical radius would be the universal toise, which would be at Paris as 881 to 864.... If we should find by experience that the pendulums were of different lengths in different places, the supposition we had made touching a universal measure depending on the pendulum would not stand, but it would not alter the fact that in each place the measure would be perpetual and invariable."

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[1] See Bassot, "Historical Sketch of the Foundation of the Metric System," *Annuaire pour l'an* 1901, publie par le Bureau des Longitudes, Paris. Translated in *School of Mines Quarterly* (New York), vol. iii. No. 1, Nov., 1901.

[2] Mouton, *Observationes diametrorum Solis et Lunae . . . Huic adjecta est brevis dissertatio de . . . nova mensurarum geometricarum idea* (Lyons, 1670), p. 427. In reference to Mouton's work an interesting paper by Professor J. H. Gore, "The Decimal System of Measures of the Seventeenth Century," in the *American Journal of Science* (Third Series, vol. xli. Jan., 1891, p. 22), should be consulted. Professor Gore quotes from Mouton's writings and describes his researches in order to show that the essential features of the Metric System were first announced by him. Furthermore he does not consider that due credit was given by the French scientists who founded the system and made use of Mouton's ideas.

[3] *Horologium Oscillatorium*, 4 prop. 25 (Paris, 1673).

[4] *Mesure de la Terre*, reprinted in *Anciens Mémoires*, vol. vii. p. 133.

Similar in character to the plan of Mouton, but considerably later (1720), was a proposition made by Cassini, in his celebrated work, *De la grandeur et de la figure de la Terre* (pp. 158, 159), recommending the adoption of a unit known as the *pied geométrique.* This was equal to $\frac{1}{6000}$ part of a minute of arc of a great circle, and 6 *pieds* formed a toise. This foot had a length almost half that given by the $\frac{1}{10000000}$ part of the radius of the earth.

Subsequently another plan involving the length of the second's pendulum as a unit, was brought forward and developed by Du Fay, and this, after his death, was elaborated and continued by La Condamine (1747),[1] who provided against the variation in length at various latitudes by taking as his unit the length of the second's pendulum at the equator (36 inches 7·15 lignes of the toise of Peru), which he together with Godin and Bouguer had quite accurately determined at Quito, while engaged in measuring an arc of meridian at the equator in 1735-1737. La Condamine also appreciated the advantages of the decimal division of measures of length, and saw the necessity for reforms in the measures of area, capacity, weight, etc., so that all might be brought into harmony with the linear measures, and thus be equally stable and invariable. He was farsighted enough to suggest, what has since been such a valuable feature of the metric system, namely the advantages of international joint effort in making the desired changes, and advocated consulting with the academies of foreign countries in this matter.

Worthy of record also is the proposition made by M. Prieur Du Vernois,[2] who urged as the unit of length, that of the second's pendulum, in preference to that of a fraction of an arc of meridian, on the ground that the former could be reproduced more readily. He advocated taking the length of the pendulum at a single point, suggesting the Royal Observatory at Paris, and then making a standard of platinum, correct at a certain temperature such as 10°, which would be deposited in the Hotel de Ville. One-third of the length of this standard would be the French or natural foot, which would be divided into 10 inches, each inch in turn being

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[1] *Mémoires de l'Academie des Sciences*, p. 489, 1747.

[2] See Prieur (Du Vernois), *Mémoire sur la nécessité et les moyens de rendre uniformes dans le royaume toutes les mesures d'entendue et de pesanteur*, etc. (Paris, 1790), pp. 9-11.

divided into 10 lignes. Multiplying the foot by ten would give the national perch, while an area ten perches square would be the national arpent. Units of volume would be measured by cubes of lignes, inches, and feet, and the unit of mass would be a national pound corresponding to the mass of a cube of distilled water at some determined temperature, ten inches square on each edge. Prieur also advocated a decimal system of money, in which the *livre* (franc) was divided into tenth and hundredth parts known as *decimes* and *centimes*.

During the eighteenth century such schemes as have just been described were proposed by scientists for the improvement of the weights and measures, and although they were brought to the attention of the French Government they did not meet with such approval as to secure their adoption. Indeed there was no lack of plans proposed by the scientific men, and the government realized the necessity for uniformity throughout the realm, but the various schemes were discussed and discarded without any definitive action, and, just as in later times, the difficulties attending the introduction of a new system were anticipated and feared. In fact Necker, in a report made to Louis XVI. in 1778, speaks of the proposed reform of weights and measures with considerable diffidence. He writes, "I have occupied myself in examining the means which might be employed to render the weights and measures uniform throughout the kingdom, but I doubt yet whether the unity which would result would be proportionate to the difficulties of all kinds which this operation would entail on account of the changing of values which would necessarily be made in a multitude of contracts, of yearly payments, of feudal rights and other acts of all kinds. I have not yet renounced the project, and I have seen with satisfaction that the Assembly of Haute-Guyenne have taken it into consideration. It is in effect a kind of amelioration which can be undertaken partially, and the example of a happy success in one province would essentially influence opinion."[1]

With the changes wrought by the Revolution it was possible to gain at the hands of the public consideration for radical ideas in science as well as in government and religion. The schemes

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[1] Necker, *Compte rendu au Roi de* 1778, Bigourdan, *Le Système Métrique*, (Paris, 1901), p. 11.

and discussions already mentioned paved the way for the favourable reception of a plan for reform when it was urged in the National Assembly by a bold and able leader. Such was Talleyrand, then Bishop of Autun, who brought the matter to the attention of the National Assembly in April, 1790. He not only appreciated the necessity for a uniform system of weights and measures for France, but also the desirability of a system that would be truly international rather than merely the weights and measures of Paris. He proposed as a fundamental unit the length of a pendulum beating seconds at 45° latitude, and as a unit of weight that of a cube of water whose height should be one twelfth the length of the pendulum. New and most careful measurements were to be undertaken to determine the length of the pendulum, and for this purpose a joint commission of the Paris Academy of Sciences and the Royal Society of London was to be established. Talleyrand's proposal, after being considered by the Committee on Agriculture and Commerce and discussed in a report by the Marquis de Bonnay, was brought before the National Assembly, where, in the course of the general discussion upon it, the advantages of a decimal division were urged. The report was accepted and a decree was rendered on May 8, 1790, which was sanctioned by Louis XVI. on August 22 of the same year. Inasmuch as this decree describes with some detail the existing condition and the method of making the change, it is given below in full. It runs:

"The National Assembly, desiring that all France shall forever enjoy all the advantages which will result from uniformity in weights and measures, and wishing that the relation of the old measures to the new should be clearly determined and easily understood, decreed that His Majesty shall be asked to give orders to the administrators of the different departments of the kingdom, to the end that they procure and cause to be remitted to each of the municipalities comprised in each department and that they send to Paris to be remitted to the Secretary of the Academy of Sciences a perfectly exact model of the different weights and elementary measures which are in usage.

"It is decreed further that the King shall also beg His Majesty of Britain to request the English Parliament to concur with the National Assembly in the determination of a natural unit of measures and weights; and in consequence, under the auspices of the two nations, the Commissioners of the Academy of Sciences of Paris shall unite with an equal number of members chosen by the Royal Society of London, in a place which shall be respectively decided as most convenient, to determine at the latitude of 45°, or any other latitude which may be preferred, the length of the pendulum, and to deduce an invariable standard for all the measures and all the weights; and that after this operation is made with all the necessary solemnity, His Majesty will be asked to charge the Academy of Sciences to fix with precision for each royal municipality the relation of the old weights and measures to the new standard, and to compose afterward for the use of the municipalities the usual books and elementary treatises which will indicate with clearness all these propositions.

"It is decreed further that these elementary books shall be sent at the same time to all the municipalities to be distributed: at the same time there shall be sent to each of the municipalities a certain number of new weights and measures which they shall distribute gratuitously to those who would be caused great expense by this change; and finally, six months only after the distribution, the old measures shall be abolished and replaced by the new.

"The National Assembly decrees that the Academy, after consultation with the officers of the Mint, shall offer their opinion as to the suitability of fixing invariably the inscription of the coined metal to the end that the kinds shall never be altered except in their weight, and whether it would not be useful that the difference tolerated in the coins under the name of remedy be always beyond requirement, that is to say one piece may exceed the weight prescribed by law but must never be inferior.

"Finally, the Academy shall indicate the scale of division which it believes most convenient for all weights, measures and coins."

Under the terms of this decree the Academy took up its work in earnest, and on October 27, 1790, its committee consisting of Borda, Lagrange, Laplace, Tillet, and Condorcet, made a report in which they urged the adoption of the decimal division of the moneys, weights, and measures. This report dealt with the comparative merits of the decimal and duodecimal system of calculation, and discussed many of the questions bearing on this subject which have been argued at such length before and since. Next in importance after settling on the principle of decimal division was the selection of a unit of length, and a committee consisting of Borda, Lagrange, Laplace, Monge, and Condorcet, presented a report to the Academy on March 19, 1791, in which they stated that, in their opinion, the units suitable for adoption as the basis of a uniform and rational system of weights and measures were three in number, as follows: the length of a second's pendulum, the quadrant of a great circle of the equator, and the quadrant of a great circle of meridian. Considering the relative advantages and drawbacks of each of these with great care and deliberation, the committee concluded that while the length of the second's pendulum was easily determined and susceptible of verification, it was dependent on the acceleration due to gravity, and that it was necessary to have the position specified exactly. The most desirable point would be at 45° latitude, a mean distance between the equator and the pole. At the latter points, owing to flattening of the earth at the poles, pendulums vibrating with the same period would have unequal lengths, that at the equator being shorter as the force of gravity there owing to the greater radius of the earth is less intense. But with the pendulum a new and unlike element, namely the second, is introduced, and this depends upon the arbitrary division of the day. The preference of the committee was for a terrestrial arc, inasmuch as it bore a nearer relation to the ordinary method of measuring distances, and their choice was in favor of an arc of a meridian rather than one of the equator. This decision was due to the fact that such an arc could be measured with greater facility, and also in several countries, while in addition no more assurance of the regularity of the equator than that of a meridian could be given.

After an arc had been measured the length of a quadrant could then be computed, and one ten-millionth of its length could be taken as the base or fundamental unit of length. In other words the quadrant was to be measured in a single unit of length on a decimal basis, instead of in the former degrees, minutes, and seconds. The plan proposed by the committee was to measure an arc of meridian between Dunkirk, on the northern coast of France, and Barcelona on the Mediterranean Sea, largely because these two places were each situated at the sea-level in the same medidian, because they afforded a suitable intervening distance of about 9° 30′, the greatest in Europe available for a meridian measurement, because the country so traversed had in part been surveyed trigonometrically previously by Lacaille and Cassini in 1739-1740, and furthermore because such an arc extended on both sides of latitude 45°. The committee outlined six distinct operations essential for the work. They were as follows:

1. The determination of the difference in latitude between Dunkirk and Barcelona.
2. The measurement of the old bases.
3. The verification and measurement of the series of triangles used in a previous survey, and extending the same to Barcelona.
4. The observation of the pendulum at 45° latitude.
5. Verification of the weight in vacuum of a given volume of distilled water at the temperature of melting ice.
6. Comparison of the old and new measures, and the construction of scales and tables of equalization.

The National Academy straightway adopted the recommendations of the committee, adopting the length of one fourth of a terrestrial meridian as the basis for the measures of length, and providing for the measurement of the arc from Dunkirk to Barcelona, and the appointment of supervisory committees by the Academy of Sciences. This latter body then addressed itself to the consideration of a suitable nomenclature, and fixed the length of the new unit provisionally at 36 inches 11·44 lignes, and assigning the name *Metre* to the one ten-millionth part of the quadrant of the earth's meridian.[1] The relations between the measures of length and capacity, capacity and weight, and weight and money were also considered. The provisional meter was derived from a calculation of the observations made by Lacaille when measuring a meridian in France in 1740. By this the value of one degree was given as 57,027 toises, which multiplied by 90 would give the length of the quadrant or distance from pole to equator, as 5,132,430 toises. Taking the ten-millionth

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[1] Report of May 29, 1793.

COMPARATIVE TABLE OF THE DIVERSE NOMENCLATURES PROPOSED FOR THE NEW DECIMAL MEASURES.

	Methodic Nomenclature.	ACADEMY Nomenclature with Simple Names.	LAW of August 1, 1793.	LAW of 18 germinal, year III. April 7, 1795.	RESOLUTION of 13 brumaire, year IX. November 4, 1800.	VALUES.
LENGTHS.	—	—	Quart du méridien,	—	—	40.000.000 mètres.
	—	Décade,	—	—	—	1.000.000
	—	Degré,	Grade or Degré décimal,	—	—	100.000
	—	Poste,	—	Myriamètre,	Lieue,	10.000
	Millaire,	Mille,	Millaire,	Kilomètre,	Mille,	1.000
	—	Stade,	—	Hectomètre,	—	100
	—	Perche,	—	Décamètre,	Perche,	10
	Mètre,	Mètre,	*Mètre,*	Mètre,	Mètre,	1
	Déci-mètre,	Palme,	Décimètre,	Décimètre,	Palme,	0,1
	Centi-mètre,	Doigt,	Centimètre,	Centimètre,	Doigt,	0,01
	Milli-mètre,	Trait,	Millimètre,	Millimètre,	Trait,	0,001
VOLUMES.	Muid,	Tonneau,	*Cade,*	Kilolitre,	Muid,	Mètre cube.
	Déci-muid,	Setier,	Décicade,	Hectolitre,	Setier,	—
	Centi-muid,	Boisseau,	Centicade,	Décalitre,	Boisseau or Velte,	Decimètre cube.
	Pinte,	Pinte,	*Pinte,*	Litre,	Pinte,	—
	—	—	—	Décilitre,	Verre,	—
	—	—	—	Centilitre,	—	—

WEIGHTS.	Millier,	Millier,	*Bar* or *Millier*,	—	Millier,	—
	—	Quintal,	Décibar,	—	Quintal,	—
	—	Décal,	Centibar,	Myriagramme,	—	—
	Grave,	Livre,	*Grave*,	Kilogramme,	Livre,	—
	Déci-grave,	Once,	Décigrave,	Hectogramme,	Once,	—
	Centi-grave,	Drâme,	Centigrave,	Décagramme,	Gros,	—
	Milli-grave,	Maille,	*Gravet*,	Gramme,	Denier,	—
	—	Grain,	Décigravet,	Décigramme,	Grain,	—
	—	—	Centigravet,	Centigramme,	—	—
	—	—	Milligravet,	Milligramme,	—	—
SURFACES.	—	—	*Are*,	Hectare,	Arpent,	10.000 mètres carrés.
	—	—	Déciare,	—	—	1.000
	—	—	Centiare,	Are,	Perche carrée,	100
	—	—	—	—	—	10
	—	—	—	Centiare,	Mètre carré,	1
KINDLING WOOD.	—	—	—	Stère,	Stère,	Mètre cube.
	—	—	—	Décistère,	Solive,	—
MONEYS.	—	Unité monétaire,	*Franc d'argent*,	Franc,	Franc,	—
	—	Dixième, de l'unité	—	Décime,	Sol,	—
	—	Centième, de l'unité	—	Centime,	Denier,	—

From Bigourdan, *Le Système Métrique*.

part of this value, and reducing it to the feet and lignes into which the toise was divided, the length of 3 feet 11·44 lignes was obtained. To show how little this provisional meter varied from the meter finally determined by the commission in 1799, it may be stated that the latter length in the same units is 3 feet 11·296 lignes, or a difference of about ·33 millimeters, an amount considered quite insignificant in every-day dealings. A standard of the provisional meter in brass was duly constructed by Lenoir in Paris, and is preserved in the Conservatoire des Arts et Metiers at Paris.[1]

The committee was unable to decide definitely on a system of nomenclature, and accordingly proposed two schemes: one, as they termed it, methodical, in which Latin prefixes were used for the various units; the other simple monosyllabic names which they believed would be more readily adopted by the general population. The Convention, which in the meanwhile had replaced the National Assembly, adopted the recommendations of the committee, but preferred to use the methodical nomenclature. This decree was dated August 1, 1793, and called attention to the importance of the steps being taken to secure uniformity of weights and measures in France, and outlined the methods of practically establishing the new system throughout the country. The suppression of the Academy of Sciences occurred a few days (August 8, 1793) after passing this decree, and this event, together with various legislative enactments from time to time, had the effect of causing changes in the personnel of the scientific staff entrusted with the development of the system and some differences in the method of procedure. The place of the Academy was taken by a newly constituted National Institute of Sciences and Arts, which continued the scientific oversight, and in general the undertaking was pushed forward as rapidly as is possible with work of such character.

As showing the extent to which the desire for changes and reforms was being manifested in France at this time, it may not be inappropriate to refer at this point to the innovations introduced in the calendar whereby the decimal system was here applied also. By a decree of November 24, 1793, time was to be

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[1] Bigourdan, *Le Système Métrique* (Paris, 1901), chap. ix. pp. 90-93. Méchain and Delambre, *Base du Système Métrique* (Paris, 1806-1810), vol. iii. pp. 673-690.

reckoned from the establishment of the French Republic, September 22, 1792, the day of the autumnal equinox. The year as formerly was to be divided into twelve months, but each of these was to be divided into three weeks, or decads, of ten days each. Each day was to be divided into ten hours, and each hour into one hundred minutes of one hundred seconds each. A picturesque feature was the grouping of the months according to the seasons with a different termination for the names of each season. Thus, beginning with the autumn equinox, Vendémiaire was the month of vintage, and was followed by Brumaire, the month of fogs, and Frimaire, the month of incipient cold. At the winter solstice came Nivose, the month of snow, and then Pluviose, the month of rain, and Ventose, the month of wind. The spring months were, Germinal, the month of buds; Floreal, the month of blossoms; and Prairial, the month of flowering fields. In the summer came Messidor, the month of harvests; Thermidor, the month of heat; and Fructidor, the month of fruits.

This changed calendar was used until 1806, when the Gregorian calendar was resumed, but the division of the day into 100,000 parts was abandoned in 1795. The lack of success of this method of dividing time can readily be explained, and by reasons which have but little bearing on the science of metrology. The doing away with the Christian Sabbath, the addition of a festival season, the changing of well-established modes of life by legislative enactment could hardly but be expected to fail of adoption. Furthermore, the Gregorian calendar was at this time practically universal, and furnished no inconvenience either to scientific men or to the general public. It was a case of change merely for the sake of innovation, and as such was destined to fail.

The time being ripe for further and more definite legislation on the subject of the new scheme of weights and measures, after Prieur (de la Côte d'Or) had made a full and comprehensive report describing the status of the work of establishment and recommending a new system of nomenclature, the Convention enacted the Law of 18 Germinal an III. (April 7, 1795), which defined precisely the different units, provided for standards, and the proper distribution of secondary standards, and the exact determination of the units of length and mass according to the original plan. Article 5 of this decree is worth quoting in full, as it gives precise definitions of the elementary units of the metric system. It reads:

"Art. 5.—The new measures will be distinguished by the name of measures of the Republic: their nomenclature is definitely adopted as follows:

"*Meter*, the measure of length equal to the ten-millionth part of a terrestrial meridian contained between the north pole and the equator.

"*Are*, the measure of area for land equal to a square ten meters on each side.

"*Stere*, the measure designed especially for fire-wood, and which shall be equal to a meter cube.

"*Liter*, the measure of capacity both for liquids and dry materials, whose extent will be that of a cube of one-tenth of a meter.

"*Gramme*, the absolute weight of a volume of pure water equal to a cube of one-hundredth part of a meter, and at the temperature of melting ice.

"Finally the unit of coinage shall take the name of franc to replace the livre used until to-day."

Greek prefixes were provided to denote the multiples of the various units and the Latin prefixes for the subdivisions, while in the measures of weight and capacity, provision was made in addition for double and half measures.

Under the provision of this law, the scientific work was taken up with vigor, and the Government appointed a commission of twelve to complete the original determinations of length and mass. This body included Berthollet, Borda, Brisson, Coulomb, Delambre, Haüy, Lagrange, Laplace, Méchain, Monge, Prony, and Vandermonde, all of whom had been interested actively in the work previously accomplished. This commission was then subdivided, Delambre and Méchain taking charge of the astronomical and geodetic work, Borda, Haüy, and Prony of the determination of the units of weight, Borda and Brisson of the construction and verification of the provisional meter, and Berthollet, Monge and Vandermonde of the construction of the definite meter. The length of a second's pendulum had already been determined by Cassini and Borda at Paris, and was found to be equal to 3 feet 8·5593 lignes of the toise of Peru.

The measurement of the arc of meridian was the most important of the duties of the commission, and involved a vast amount of labor, both in observations in the field and in the reduction and calculation of these observations. The work was originally commenced in 1792 by Méchain and Delambre, and was carried on by them through various vicissitudes caused by changes in political conditions, with their consequent effect on the general and scientific plans for the various operations.

Before describing their work, however, it may be of advantage to outline the underlying principles of a geodetic or trigonometrical survey such as is necessary to determine the length of an arc on the surface of the earth. Such a survey naturally involves the measurement of considerable distances, taking into consideration the curvature of the earth's surface, and requires a system or network of triangles connected one with another by means of common sides. The vertices are stations usually situated on some high altitude, or at any event so selected that each is visible with a telescope from several others. Always at one end, and often at or near both ends, there is what is known as a baseline, a horizontal distance on level ground actually measured with a linear standard to as high a degree of precision as is possible. This involves measuring a distance of from one to ten kilometers by means of rods, bars, or steel tapes, whose lengths have been determined with great accuracy at a standard temperature, to which by correction the actual measurements may be reduced. Care must be taken to place the standards perfectly horizontal and end to end when they are being moved over the measured distance, or to make suitable corrections, and to observe the temperature. In this way the base line, or one side of the triangle, marked in the accompanying diagram by a heavy line, is accurately determined, and it is advantageous in an extended survey to have the base lines at or near sea-level.

After the base line is determined, then the triangulation may be reduced and the distance calculated between the remote ends of the arc. If reference is made to plate vii. vol. i. of the work[1] of Delambre and Méchain here reproduced, it will be possible to illustrate the general method. The base shown between Salces and Vernet is near Perpignan, in the south of

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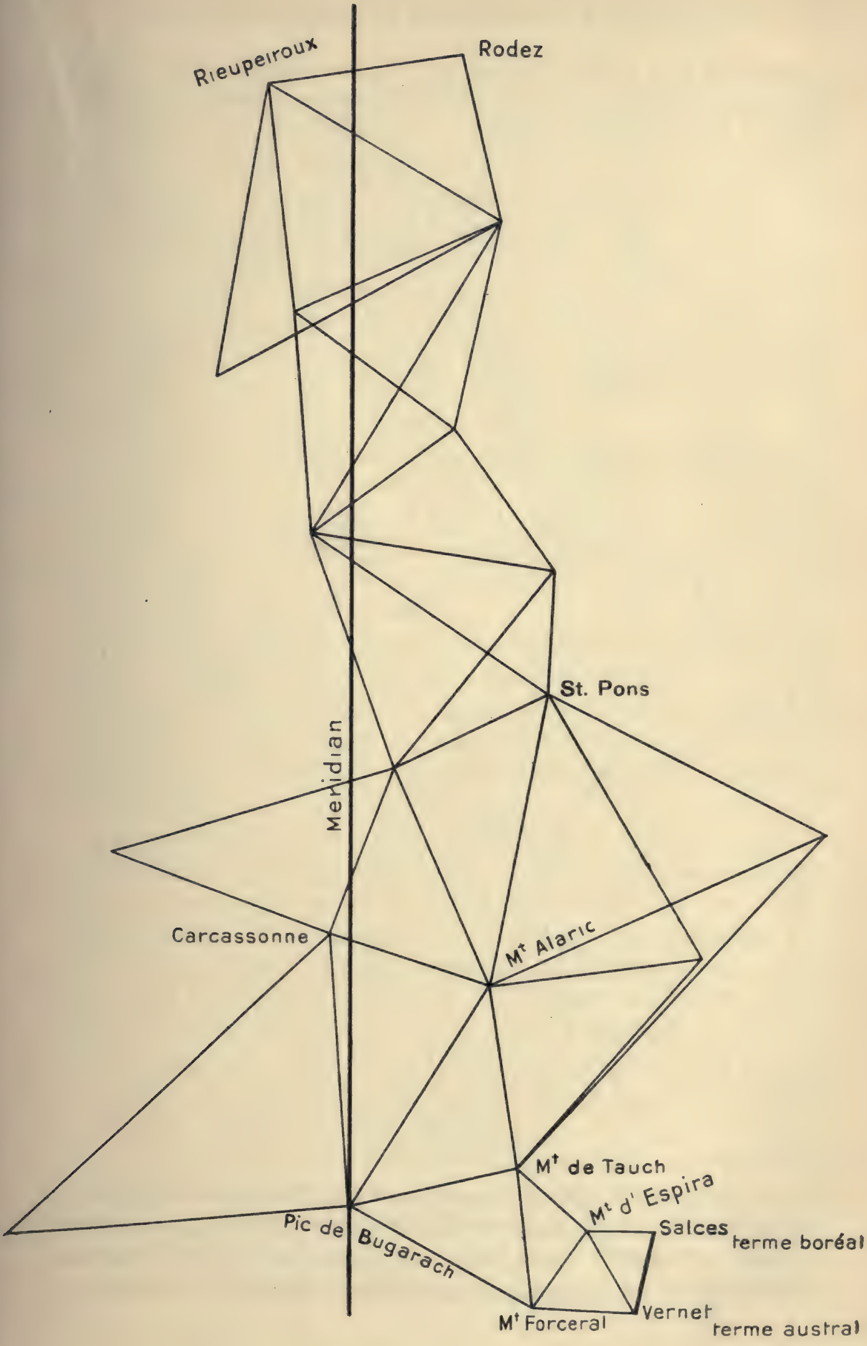
[1] *Le Base du Système Métrique*, vol. i.

France, and at the end of the old arc previously measured. This distance is actually measured with the base line apparatus. Then by means of a divided circle, capable of measuring angles in both a horizontal and vertical plane, and transit or theodolite placed at the "terme boreal" (north end of the base line), the angle between the direction to Mt. d'Espira and to Mt. Forceral is measured, and then at the "terme austral" the corresponding similar angles are measured. Thereupon the instrument is taken to Mt. d'Espira and the angles around that point determined. This is the beginning of a long series of angle determinations at all the points of observation, as Mt. de Tauch, Pic de Bugarach, Mt. Alaric, Carcassonne, etc. All of the measurements are continually checked by the fact that the sum of all the angles around a single point, as Mt. Alaric, must equal 360°, and that the sum of the three angles in any triangle must equal 180°. In any triangle, if one side and two angles, or two sides and one angle, are known, then it is a simple matter to calculate the other parts.

In this way it is not only possible to calculate the length of the sides of all the numerous triangles formed between Barcelona and Dunkirk, but also the projection of each upon the true north and south meridian. For example, as soon as the linear distance from Mt. Alaric to St. Pons is known, and the angle which the direction makes with the true meridian, then it is simple to calculate how far one is north of the other, or in other words, the section of the meridian corresponding to the distance of St. Pons due north of Mt. Alaric. Thus ultimately the distance of Dunkirk due north of Barcelona is calculated. The numerous triangles give continual checks upon the work, as do also other base lines distributed along the line of triangulation.

The foregoing gives the merest outline of the work of triangulation, as there are numerous refinements and modifications involved in both observation and computation, which make the calculation one of no small magnitude. This, however, is but half of the work. There must be found, with an equal degree of precision, the geographical position, or, more particularly, the latitude, of the two extremities of the meridian by astronomical methods. In kind this is similar to the finding of the position of a vessel at sea, but more refined methods of observation are


Rieupeiroux
Rodez
St. Pons
Meridian
Carcassonne
Mt Alaric
Mt de Tauch
Mt d' Espira
Salces terme boréal
Pic de Bugarach
Mt Forceral
Vernet terme austral

necessary, and, at the present day, the use of the zenith telescope is considered the most accurate of the several methods of determining the latitude of a place.

At the time of the measurement of the Dunkirk-Barcelona arc, however, the astronomers used the method of upper and lower transits of certain stars near the north pole of the heavens. Referring to the accompanying figure, *NDBES* represents a meridian of longitude through the place, D, the latitude of which is sought. That is, the plane of the paper is a plane through the axis of the earth NS and the place D. Evidently then the angle DCE is the latitude of the place D, and the angle DCN is called the colatitude. If the line DM indicates the direction in which a star appears, as seen from D at the instant when it passes the meridian, then the angle ZDM may be observed, and is called the zenith distance of the star. The lines DP, $D'P'$ and SCN are parallel, and indicate the direction to the celestial pole, that is, to the point where the axis NS pierces the heavens, then the angle ZDP is equal to DCN the colatitude of the place. The angle MDP is the polar distance of the star.

A series of determinations of the zenith distance of Polaris, the "north star," made on Jan. 17th, 1796, at Dunkirk, for the upper transit, gave 37° 11′ 44″·36. Adding to this the pole distance of Polaris, 1° 46′ 39″·60, gives the colatitude 38° 57′ 44″·36, and the latitude, or 90° minus the latitude, 51° 2′ 15″·64. In the case of a lower transit, where the star crosses the meridian below the pole, the pole distance would be subtracted from the zenith distance. That is to say, $Z'D'P' = Z'D'M' - M'D'P'$. A similar determination at Barcelona, made on Dec. 17th, 1793, gave as the latitude of that place, 41° 22′ 47″·83. This would give as the difference of latitude between Dunkirk and Barcelona, 9° 39′ 27″·81.

A final determination of the difference of latitude between Dunkirk and Montjouy (Barcelona) 9°·67380, and the distance, measured in toises, was found to be 551 584·72. If the refinements of the polar flattening of the earth, etc., are neglected for the moment, then 551 584·72 divided by 9·67380 would give 57 018·7 as the number of toises in one degree of latitude. This number, 57018·7, multiplied by 90, gives 5 131 680. One ten-millionth part of this, or 0·5131680 of a toise, would then be the ideal meter. Naturally, in the actual calculation, all the corrections and refinements were applied.

It must be remembered that in making these measurements much depends upon the accuracy of graduation of the circles, and that many measurements must be made and an average taken so as to obtain in each instance a mean value. The errors can be distributed by the two considerations referred to above, that the sum of all the angles around a point must be 360 degrees, and that the sum of the three interior angles of any triangle must equal 180 degrees. Furthermore, when the observations are reduced, allowance must be made for the difference in elevation of the stations and for the curvature of the earth, which, amounting to as much as 7 inches for each mile, becomes an important quantity in an extended survey. Triangulations analogous to those here indicated, carried out over the whole surface of a country, are the basis of all accurate map making, and, in the United States, an arc of longitude has been measured which extends across the continent.

The task of measuring the French meridian was divided by Delambre and Méchain, the former being assigned the northern portion between Dunkirk and Rodez, a distance of 380,000 toises, while to Méchain was given from Rodez to Barcelona, a distance of 170,000 toises. The reason for this unequal division was that the northern part of the meridian was situated in a much more accessible country, while Méchain's portion was in the mountainous region of Spain. In addition, the northern part had been measured twice previously, and the stations had been selected and recorded. On June 10, 1792, the King issued a proclamation, in which Delambre and Méchain were commended to the good offices of government officials and citizens generally, and various rights and privileges were secured to them. Both scientists straightway proceeded to their duties, but, owing to the turbulent conditions in the country, due to the Revolution, they encountered from the beginning constant embarrassment and difficulties. In addition to being arrested and deprived of ordinary facilities to carry on their work, they met with little sympathy and co-operation on the part of officials and people, and experienced great difficulty in erecting and maintaining their signals, which were oftentimes believed to have been built for purposes of military communication.

Méchain in Spain had a certain amount of assistance from the government of that country, but here, as in southern France, he was harassed and interfered with by political troubles. In fact, these two resolute engineers experienced almost incredible difficulties, being arrested by the various governing bodies that were at that time successively administering the affairs of France, deprived of liberty and freedom, prevented from working by accident and disease, and, in short, accomplishing most creditable results under remarkably adverse circumstances.

Finally, in November, 1798, Méchain and Delambre, having completed their work, arrived at Paris with a record of their observations, and an international commission invited by the Directory proceeded to examine and approve the geodetic and other scientific work accomplished in laying the foundation for the metric system. This commission consisted of delegates from the Batavian Republic, the Cis-Alpine Republic, Denmark, Spain, Switzerland, the Ligurian Republic, Sardinia (later from the provisional government of Piedmont), the Roman Republic, and the Tuscan Republic, in addition to a French Committee composed of the physicists and mathematicians who had been chiefly concerned with the development of the system. The commission divided itself into three sections, each of which carried on a most thorough examination of the work already done, and made further calculations and verifications to establish its accuracy and reliability.[1]

The first section made a comparison of the bar used in measuring the length of the two bases at Melun and Perpignan, and found that it corresponded exactly with the toise of Peru. Examining the toise of Mairan, constructed from the length of the pendulum beating seconds at Paris, it was found to be ·03413 line shorter than the toise of Peru. The second section studied the measurement of the arc of meridian and the actual length of the meter, measuring the bases, examining the angles of each triangle, and finally computing separately their dimensions, employing different tables of logarithms. The report which was prepared by Van Swinden, the delegate of the Batavian Republic, one of the committee to whom was assigned the actual calculation, shows how carefully the work had been done, for, employing the base at Melun as a starting point in computing the triangles, it was found that the difference between the computed and measured lengths of the base at Perpignan was ·160 toise (12·28 inches = 31·19 cm.). When it is remembered that the length of the Perpignan base was 6006·25 toises, and that of Melun 6075·9

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[1] For a full account of this work reference should be made to Méchain and Delambre, *Base du Système Métrique* (Paris, 1806-1810), vol. iii.

toises, and that they were 550,000 toises apart, the accuracy of the measurement may be appreciated.

The flattening of the earth was also computed, employing the present measurements in connection with those made in Peru, and it was found to be $\frac{1}{334}$.[1] The most important result was the calculation of the length of the quadrant of the earth's meridian, 5,130,740 toises, which straightway gave 3 feet 11·296 lignes as the true length of the meter instead of 3 feet 11·442 lignes, the length of the provisional meter provided by the law of August 1, 1793.

The third section, for which Tralles, the Swiss scientist, prepared the report, considered the determination of the unit of weight and the construction of the standard kilogram which had been prepared by Lefèvre-Gineau, according to plans made by Lavoisier and Haüy, who performed the first experiments for this determination.[2] The preparation of this standard required much elaborate experimental work, and it was finally ascertained that the weight of a cubic decimeter of distilled water at its temperature of maximum density and weighed in vacuo, was 18,827·15 grains, the mean of the sum of the weights of Charlemagne, which had been employed as the French standard for over 500 years. While it is not possible here actually to describe this determination of the unit of weight, nevertheless it is interesting to record that Lefèvre-Gineau and his assistant Fabbroni discovered that the maximum density of water was reached at 4° Centigrade.

From the sectional reports just mentioned, a general report was compiled by Van Swinden and presented to the Institute.[3] The actual meter standards were then constructed by Lenoir and carefully compared with the toise standards. A platinum meter was adopted as the true meter, and was deposited in the Archives of State, whence it was subsequently known as the Meter of the Archives. Two other platinum standards[4] were constructed at the

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[1] The accepted value to-day is $\frac{1}{294\cdot9784}$, Clarke's *Spheroid*, 1866.

[2] See Dumas, *Lavoisier's Works*, vol. v.

[3] See Méchain and Delambre, *Base du Système Métrique*, vol. iii. p. 592.

[4] See C. Wolf, "Recherches historiques sur les étalons de poids et mesures de l'Observatoire," *Ann. de l'Observatoire*, Mem. xvii. p. 52, 1883; also *Ann. de Chim. et Phys.*, 5 s. vol. xxv. p. 5, 1882.

same time, and are now known as the Meters of the Conservatory and Observatory respectively. Iron standards were constructed also, and were distributed among the delegates. There was also constructed at the same time a platinum kilogram, and these standards (kilogram and meter) were formally presented by a delegation of the Institute to the Corps Législatif on June 22, 1799, and after being duly received were deposited in the Archives of the Republic. On December 10 of the same year by statute the provisional meter was abolished, and the new meter and kilogram definitely fixed and defined, and the standards presented by the Institute to the Republic were adopted as the definite standards of weight and length.

This act was known as the law of the 19 Frimaire, year VIII., and is as follows.[1] "Article first.—The provisional determination of the length of the meter at 3 pieds, 11·44 lignes, ordained by the laws of Aug. 1st, 1793, and the 18th Germinal, year III. (April 7, 1795), stands revoked and void. The said length, forming the ten-millionth part of the arc of the terrestrial meridian, comprised between the North Pole and the Equator, is definitely fixed, in its relation with the old measures, at 3 pieds, 11·296 lignes.

"Article second.—The meter and the kilogram in platinum, transmitted the four Messidor last, to the Corps Législatif, by the National Institute of Sciences and Arts, are the definite standards of the measures of length and of weight throughout the Republic. Some exact copies of the same will be put in the hands of the Consular Commission, in order to serve as models for the construction of new measures and new weights.[2]

"Article third.—The other dispositions of the law of the 18 Germinal, year III., concerning all that is relative to the Metric System, as well as to the nomenclature and the construction of the new weights and the new measures, will continue to be observed."

Provision was made (Article IV.) for a commemorative medal, which, however, was never made officially, and not actually until

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[1] Bigourdan, *Le Système Métrique* (Paris, 1901), pp. 176-177.

[2] This article was repealed in the law of July 11, 1903, by which the international meter and kilogram were officially recognized, and the French copies (meter 8 and kilogram 35) were made the national standards.

1837, when the ideas of the Institute in regard to such a medal were carried out by MM. Gonon and Penin.

With the scientific determination of the units and the construction of the standards accomplished, there remained but to effect the general adoption of the new weights and measures. Several conditions tended to delay this, and at times there was even pronounced opposition. Chief, perhaps, was the change in political conditions occurring in France, and it was but natural to expect on the part of an imperial government little interest in reforms effected during the republican regime. Furthermore, there was criticism of the system on account of the lack of uniformity and organization, as shown by contradictory legislation, and also on account of its nomenclature, much opposition being manifested to the use of Greek prefixes. The chief difficulty, however, was the lack of secondary standards, which were to have been constructed and distributed at the expense of the State. Accordingly, it was necessary to repeal such legislation, as the expense involved was much greater than the government could afford. Moreover, the temporary office or agency of weights and measures had been abolished too early to give the much-needed assistance in accustoming the people to the use of the new system. There was also embarrassment, due to the fact that, previous to March 15, 1790, there had been public scales where the people could weigh their merchandise. These institutions, which had been done away with by law, it became necessary to re-establish, and this was done for cities of over 5000 inhabitants by the Act of 27 Brumaire, year VII. (November 17, 1798), and subsequently for such other cities as was necessary.

In the meantime, there were not only officials for weighing and measuring, but also private individuals who carried on a similar business, and were ready to employ the old as well as the new and legal measures. As a result, serious abuses and frauds prevailed, and the general appreciation of the merits of the new system was decidedly lukewarm. Nevertheless, it made progress, and was early adopted for all scientific works and papers published by the Institute to the exclusion of all other systems. The growth, however, was not as much among the citizens at large as among the government officials and scientific men. The reasons given were chiefly that both names and values were changed, that foreign names and words were employed, that the names were too long, and that the old weights and measures were persistently used in bills and accounts. To answer these objections, but with the result of complicating matters further, a decree was issued 13 Brumaire, year IX. (November 4, 1800), which stated that the decimal system of weights and measures would definitely be put into execution for the entire republic beginning 1 Vendémiaire, year X., and, in order to facilitate its use, the names given to weights and measures in public documents, as in customary usage, should be explained by French names as given in a list, which to a certain extent corresponded to the simple nomenclature tentatively submitted by the committee of the Academy of Sciences in 1793. There was to be no synonym for the meter, and every measure to which a public denomination was assigned must be a decimal multiple or subdivision of that unit. For the measurement of cloth the meter, with its tenth and hundredth divisions, was to be employed, while the term *stere* was to be used still as a measure of firewood and as a solid measure, a tenth part of this measure being adopted for carpentry and known as a *solive.* The decree also provided that the new names should be inscribed on the weights already constructed, and that either one system or the other must be employed.

While this action tended to weaken the integrity of the metric system, yet it preserved its fundamental feature of decimal division, but it was followed by a decree of Napoleon of February 12, 1812, which had a most serious effect on the work already accomplished, and threatened its very existence. Despite the objections of Laplace and other scientists, a system of measures termed "*usuelle*" was established in which the metric system was employed as the basis, but which made use of such multiples and fractions as would bring about measures that would harmonize with those long established by the usage of commerce and of the people generally. The space of ten years was fixed for a period during which actual experience might occasion further needs of further changes in weights and measures. The legal or metric system was to be taught in all the schools, including the primary schools, and was to be employed in all official transactions, markets, etc. To carry out the provisious of this decree an elaborate series of rules were published by Montalivet, Minister of the Interior, March 28, 1812.

The "*usuelle*" measures were all defined in terms of the metric system, and there were included a large number corresponding to those in daily use. Thus the toise was the length of two meters, and was divided into six feet, each of which was defined as one-third of a meter. The foot, in turn, was divided into 12 inches, and each inch into 12 lignes. For the measurement of cloth and fabrics there was an aune, equal to 12 decimeters, divided into halves, quarters, and sixteenths, and also into thirds, sixths, and twelfths. These divisions for toise and aune were to be marked along one face of the scale or measure, while the other must have the regular metric divisions on the decimal basis. Various weights and measures for retail business were provided and defined, in which the subdivision was by halves or some other non-decimal factor not always the same. Thus, for the measure of capacity, such as grain, there was the *boisseau*, defined as $\frac{1}{8}$ of a hectoliter, with a double, half, and quarter boisseau. The liter also was divided into halves, quarters, and eighths, and the shape and material of measures for various liquids was specified. The *livre* or pound was defined as equal to 500 grams or a half kilogram, and was divided into 16 ounces of 8 *gros* each. Provision was made for the verification and sealing of weights and measures by a government bureau, and also for the construction and distribution of secondary standards to the various departments.

The use of measures other than the legal ones and those specified in the decree was forbidden as contrary to law. The legal system was still to be employed in all government works, officially and in commerce, and it was explained that the decree was designed only to affect retail business and the small trading of daily life. All formal notices must be expressed in legal measures rather than in those tolerated, and the legal system was to be taught in the public schools, including the primary schools, in its completeness. This law was in force until 1837, and its results were most unsatisfactory, since it simply added to the confusion by increasing the number of weights and measures. As, in any event, it was necessary to wait until the people at large gradually abandoned the old measures, it served no useful purpose in the transition period to add new measures that essentially were neither new nor old. The prejudice of the people was slowly overcome, however, and the instruction given in the schools gradually had its effect. From government use and general commerce the use of the legal system extended slowly among retail dealers and small consumers.

After an experience of a quarter of a century with the *usuelle* measures, it was thought that the time had arrived to use the metric system exclusively, and an attempt to that end was made in a bill presented in the House of Deputies, February 28, 1837. The matter was vigorously discussed in the chamber, and was considered by several committees, by whom a plan for suitable legislation was proposed. Attention was called to the survival of the old measures and their general use, and to the fact that the *mesures usuelles*, while they had contributed much to increasing the use of the metric system, nevertheless, being founded on the measures of Paris, were not particularly useful where these measures had not been previously employed, as was the case in certain parts of the realm. A general discussion of nomenclature, systems of division, etc., took place, but the advocates of the metric system were most earnest in resisting any modifications, and it was argued that the yielding to prejudice manifested in the legislation of 1812 had been a serious mistake. It was also urged that people forced to employ the new system, in order to sell their goods, would soon learn, and that no new measures should be constructed whose contents were not in exact accord with the metric system. Accordingly, after considerable discussion, the following Act was passed by the Chamber of Peers and the Chamber of Deputies, and was promulgated July 4, 1837.

Article I.—The decree of February 12, 1812, concerning weights and measures, is hereby repealed.

Article II.—The use of instruments for weighing and measuring, constructed in accordance with Articles II. and III. of said decree, shall be permitted until January 1, 1840.

Article III.—After January 1, 1840, all weights and measures, other than the weights and measures established by the laws of 18 Germinal, year III., and 19 Frimaire, year VIII., constituting the decimal metric system, shall be forbidden, under the penalties provided by article 470 of the Penal Code.

Article IV.—Those possessing weights and measures, other than the weights and measures above recognized, in their warehouses, shops, workshops, places of business, or in their markets, fairs, or emporiums, shall be punished in the same manner as those who use them, according to article 479 of the Penal Code.

Article V.—Beginning at this same date all denominations of weights and measures other than those given in the table annexed to the present law, and established by the law of the 18 Germinal, year III., are forbidden in public acts, documents, and announcements. They are likewise forbidden in acts under private seal, commercial accounts, and other private legal documents. Public officers violating this law are subject to a fine of 20 francs, which shall be collected compulsorily as in a matter of registration. The fine shall be 10 francs for other violators, and shall be imposed for every single act or writing under private signature, but in commercial accounts there shall be only one fine for every case in which the prohibited terms are used.

Article VI.—Judges and arbitrators are forbidden to render any judgment or decision in favor of any particular items in the accounts or writings in which the denominations forbidden by the preceding article shall have been inserted until the fines provided by the preceding article shall have been paid.

Article VII.—The inspectors of weights and measures shall discover violations provided for by the laws and rules concerning the metric system of weights and measures. They may proceed to seize weights and instruments whose use has been prohibited by the said laws and rules. Their testimony in a court of justice shall be considered as direct proof. The inspectors will take oath before the tribunal of the arrondissement.

Article VIII.—A royal ordinance shall regulate the manner in which the inspection of weights and measures shall be accomplished.

As the metric system gradually became firmly established in France, the French Government, through diplomatic channels, called attention of the various nations to its many advantages, and, at the same time, distributed a number of copies of the Meter of the Archives, which had been prepared at the Conservatoire des Arts et Métiers, where now the work of preparing standards and of carrying on other operations in connection with the weights and measures took place. For this bureau, a new comparator, capable of exact measurement and facilitating the operation of comparison, had been constructed by Gambey, and it enabled a large number of accurate standards to be prepared for commercial and industrial use, though in most cases no remarkable degree of precision was obtained. Important work, however, was done in the study of platinum standards of the meter for the Prussian Government, preparatory to the general adoption by that country, of the metric system. This work was carried on by Regnault, Le Verrier, Morin, and Brix.[1]

With the growing use of the metric system for scientific work, not only in France, but throughout Europe, the importance of the accuracy of its fundamental units became a matter of interest to mathematicians and geodesists in several countries. Increased activity in geodesy had brought about a number of measurements of arcs of meridian, and with the resulting data it became possible to compute anew the shape of the earth and the length of the quadrant. Any change in this last quantity, of course, affected the length of the meter as the fundamental unit of length, and called it into question as an absolute and natural standard. That such was the case was early demonstrated by Bessel,[2] while General T. F. De Schubert of the Russian Army, Colonel George Everest of the British Army, and Captain A. R. Clarke of the British Ordnance Survey, made geodetic measurements and studies, which enabled them more accurately to determine the shape of the earth. As a result of this work, it was found impossible to depend upon the accuracy of the determination of the measurement of the quadrant of a great circle, as it would vary in different places, and required a most exact knowledge of the shape of the earth.

These questions, it must be remembered, were purely scientific, and did not influence the practical development of the system

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[1] Benoît, "De la Précision dans la Détermination des Longueurs en Métrologie," *Rapports Congrès International de Physique*, Tome 1, 1900, p. 45.

[2] "Ueber einen Fehler in der Berechnung der Französischen Gradmessung und seinen Einfluss auf die Bestimmung der Figur der Erde." *Schum. Ast. Nachrichten*, 1844, vol. xix. No. 438, pp. 98-1160.

either in France or abroad, but they provoked much discussion among scientific men. With the series of world's expositions, which began with that at London in 1851, an opportunity was given to the people at large to examine and appreciate the benefits of an international system of measures, while statistical and scientific congresses saw the advantages resulting from the use of uniform weights and measures. Important among these was a convention formed largely of the official delegates to the Paris Exposition of 1867, which adopted a series of resolutions in which the superiority of the metric system of weights and measures was conceded, the benefits of uniformity stated, and its adoption by the civilized world urged. Furthermore, the convention deemed it advisable to advocate the study of the metric system in the public schools, and to recommend its use for scientific publications, public statistics, postal service, in customs, and in all works carried on by the governments.

In the same year the International Geodetic Association, composed of delegates from the leading countries of Europe, met at Berlin, and was engaged in the discussion of topics of great concern to all interested in scientific measurement. Inasmuch as many of the standards of length used for base measurements were all end standards,[1] which doubtless had become worn, or possibly were inexact, these geodesists considered it of the utmost importance that there should be new and common standards as absolutely correct as then existing conditions of metrological science could make them. This having been done all base measurements could be referred to the same linear standard, thus insuring that all European geodetic work could be comparable, and could be reduced so that a degree of a great circle of the earth could be determined with accuracy from a number of different measurements. This convention decided that the interests of science in general, and of geodesy in particular, demanded a uniform decimal system of weights and measures throughout Europe, and recommended the adoption of the metric system without essential change, and especially without the metric foot.[2] In order to

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[1] There were by this time a few geodetic line standards, among others those of Spain, Egypt, and probably that of Clarke.

[2] Bericht über die Verhandlungen der von 30 September bis 7 Octobre, 1867, zu Berlin abgehaltenen allgemeinen Conferenz der *Europaischen Gradmessung*, Berlin, 1868, p. 126.

secure such a uniformity of measures the convention decided in favor of the construction of a new European prototype meter differing in length as little as possible from the Meter of the Archives at Paris, and compared with it to the highest degree of accuracy possible. In its construction there would be observed all refinements secured by the advance of metrological science, and especially there would be considered its availability for comparisons with secondary standards of length. The construction of the new standard was to be undertaken by an international commission appointed by the respective governments, and the desirability of establishing an international bureau of weights and measures was expressed. Thus the metric system came to be recognized as something of international concern, and its preservation and improvement a matter that concerned the world at large as well as France.

The action of the Association Géodésique was echoed by the St. Petersburg Academy of Sciences, and this body expressed the interest of the scientific world at large in a proper standard of mass, as well as a new standard of length, in a communication to the Paris Academy of Sciences in 1869, in which they suggested taking common steps towards the establishment of an international metric system. This proposition was not enthusiastically received in France, where many of the scientific men thought that the meter and the kilogram were the work of French savants, and looked upon them as something that should not be tampered with, especially by alien scientists; but those more especially interested in metrology perceived that the application of recent advances in the theory and practice of the science of weighing and measuring was desirable, and that new standards could be constructed with profit, provided that the original standards should remain as the underlying basis of the system. Accordingly, on the representation of the Paris Academy of Sciences, the French Government took up the matter, and after an examination of the question in its different aspects by a committee consisting of representatives from the Academy of Sciences and the Bureau of Longitude, a report was made in favor of the proposed plan, and the Minister of Agriculture and Commerce (Alfred Leroux) brought the matter to the attention of the Emperor, Napoleon III., in a long and comprehensive statement, dated September 1, 1869, favoring the calling of an international conference.[1]

This report was approved by the Emperor, and the French Government communicated through diplomatic channels with the various nations, inviting them to send delegates to a conference to be held at Paris to discuss the construction of a new prototype meter as well as a number of identical standards for the various participating nations. This action was especially important as emphasizing the international character of the system by allowing the participation of a number of nations in the construction of a standard that would serve for all, France included. It was also an admission on the part of the French Government that a new (line) standard (*mètre à trait*) was necessary, and that every means should be taken to conserve the metric system by putting its standards on a permanent basis.

The invitation was accepted by the nations to which it was extended, and in August, 1870, delegates from twenty-four States met at Paris. In the meantime, in order to make suitable preparations, and to lighten the work of the International Commission as much as possible, the French members had assembled, and since September 1st, 1869, had been actively engaged in studying the subject, especially on its scientific side, and preparing a working basis for the conference.[2] Owing to the breaking out of the war between Germany and France this session was of short duration, but it was decided that instead of a single new standard a number of identical standards should be constructed for the nations participating in the convention, and that one of the number should be chosen as the international standard, and should be deposited in some convenient place accessible to all the participating countries, and under their common care.

Summoned anew by the French Government, the International Commission met under more peaceful auspices at Paris, on September 24, 1872, thirty States being represented by fifty-one delegates, among whom were included many distinguished scientists, and, as was natural, the foremost metrologists of the world. By reason of the previous session, and the activity of the French committee in the interval that had elapsed, the work of the Commission was very clearly mapped out, and

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[1] Bigourdan, *Le Système Métrique* (Paris, 1901), pp. 265-272. [2] *Ibid.* p. 273.

little time was spent in mere preliminary discussion. The first and most important announcement was the report of the French Committee, that after a careful examination had been made of the standards of the Archives, the Meter was found in a very satisfactory state of preservation, and in such condition as to inspire all confidence in any operations for which it might serve as a base. Likewise, the Kilogram of the Archives also was found to be perfectly preserved. Comparisons which were effected between the prototype meter and its contemporaries of the Conservatory and the Observatory demonstrated that the Meter of the Archives had not appreciably altered in length.[1]

The Commission was divided into eleven committees composed of delegates specially qualified for the separate branches of the work, and the subjects assigned to each committee were as follows: Study of the ends of the meter of the Archives, material for the new meter, its form and method of support, thermometry and expansion, normal temperature of the meter and kilogram, weights in vacuum or in air, comparator, creation of an international bureau of weights and measures, weight of a cubic decimeter of water, material and form of the standard kilogram, balances and methods of weighing, and preservation of the standards and providing for their invariability.

Addressing themselves to the consideration of these topics, the commission speedily reached satisfactory conclusions, and specific resolutions were adopted outlining the plans to be followed and the direct decisions which the Commission had arrived at.[2]

These resolutions were in substance as follows: The *Mètre des Archives* was to be the point of departure, and was to be reproduced by a *mètre à traits* (line standard), it having been found that the ends of the platinum bar of the historic meter were sufficiently well preserved to warrant employing it as an original standard. This last matter, however, would be finally determined when the actual work of comparison had commenced. The identical copies of the standard meter to be furnished to each of

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[1] Bigourdan, *Le Système Métrique*, p. 274.

[2] For complete text of resolutions and discussion, see Bigourdan, *Le Système Métrique*, pages 299-313. A translation of the same will be found pages 52-55, "Report of the Committee on Coinage, Weights and Measures," of the House of Representatives, 46th Congress, first Session, Report 14, 1879.

the countries were to be *mètres à traits*, but at the same time a number of end standards (*mètres à bouts*) whose equations would also be determined, would be constructed for such countries as specially desired them. The new standards were to represent the length of a meter at 0 degree centigrade, and the material was to be an alloy of platinum 90 per cent. and iridium 10 per cent., with a tolerance of 2 per cent. either in excess or deficiency. The measuring bars were to be constructed from a single ingot produced at one casting and carefully annealed. Their length in the case of the *mètres à traits* was to be 102 centimeters, and their cross section was carefully designed according to specification by Tresca.[1] Detailed instructions were also adopted for the determining of the expansion, the marking, and the calculation of the equations of the different standards. The action of the Commission in reference to the kilogram was as follows (Section xxii.): "Considering that the simple relation which was established by the originators of the metric system between the unit of weight and the unit of volume is represented by the actual kilogram in a manner sufficiently exact for the ordinary uses of industry and of commerce, and even for most of the ordinary requirements of science; considering also that the exact sciences have not the same need of a simple numerical relation, but only of a determination of such relation as perfect as possible; and considering the difficulties that would arise from a change in the actual unit of the metric system, it is decided that the international kilogram shall be derived from the *kilogramme des Archives* in its actual state." The international kilogram was to be determined with reference to its weight in a vacuum, and the material of the standards was to be the same alloy of platinum-iridium as was employed for the standard meters. In form the international kilograms were to resemble the Kilogram of the Archives, being cylindrical, with height equal to the diameter, and with the edges slightly rounded. It was also decided that the determination of the weight of a cubic decimeter of water should be made by the Commission, and that a new balance of extreme precision should be constructed and employed. The method of weighing and determining the volume of the kilograms was outlined, but it was decided that, as also in the

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[1] See chapter x., p. 254.

case of the *mètre des Archives,* the *kilogramme des Archives* should not be placed in a liquid until the end of the operations.

The plan for actually carrying out the work of the Commission involved the construction of as many identical standard meters and kilograms as were needed by the countries interested, all of which should be made and compared by the Commission, and required that a standard meter and a standard kilogram should be selected as international prototype standards in terms of which the equations of all the others should be expressed. The actual construction of these new standards, the tracing of the defining lines, and the comparison with the standards of the Archives, were entrusted to the French section of the Commission, which was to perform the work with the concurrence and under the general direction of a permanent committee of twelve members duly appointed to have general supervision of the work.

The Commission also advocated the founding of an international bureau of weights and measures, to be located at Paris, which would be both international and neutral, and supported by the common contributions from the nations party to a treaty creating such an establishment. It was proposed that it should be under the supervision of the permanent committee of the International Metric Commission, and should be used for the comparison and verification of the new metric standards, for the custody and preservation of the new prototype standards, and for such other appropriate comparisons of weights and measures as might come before it in proper course. In accordance with the suggestions of the Commission, the French Government again communicated diplomatically with the various governments relative to the establishment of such a bureau, and the reports of the various delegates having in the meantime been made, and the project in all its details thoroughly understood, on May 20, 1875, a treaty was concluded at Paris, in which the recommendations of the Commission were put into effect.[1] This treaty was duly signed by accredited representatives of the following countries: United States, Germany, Austria-Hungary, Belgium, Brazil,[2]

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[1] See Bigourdan, *Le Système Métrique*, pp. 328-337. U.S. House Representatives, Committee on Coinage, Weights and Measures, 46th Congress, 1st Session, Report No. 14, pp. 43-50.

[2] Brazil did not ratify the treaty.

Argentine Confederation, Denmark, Spain, France, Italy, Peru, Portugal, Russia, Sweden and Norway, Switzerland, Turkey, and Venezuela. Of the countries present at the conferences, Great Britain and Holland declined to participate in the treaty or to contribute to the expense of an international establishment for the metric system. The British Government, in explanation of this action, stated that they could not recommend to Parliament any expenditure in connection with the metric system, inasmuch as it was not legalized in that country, nor could it support a permanent institution established in a foreign country for its encouragement. A change of feeling, however, took place in England, and in September, 1884, Great Britain joined the Convention. With the treaty were signed at the same time a series of regulations for the newly created bureau, and a set of temporary or transient provisions referring to the work already in hand which had been undertaken by the French section under the direction of the conference of 1872.

The treaty provided for the establishment and maintenance, at the joint charge of the contracting parties, of a scientific and permanent international bureau of weights and measures, to be located at or near Paris, in a territory to be kept strictly neutral. The bureau was to be installed in a special building, supplied with the necessary instruments and apparatus, and was to be conducted by an international committee, composed of fourteen delegates, each from a different country, with a personal scientific staff of a director with assistants and workmen. The first duty of the bureau would be the verification of the new international metric standards then in progress of construction, but, in addition, it would have such permanent functions as the custody of the new international metric prototypes, all future official comparison with those of the national standards, comparisons with the metric standards of other units, the standardizing of geodetic instruments and other standards and scales of precision, and, in short, to undertake such scientific work connected with metrology as would be possible with its equipment, and which would supply the greatest benefits to the supporting nations. The expense of the new establishment was to be met by contributions from the various signatories to the convention, on the basis of their respective population, multiplied by the factor 3 for countries where the metric system was obligatory, by 2 where it was legalized but not obligatory, and by 1 where it was not yet legalized.[1]

The treaty was ratified by the various contracting governments, and the international committee from the conference of 1872 was continued under the presidency of General Ibanez of Spain, and authorized to begin the preliminary operations. The first question was to find a suitable location for the laboratories of the bureau, and this was solved by the offer of the French Government to turn over, without charge, the Pavillon de Breteuil, including a tract of land about two and a half hectars in extent, situated on the bank of the Seine near Sèvres, at the entrance of the Park of St. Cloud.[2] This building, which is on a hill, dates back to the time of Louis XV., and was used by kings and emperors as a palace and place of resort, especially by Napoleon I., who, it is said, was at times wont to study here. The *pavillon* itself was in bad repair, having been damaged in the siege of Paris, but the walls were in good condition, and it was decided to put the building in order to be used for the offices of the bureau and the residence of the staff, and to construct a new and special building for the actual scientific work and for the safe keeping of the international prototypes. The latter *observatoire* or laboratory, a one-story building, was completed and the apparatus installed from 1878, and has been in constant use ever since. Its equipment has for the most part been specially provided, and includes, without doubt, the most complete and accurate instruments of precision in existence. Each of these merits a complete description, which is of course not possible in these pages, but some of the essentials of the more important instruments will be found described in the chapter on Standards.[3]

The construction of the new standards involved greater difficulties than had been anticipated. The French section had melted an ingot of the platinum-iridium alloy specified by the conference of 1872, but it was found to contain impurities

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[1] It has recently (1906) been proposed by the Committee to drop the coefficients.

[2] For description see Bigourdan, *Le Système Métrique* (Paris, 1901), pp. 353-362. Guillaume, *La Convention du Mètre* (Paris, 1902), pp. 21-25.

[3] See chapter x.

in the form of slight admixtures of rhodium, ruthenium, and iron. This, accordingly, provoked a controversy, which, however, was settled by obtaining eventually material which satisfied all the requirements.

From time to time, as occasion demanded,[1] the International Committee held various meetings connected with the maintenance and operation of the Bureau International, and in 1887 a resolution was passed defining the unit of mass as follows:

"The mass of the international kilogram is taken as unity for the international use of weights and measures."[2]

This definition enabled a more perfect statement of the fundamental basis of the metric system to be made, and produced an increased exactness which was most desirable. In 1889 a second International Conference was assembled, which passed on the work of the International Committee, and approved the standards which were submitted for their examination, together with a record of all experiments and investigations that had been made in their preparation. The conference definitely adopted the international prototypes of the meter and of the kilogram as the standards of length and mass respectively, and the centigrade scale of the hydrogen thermometer was adopted for their definition and determination. The national prototype standards were also approved, and were distributed by lot to the various countries contributing to the Bureau, and, finally, a committee was appointed to deposit the international standards,—meter and kilogram,—in the safe of the vault of the Observatory at Breteuil designed for their reception, and this was accomplished with the observance of all due formality,—the various keys of the apartment being distributed to different officers,[3] whose joint presence was necessary for any examination of the standards.

Mention might properly be made of the elaborate scientific researches carried on at the Bureau, and the valuable memoirs[4]

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[1] Formerly every year; now every two years.

[2] *Procès-verbaux du Comité International des Poids et Mesures pour* 1887, p. 88.

[3] The president of the International Committee, the director of the French Archives, and the director of the Bureau.

[4] See *Travaux et Mémoires du Bureau International des Poids et Mesures* (Paris, 1881—).

published at frequent intervals in which these are described. With the determination of the prototype standards for the meter and the kilogram accomplished, many other problems in metrology, such as the study of temperature measurements, the determination of the meter in terms of the wave-length of light, the construction of standards for electrical measurements, the study of alloys for standards, especially those used in geodesy, etc., have received attention from the scientific staff, and the work accomplished has been of marked and permanent value.

CHAPTER III.

DEVELOPMENT OF THE METRIC SYSTEM IN EUROPE.

WHILE an international system of weights and measures was contemplated by the French scientists, yet in the formulation of the metric system comparatively little general interest was manifested by other nations, and comparatively little aid was given by their scientific men. We have seen how an international commission of scientists examined and approved the determination of the meter and kilogram, and the important parts played by Van Swinden and Trallès in this work of verification.[1] These foreign delegates appreciated the advantages of the new system, as did other men of science, but the times were unpropitious for innovations which would unsettle and change the ordinary habits and customs of the people. Inasmuch as France was at war with the greater part of Europe during the opening years of the nineteenth century, the mere mention of the source of reforms in weights and measures was in many instances an argument against their adoption. Furthermore, the actual governments themselves were changing constantly in many parts of Europe, and the struggle for territory and national existence was of more immediate importance than such minor matters as those concerning commerce and the domestic life of the people. Indeed, had the change been attempted generally at this time it would hardly have met with success; for, as we have seen in the case of France, not only was compulsory legislation eventually necessary, but an

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[1] The names of nine foreign scientists were attached to the documents accompanying the standard meter and kilogram when given to the French Government for deposit in the Archives.

able and active administration working on some wise and permanent plan was required to put it into effect. Consequently, before any general consideration of adopting the new system could take place, it was necessary that there should be permanence and stability in the various governments.

As the fixing of weights and measures is manifestly an attribute of government, so any successful reforms must depend upon the character and strength of a particular government, and in order to influence neighboring countries the territory affected should be comparatively large and the number of its inhabitants considerable. Consequently the adoption of the metric system, in a half-hearted way, by a petty kingdom here and a principality there, likely at any time either to be absorbed by its neighbors, or to conquer and to rule them, would and did have little influence on the general ultimate use of the new weights and measures. This, however, must not be understood as implying that at the beginning of the nineteenth century there was no need for reforms either in Europe at large or in particular states. Mediaeval conditions survived, and the same evils that prevailed in France were experienced throughout Europe. The same name was applied to measures whose values varied considerably not only in different states but even in different cities of the same state. Lack of uniformity, both in units and standards, was universal, with the natural result of hindering commerce and of generally cheating the less intelligent party to any transaction. True, French conquest had carried with it the metric system, but it was used merely under compulsion, and so soon as there was a change in political conditions the old measures were resumed. Aside from the scientific propaganda, due to the undisputed pre-eminence of French workers in exact and applied science, comparatively little could be done towards forcing the issue, and the adoption of the metric system waited largely on political circumstances which affected the life and commerce of the people at large, and which were duly appreciated by statesmen. These conditions were brought about by the decline of war, and the resulting opportunity for the people to turn to the pursuits of farming, commerce, and manufacturing. If a number of states or cities were brought into closer political relations, forming a larger state or possibly a confederation, their commercial relations naturally developed, and in order to increase the wealth and resources of the state, both material and military, it was essential that the government should take such measures as would best stimulate commerce and manufactures. Accordingly, it was early recognized that uniformity of weights and measures within the boundaries of a state not only contributed but was essential to the welfare of its inhabitants, while, furthermore, its foreign commerce was increased by having the same weights and measures as its neighbors. When we join to these considerations the fact that the separate systems in nearly all cases were illogical, inconvenient, and lacking in uniformity and facility of use, we have the explanation of the eventual spread of the metric system in Europe.

On the return of Trallès from Paris he endeavored to introduce into Switzerland the metric weights and measures, and on March 4th, 1801, a law was passed adopting these measures ; but, against his advice, special names were given to the various measures. Likewise, Van Swinden, after his return to Holland from Paris, attempted to bring about the adoption of the metric weights and measures in his own country, and in 1802 the Corps Législatif decided in part on the new system. Yet so many features were lacking from their plan, that the completeness and general availability characteristic of the system were much impaired, to the great regret of the scientist. No record has been found to indicate whether the law was repealed or never came into effect, but with the invasion of Holland by Napoleon, a decree of January 11, 1811, referred the weights and measures of that country to those of the metric system.[1]

In Milan, in 1803, the meter and the kilogram were adopted as the basis of a series of measures arranged on a decimal scale, but new and local names were given to them. Thus the *braccio*, as the unit of length, was equivalent to the meter, while the kilogram was known as a *libbra metrica*, or metric pound. In Baden, in 1810, a *pfund*, equal to one-half of the kilogram, was adopted as the unit of weight, and was decimally subdivided. The unit of linear measure was the *ruthe*, which was equivalent to three meters,

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[1] Bigourdan, *Le Système Métrique*, p. 241. On August 21, 1816, a law was enacted establishing the metric system, and later additional Acts were passed which will be alluded to in the course of a few pages.

while the dry and liquid measures of capacity were also defined in terms of the French metric measures. However, subsequent legislation was required, and by an order dated August 21, 1828, the new measures were made compulsory with the year 1831. Somewhat similar steps were taken also in Hesse-Darmstadt in 1821, the *pfund* and the *shoppen* being made equal to one-half a kilogram and one-half a liter respectively, while the *fuss*, or linear unit, was one-fourth of the meter, and the *elle* four-fifths. In Switzerland, in 1828, it was proposed to adopt a common system of weights and measures for the various cantons, and in 1835 twelve of these divisions entered into an agreement known as the "Maass concordats," to which reference will be made later. This plan consisted essentially of the usual measures defined in terms of the metric units.

The French Government, as we have seen, having experienced difficulty in securing the exclusive use of the metric system by its own people did not take active measures towards extending its use abroad until after the passage of the law of 1837, which rendered the system universal and compulsory throughout France. In 1841 the Minister of Agriculture and Commerce, Cunin-Gridaine, considered that much good would be accomplished by the exchange of standards of weights and measures between France and the important commercial countries of the world. He was supported by the Minister of Foreign Affairs, Guizot, who arranged for such an exchange through the diplomatic channels of the various governments.[1] Accordingly these standards were duly sent, and in 1853 the United States received a complete series of French standards, which included a steel meter that had been compared with the platinum standard at the Conservatoire des Arts et Métiers, and likewise a gilt kilogram whose constants had been determined in terms of the kilogram of the Archives.

The beginning of a general feeling in favor of the universal adoption of a single system of weights and measures, and the opinion that for this purpose the metric system was the most suitable, may be considered to date from the London Exposition of 1851, to which reference has already been made. Despite the fact that metric weights and measures had been used, and their adoption advocated by scientific workers, it cannot be said

[1] Bigourdan, *Le Système Métrique*, p. 245.

that before this time the importance of the subject was recognized generally, and that economists and statesmen had thoroughly realized the benefits that would ensue from a single and universal system of weights and measures, as well as a common and universal basis for coinage, in which there should be a single, and preferably decimal, principle of division. But from such a beginning the agitation spread, and nearly every nation soon had a group of earnest advocates of the metric system, which included not only such scientific men as chemists, physicists, astronomers, and engineers, not to mention economists and statisticians, but also merchants and manufacturers. This was due to the bringing together from many quarters of the globe of a large number of representative merchants, producers, and manufacturers, with their various wares and products, and also scientific men and others who were called to pass upon the comparative merits of the various articles on exhibition. At the conclusion of the London Exposition, the Society of Arts, in a communication addressed to the Lords of the Treasury, asked if it were not possible that some arrangement could be made whereby a universal decimal system of moneys, weights, and measures could be adopted in common for all the nations of the world. This was possibly the first expression in England, outside of scientific circles, of the general advantages of universal weights and measures, and particularly those that would accrue to commerce by the adoption of a uniform decimal system. In 1855 an international statistical congress was held at Paris, and on the motion of James Yates, a member of the Royal Society of London, it was decided to form an International Association, to advance the adoption of a decimal system of weights and measures and moneys. This association made an examination of the different systems employed throughout the earth, and decided that the metric system, on account of its scientific character and general availability for international trade, was to be preferred, and accordingly made a recommendation in its favor. The sentiment was further echoed by members of the International Jury of the Paris Exposition of 1855, who formally adopted resolutions in favor of the metric system, recommending it to the attention of their respective governments, and urging its adoption on the ground that it would not only promote commerce, but also peace and unity of feeling throughout the world, praising especially its decimal basis.[1]

A Committee of Weights and Measures and of Moneys, composed of delegates of various countries to the Paris Exposition of 1867, was formed at the initiative of these delegates, and took action in favor of the decimal system, and urged the adoption of uniform weights and measures throughout the world. While this committee enjoyed no official standing, yet it adopted resolutions recommending the study of the metric system in all the schools, and its recognition in all public meetings. Furthermore, its exclusive use in scientific and statistical publications, for postal purposes, in the customs, as well as in public works, and in all other branches of government administration was recommended.[2]

In the meanwhile, the inconvenience and confusion caused by different weights and measures throughout Central Europe had reached a point where positive action was necessary. Under more peaceful conditions, commerce and industry were beginning to flourish, and the lack of uniformity in weights and measures was proving a serious hindrance to trade. In a comparatively small territory there was a considerable number of different states with different systems of weights and measures, as well as with different tariff and customs regulations, which seriously interfered with the easy transaction of international business. The multiplicity of these measures involved the employment of an inordinately large number of clerks and computers in custom houses and counting rooms to change from one system to another weights, measures, and moneys, as specified in invoices, and other documents. It was doubtless also realized that to carry on commerce there must be an easy standard of comparison between the goods of the home country and those of other foreign countries. The money alone was recognized as a sufficient cause of trouble, and extensive reforms, such as the decreeing of uniform (Metric) weights for metallic currency by the Vienna Coin Treaty of January 24, 1857, and a similar action by the so-called Latin Union of 1865, improved materially conditions in this respect, and it may be remarked that in both instances the currency was put on a decimal basis.

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[1] Bigourdan, *Le Système Métrique*, p. 248.

[2] *Ibid.* p. 248.

With the weights and measures, however, the first steps toward uniformity were taken when the metric system was adopted for customs purposes, some time before its legal adoption for general use in the separate states. Thus the German Zollverein (Customs Unions)[1] adopted for use in the customs a standard metric pound (*zollpfund*) which was one-half of a kilogram, and with it a *centner* of 50 kilograms. These units of weight came into effect January 1, 1854, and the *pfund*, which was divided into 30 *loth*, was adopted by the German-Austrian Zollverein, for postal purposes, on the same date. In 1856 the use of the metric pound and centner was further extended, and in 1857 a coin pound or *münzpfund* (500 grams) was employed for coinage purposes. The railways also followed the example set by the customs, and throughout the countries constituting the Zollverein all freight was weighed by the metric pound. Thus it will be seen that the entering wedge of the metric system in Europe outside of France was in the adoption of uniform weights for international trade, which led to a general knowledge of its merits and appreciation of the advantages of uniformity.

The natural and immediate result was the adoption of the " zollpfund " as the unit of weight in a number of states, and with this came a general understanding of the inconvenience attending the use of different standards for measures of length, capacity, etc. In consequence, a commission of scientific men was appointed from the federated German states to examine the question thoroughly, and formulate a national system of weights and measures. They reported in 1861 that the metric system already possessed the advantages sought after, and that greater benefits would ensue from its adoption as a whole than by devising a new system or by endeavoring to harmonize existing standards.

The method of the change in Germany is well worth careful study from the student of metrology and of public affairs, inasmuch as here were represented most of the problems which

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[1] The Zollverein, or union of German states to secure among themselves freedom of trade and uniformity of duties on foreign imports, was proposed by Prussia in 1818. The North and South German Unions, formed for this purpose, were united in 1829 by a treaty which became effective in 1834, and in 1854 a strong union of nearly all the German states was brought about.

would be encountered were the same change to be made in the near future either in the United States or in Great Britain. In fact, the conditions may be said to be practically the same, for although standards and processes based on Anglo-Saxon measures have since developed to such an extent that a change would be a serious matter, yet, at the same time, the use and knowledge of the metric system have also increased, so that on this score the change would be far less difficult now than it was for Germany in 1870. Furthermore, reforms in arbitrary gauges and methods of measurement are now required in various lines of industry and manufacturing, which make the present an especially appropriate time for a general change in measures. Consequently, by studying methods and conditions in Germany at the time of this change, it is fair to say that an accurate knowledge of the general features of any present problems of this description will be gained, and it is also safe to say that the final advantageous outcome would be reproduced in either the United States or Great Britain, though the time necessary to accomplish such a consummation may reasonably be a subject for difference of opinion and argument.

The first legislative step in the introduction of the metric system into Germany was the adoption of resolutions to that effect by the Federal Council and the Parliament of the North German Confederation, which were published under the date of August 17, 1868.[1] These resolutions provided that the metric system should be adopted in place of the weights and measures previously in use, and that the system should be optional on January 1, 1870, and obligatory on January 1, 1872. No change in the nature or execution of this plan occurred when in April, 1871, the confederation was superseded by the empire. There was duly established the "Normal-Aichungs-Kommission," which was charged with the work of furnishing detailed directions and specifications as to the material, shape, and other characteristics of the weights and measures, and also with supplying the "marking" office and its various local branches with such implements as would enable it to mark and stamp all weights and measures which should be presented to it. It was also ordered

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[1] W. Foerster (former Chief of the German Bureau of Weights and Measures, and President of the International Committee of Weights and Measures), pp. 12, 13, House of Representatives, Report No. 2885, 54th Congress, 2nd Session, 1897.

that the confederated governments publish the calculations giving the figures for the legal equivalents of the new weights and measures as compared with the old.[1] The Commission had charge of the introduction of the new system throughout the confederation, supervising all measures to facilitate its speedy acceptance, and with definitely carrying it into effect. The various states of the confederation appointed officials for the actual marking and stamping of the measures and weights, and prescribed regulations for the administration of such bureaus. In the ten months previous to the date assigned for the beginning of the optional use of the metric weights and measures, the Commission provided all the marking offices with standards for the verification of such weights and measures as should be presented to them for legalization, and immediately after these needs had been met the manufacturers were provided with proper standards, so that they could at once commence the manufacture of weights and measures for general sale and use. Such weights and measures, adequate in number and of high accuracy, were soon forthcoming, and by the end of the first half of the year 1870 a large part of the people of Germany became well acquainted with the new measures, their decimal division appealing particularly to the industrial and technical workers.

In 1870 occurred the war with France, and, while it prejudiced many of the people against the new weights and measures, nevertheless it more closely united Germany and thus offset any difficulties on this score. In short, on the arrival of the specified date, January 1, 1872, when the use of the old weights and measures must cease and the metric system be the only legal system, not only were the new weights and measures supplied to all places throughout Germany where merchandise was sold, but the various tradesmen and others concerned had actually learned the use of meter sticks, liter measures, and the series of gram weights. This record is somewhat remarkable, as in Germany there was not one system of weights and measures, but, as has been shown, a large number of different systems which the new measures had to supplant. Germany, however, enjoyed one great advantage in the adoption of the metric system in the extensive use in a number of the

[1] Same Report, pp. 7, 8.

states of the "zollpfund" or customs pound, above mentioned, which we have seen was the weight of 500 grams or a half kilogram. Weights of this denomination were actually in existence in considerable numbers and were widely employed, but the subdivisions were not usually on a decimal or metric basis, and only in one state, Hanover, was there a division into 1000 half grams. Two of these *pfund* weights immediately furnished a legal kilogram, and, while their use interfered somewhat with the development of the decimal principle, nevertheless it served to accustom the people at large to the new mode of reckoning. The liter measures were accepted even more readily than those of mass. The relation between the unit or liter and the measure of length and the weight of water served to commend the new system readily to those dealing with fluids, while a number of simple tables were prepared officially to explain the simplicity of the system.

In contrast to the ease with which the liter and the gram series were adopted, mention must be made of the change in the measures of length. The principal measures of length were the ell and the foot, which, though varying greatly among the various German states from a metrological standpoint, were approximately the same, or sufficiently so at least, to convey to the ordinary person a certain rough idea of extension which for many purposes sufficed. Furthermore, the foot and ell differed so much from the meter and its subdivisions that the purchasing public could not transfer readily the price of cloth or other material when conceived or expressed in these units to the meter, and thus obtain even an approximate idea of value. It was also argued that the meter was not as convenient to think in as the foot for architects and mechanics, by some of whom opposition to the new measures was manifested; but this feeling soon died away, and the new measures were soon universally employed in all works and calculations.

That the metric system has contributed materially towards the upbuilding of German commerce and industry is universally conceded, but, of course, since its adoption so many causes have acted to this end, that it is not possible to state precisely just what part the international measures have played. Suffice it to say, that in manufacturing, especially of articles where precision of measurement, and interchangeability of parts are essential, the Germans have vastly improved and increased their output, which must in a certain degree be due to this cause. Inasmuch as the metric system was employed extensively in scientific work previous to its general adoption, the increased activity of German investigators in fields where measuring is essential is not necessarily a result, but the readiness with which industrial workers have availed themselves of the scientists' labors has doubtless been facilitated by the fact that their processes and results were expressed in a language that readily could be understood.[1]

Austria, where there was much the same variation of feet, pounds, etc., as in Germany, followed that country's example, and on July 23, 1871, the Parliament passed a law providing for the permissive use of the metric system after January 1, 1873, and its compulsory use after January 1, 1876. At the same time it published official tables of equivalents between the old and new measures, and established a standard meter, which was an end standard of glass, and a standard kilogram of rock crystal, these being legally supplanted in 1893 by the copies of the international standard meter and kilogram received from the International Bureau. The old measures, especially those known as the "Lower Austrian System," were quite unlike those of the metric system, and at first it would appear that there would have been great difficulty in bringing about a change; but for a while a binary system of division was tolerated, and certain weights and measures approximate in value to the older ones temporarily were employed. In the meantime newspapers and schools were zealously educating the people to the new order, while the government prepared an adequate number of approved weights and measures, as well as supervised the construction of others according to standard regulations. The four years appointed for the transitional period proved ample, and there was no expressed or obstinate resistance on the part of the people. In fact, it was the general opinion that any lack of completeness

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[1] See Promemoria of German Imperial "Normal-Aichungs Kommission" in House of Representatives, Report No. 2885, 54th Congress, 2nd Session, 1897, pp. 7-9.

in the adoption of the system was due rather to laxity on the part of the municipal authorities than to any pronounced feeling of the public at large.[1]

In Hungary, by the law of 1874, Article VIII., the metric system was established to be in force from January 1, 1876, but its use was sanctioned six months earlier, and finally, in 1901, the international standards were duly established by law. The method of making the change was in the main the same as in Austria, and the new weights and measures were quickly naturalized and adopted by the people generally, though in isolated districts the old usage was maintained for many years.

Outside of France, Belgium is one of the earliest countries to use the metric system, as it was established there by the law of August 21, 1816, at a time when that country was united with Holland.[2] The names of the old units were applied to the metric values, but instruction in the metric system was given in the schools, so that, after the system had been rendered compulsory from 1820, by 1836 it was possible to withdraw the Belgian names, and in 1855 the exclusive use of the French

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[1] See pp. 9, 10, House of Representatives, Report No. 2885, 54th Congress, 2nd Session, 1897. In addition to this report, which contains information furnished by European governments to ambassadors and ministers of the United States on the subject of the adoption of the metric weights and measures by the different countries, a summary of foreign legislation on the Metric System prepared by J. K. Upton, chief clerk of the Treasury Department, and later Assistant Secretary of Treasury, contained in Report No. 14, House of Representatives, Committee on Coinage, Weights and Measures, 46th Congress, 1st Session, 1879, has been drawn upon for dates and details given in the following pages concerning the adoption of the metric system by the nations of Europe. Somewhat more recent are the summaries contained in Guillaume, *La Convention du Mètre* (Paris, 1902), Annexe iv. pp. 218-226; "Résumé de quelques Legislations relatives aux Poids et Mesures," *Annexe aux Procès-verbaux des Séances du Comité international des Poids et Mesures*, Session de 1901, 2e Serie, Tome 1 (Paris, 1901); *Reports from Her Majesty's Representatives in Europe on the Metric System*, part i., July, 1900, *English Parliamentary Accounts and Papers*, 1900, vol. xc.; *Reports from Her Majesty's Representatives Abroad*, part ii., February, 1901, *English Parliamentary Accounts and Papers*, 1901, vol. lxxx. The latter are particularly full, and give an interesting account of the transition period, as well as the extracts from the laws in many instances. There is also available the *Seizième Rapport aux gouvernements signatoires de la Convention du Mètre* and the *Comptes rendus de la deuxième Conférence générale des Poids et Mesures*, 1895.

[2] See *ante*, p. 82.

names and measures was established by law. The Belgian standards of mass and length were copied from those in France, being legalized in 1848, but they were damaged in the fire of 1883 at the Palais du Nation, so that the international prototypes which were received in 1894, and duly legalized, were most acceptable.

The use of the metric system in Egypt is of interest, inasmuch as that country is so largely under British influences, both commercial and political. The metric system was established on a permissive basis in 1873, by a decree of Khedive Ismail, which, however, was not enforced, so that in 1886 a commission was appointed to consider the adoption of the metric system, and reported in its favor. By 1892 its use had extended, so that it was possible for the government to adopt it for use in all transactions between it and private parties, except for measurement of land and the tonnage of ships. It has been employed in the public works department, where large engineering projects have been supervised and executed by British engineers, who have recognized its many advantages, and also in the customs, post office, and railways. While the old native measures still remain in daily use, yet the metric system is being taught in the government schools, and as rapidly as is possible for an oriental people, with their traditions and conservatism, it is growing into increased use.

Greece is an example of a country where the Government though having adopted the metric system is unable to secure its use by the masses of the people. The metric system was established by a royal decree of September 28, 1836, with Greek names for the different weights and measures; but its use is largely confined to the Government in its various transactions involving measures of distance and area, the Government in common with the general public employing the *oke* = 1·282 kilograms as a unit of weight, and a measure of the same name = 1·33 liters as a unit of capacity. This is undoubtedly due to the fact that the amount of international commerce in Greece is comparatively limited, and that the people at large have but little interest in general commerce as such, while the Government is indisposed to press reforms of this character.

The conquest of Lombardy and Venetia by Napoleon in 1803 was the means of inaugurating the metric system in Italy, but its general use did not follow except in governmental transactions, and the bulk of the people resisted this effort on the part of foreign conquerors. In some of the various kingdoms and principalities it was found convenient to adopt the metric weights and measures,[1] but it required the establishment of the Kingdom of Italy in 1861 to ensure complete uniformity and the thorough adoption of the system. Here, again, we see that one of the consequences, or possibly a necessary attribute, of the establishment of a nation from a number of separate states is that there should be a single and uniform system of weights and measures. Accordingly, by the law of July 28, 1861, the metric system was rendered obligatory throughout the kingdom after January 1, 1863, and this was reinforced by a law passed in June 23, 1874; and on August 23, 1890, the international standards were established by a royal decree.

The Japanese have for some time used metric weights in their coinage, and in 1891 a law was passed in which the ancient measures were reorganized and based on those of the metric system, which was also duly recognized. The various national units, which are divided either decimally[2] or sexagesimally, are defined in terms of the metric units, so that little difficulty would be experienced in passing from one to the other, and, in fact, tape measures are frequently graduated on both sides with the two scales, while on a map both scales are usually given.

We have seen above[3] how the metric system was introduced into Holland when it formed one country with Belgium in 1816, and it gradually enjoyed wider use until in 1869 the French names were adopted to designate the different units, while permitting the older and national names to be used for ten years longer. The royal standards of the Netherlands were constructed by a commission of Dutch scientists, and while they

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[1] Metric System was made compulsory in Piedmont in 1845; introduced into Modena in 1849, with eight years for its gradual adoption; adopted in part of Papal States in 1859; in 1861 adopted in Sardinia; in 1863 adopted in Neapolitan provinces, in 1869 in Venice, and in 1870 in Rome.

[2] Japanese measures below a *shaku* $= \cdot 99421$ feet $= \frac{1}{3 \cdot 3}$ meter are decimally divided, rendering their comparison with metric measures in the case of drawings or diagrams very easy.

[3] See *ante*, pp. 82 and 91.

resemble those of the International Commission, were derived directly from the standards of the Archives. The Dutch standard meter is 2·7 microns longer than the international standard.

When a decree was issued in Portugal in 1852 providing for the introduction of the metric system, it was provided that it should be in full legal operation within a space of ten years. It was planned that the introduction should be by successive stages, beginning with the Government, and various schemes and tables of legal equivalents were to be prepared and distributed. It was not possible to bring about the change during the specified time, so that subsequent statutes were necessary, and it was not until 1872 that the metric system was officially in universal use. The introduction of the new weights and measures was attended with no difficulty, save the lack of intelligence of the people of the lower and agricultural classes, and among them the force of custom and tradition has proved so strong that old weights and measures still remain, though they cannot be used in any receipt or legal document. The metric system is, however, greatly appreciated by the commercial interests, and is slowly but surely making progress among the people at large. In fact, it will be seen that among intelligent people such a change occasions comparatively small inconvenience and is quickly effected; but where there is a low general standard of education, as in Portugal, the people are conservative and unwilling to accept innovations, as they are unable to appreciate their utility.

Russia, no less than other countries, early felt the necessity for reforms in its systems of weights and measures, and in 1833 the original Russian units were defined in terms of English feet,—the legal unit being the *sagène*, which was equal to seven English feet. The standard for this unit was constructed with great exactness, and was compared with the English yard, and from it the various other measures were derived. Nevertheless it was found necessary to replace the *sagène* by the *archinne*, which is $\frac{1}{3}$ *sagène* or ·71112 meter. The metric system is now permissive under the terms of the law of June 4-16, 1899, which became effective January 1, 1900; yet it is noteworthy that its international character is recognized by defining the national standards, the *livre* and the *archinne*, in terms of the international prototypes.[1] The metric units are largely employed in Russia, as elsewhere, for scientific work, and there is said to be a strong feeling towards the complete adoption of the system, which for a number of years has been used by the pharmacists of the empire, and since 1896 by the medical departments of the Russian army and navy. The metric system is also used in the customs service, with indications of further extensions. In Finland, where a higher standard of education prevails, the metric system has been employed with considerable success since 1892, and no difficulty attending its introduction was experienced.

Notwithstanding the fact that a large part of the preparatory work in determining the length of the earth's quadrant had been done in Spain, that country did not adopt the metric system until 1849, though previously it had been under discussion, and so early as 1807 a number of metric scales had been constructed at Madrid. The law of 1849, which provided that the system should go into force in 1853, and actually became operative throughout the entire kingdom in 1855, defined the meter in terms of the dimensions of the earth, and the other units as deduced from the meter. These definitions remained in force until 1892, when the receipt of the copies of the international prototype meter and kilogram, prepared by the Bureau International, necessitated the restatement of the law in which these standards and their relation to the international prototypes of the Bureau were duly recognized.

In Sweden a royal decree was issued November 22, 1878, by which the use of the metric system was made optional from the following January 1, and after ten years was to be made compulsory. The usual official tables and information in various and convenient forms were distributed during this transition period, but it was not until the end of the appointed time that the metric system came to be used generally. After that its employment became practically universal and no difficulties or opposition were experienced.

In Norway the metric system was employed in the postal service, by the Act of May 3, 1871, and in the same year the gram was adopted as the unit of weight by the medical profession of that kingdom. In 1879, on July 1, the use of the metric system for all private business became optional, but from this date it was

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[1] See *Procès-verbaux du Comité international des Poids et Mesures*, Session 1897, p. 155.

to be used exclusively by the Government in all its transactions, such as the collection of customs duties, public accounts, taxes, etc. Then on July 1, 1882, the use of the metric system was made obligatory in all transactions, both public and private, and no other weight, measure, or coinage other than metric was permitted. It is interesting to note that during the three years of the transitional period the government altered certain of the older weights and measures, making them conform to the metric system. Thus all weights of one pound and over during the first two years were regulated and made over free of cost, so that the old Norwegian "skaal-pund" and the old "bismer-pund" used with the steelyards were slightly increased so as to weigh half-kilograms. Likewise the old "korn-tönde," or corn measure, was adjusted to hold 140 liters, and a half measure to hold 70 liters. In the third year of the change period, however, a fee was required for these alterations, and after the compulsory use of the new weights and measures they were absolutely prohibited.

In the case of Norway we have an approximate statement[1] of the cost of the introduction of the metric system as given in a statement of the value of instruments sold in the years 1877-84 by the Weights and Measures Office, but this does not of course include the private sale of metric weights and measures. In this connection it must be borne in mind that the population of Norway at this time was somewhat less than 2,000,000.[2] The statement is as follows:

Public expenses—	
Purchase of standards, weights and measures and apparatus - - - - - -	£2,844
Plans and drawings - - - - - -	217
Models - - - - - -	306
Controlling apparatus for town and country police - - - - - -	1,650
Adaptation of old instruments to the metric equivalents - - - - - -	3,111
	£8,128

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[1] *Reports from Her Majesty's Representatives in Europe on the Metric System*, part i., July, 1900, pp. 63, 64; *E.P.P.*, 1900, vol. xc.

[2] Dec. 31, 1882, 1,913,000.

Private expenses—	
Adaptation of old instruments to the metric equivalents - - - - -	£2,044
Purchase of new metric instruments - -	35,761
Total cost of introduction	£45,933

In Switzerland there was even more than the usual diversity of weights and measures in the different cantons, but after 1822 in some of these divisions a system based on the metric measures and having a foot of 30 centimeters and a pound of 500 grams was established. By an agreement known as the "Maass concordats," dated August 17, 1835, twelve cantons united in establishing this system, and by subsequent additions to the convention and by legislation it became operative throughout the nation, being by an Act of Dec. 24, 1851, the national and compulsory system throughout the confederation after December 31, 1856. In this system the legal unit of length was the *pied* or foot, equal to 30 centimeters, divided decimally, and having such multiples as the *brache,* 2 feet; the *aune,* 4 feet; the *toise,* 6 feet; the *perche,* 10 feet; and the *lieue,* 16,000 feet. The *livre* or pound equal to 500 grams could be divided either on a binary or a decimal system, while for dry capacity the unit established was the *quarteron,* equal to 15 liters, and for liquid capacity the *pot,* equal to one and a half liters. On July 3, 1875, the Federal Chamber passed a law providing that the complete metric system should be used after January 1, 1877, and that the standards then in course of preparation by the International Commission should be the legal and national standards. These international prototype standards were received in 1889, and were duly substituted for the older standards.

In Turkey, metrological, like other reforms, have not achieved the success deserved, largely on account of the character of the people and the Government. In 1886 a law was passed providing for the establishment of the metric weights and measures in Constantinople, and making their use compulsory after five years, and in 1891 ancient measures were confiscated and destroyed; but it has been recognized as practically impossible to enforce the system, and old and new units and standards have flourished side by side. In fact, experience demonstrates the strength of the proposition that weights and measures and their preservation intact and uniform are correlatives of government, and where the latter is weak or deficient in character, a satisfactory condition of these necessary adjuncts to commerce cannot be maintained. Nevertheless, in 1900, it was reported[1] that all scales imported into the Ottoman Empire must be marked in the metric system, and all weights and measures marked according to the old systems were liable to confiscation.

In England the need of an international and decimal system of weights and measures was realized as early[2] as 1783 by James Watt, who had considerable difficulty in reducing the weights and measures used by Lavoisier and Laplace in some experiment to the English weights and measures used by Kirwan in some similar work. Writing to the latter under date of November 14, 1783, he said:[3] "It is therefore a very desirable thing to have these difficulties removed, and to get all philosophers to use pounds divided in the same manner, and I flatter myself that may be accomplished, if you, Dr. Priestley, and a few of the French experimenters will agree to it; for the utility is so evident that every thinking person must immediately be convinced of it. My proposal is briefly this:

Let the philosophical pound consist of 10 ounces or 10,000 grains.
„ „ ounce „ „ 10 drachms or 1000 „
„ „ drachm „ „ 100 grains.

Let all elastic fluids be measured by the ounce measure of water, by which the valuation of different cubic inches will be avoided, and the common decimal tables of specific gravities will immediately give the weights of these elastic fluids." Farther on in the letter he says, "I have some hopes that the foot may be fixed by the pendulum, and a measure of water, and a pound derived from that; but in the interim let us at least assume a proper division which from the nature of it must be intelligible, as long as decimal arithmetic is used."

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[1] *Board of Trade Journal* (London, Feb. 22, 1900), vol. xxviii. p. 449.

[2] In 1620 Edmund Gunter had proposed a decimal measure for land with a surveyor's chains of 100 links.

[3] A. Siemens, *Journal Institution of Elect. Engineers of Great Britain*, vol. xxxii. pp. 278-9.

A few days later (Nov. 23, 1783), Watt wrote to M. de Luc calling attention to the difficulties of comparing the work of investigators in different countries on account of the diversity in weights, and also on account of " the absurd subdivisons used by all Europe," even if the weights were the same. He describes the plan outlined above, and suggests dividing the Paris pound into 1000 parts. M. de Luc was asked to communicate with Laplace on this subject, and three years later when Watt visited Paris he met Lavoisier, Laplace, Monge, and Berthollet, whom we have seen were deeply interested in the reform of weights and measures. It is fair to assume that the subject was discussed by Watt among them, and that they listened to the suggestions and ideas of the English engineer, and this view is strengthened by the provision inserted in the bill for the reform of the French weights and measures that the French Academy and the Royal Society appoint a joint committee to discuss universal weights and measures.[1]

England, however, declined to co-operate with the International Commission which examined the work of the French scientists on which the metric system was based, and this attitude, as well as a subsequent antipathy to the French system, was doubtles due to the national feeling towards France. Mention, however, should be made of the fact that in 1789 Sir John Riggs Miller called the attention of Parliament to reforms in weights and measures, moving for the appointment of a committee " to investigate and report on the best means for adopting an uniformity of weights and measures." He, too, had in mind the length of the second's pendulum as a basis of linear measure, and his plan was supported by the Rev. George Skene Keith, who further urged that any new system should be a decimal one. The desirability of a decimal system that should include not only weights and measures, but also coinage, began to be felt, and in 1814 Sir John Wrottesley brought such a scheme to the notice of Parliament. The result of the agitation was that in 1819 a commission which included Dr. Thomas Young, William H. Wollaston, and Captain Henry Kater reported adverse to the adoption of the decimal scale, but the cause continued to be

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[1] See M'Leod, "Notes on the History of the Metrical Measures and Weights," *Nature* (London, 1904), No. 1792, vol. lx. pp. 425-427.

argued, and at every discussion of changes in weights and measures, the metric system had its advocates in increasing numbers.

In 1816 a resolution was passed in Parliament providing for a comparison of the imperial standard yard with the French standard meter, this duty being assigned to the Royal Society. That body received from Paris two platinum meters which had been compared by Arago with the French standard. One was an end standard which was exactly equal to the meter at the temperature of melting ice, while the other was a line standard which at the same temperature was short by ·01759 mm. These meters were carefully compared by Captain Kater with the Shuckburgh scale, and when referred to the Parliamentary standard the true length of the meter was determined at 39·37079 British inches, a value which was legalized by Parliament in its Act of 1864 which permitted the use of the weights and measures of the metric system.

Meantime the scientists and others had called for reforms in the British system which would involve more than merely the construction of new standards. In considering this subject, and especially in its bearing on the adoption of a decimal system, a committee of the House of Commons, reporting in 1862, stated that "it would involve almost as much difficulty to create a special decimal system of our own, as simply to adopt the metric decimal system in common with other nations. And, if we did so create a national system we would, in all likelihood, have to change it again in a few years, as the commerce and intercourse between nations increased, into an international one." The scientific men, and those who had been careful observers at international expositions and conventions, were now making their influence felt, and in 1864 was passed the Act mentioned above, which allowed the use of the metric system of weights and measures. Not satisfied with this step, the metric advocates in 1868 proposed a bill making the system compulsory, but after a second reading it was dropped. In the meanwhile the Standards Commission, of which Sir G. B. Airy, the astronomer-royal, was chairman, carefully studied the subject of weights and measures for the kingdom, and their second report, dated April 3, 1869, is devoted to the metric system

The status of the metric system was defined in 1878 by the Weights and Measures Act, under the terms of which (clause 32) the Board of Trade was authorized " to verify metric weights and measures which are intended to be used for the purposes of science or of manufacture or for any lawful purpose, not being for the purpose of trade within the meaning of this Act."

The legislation of August 8, 1878, still left much to be desired, and in 1895, in response to demands for further action, a committee was appointed from the House of Commons to investigate the matter anew. This committee heard numerous witnesses and carefully considered their testimony, giving ample opportunity for both sides of the question to be discussed. In their report they recommended:

"(*a*) That the metric system of weights and measures be at once legalized for all purposes.

"(*b*) That after a lapse of two years the metric system be rendered compulsory by Act of Parliament.

"(*c*) That the metric system of weights and measures be taught in all public elementary schools as a necessary and integral part of arithmetic, and that decimals be introduced at an earlier period of the school curriculum than is the case at present."

Parliament acted on that portion of the report providing for the legalization of the metric weights and measures for all purposes, passing a bill to that end May 27, 1897, but hesitated when it came to making the system compulsory. On the following year in an Order in Council dated May 19, 1898, after an investigation by a committee of the Royal Society, the various units were defined and their legal equivalents in the customary weights and measures given. These differ by minute amounts from those of the United States.

In 1903 it seemed to the members of the Decimal Association, an influential organization which had been formed to further the adoption of the metric system and of a decimal system of coinage, that popular feeling in favor of radical reforms in the system of weights and measures was increasing, and that it was an opportune time to make another attempt. Accordingly Lord Belhaven and Stenton introduced such a bill, which was supported on its introduction by Lord Kelvin and later by Lords Rosebery, Spencer, and Tweedmouth, and after a third reading was passed and sent to the House of Commons, where, however, it was never brought up for passage.

This bill was endorsed by a large number of town, city, and county councils, and by over fifty chambers of commerce, including some of the most important in the kingdom. Furthermore, in addition to petitions from forty-two trades unions, representing some 300,000 members, received while the bill was in the House of Lords, there was a resolution unanimously passed by the Congress of Trades Unions meeting at Leeds in September, 1904, and representing some 5,000,000 workmen, in which it was resolved to petition the House of Commons in favor of the bill. There were also petitions from sixty Teachers' Associations, Inspectors of Weights and Measures in eighty districts, and thirty Retail Trades' Associations, besides numerous Chambers of Agriculture and Farmers' Associations. Thus it will be seen that the bill was supported by eminently practical people as well as scientists and theorists, and it is interesting to state that in Great Britain retail tradesmen and workmen have been alive to the many merits of the metric system.

The bill of 1904 provided for the establishment of the standard kilogram and meter from the first day of April, 1909, as the imperial standards of weight and of measure, though for sufficient cause this date could be postponed by an Order in Council. It also provided for Parliamentary copies of the substituted imperial standards, and that future deeds, contracts, etc., must be in terms of the metric system. The bill also made due provision for various adaptations made necessary by the change, and prescribed the general method in which it should be carried out.

In Australia an active demand was made for the introduction of the metric system, and in 1905 it was proposed to introduce into the Federation Parliament a bill with this object. In the same year the neighboring colony of New Zealand adopted the metric system as its legal system of weights and measures.

Great Britain, however, played an important part in the development of scientific measures, namely, in working out the C.G.S., or Centimeter-Gram-Second system, as was done by the British Association for the Advancement of Science. This system was based, as the name implies, on the metric units of length and mass, and has been of the greatest benefit to science, being universally adopted by physicists and engineers, and will be found discussed more at length farther on in this volume.[1]

In Mexico the Metric System came into effect on the first of January, 1862, in accordance with the terms of a law of March 15, 1857, and a second law of March 15, 1861, which provided for the exclusive use of the Metric Weights and Measures for all purposes. While the new system was adopted by the Government, yet private individuals did not take it up, and there was needed an imperial decree, issued in November, 1865, which declared the Metric System alone valid throughout the country. For a number of years the old and new measures were used side by side, and also, with the introduction of railways and of machinery for mining and other purposes from the United States, the English foot and pound; but gradually the Metric measures asserted their supremacy, and now they are almost exclusively used. Mexico became a party to the International Convention of Weights and Measures in 1890, and in 1896 it formally adopted the international standards for the meter and kilogram.

Throughout South and Central America the Metric System is largely employed, and in nearly all cases it is the legal system of the different countries. There has been, however, great difficulty in maintaining this system as the only one, since in numerous instances the people have preferred to use the older units derived from Spanish and other sources, while exporters doing business with Great Britain and the United States have made use of the Anglo-Saxon units. This, of course, is due in great part to the lack of stability of the South American governments, but conditions in this respect are improving, and the use of the metric weights and measures is now practically universal throughout South America. It was on this account that representatives of these countries assembled at the International American Conference at Washington in 1890 advocated the adoption by the United States of the Metric Weights and Measures. Beyond the dates of adoption, as given by the accompanying table, there is but little to say as regards the individual countries

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[1] See Chapter ix. p. 205.

While in the foregoing paragraphs an attempt has been made to summarize briefly when and how the metric system was adopted by the more important nations of the world, it is possible to obtain this information for the remaining countries of the world by reference to the accompanying tables, which indicate the time at which metric measures were first adopted, when made compulsory, and, so far as can be ascertained and briefly stated, the extent to which they have replaced other and older measures. These tables speak for themselves, and illustrate most forcibly the spread of the system. They are based on a somewhat similar table published as an Appendix, p. 67, of a Report from the Select Committee on the Weights and Measures (Metric System) Bill [H.L.], May 5, 1904, to be found among the Parliamentary Papers of that year, on the Reports of British Consular officials abroad, to which reference has already been made (see footnote, p. 91), and other official sources of information.

EUROPE.

	Date of First Introduction.	Period for Compulsory Adoption. (a) Nominal. (b) Actual.	REMARKS.
Austria, - -	1871	(*a*) 4 years (*b*) 4 years	No public objection to the introduction of the system. Use of old weights and measures due to laxity of municipal officials rather than prejudice.
Hungary, -	1876	(*a*) 6 months	Old measures survived for a time, and are occasionally in use in isolated districts. Metric system, broadly speaking, quickly became naturalized.
Belgium, -	1816	(*a*) 3½ years (*b*) 39 years	Original law not rigorously enforced. At present universal employment of metric system.
Bulgaria, -	1888	(*a*) 3 years	Old measures and weights not entirely supplanted.
Denmark, -	—	—	Metric system used in State Railway reports and in statistics.
France, - -	1793	(*a*) 1 year (*b*) 47 years	Original law not rigidly applied. In 1837 metric system made compulsory in two and a half years.
Germany, -	1868	(*a*) 3½ years	Old length and surface measures still found occasionally among the people. Otherwise use of metric system complete and general.
Greece, - -	1836	--	No compulsion, and used by the Government only for certain purposes. Not used by people or in commerce.
Italy, - -	Varied in different parts from 1845-1870	—	Old measures and weights still found in Southern Italy. In Northern Italy change was complete, and was welcomed by the people.
Luxemburg, -	1816	—	No serious difficulties experienced and many practical advantages realized. Through force of tradition and custom old weights and measures are occasionally used, but they are now practically obsolete.
Montenegro, -	1888	—	Slight difficulty in enforcing the introduction of the metric system, which is now used universally. The only other measure is the Turkish "*oka*," used by the people but not by the Government.

EUROPE (*Continued*).

	Date of First Introduction.	Period for Compulsory Adoption. (*a*) Nominal. (*b*) Actual.	REMARKS.
Netherlands, -	1816	(*a*) 3½ years	Some difficulty experienced in making the change, so that the complete assimilation of the metric system was gradual. Occasionally traces remain of the older weights and measures.
Portugal, -	1852	(*a*) 10 years (*b*) 19 years	Delay in introduction attributed to ignorance of the people. In provincial districts 75 per cent. of population still unable to read or write.
Russia, - -	1900 (optional)	—	Metric system used in the Customs' service, in pharmacy, and by the medical departments of the Army and Navy. In Finland it was made permissive in 1886 and compulsory in 1892.
Servia, - -	1873	(*a*) 6 years (*b*) 10 years	Metric system has proved satisfactory in practice, and has had a beneficial effect on trade with other countries.
Spain, - -	1849	(*a*) 3½ years (*b*) 19½ years	Passive resistance manifested at time of making change. Old measures still found in smaller towns, but not the weights.
Sweden, - -	1878	(*a*) 10 years	No great difficulty experienced in making the change.
Norway, -	1899	(*a*) 3 years	No great difficulty experienced in making the change, which was welcomed by the commercial interests and worked no appreciable hardship on the lower classes.
Switzerland, -	1875	(*a*) 1½ years	No great difficulty in the towns but less easy of introduction in the country.
Turkey, - -	1886	(*a*) 5 years in Constantinople	Despite confiscation, compulsory measures in Constantinople have resulted in a failure.

NORTH AND SOUTH AMERICA.

	Date of First Introduction.	Period for Compulsory Adoption. (*a*) Nominal. (*b*) Actual.	REMARKS.
Argentina,	1863 (optional) 1887 (compulsory)	(*a*) 10 years	Little difficulty encountered in introducing metric system, and only traces of old names and measures remain. Increased trade with France and Germany believed to have resulted.
Bolivia,	—	—	
Brazil,	1862	(*a*) 10 years (*b*) 12 years	No difficulty encountered in its introduction. System found to have facilitated commercial calculations.
Chile,	—	—	Use attended with considerable success and appreciated for facilitating commercial calculations.
Colombia,	1853	—	No difficulties encountered in use of system, which is used more generally each year. Law allows any measures to be used, so that the old Spanish weights and measures are still found.
Costa Rica,	1858	—	
Ecuador,	1856	(*a*) 10 years	Metric system used officially, but Spanish measures hold their ground and are employed almost entirely in commerce.
Guatemala,	1894	—	Used since 1894 for Customs' duties and (generally) in public documents, but not generally among the native tradespeople and Indians.
Mexico,	1862 (optional) 1895 (compulsory)	(*a*) 15 months	Introduction of metric system considered by Government an unqualified success, and trade and commerce have benefited. Old Mexican yard and pound still found, but these are diminishing.
Nicaragua,	—	—	
Paraguay,	—	—	

NORTH AND SOUTH AMERICA (*Continued*).

	Date of First Introduction.	Period for Compulsory Adoption. (*a*) Nominal. (*b*) Actual.	Remarks.
Peru, - -	1862	—	Slow progress at first. Not used even by Government. Recently increased use and required for all Government work. Old Spanish measures persist, and forty years has not made any visible alteration in common usage.
Uruguay, -	1862 (optional) 1894 (compulsory)	—	Law of 1894 very stringent, and metric measures and weights gradually supplant the older ones. Change considered beneficial.
Venezuela, -	1857	—	Metric system used seldom except officially. Local and ancient weights and measures, as well as Anglo-Saxon measures, are employed.
United States,	1866 (optional)	—	Metric system used in science and education, also in some modern technical processes and electrical work. Use increasing but not general.

ASIA AND AFRICA.

Japan, - -	1891	—	Metric system is legalized and official equivalents have been enacted. Japanese measures are the standard, and the metric system, while known, is not generally used.
Siam, - -	1889 for Pub. works 1892 for Railways	—	
Egypt, - -	1873 1892	—	Used officially and by engineers, architects and contractors, but most of the wholesale and retail trade employs old Egyptian weights and measures.
Tunis, - -	1895	—	

CHAPTER IV.

WEIGHTS AND MEASURES IN THE UNITED STATES.

In the early days of the American colonies the weights and measures, like the coinage, were based almost entirely on those of the mother country, and where statutes were enacted providing for standards, these were derived from the standards of the Exchequer of England. Inasmuch as that country was the chief source of supply as well as a market for merchandise, and the commercial dealings were very largely with its inhabitants, such a condition was most natural, and inasmuch as trade was not particularly extensive, such a system of weights and measures amply sufficed.[1] During the Revolution, however, it was realized that all possible means should be taken to secure uniformity in commercial practices, and the need of a single national system of money and weights and measures was early appreciated. In the Articles of Confederation adopted by the Continental Congress, November, 15, 1777, it was provided in section 4, article ix., that "The United States in Congress assembled shall also have the sole and exclusive right and power of regulating the alloy and value of coin struck by their own authority, or by that of the respective states; fixing the standard of weights and measures throughout the United States; . . ." By the Federal Constitution, Congress is explicitly given the power to fix the standard of weights and measures, the fifth paragraph of section 8 of article i. stating that the Congress shall have the power "to coin money,

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[1] See John Quincy Adams, "Report on Weights and Measures" (Washington, 1821), for summary of colonial, state, and territorial legislation, pp. 94-117.

regulate the value thereof and of foreign coins, and fix the standards of weights and measures." It is somewhat curious that the fixing of the standards of weights and measures is almost the only power expressly and specifically conferred on Congress which that body has refrained from exercising down to the present time, notwithstanding its constant and most active interest in the coinage of money, as evinced by a vast amount of discussion and legislation.

In the days before and during the Revolution the coinage of various nations as well as from different state mints passed in circulation, causing an inexpressible confusion of values and rates of exchange, and it was but natural that uniformity and simplicity should be desired. That this could best be attained by a decimal system was appreciated as early as 1782, when Robert Morris, the Superintendent of Finance, an office corresponding to that of the present Secretary of the Treasury, wrote to the President of Congress "that it was desirable that money should be increased in the decimal Ratio, because by that means all calculations of Interest, exchange, insurance, and the like are rendered much more simple and accurate, and, of course, more within the power of the great mass of people. Whenever such things require much labour, time, and reflection, the greater number who do not know, are made the dupes of the lesser number who do."[1] In accordance with the suggestions made, an elaborate report on the question of a system of currency for the United States was prepared by Thomas Jefferson, and on July 6, 1785, a decimal system of coinage was adopted.[2] In the following year, August 8, the complete system was duly determined, and the amounts, nomenclature, and value of the various coins fixed.[3] The success of the new currency was soon assured, and it received favorable commendation both at home and abroad.

The reasons influencing its adoption would seem to have demanded a similar system of weights and measures, and it is perfectly evident that clear thinkers like Morris and Jefferson

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[1] Watson, *History of American Coinage* (New York, 1899), p. 10, quoting from Wharton's *Diplomatic Correspondence*, vol. v. pp. 103-110.

[2] See Watson, p. 16; also MS. *Reports of Committee on Finance of the Continental Congress*, No. 26, pp. 537-560.

[3] *Journal of Congress*, vol. xxxviii. No. 1.

were alive to its advantages; but even at these early times, as well as subsequently, there was considerable disinclination on the part of Congress to take any measure looking toward the establishment or reform of these important adjuncts to commerce. In fact, while there have been numerous suggestions on the subject of weights and measures from Presidents in their messages, there has been comparatively little legislation, and more has been accomplished in the way of establishing and changing standards by Executive order than by direct legislation.

President Washington, however, early realized the importance of the matter, and in his first speech or message to Congress, delivered January, 8, 1790, he said, "Uniformity in the currency, weights, and measures of the United States is a subject of great importance, and will, I am persuaded, be duly attended to." Accordingly, the House of Representatives referred the matter to the consideration of the Secretary of State, Thomas Jefferson, and requested him to prepare a report dealing with the subject. Mr. Jefferson had been in Paris as Minister of the United States, and doubtless was well acquainted with the measures to reform the weights and measures of that country which had been and were then under discussion. For this reason, as well as on account of his connection with the establishment of the national currency on a decimal basis, his selection was most fortunate, and within a few months (July 4, 1790) a report was submitted containing two complete and distinct plans.[1] He suggested as the standard of linear measure a uniform cylindrical rod of iron of such length that in 45 degrees latitude at sea level and constant temperature it should perform its vibrations in small and equal arcs in one second of mean time. Such a rod would have a length of 58·72368 inches, corresponding to a length of a seconds' pendulum of 39·14912 inches. In one of the plans proposed he adapted the existing system to this standard, thus securing uniformity and stability, while in the other, which he considered available for future use, he proposed a new and strictly decimal system which was remarkably complete and comprehensive. Mr. Jefferson was convinced of the utility of the decimal system, and in his proposed scheme of weights and measures for the American people he aimed

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[1] See *The Works of Thomas Jefferson* (edited by H. A. Washington, New York, 1884), vol. vii. pp. 472-495.

to reduce "every branch to the same decimal ratio already established in their coins, and thus bringing the calculation of the principal affairs of life within the arithmetic of every man who can multiply and divide plain numbers." The success which has attended the decimal currency of the United States shows that Jefferson was wise in his plan for a similar division for weights and measures, and had his proposals been adopted much confusion and inconvenience would have been spared the people of the United States. Furthermore, but little difficulty would have attended its adoption, as the fundamental unit, the foot, differed but slightly from the foot then in use. This foot was derived by Jefferson by taking one-fifth of the length of the rod forming the second's pendulum and then employing multiples and sub-multiples in building up a series of measures of length. A table of these units would read as follows:[1]

10 points make 1 line.
10 lines make 1 inch.
10 inches make 1 foot.
10 feet make 1 decad.
10 decads make 1 rood.
10 roods make 1 furlong.
10 furlongs make 1 mile.

Naturally the squares and the cubes of these units formed the units for area and volume, while for capacity the cubic foot was selected forming the bushel, which was then divided and multiplied decimally to give other measures. Likewise the cubic foot of water, which weighed 100 pounds of 10 ounces each, gave the basis of the measures of weight, and these also were arranged decimally. Hardly too much in praise of this system of Jefferson's can be said, and its adoption by Congress would have exerted a wonderful effect on metrology, not only in the United States but also in the world at large. It will be remembered that at this very time France was constructing its metric system, while England, appreciating the confusion attending its complex and unwieldy system of measures, was in good temper for a change. Jefferson's system, although designed to have certain points of contact with the then existing system so as to make

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[1] *The Works of Thomas Jefferson* (New York, 1884), vol. vii. p. 488.

it easy of adoption, nevertheless was perfectly uniform and symmetrical, and while possibly less scientific and precise than the French system, yet it possessed all the characteristic features of convenience, symmetry, and completeness. Congress received this able report, but did not adopt either of Jefferson's suggestions, doubtless on account of the similar agitation for changes in weights and measures then taking place in France and England, and its desire to await their outcome.

The pressing need of some action for this country, nevertheless, was realized by the executive branch of the Government, and again in his annual message to Congress on October 25, 1791, President Washington reverted to the subject, stating that "A uniformity in the weights and measures of the country is among the important measures submitted to you by the Constitution; and, if it can be derived from a standard at once invariable and universal, must be no less honorable to the public councils than conducive to the public convenience."

A committee of the Senate appointed November 1, 1791, then took the matter under advisement, and on April 5, 1792, presented a report[1] favoring the adoption of Jefferson's decimal plan, and containing directions for the scientific construction of a standard of length which would be divided into five equal parts, each of which would correspond to a foot. The report also contained information relative to the measures for the survey of land, units of weights, etc. Several reports were submitted by this committee, and it was finally decided (1793) "that the Standards should be the mean of those found in the country." No legislative action was taken by the Senate, and for several years there is apparently no record of any great interest manifested in the subject by Congress. In the meantime France had adopted the Metric System with a hope that it would become universal, and on January 8, 1795, the President transmitted to Congress a communication[2] from the Minister of the French Republic, describing in detail the new system of weights and measures, the standards of length and weight, and the method of dividing the standards into decimal parts. A committee from the House of Representatives proceeded to study this plan, together with that of Jefferson,

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[1] *Journal of the Senate, Second Congress, First Session*, pp. 173, 174.

[2] *Executive Docs., Third Congress, Second Session.*

and reported in the following year; but their recommendations were of a general character, and involved experimental work by scientists, which was never authorized by Congress. It may be said in passing, Jefferson did not advocate the adoption of the French system, as he did not approve of the use of a fundamental unit derived from an arc of meridian in preference to the length of a seconds' pendulum.[1] As to his own plans, he was not a zealous advocate of either of the propositions he had advanced, and was willing to leave the entire matter to Congress.

The difficulties with France, the war with Great Britain, and the consideration of various matters, political and otherwise, left little time for Congress to act on matters of weights and measures, and accordingly there was no legislative action for a number of years. In the meantime the Coast and Geodetic Survey requiring some standard of length, imported from England, in 1814, an 82-inch brass bar scale made by Troughton of London. Thirty-six inches taken on this scale, between divisions 27 and 63, were adopted as the standard yard for the United States by the Treasury, and this distance was used by other departments.[2] The meter, however, was selected at the outset for actual surveying operations by the Coast and Geodetic Survey, and for this purpose has since been continuously employed in its various triangulations. The metric standards were a brass meter bar constructed in Paris by Lenoir in 1813 for Mr. Hassler, and one of the original secondary iron-bar standards constructed by the same maker for the French Metric Committee in 1799, and presented to Mr. Hassler by Tralles.[3] This latter standard was employed by the Coast Survey until the receipt of the international standards in 1890, and is now to be seen in the vault of the Bureau of

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[1] This is shown plainly in several of Jefferson's letters contained in the *Works of Thomas Jefferson* (New York, 1884), particularly those to William Short (vol. iii. p. 276), Dr. Robert Patterson (vol. vi. p. 11), and John Quincy Adams (vol. vii. p. 87).

[2] See F. R. Hassler, *Report on Weights and Measures*, Document 299, 22nd Congress, 1st Session, 1832, p. 40. Also *U.S. Coast and Geodetic Survey Report*, 1877; Appendix 12.

[3] See Hassler, *loc. cit.*, p. 75, for translation of Tralles' description of these standards. Also *Transactions of American Philosophical Soc.* (Phila., 1825), vol. ii. p. 252; and *Special Publication No. 4*, U.S. Coast and Geodetic Survey, p. 31 (Washington, 1900).

Standards at Washington. It is of rectangular cross section 9 mm. × 29 mm., and is, of course, an end standard.

Reforms in weights and measures were not proceeding any more satisfactorily abroad than in the United States. Great Britain had been unable "to reduce into any simple order the chaos of their weights and measures,"[1] as Jefferson wrote to Secretary of State Adams in 1817, while in France the Metric System was not securing the ready adoption that was desired. The countries conquered by Napoleon and compelled to adopt it, returned to their old ways once compulsion was removed; and even in France, as we have seen, there was considerable doubt as to the practical and ultimate success of the new system, while the decimal division of time and the decimal measurement of the circle had proved distinct failures. Therefore, it is not hard to explain the hesitation in the United States about adopting the French system. That some measures were needed we learn from the message of President Madison to Congress in 1816, when he said:

"Congress will call to mind that no adequate provision has yet been made for the uniformity of weights and measures contemplated by the Constitution. The great utility of a standard fixed in its nature, and founded on the easy rule of decimal proportions, is sufficiently obvious. It led the Government at an early stage to preparatory steps for introducing it, and a completion of the work will be a just title to the public gratitude."

Congress referred the matter to the Secretary of State, John Quincy Adams, and that official undertook a thorough analysis and study of the whole subject. To him Jefferson wrote in the letter already quoted:[2] "I sincerely wish you may be able to rally us to either standard, and to give us an unit, the aliquot part of something invariable which may be applied simply and conveniently to our measures, weights, and coins, and most especially that the decimal divisions may pervade the whole." Adams realized that the matter was one of extreme importance that could not be settled offhand, and on his own account examined the question in all its many aspects, his conclusions being given in a report[3] submitted on February 22, 1821, that has since been

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[1] *Works of Thomas Jefferson*, vol. vii. p. 89.

[2] *Ibid.*

[3] J. Q. Adams, *Report upon Weights and Measures*, Washington, 1821.

considered almost a classic in American metrology. While the Secretary of State was so engaged, a committee from the House of Representatives also considered the question of weights and measures, and, January 25, 1819, submitted a report virtually advising the adoption of the first plan proposed by Jefferson, and recommending that models of the yard, bushel, and pound, conforming to those in most common use, be made under the direction of a commission to be selected by the President, and which, if satisfactory to Congress, should be declared the standard weights and measures of the United States. Again, Congress failed to take action on this recommendation, and when, two years later, Secretary Adams submitted his report, in which he recommended that no present change in the weights and measures of the country be attempted, but that the standards should remain as they were, that body had no disposition to oppose his suggestions, and nothing was accomplished.

The report, however, is worth more than passing notice, for although Adams did not believe that the introduction of the Metric System into the United States at that time was practicable, nevertheless he was as alive to its symmetry, completeness, and general desirability, as he was to the many advantages attending the introduction of a universal system of weights and measures throughout the great countries of the world. While it is, of course, impossible to do justice to the completeness and philosophic treatment of the subject in this report by any summary or brief extracts, nevertheless a few passages will show how keen was Mr. Adams' understanding of the matter, and how well he appreciated the advantages of the French system. He said:[1] "This system approaches to the ideal perfection of uniformity applied to weights and measures, and whether destined to succeed or doomed to fail, will shed unfading glory upon the age in which it was conceived, and upon the nation by which its execution was attempted, and has in part been achieved. In the progress of its establishment there it has often been brought in conflict with the laws of physical and of moral nature, with the impenetrability of matter, and with the habits, passions, prejudices, and necessities of man. It has undergone various important modifications. It must undoubtedly submit to others

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[1] J. Q. Adams, *Report*, p. 48.

before it can look for universal adoption. But, if man upon earth be an improvable being; if that universal peace, which was the object of a Savior's mission, which is the desire of the philosopher, the longing of the philanthropist, the trembling hope of the Christian, is a blessing to which the futurity of mortal man has a claim of more than mortal promise; if the spirit of evil is, before the final consummation of things, to be cast down from his dominion over men, and bound in the chains of a thousand years, the foretaste here of man's eternal felicity, then this system of common instruments, to accomplish all the changes of social and friendly commerce, will furnish the links of sympathy between the inhabitants of the most distant regions; the meter will surround the globe in use as well as multiplied extention, and one language of weights and measures will be spoken from the equator to the poles."

As regards the metric or, as he terms it, the French system in the abstract or as an ideal system, no one could be more enthusiastic than Mr. Adams. He says:[1] "The single standard, proportional to the circumference of the earth; the singleness of the units for all the various modes of mensuration; the universal application to them of decimal arithmetic; the unbroken chain of connection between all weights, measures, moneys, and coins; and the precise, significant, short, and complete vocabulary of their denominations: altogether forming a system adapted equally to the use of all mankind; afford such a combination of the principle of uniformity for all the most important operations of the intercourse of human society; the establishment of such a system so obviously tends to that great result, the improvement of the physical, moral, and intellectual condition of man upon earth; that there can be neither doubt nor hesitancy in the opinion that the ultimate adoption and universal, though modified, application of that system is a consummation devoutly to be wished."

The strongest praise for the French system is for the time that it will save, and here Mr. Adams states,[2] "Considered merely as a labor-saving machine, it is a new power offered to man incomparably greater than that which he has acquired by the new agency which he has given to steam. It is in

[1] J. Q. Adams, *Report*, p. 90.

[2] *Ibid.*, p. 91.

design the greatest *invention* of human ingenuity since that of printing."

Mr. Adams, while he realized the desirability of universal measures, believed that they could only come "by consent and not by force," and mindful of the difficulties attending the introduction of the metric system in France, and of certain of its features being susceptible of further improvement, thought it to be the best policy for the United States first to confer with foreign nations as regards the future and ultimate establishment of universal and permanent uniformity, and, meanwhile, to secure for the weights and measures in use throughout the United States a more perfect uniformity by suitable legislation especially avoiding for the time being any innovations. The conclusion of the report is no less interesting than its other sections: It states,[1] "France first surveyed the subject of weights and measures in all its extent and all its compass. France first beheld it as involving the interests, the comforts, and the morals of all nations and of all after ages. In forming her system she acted as the representative of the whole human race, present and to come. She has established it by law within her own territories, and she has offered it as a benefaction to the acceptance of all other nations. That it is worthy of their acceptance is believed to be beyond question. But *opinion* is the queen of the world, and the final prevalence of this system beyond the boundaries of France's power must await the time when the example of its benefits, long and practically enjoyed, shall acquire that ascendancy over the opinions of other nations which gives motion to the springs and direction to the wheels of power."

It is doubtful if a stronger statement of the abstract merits of the metric system could be made than is contained in this report. Mr. Adams, however, was in error in believing that concerted action was necessary to secure the adoption of a universal system, as it has come about gradually, and has been adopted by the various nations of the world at such times as seemed to them suitable and convenient. Again, experience has shown the error of Mr. Adams' view on the decimal division of the United States coinage. He says (page 81), "The convenience of decimal

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[1] J. Q. Adams, *Report*, p. 135.

arithmetic is in its nature merely a convenience of calculation; it belongs essentially to the keeping of accounts; but it is merely an incident to the transactions of trade. It is applied, therefore, with unquestionable advantage to moneys of account, as we have done: yet even in our application of it to the coins, we have not only found it inadequate, but in some respects inconvenient."

This famous report has been quoted most extensively by writers on American metrology, and passages are cited with great enthusiasm by both metric and anti-metric advocates in support of their respective positions. While conceding its great breadth and philosophical character, yet at the present time it is worth considering whether too much stress has not been laid on this celebrated document. Although President Adams was a zealous student, errors of statement are to be noted, while at the same time advances in the science of metrology have made it necessary to look at certain matters in a new light.

There was at least one department of the U.S. Government—namely, the Mint—where any uncertainty of weight could not for obvious reasons be tolerated. Accordingly, Minister Gallatin was instructed to procure from England a copy of the imperial standard Troy pound which had been adopted in 1825. This he did, and the standard, after having been most carefully compared by Captain Kater, was transmitted to the United States, and by Act of Congress of May 19, 1828,[1] was duly established as the coinage standard of the United States, the Act being remarkable in that it is the only legislative Act legalizing any of the customary measures, and establishing a standard for such purpose. The Act provides, that "For the purpose of securing a due conformity in weight of the coins of the United States to the provisions of this title, the brass troy-pound weight procured by the minister of the United States at London, in the year eighteen hundred and twenty-seven, for the use of the Mint, and now in the custody of the Mint at Philadelphia, shall be the Standard troy pound of the Mint of the United States, conformably to which the coinage thereof shall be regulated."[2]

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[1] C. 131, Sec. 50, 17 statutes 432. Revised statutes 3548.

[2] A description of this standard, together with the various certificates of individuals concerned with its construction, testing, receipt, etc., including Captain Henry Kater, Minister Gallatin, and President John Quincy Adams,

On May 29, 1830, the Senate passed a resolution ordering the comparison of the standards of weights and measures used by the different custom-houses, and when these measures or copies were called in to the Treasury Department for examination, it was found that there was the greatest lack of uniformity throughout the various customs districts. In many cases the various state or local sealers of weights and measures were appealed to not only for purposes of comparison, but even for the correction of the standards.[1]

The resulting diversity of weights and measures naturally was not without its effect on the revenues of the Government, in addition to violating that section of the Constitution which provides that taxes shall be uniform throughout the United States. The national standards upon which the measurements made in the custom-houses were based are thus described in the following extract from the report of S. D. Ingham, Secretary of the Treasury, March 3, 1831:

"Among the instruments which had been procured, some years ago, under the direction of the President, for the survey of the coast, was a standard measure of length, exactly corresponding with the British Parliamentary standard, as established in 1758, with which that of 1760 is identical, as tested by Sir George Shuckburgh in 1798, and by Captain Kater in 1821, on the occasion of the last determination of the weights and measures in England, when it was adopted as the legal unit. This standard measure has, by means which will be explained in a future report, been compared with the pendulum vibrating seconds in London, and also with the French meter, which is based upon measurements of arcs of a meridian of the earth. With such evidence of its character, and such an opportunity of correcting any alteration by reason of decay, it was without hesitation, adopted as the unit for the comparison of measures of length.

"The troy pound used in the Mint is known to be identical with the latest established standard troy pound of Great Britain, as regulated by the British laws, and standarded by Captain

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will be found contained in an interesting history of the weights and measures of the United States, by O. H. Tittman, in the *United States Coast and Geodetic Survey Report* for 1890, Appendix 18, pp. 736-8.

[1] Hassler, p. 6 (House of Reps. Doc., No. 299, 22nd Congress, 1st Session).

Kater in 1824, having been constructed by him at the special request of Mr. Gallatin, upon the same principles and in the same manner that he had employed in the construction of the British standard."[1]

Preparations were duly made to construct from these standards the standards for the custom-houses, and on June 14, 1836, a joint resolution was adopted by both Houses of Congress providing that there should be constructed in the office of the Coast Survey for every state and territory, complete sets of standards equal to those made for the custom-houses, "to the end that a uniform standard of weights and measures may be established throughout the United States," and in July, 1838, it was ordered that balances for the accurate comparison of weights should be similarly constructed and distributed to the states and territories. The standard weights were given to the custom-houses in 1836, and in the following years the standard yards, which were based on the Troughton scale, and liquid measures were distributed. By 1856 the various states of the Union were supplied with sets of standards, and shortly after their receipt the individual states enacted statutes establishing them as the standards of weights and measures.[2] This work was important, as being the first practical and systematic attempt to secure general uniformity of weights and measures throughout the country, and as an early example of refined constructive scientific work being carried on by the national government for the benefit of the people at large in their commercial relations.

It should be said in passing that the early work of establishing the standards of weights and measures for the United States was done by Professor F. R. Hassler, the superintendent of the Coast Survey, from its inception to his death, and during these years many interesting reports dealing with the scientific and other features of the work were prepared by him.[3] To

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[1] Extract from the report of S. D. Ingham, Secretary of State, March 3, 1831, House of Representatives, Doc. No. 299, July 2, 1832, 22nd Congress, 1st Session.

[2] See *Laws Concerning the Weights and Measures of the United States*, an official compilation of the United States Bureau of Standards of legislation on this subject (Washington, 1904).

[3] See partial bibliography in House of Representatives, Report No. 3005, 56th Congress, 2nd Session.

Professor Hassler was due the derivation of the standard avoirdupois pound from the standard Troy pound, and so accurately was the work accomplished that when the British Government sent over in 1856 a copy of the standard avoirdupois pound, there was found a difference of ·001 of a grain between British and American standards. He also connected the units of capacity with those of weight, by using in his experiments, which were begun in 1830, distilled water at its temperature of maximum density, and thus was able to determine and construct accurate standards.

On the death of Mr. Hassler in 1843, Professor A. D. Bache became the head of the Coast Survey, and manifested considerable interest in the work of the Office of Weights and Measures, supervising the completion and distribution of the state standards begun by Mr. Hassler, and in his reports making recommendations looking towards the improvement of the United States system of weights and measures, and also the establishment of a universal system.

With the distribution of the standard weights and measures, there resulted the natural inquiries as to their origin and value, and the legal enactments upon which they were founded. Professor Bache in his report for 1848[1] summarizes the essential facts relating to them. The actual standard of length is the 82-inch Troughton scale (which has been already described); "the units of capacity measure are the gallon for liquid and the bushel for dry measure. The gallon is a vessel containing 58,372·2 grains (8·3389 pounds avoirdupois) of the standard pound of distilled water, at the temperature of maximum density of water, the vessel being weighed in air in which the barometer is 30 inches at 62° Fahrenheit. The bushel is a measure containing 543,391·89 standard grains (77·6274 pounds avoirdupois) of distilled water at the temperature of maximum density of water, and barometer 30 inches at 62° Fahrenheit." The gallon is thus the wine gallon of 231 cubic inches nearly, and the bushel the Winchester bushel nearly. The temperature of maximum density of water was determined by Mr. Hassler to be 39·85° Fahrenheit. The standard of weight is the Troy pound copied by Captain Kater in 1827 from the imperial Troy

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[1] 30th Congress, 1st Session, Senate Executive Doc. 73 (1848), p. 8.

pound for the United States Mint, and preserved in that establishment. The avoirdupois pound is derived from this: its weight being greater than that of the Troy pound, in the proportion of 7000 to 5760; that is, the avoirdupois pound is equivalent in weight to 7000 grains Troy. The multiples, as well as subdivisions of the pound, are based upon this standard, the weight of which was determined by the best means attainable at that time, in grain weights, by Troughton, at the Mint, and at the Office of Weights and Measures, in presence of Mr. Hassler, and of the Director of the Mint, Dr. Moore. From these determinations resulted the pound weights of the Office of Weights and Measures, which are therefore copies of the Troy pound of the United States Mint or derived from it. The pound is a standard at 30 inches of the barometer and 62° Fahrenheit thermometer. The Troy pound of the Mint was found, in the comparisons of Captain Kater, to be heavier than the imperial Troy pound by only ·0012 of a grain.

"The measures of length and capacity, and the weights just referred to, have been adopted by the Treasury Department as standards for the measures and weights of the custom houses of the United States, and reported as such to Congress in 1832. . ."

That the system was then unsatisfactory in many respects we have abundant testimony. The simplification of the existing weights and measures, and the issuing of correct standards had been provided for as Adams had suggested, but nothing had been done to improve the system or towards co-operating with foreign nations in establishing a universal system, as Adams had also suggested. On the conditions as they then existed Professor Bache's observations are of interest. In a report made in 1848 he says:[1]

"No one who has discussed the subject of weights and measures in our country has considered the present arrangement as an enduring one. It has grown up with the growth of European society, and is deficient in simplicity and in system. The labor which is expended in mastering the complex denominations of weights and measures is labor lost. Every purpose for which weights and measures are employed can be answered by a simple and connected arrangement."

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[1] *Executive Document* 84, Thirteenth Congress, 1st Session, July 30, 1848.

Professor Bache believed that inasmuch as it was the practically universal opinion of all who had studied and written on American weights and measures that the system then in use must be considered temporary, and eventually be replaced by a more convenient and systematic arrangement, and wrote in reference to Adams' plan for an international conference on the subject as follows: "The present time seems especially to invite an effort of this kind. In England the subject of weights and measures is under consideration by a commission; and on the Continent the new relations of states hitherto separated appears to be favorable to this object. Such changes can be readily effected by suitable means in one generation, by introducing the new measures through the elementary schools." In a subsequent report Professor Bache asks, "Has not the time arrived, in the general progress of commercial and international intercourse, and the rapid advance of our own country in science, wealth, and power, when her voice should be heard in an important matter like this? Should not Congress make the proposition to all nations, to meet, by their representatives, and consult for the purpose of establishing uniformity of weights and measures? Such action could not fail to meet with a response due to the greatness of the subject, and if the great object be attained, to lead to results productive of vast and lasting benefit to the human race."

While it is quite natural that opinions in favor of the adoption of the metric system should be given by officials of the bureau of weights and measures, and by Secretaries of the Treasury, it is possible to recognize the beginning of a distinct general feeling and movement in favor of reforms in American weights and measures. This may be traced largely to the increasing numbers of scientific and professional men who were sent to Europe for education, and, who having used the metric system in the schools and laboratories of France and Germany, became enthusiastic advocates of the system, with the result that on their return to the United States they adopted it for their own scientific work, and taught it to their students. In chemistry especially its pre-eminence was early recognized, and American chemists soon fell in with the universal system which by this time was employed in all the European journals and standard works.[1] American diplomats and representatives to various international conferences also became convinced of the desirability of a uniform system of weights and measures, and their influence was also exerted in stimulating a feeling in favor of reforms.

In February, 1854, the American Geographical and Statistical Society, of which George Bancroft, the historian and Minister to Spain, was then president, presented a memorial to Congress in which the appointment of a joint scientific commission to consider a uniform system of weights and measures based on a decimal system was urged. This was one of the earliest of a number of similar resolutions which have since been addressed to Congress. Of more importance, however, as coming from the people at large rather than from scientific bodies, were the resolutions adopted by the legislatures of various States. The legislature of New Hampshire, by joint resolution approved on June 28, 1859, requested their senators and representatives to urge upon Congress the adoption of a decimal system, while the legislature of Maine, March 20, 1860, by joint resolution, expressed in still more decided language, their desire for a uniform international system of weights, measures, and coins. This action was soon followed by a similar resolution by the legislature of the State of Connecticut, which in June, 1864, took an important step in recommending to the proper school officers, that they should provide for the teaching of the metric system in all the schools of the State. From this time interest in the metric system in connection with the study of the arithmetic in the schools increased, so that the pupils within a few years became aware of the existence of the system, although often in the method of presentation of the subject in text-books, and by teachers there was little to commend it to the young mind. The problems were usually those involving conversion from the common system to the metric, and as such, were not likely to inspire any great degree of appreciation for the latter.

The Civil War so occupied the legislative and executive departments of the Government that there was little opportunity

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[1] The use of the metric measures in American College text-books, in physics and chemistry, dates from 1868-1870. In similar works for high schools the new system was used from 1878. R. P. Williams before Am. Chem. Soc., June, 1900.

for any marked progress on the part of Congress or the officials. The condition of affairs is stated by Salmon P. Chase, Secretary of the Treasury, in his annual report December 9, 1861, where he writes: "The Secretary desires to avail himself of this opportunity to invite the attention of Congress to the importance of a uniform system and a uniform nomenclature of weights and measures, and coins to the commerce of the world in which the United States already so largely shares. The wisest of our statesmen have regarded the attainment of this end so desirable in itself as by no means impossible. The combination of the decimal system with appropriate denominations in a scheme of weights, measures, and coins for the international uses of commerce, leaving, if need be, the separate systems of nations untouched, is certainly not beyond the reach of the daring genius and patient endeavor which gave the steam engine and the telegraph to the service of mankind. The Secretary respectfully suggests the expediency of a small appropriation to be used in promoting interchange of opinions between intelligent persons of our own and foreign countries on this subject."

In 1863 the United States was represented abroad at two important international congresses, both of which took action on the matter of weights and measures which commended itself to the American delegates. At the International Statistical Congress held at Berlin, a committee appointed at the Paris meeting three years previously, to consider the question of uniform international weights, presented a report in which the subject was carefully considered and as a result of which the Congress resolved that the same measures for international commerce was of the highest importance, and that the metric system was the most convenient of all that could be recommended for international measures.[1] At a previous session this body had recommended that the countries which employed weights and measures other than the metric should give in adjoining columns the metric equivalents of all statistics.

The other international congress referred to was a postal congress held at Paris in May, 1863, and which resulted in important measures towards securing uniformity of weights

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[1] Samuel B. Ruggles, *Report on International Statistical Congress at Berlin in respect to Uniform Weights, Measures, and Coins* (Albany, 1864), pp. 43, 44.

throughout the world. It was here recommended, that, "Sec. 7. The rates upon international correspondence shall be established according to the same scale of weight in all countries," that "Sec. 8. The metrical system, being that which best satisfies the demands of the postal service, should be adopted for international postal relations, to the exclusion of every other system"; and that "Sec. 9. The single rate upon international letters shall be applied to each standard weight of 15 grams or fractional part of it." This proposition proved satisfactory to the various nations and accordingly was incorporated in the International Postal Convention.

In 1866, when the resolutions authorizing the use of the metric system of weights and measures was passed by the Congress of the United States, which is referred to at more length below, an Act was also passed enabling the Post Office Department to use the metric weights and measures for foreign and other purposes, and the law was re-enacted in 1872 and now reads (*Revised Statutes of the United States*, Sec. 3880), "The Postmaster-General shall furnish the post-offices exchanging mails with foreign countries, and to such other offices as he may deem expedient, postal balances denoted in grams of the metric system, fifteen grams of which shall be the equivalent for postal purposes of one half ounce avoirdupois, and so on in progression." The interchange of mail by all the civilized countries of the world represents the most extensive use of a uniform system of weights and measures in the world and has been carried on for many years without the slightest confusion or embarrassment. All mail matter transported between the United States and the fifty or more nations, signatories of the International Postal Convention, including the United States and Great Britain even, is weighed and paid for entirely by metric weight.

The serious consideration of the metric system in the United States by the people at large may be said to date from 1866 when Congress passed a Bill which was approved by the President authorizing the use of the metric system of weights and measures. In this action Congress had the advice of the National Academy of Science, which had appointed in 1863, at the request of the Secretary of the Treasury, a special committee to consider the matter. In its report, which was adopted by the Academy, occurs the following passage, which seems to sum up the situation: "The committee are in favor of adopting, ultimately, a decimal system: and in their opinion, the metrical system of weights and measures, though not without defects, is, all things considered, the best in use. The committee therefore suggest that the Academy recommend to Congress to authorize and encourage by law the introduction and use of the metrical system of weights and measures, and that, with a view to familiarize the people with the system, the Academy recommend that provision be made by law for the immediate manufacture and distribution to the custom-houses and States, of metrical standards of weights and measures: to introduce the system into the post-offices by making a single letter weigh 15 grammes instead of $14\frac{17}{100}$, or half an ounce: and to cause the new cent and two cent pieces to be so coined that they shall weigh respectively 5 and 10 grammes, and that their diameters shall be made to bear a determinate and simple ratio to the metrical unit of length."[1] Accordingly, by the law of May 16, 1866, the weight of the 5 cent copper nickel piece was fixed at 5 grams. This idea was extended to the silver coinage, and by the law of Feb. 12, 1873 (*Revised Statutes of the United States*, Sec. 3513), it was provided that "The weight of the half dollar shall be twelve grams and one-half of a gram; the quarter dollar and the dime shall be, respectively, one-half and one-fifth of the weight of said half dollar." The Act passed by Congress (*Revised Statutes of the United States*, Sec. 3569) on July 28, 1866, making the metric system permissive, provided that "it shall be lawful throughout the United States of America to employ the weights and measures of the metric system, and no contract or dealing, or pleading in any court, shall be deemed invalid or liable to objection because the weights and measures expressed or referred to therein are weights or measures of the metric system." The Act further provided a series of legal tables of equivalents, and upon them are based in the United States all conversions from one system

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[1] *House of Representatives, Report of the Committee on Coinage, Weights, and Measures*, 46th Congress, 1st Session, Report No. 14, p. 23, part i.

to the other, as, for example, those contained in the tables in the Appendix of this book. To further the use of the metric system Congress passed an Act, approved July 27, 1866, authorizing and directing the Secretary of the Treasury to furnish to each State one set of the standard weights and measures of the metric system. With this start the metric system has grown in the United States, and various measures looking towards its final adoption have been urged in Congress and among the people generally.

The delegates to the Paris Exposition of 1867 were particularly enthusiastic in this respect, and among them Professor F. A. P. Barnard, President of Columbia College, who, with a number of other advocates of reforms in weights and measures, formed December 30, 1873, the American Metrological Society, and was its president until his death in 1889.[1] This society, while interested in such kindred subjects as the adoption of standard time and international currency, carried on an active propaganda in behalf of the metric system, while the Metric Bureau which was organized July, 1876, with headquarters in Boston, supplied material both in the way of literature and actual weights and measures, charts, tables, etc., that was of the greatest assistance to the general public, especially teachers, who were now called upon in many States to explain and teach the principles of the system.

Sufficient interest was manifested in the subject for the United States Government to accept the invitation of the Government of France to send delegates to Paris to form an international commission to construct new metric standards. America was accordingly represented by Professor Joseph Henry and J. E. Hilgard, the latter being an active member of various important committees concerned with the construction of the standards. When this commission, after reassembling in 1872, decided that an International Bureau of Weights and Measures should be established in Paris, the plan had the approval of the delegates of this country and of the American scientific world generally, the National Academy of Sciences formally favoring the scheme and recommending to the Government the signing of such a treaty. The work of the Commission has already been

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[1] See *Proceedings, American Metrological Society*, 1873-1888 (New York).

discussed,[1] and in this connection it is necessary merely to record the fact that when the American Minister to France, Mr. E. B. Washburne, signed the convention, together with delegates from sixteen other nations, agreeing to establish and support the International Bureau of Weights and Measures, the United States became committed to the principle of international weights and measures, and privileged to participate in the benefits accruing from a common system and common standards.

In 1889, after accurate and careful construction and adjustment and comparison, the international prototype standards of the standard meter and kilogram were completed by the bureau, and were distributed to the various countries supporting the Commission. In a distribution by lot, the United States received meters Nos. 21 and 27, and kilograms Nos. 4 and 20. The seals of meter No. 27 and kilogram No. 20 were broken by President Benjamin Harrison on January 2, 1890, and they were straightway deposited in a fireproof room at the Office of Weights and Measures in the Coast Survey Building.[2] These standards were immediately adopted as the national prototype meter and kilogram, and the primary standards for the United States, and were employed as fundamental standards for deriving customary units, the yard and the pound, as well as for constructing and standardizing secondary metric standards. To obviate any possible misunderstanding, however, a formal order, approved by the Secretary of the Treasury, was issued on April 5, 1893, recognizing "the International Prototype Meter and Kilogram as fundamental standards, and the customary units, the yard and the pound, will be derived therefrom in accordance with the Act of July 28, 1866."[3]

Here, again, we find a matter of fundamental importance settled by Executive order, and the United States firmly committed to the metric system as the basis of all measures in use,

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[1] See pp. 72-77. For text of treaty, diplomatic correspondence, reports, etc., see chapters ii. and iv., Report No. 14, 46th Congress, 1st Session, *House of Representatives, Committee on Coinage, Weights, and Measures* (Washington, 1879).

[2] For technical description of the standards, certificates, reports, etc., consult *Report U.S. Coast and Geodetic Survey*, 1890, Appendix 18, pp. 746-758.

[3] Bulletin No. 26, *U.S. Coast and Geodetic Survey*, "Fundamental Standards of Length and Mass." Republished as Appendix No. 6, 1893, *U.S. Coast and Geodetic Survey Report.*

no matter what their source. So far as fundamental standards go, the only ones used by the United States are metric and international, and to them must be referred all measures, whatever their nature. These standards are known in their relation to the standards of the International Bureau at Sèvres, and to those of the various foreign countries, so that in case of their destruction they could readily be reproduced, thus guaranteeing the permanency of weights and measures founded upon them.

In fact, meter No. 27 was transported to Paris in 1904 for comparison with the standards of the International Bureau, and after several series of careful observations its value was redetermined in terms of the international standard prototype. It was found that No. 27 at 0° centigrade was too short by 2 microns, a discrepancy greater by ·55 microns than that obtained in 1888, when it was tested with the other national prototypes. This change, however, was so minute that the U.S. Bureau of Standards decided to employ the old value in all of its determinations until an opportunity had been given to compare standard No. 27 directly with the international prototype meter and with other national prototypes. Inasmuch as the relation of No. 27 to No. 21 is accurately known, as also are the values of various secondary standards in terms of both national standards, it will be seen that the Bureau of Standards is now in a position to guarantee the accuracy and permanency of the measures of the United States.[1]

That progress was being made in the use of the metric system is shown by the fact that when Congress, on March 3, 1893, passed an Act[2] establishing a standard scale for the measurement of sheet and plate iron and steel, it was expressed in terms of both the customary and metric measures. Of perhaps greater importance was the Act approved July 12, 1894 (*Revised Statutes of the United States, Supplement*, vol. ii. chap. 131, 1894), which defined and established the units of electrical measure. These were the international electrical units based on

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[1] See L. A. Fischer, "Recomparison of the United States Prototype Meter," *Bulletin of the Bureau of Standards* (Washington), pp. 5-19, No. 1, vol. i. 1904. The discrepancy mentioned has since been accounted for through a small error in the coefficient of expansion of No. 27, which was compared at different temperatures in 1888 and 1904.

[2] *Revised Statutes*, 3570, c. 231, Sec. 1, 27 Statute, 746.

the metric system which were in use by electrical engineers throughout the world, having been definitely settled at a congress held at Chicago in 1893.[1]

In 1901 the National Bureau of Standards was established by Act of Congress to take over the duties of the old Office of Weights and Measures of the Coast and Geodetic Survey, and to have somewhat broader functions, especially in carrying on standardization and other scientific work of general public advantage. To this bureau was assigned the custody of the national standards and the construction and comparison of secondary and other standards of weights and measures of all kinds. In the event of the adoption of the metric system, it would fall to this bureau to oversee the construction and certify to the correctness of the many new standards that would be required in science, commerce, and the arts. This it is well equipped to do, and has large laboratories with every facility for such work.

When new territories were added to the United States as a result of the Spanish war in 1898, it was found that the metric system of weights and measures was employed in both Porto Rico and the Philippine Islands, and the status of the system in these possessions was duly confirmed. In the proclamation of the Military Governor of Porto Rico, March 18, 1899, it was stated, "1. The use of the metrical system of weights and measures and its nomenclature are obligatory. 2. Its use is enforced in all transactions, sales, contracts, . . . 3. Wholesale and retail mercantile establishments shall sell their goods to the public conformably to the metric system." The Political Code of Porto Rico (1902), sections 230-246, definitely fixes the metric systems and gives the legal definitions. The Philippine Tariff Act (No. 230, September 17, 1901, sec. 9) contained a provision that "The metrical system of weights and measures as authorized by sections 3569 and 3570 of the Revised Statutes of the United States, and at present in use in the Philippine Islands, shall be continued." In the Government Bill of 1902 it was provided that "Sections (of the former[2] Act) are hereby amended by reducing all measurements therein, whether of distance, area, or value, to the metric system."

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[1] See p. 208, chap. ix.

[2] Philippine Government Act of 1902.

Since the first permissive legislation in 1866 there have been various Bills introduced into Congress to establish the metric system, and each successive one has come before Congress with stronger support, and likewise with stronger opposition on the part of those opposed to any change. The matter of weights and measures has been investigated most carefully by various House Committees on Coinage, Weights, and Measures, and their reports are replete with information on the subject treated from different standpoints. In 1896 two interesting reports[1] were prepared after the committee had made a careful consideration of the subject extending over two sessions, and a Bill to establish the metric system was unanimously recommended for adoption, but, however, did not pass a third reading. Again in 1901 a somewhat similar Bill was reported from the Committee, accompanied by a brief report[2] in which its passage was recommended, but unfortunately this Bill was received too late to be considered by the Congress then in session. Once more, in 1902 and 1903, the subject was discussed in committee and numerous hearings were held, the record of which was embodied in an interesting report[3] in which the establishing of the metric weights and measures as the legal standards of the United States was recommended.

The general tendency of all these Bills was the same. It was proposed that within a few months after their passage, usually at the commencement of the next calendar year, that the national Government in all its business relations, as well as in all its constructive work, should adopt the metric weights and measures exclusively, while for the public at large two or three years should elapse, after which they would become the legal system of the country. It was not proposed to resort to compulsory measures, but to so establish the new system that it would gradually extend into universal use. In the Littauer Bill introduced in 1905 it was provided only that the metric system should be employed by the Government in all its transactions and activities.

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[1] *H.R. Report* No. 795, and *H.R. Report* No. 2885, February 10, 1897, 54th Congress.

[2] *H.R. Report* No. 3005, 56th Congress, 2nd Session, March 1, 1901.

[3] *H.R. Report* No. 1701, 57th Congress, 1st Session, April 21, 1902.

Secretaries of State and Treasury, irrespective of political party, as well as other executive officers of the Government, have urged the adoption of the international system, and diplomats and consuls have repeatedly called attention to the benefits to commerce that would ensue. Scientific men and educators have unanimously urged the desirability of the change, as have many engaged in foreign commerce. Against any innovation at the present time are many manufacturers and mechanical engineers, many of whom have secured in their work a considerable accuracy of construction, especially as regards patterns based on the English measures, which they assert could only be abandoned at an expense entirely incommensurate with any possible benefit.[1] At Congressional hearings, in the scientific press, and at meetings and conventions, the question has been thoroughly debated by those interested, and the material for information is most ample. It is now, however, a matter for the American nation at large, and when the people are thoroughly convinced of the great benefits that will ensue, there will be no outcry against temporary inconvenience. The adoption of the metric system is surely in the line of progress, and when once it is realized, the United States, with its superior school system and general high order of intelligence possessed by its people, especially its workers, can make the change with a minimum of embarrassment and can avail themselves of its benefits more quickly than has been done in the past by European nations.

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[1] This point of view will be found strongly represented in Halsey and Dale, *The Metric Fallacy*, New York, 1903, one of the ablest of the anti-metric books, and one that attracted considerable attention at the time of its publication on account of the bitterness of its attacks on the metric system and its advocates. It furnished material for many reviews and discussions in the technical press, both favorable and hostile. Of the latter possibly the most interesting and able were those in the *Electrical World and Engineer* (New York), vol. xliv. No. 19, pp. 784-794, Nov. 5, 1904, and in *The Physical Review* (Ithaca), 1904.

A somewhat more scholarly, though less argumentative paper from a similar point of view, by George W. Colles, entitled "The Metric *versus* the Duodecimal System," will be found in the *Transactions of the American Society of Mechanical Engineers*, vol. xviii. pp. 492-611, 1896-1897. See also a paper by J. H. Linnard, "The Metric System in Shipbuilding," *Transactions of the Society of Naval Architects and Marine Engineers* (New York, 1903), vol. ii. pp. 168-188.

CHAPTER V.

THE METRIC SYSTEM OF TO-DAY—ITS ESSENTIAL CHARACTERISTICS AND FUNDAMENTAL PRINCIPLES.

THE metric system to-day represents a complete, uniform, and simple international system of weights and measures, and as such may be considered briefly in its entirety, and with a view of the relation of the various units to one another. In the beginning it must be understood that any particular metric unit as such does not possess any intrinsic superiority over other units, but by reason of being united into a system which is strictly symmetrical and systematized on one base ratio throughout, and with that base ratio 10, metric units have many and preponderating advantages over those of other systems. Nevertheless, bearing in mind the two conditions mentioned, which are fundamental, there is nothing to prevent other systems being constructed with other units which would no doubt be equally satisfactory. But in reply it may be said, Why should this be done, when a system exists, used not only by men of science generally but by a large part of the civilized world, the abandonment of which would surely accomplish no particular purpose. "For," says Professor R. H. Smith,[1] "no other can possibly be better in practical essentials except in substituting for ten the base twelve or thirty for measures and written numeration alike, and this latter is humanly impossible."

For ordinary purposes of simple measurement, units are grouped into five different classes, those pertaining to measures of

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[1] Professor R. H. Smith in *Journal of Institution of Electrical Engineers*, quoted by A. Siemens in *Proceedings*, *Royal Statistical Society* (London), p. 693, vol. lxvi. 1903.

length, surface, volume, capacity, and weight, or, as regards the last, speaking more exactly and scientifically, mass. These all depend upon the meter as the fundamental unit, and as a primary and essential condition of the system, all must bear a strictly decimal relation to each other. Inasmuch as in the metric system all are referred to one primary standard, the Meter, there must be necessarily absolute uniformity, and as means have been taken to preserve this standard from any deterioration due to time or other causes, there is every guarantee of the stability of the system and of its standards. Furthermore, what was once deemed desirable but found to be impossible of realization, namely, the definition of a standard by some object or circumstance in nature, has been accomplished, and to-day we have the meter precisely defined in terms of the wave-length of cadmium light by a method which is described elsewhere.[1] Thus in the event of the loss or the destruction of the International Prototype Meter or of the copies thereof, it would be possible to reproduce the exact length by experiments that to the practised physicist involve no serious difficulty.

With the fundamental unit, the International Prototype Meter, defined as the distance between two fine lines on a particular platinum-iridium bar, at the temperature of melting ice, and reproduced by national standards accurately copied therefrom and duly recognized by the laws of the countries owning them, by simply multiplying by ten successively or by a similar simple process of decimal subdivision, is built up a system of measures of length which have been demonstrated as sufficient for the needs of science, commerce, and industry. Each unit is either ten, one hundred, one thousand, ten thousand, or a million times as great as the fundamental unit of length, the meter, or a similar fraction or sub-fraction. This relation for many purposes it is convenient to express by means of the number 10 and the appropriate exponent or index, and then speak of a certain number of meters multiplied by 10, 10^2, 10^3, 10^4, 10^6, or for the sub-multiples 10^{-1}, 10^{-2}, 10^{-3}, etc. Consequently, in a number expressing a length in a metric unit, it is possible to change the unit merely by moving the decimal point or adding a requisite number of zeros to correspond with the necessary decimal multi-

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[1] See chapter x. pp. 261-266.

plication or division. Thus, as will be seen from the following table, 1 kilometer may be written as 1000 meters simply by adding three zeros to the 1, while 1 decimeter may be expressed in terms of the meter simply by moving the decimal point one place to the left. Taking fundamental units other than those of length, which, however, are derived from the meter, a similar method of decimal multiplication and subdivision enables us to derive complete sets of units for surface, volume, capacity, and mass measurements. For the first two we use the square meter and the cubic meter as the fundamental units, and for capacity the liter, and for mass the gram.

For the multiples of its principal units the metric system employs prefixes derived from the Greek as follows:

Deca	meaning	10 times	derived from	Greek	δέκα = 10
Hecto	„	100	„	„	ἑκατόν = 100
Kilo	„	1000	„	„	χίλια = 1000
Myria	„	10000	„	„	μύρια = 10000

Similarly, prefixes derived from the Latin are employed for the submultiples of the various units. These are as follows:

Deci	meaning	$\frac{1}{10}$	derived from	Latin	decem = 10
Centi	„	$\frac{1}{100}$	„	„	centum = 100
Milli	„	$\frac{1}{1000}$	„	„	mille = 1000

These seven prefixes always used in the same relation supply the means of obtaining units of a size convenient for the work in hand, and alway instantly available for conversion into units of another denomination. To facilitate remembering the fact that the Greek prefixes indicate multiples, and the Latin the submultiples, one has merely to think of the word "Gild," and understand that it stands for the initials of the motto, "Greek increases, Latin decreases." With the three primary units, involving the three names meter, liter, and gram, and the two more arbitrary units *are* and *stere*, together with the seven prefixes given above, it is possible to construct all the metric units in ordinary use, inasmuch as their relation to each other is perfectly uniform and simple.

Metric Measures of Length.

Unit.	Abbreviation.	Where Employed.	Value in Terms of Meter.	Power of 10.
Megameter,		Astronomy	1,000,000m.	10^{6}m.
Myriameter,	Mm.	Geography	10,000m.	10^{4}m.
Kilometer,	Km.	Distance	1,000m.	10^{3}m.
Hectometer,	Hm.	Artillery	100m.	10^{2}m.
Decameter,	Dm.	Surveying	10m.	10m.
Meter,	m.		1m.	
Decimeter,	dm.	Commerce	·1m.	10^{-1}m.
Centimeter,	cm.	Industry	·01m.	10^{-2}m.
Millimeter,	mm.	Science	·001m.	10^{-3}m.
Micron $=\mu$,		Metrology	·000,001m.	10^{-6}m.
Millimicron,		Spectroscopy	·000,000,001m.	10^{-9}m.
		Microscopy		

While the foregoing represent the various units of length in the metric system, and indicate the principal departments of knowledge in which they are used, it does not follow that all of them are used, or that a given length is expressed in terms of more than one. For example, a distance is not expressed as 34 kilometers, 9 hectometers, 3 decameters, and 4 meters, but as 34·934 kilometers, and all measures of length, where it is desirable to use kilometers, are expressed in that unit and a decimal fraction. Thus, for each class of measurements, as a general rule, there is used but one of the above units, as will be discussed below, and any measurement is expressed in whole numbers and decimal fractions. Each of the above units is well suited for a number of varieties of measurements, and a few of these may be conveniently outlined. The megameter, which has not received legal sanction, is but rarely encountered, and then only in astronomical work where distances of considerable magnitude are discussed. As it appears only in calculations it does not possess much general interest, and the same holds true for the myriameter formerly used in geographical work. The kilometer, on the contrary, as a unit of distance such as would be used in the measurement of the length of a railway or road, is of vast importance, and is universally employed both scientifically, as by engineers, and also in non-technical matters. It is a unit whose use presents very little difficulty to those accustomed to Anglo-Saxon measures, in that it corresponds so closely to six-tenths of a mile that such an approximation suffices for most purposes and is readily made.

The hectometer does not find extensive practical application, and is encountered chiefly in the calculations of artillerists; but even here it is preferable to use meters, and velocities, etc., are now usually calculated in the latter units. The decameter is used in surveying where it forms a base for the measure of land, since the decameter squared gives the are, which is the principal unit of land measure. The classes of measurement for which the meter is available are numerous and apparent. For the measure of cloth and similar fabrics it is eminently suitable, and as the yard is approximately ·9 of the meter there is no very violent break in passing from one to the other, as would be done by the purchaser of cloth for a dress. The meter would be used by the stone mason in the measurements of a length of wall, or by a carpenter or architect in his specifications and plans for structural work, and is in every way as suitable a unit as the yard, aside from the inherent merits of its connection with the metric system. In the decimeter there is a unit intermediate between the meter and the centimeter, and on that account not as much used as either. Furthermore, the decimeter does not correspond to any unit that has been in recent use by non-metric countries, and in the Anglo-Saxon system its nearest equivalent is the hand of four inches, long obsolete, except in measuring the height of horses. The decimeter is too short to fill the place of the foot and too long to supplant such a unit as the inch. Nevertheless, it is at the disposal of those who desire such a unit, and as three decimeters will approximate a foot, it may find increased application, but its use has never been great in the countries employing the metric system. The centimeter, on the other hand, is a most useful and convenient unit, and is susceptible of wide application. For the carpenter or cabinetmaker in giving the dimensions of a door or window, the size of a plank, that is, its breadth and thickness, or the dimensions of any ordinary objects, such as tables, chairs, etc., the centimeter fills every requirement, and in scientific work it is customary to express dimensions of apparatus and all ordinary measurements in its terms. For many years in the United States library catalogue cards and other furnishings, such as pamphlet cases, have been standardized and sold according to metric measure, and the centimeter has been the unit adopted. It takes the place of the inch, and while it requires a larger number to express a given distance, yet it is likely to lead to greater exactness where it is not desirable to employ fractions. The millimeter is the unit of science and exact mechanical work. It affords an integral unit for minute measures, speaking comparatively, and its decimal subdivision is peculiarly suitable for this class of work. In ordinary life its chief application is to the measurement of thickness, such as metals, paper, glass, etc., and particularly in the measurement of diameters of wire, tubing, and other materials which enter into mechanical construction. Thus, measurements in millimeters are designed to take the place of arbitrary gauges where the problem of original standards, which in turn are based on standards of length, works against general uniformity and convenience. For the measurement of screw-threads the millimeter is also employed, and in France, Germany, and Switzerland millimeter sizes for screws and thickness and diameters have been found to be far more convenient than arbitrary gauges. While the millimeter answers many purposes of the scientist, yet it does not carry him far enough, and accordingly there is the micron, which is one-thousandth part of it. This affords a convenient unit for the microscopist and the spectroscopist when they venture into the regions beyond the range of the human eye; and to secure a still greater refinement we have the millimicron, or again the thousandth part.

With such units as the foregoing, the next point is how are they applied, and how are they concretely represented by scales or other devices? The longest scale is that of the geodesist or engineer employed in measuring his base line for trigonometrical surveying of greater or less accuracy as the occasion may warrant. The best modern practice involves the use of a steel tape or wire, or one made of an alloy of steel with a smaller tendency to expand and contract with changes in temperature, which under a constant tension gives an exact representation of a distance as determined with a standard of length.[1] Such tapes or wires are usually of 100, 200, or 300 meters, while the ordinary chain or tape of the land surveyor is either a double or single decameter on which are marked the meters and such other subdivisions as are desired, the double decameter being known as a metric chain. The next measure of length in point of size is the double meter, which may be either a rod or tape. If a rod, its material and subdivision are dependent on the use for which it is designed, as a metal scale lends itself more readily to permanent and accurate graduation, and is less susceptible to change with time and temperature; the latter condition, in fact, may be accurately and satisfactorily accounted for by knowing the coefficient of expansion of the bar and the temperature at which it is used. The tape may be either of metal or linen, and is a convenient measure for many purposes. There are also constructed meter scales, half-meter scales, double and single decimeter scales, the shape and material as well as the accuracy of graduation depending on the purposes for which they are to be used. When it comes to the division of millimeters it is necessary to employ a dividing engine,[2] and the finest scales are ruled on glass or upon a smooth and even substance, such as speculum metal platinum-iridium, or nickel steel. The glass scales are, of course, to be used with the microscope, and similar scales can be constructed photographically by reducing in a desired proportion.

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[1] There are also standard bars used in the most refined base measurements, such as that at Holton, Mich., which was of 5 meters length. These bars require the most careful levelling, are packed in ice at the time of making the measurement, and are only used when the greatest accuracy is desired, as the refinements of a laboratory are involved in a field operation. See Woodward, "The iced bar and long tape base apparatus and the results of measures made with them on the Holton and St. Albans bases," part ii. of Appendix No. 8 of *Report of United States Coast and Geodetic Survey for* 1892, pp. 334-489. Professor Woodward also discusses "Long Steel Tapes" in a paper presented to the International Engineering Congress of 1893, and printed in the *Transactions of the American Society of Civil Engineers*, vol. xxx. p. 81.

[2] See chapter x.—Standards and Comparison, p. 225.

Measures of Surface.

	Abbreviation.	Number of Square Meters.
Square kilometer, -	km^2.	1,000,000m^2.
Hectar (square hectometer),	ha. – hm^2.	10,000m^2.
Ar (square decameter), -	a. – dm^2.	100m^2.
Centiar or square meter,	ca. or m^2.	1m^2.
Square decimeter, -	dm^2.	·01m^2.
Square centimeter, -	cm^2.	·0001m^2.
Square millimeter, -	mm^2.	·000,001m^2.

For the measurement of surfaces it is customary to employ as a unit a square or quadrilateral figure bounded by four equal sides at right angles to each other. In such a unit the sides are usually made equal to the linear unit, hence in the metric system a square of this nature would have for each side a meter, and would be known as a square meter, forming the principal unit for the measurement of surface. The next greater unit would be formed by a square whose bounding sides were each equal to a decameter, and consequently would include 100 of the principal units. If our units of length increase by a ratio of 10, it is obvious that the unit of surface based on these same units of length must increase by the square of 10 or by 100 as is indicated by the table. The same nomenclature is retained, but the word square is prefixed, and in the case of the units formally adopted for the measure of land, the terms *hectar* and *ar* have been selected to designate respectively the square hectometer and the square decameter. In writing and converting the measures of area it is necessary to multiply or divide by 100 when changing to a larger or smaller unit, consequently in the decimal fraction each metric unit must be given two places of figures. For example, to write as square meters 984·8963 square decimeters, it would be necessary to move the point two places to the left and we would have 9·848963 square meters, which also could be written 9 square meters, 84 square decimeters, 89 square centimeters and 63 square millimeters, or even 9848963 square millimeters if it was so desired. The square kilometer is employed in topographical work on a large scale, or in cartography in summing up the area of a country or large region. For fields the hectar is used, and is parallel to the acre, which contains ·4047 hectars. For land of smaller dimension, such as city lots, it is customary to use the are. The measurement of surfaces, as of walls by the painter or paperhanger, or of floors by the dealer in carpets, is naturally made by the square meter. Such measurements as the square decimeter and the square centimeter are useful for purposes that will naturally suggest themselves, but again attention may be called to the fact that scientific men prefer to use the square centimeter and the cubic centimeter also as much as possible.

Measures of Volume.

The volume of a body, or the amount of space that it occupies, is usually measured by a unit known as a cube, which is a parallelopipedon bounded by six equal squares. In the metric system the principal unit is the cubic meter, a cube each of whose faces is a square meter, and consequently whose edges are each a meter in length. The cubic meter is the largest unit of volume in the metric system, though logically there is no reason why cubic decameters, hectometers, and kilometers should not be employed were there any necessity for their use, which there is not. Therefore we have only to concern ourselves with the submultiples of the cubic meter. On the decimal principle the next smaller unit must be one in which the size is determined by the tenth of the meter, or the decimeter, or a cube each of whose edges is a decimeter. Obviously, to make a cubic meter ten rows of these cubes, arranged so that they are ten in length, will have to be placed ten deep, or one thousand of our cubic decimeters must be used. So that where the unit of area required a ratio of 100 to pass from a smaller to a greater, the units of volume need a ratio of 1000; that is, three figures of integers or of the decimal fraction are required for each unit. Thus a cubic meter will contain 1000 cubic decimeters, or 1 000 000 cubic centimeters, or 1 000 000 000 cubic millimeters. We may read 76·854 673 2 cubic meters as 76 854·673 cubic centimeters, or, were it desirable, 76 854 673 cubic millimeters. Or we could read the above expression as 76 cubic meters, 854 cubic decimeters, and 673 cubic centimeters.

The cubic meter is employed in all cases where any considerable quantity of a substance must be considered. Thus the amount of material excavated from a foundation, railway cut, or canal, would be expressed in cubic meters, as would be blocks of marble or the contents of a tank or reservoir. When the cubic meter is applied to the measurement of firewood it receives a new name, *stere* (= 35·317 cubic feet or ·27 cord), and as a pile of wood can be divided or increased readily, the name of *decistere* is given to the one-tenth part, and that of *decastere* to ten times the unit quantity. The cubic decimeter is an intermediate unit like the corresponding decimeter and square decimeter, but it possesses importance, inasmuch as it is the volume of the liter (very nearly), and as such is frequently employed in calculations where it is desired to obtain the capacity of a given space, as will be explained further on under measures of capacity. The cubic centimeter answers for many purposes, and is the usual unit for scientific work. Thus in pharmacy by the volumetric method (see page 194) almost all liquids are compounded by taking the desired quantities in cubic centimeters, while to determine standard pressure reference is made to that of a column of 75 cubic centimeters of mercury at 0° centigrade.

Measures of Capacity.

Hectoliter, - - -	hl.	100 liters.
Decaliter, - - -	dal.	10 liters.
Liter, - - -	l.	
Deciliter, - - -	dl.	·1 liter.
Centiliter, - - -	cl.	·01 liter.
Milliliter, - - -	ml.	·001 liter.

The close connection between measures of volume and capacity is obvious, and the founders of the metric system took as their unit of capacity the volume of a cubic decimeter. Subsequent measures of the kilogram, and the mass of water necessary to amount to this weight, resulted in the conclusion that for strictly scientific purposes this was inaccurate, and consequently the legal definition is in the words of the International Committee, " The liter is the volume occupied by the mass one kilogram of pure water at its maximum density and under normal atmospheric pressure," and this decision was duly sanctioned by the general conference of 1901. As the result of a large number of careful experiments it was found that a mean value for the mass of a cubic decimeter of water at 4 degrees centigrade (its temperature of maximum density) would be ·999974 kilogram, and that the error of assuming the liter equal to the cubic decimeter would be only about one part in 30,000, an amount only appreciable in the most refined measurements. The liter is subdivided on a decimal basis, while its multiples are similarly arranged, and from what has preceded it will be possible to understand the various units merely by referring to the table. In actual practice the liter and the hectoliter are the units chiefly employed, as for many reasons it is preferable to employ cubic centimeters for smaller measures, while the decaliter, being an intermediate measure, does not come into wide use. The liter and all the measures of capacity are used for both dry and liquid substances; but it is a tendency of modern metrology quite independent of the metric system to do away so far as possible with dry measures of capacity and buy and sell such substances by weight.[1] The liter, however, can be used to measure all liquids (such as water, milk, wine, beer, oil, etc.), vegetables, grains, seeds, etc., in ordinary retail transactions. When large quantities of the commodity are dealt in or discussed, then it is customary to use hectoliters. The liter corresponded so closely to the ancient French *pinte* (·981 liter) which it supplanted that its use did not occasion any difficulty, and as it is intermediate in value between the American dry (= 1·1012 liter) and liquid quarts (= ·94636 liter) its employment would result in a simplification of measures, and would involve no inconvenience.

The adoption of metric measures of capacity in the United States would result in important simplifications, as the present measures differ from those of Great Britain, and possess no intrinsic merits of their own. In fact, in the Anti-metric Argument of the Committee of the American Society of Mechanical Engineers (vol. xxiv. New York, 1902), which opposes most bitterly any attempt at the introduction of the metric system, it is stated (p. 676), "That there is no reason for the English

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[1] In Europe the practice of selling liquids by weight is also increasing.

system retaining the gallon and the bushel except that they are in such common use. For convenience in computation it would be well if the gallon were 216 cubic inches, or the cube of 6 inches, and the bushel 1728 cubic inches, or 1 cubic foot."

In constructing the actual measures of capacity their range is extended by binary subdivision and doubling, so that all possible capacities can be measured and substances sold on a basis of the simplest mental process, namely, that of halving. Actual measures in the form of wooden vessels for measuring grain with a capacity of one hectoliter and less are constructed with their internal height and diameter equal, while for measuring liquors, wines, and alcohol, the French laws provide that the internal height should be twice the internal diameter. Oil and milk measures are of tin, and their internal height and diameter are equal.

Measures of Mass.

Metric ton,	t.	10 Quintals	1000 Kilograms	1,000,000 grams	10^6g.
Quintal,	q.	10 Myriagrams	100 „	100,000 „	10^5g.
Myriagram,		10 Kilograms	10 „	10,000 „	10^4g.
Kilogram,	kg.	10 Hectograms	—	1,000 „	10^3g.
Hectogram,		10 Decagrams	—	100 „	10^2g.
Decagram,		10 Grams	—	10 „	10g.
Gram,	g.	10 Decigrams	—	1 „	g.
Decigram,	dg.	10 Centigrams	—	·1 „	10^{-1}g.
Centigram,	cg.	10 Milligrams	—	·01 „	10^{-2}g.
Milligram,	mg.	—	—	·001 „	10^{-3}g.

By mass is meant the actual quantity of matter which a body contains, and it is to be distinguished from weight, which is the force with which a body is attracted to the earth. Now, as this force of attraction depends upon the mass of a body, it follows that the weight of different bodies at the same place is proportional to their respective masses. But as the force of attraction or gravity varies at different points on the earth's surface, it is obvious that bodies of the same mass will have different weights at different places. Originally, as we have seen, the gram was defined by the decree of 18 Germinal, year III.,[1] as "The absolute weight of a volume of pure water equal to a cube of the one-hundredth part of a meter and at the temperature

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[1] See p. 54.

of melting ice," and on this basis the Kilogram of the Archives was constructed. However, after the construction of the International standard kilogram it was deemed desirable to define formally the kilogram, and at a meeting of the International Committee on October 15, 1889, it was decided that "The mass of the international kilogram is taken as unity for the international system of weights and measures," and this decision was confirmed at the third general conference held at Paris in 1901. While the gram is the fundamental unit of mass, yet in actual practice, as in the construction of the standard, it has been found rather small for most weighings, and consequently the kilogram is employed as a practical unit.

There is, of course, the same wide range of units of weights as in other classes of measures, and on precisely the same decimal basis, as the table plainly sets forth. The same considerations govern their use, and we find that the number of units in actual use is but a small part of those available. Thus, for large weights the metric ton is the unit employed, and is used in the weighing of ore, coal, hay, and other substances dealt in in large quantities. It is employed in estimating the mineral production of the world, being a convenient weight to which the output of different nations may best be reduced for purposes of comparison and statistical study. It corresponds so closely with the long ton of 2240 pounds (a metric ton equals 2204·62 lbs.) that for many purposes it is practically equivalent. The quintal has the same line of uses as the hundredweight, which either as 112 pounds or 100 pounds is still employed in some branches of trade. It would be substantially equivalent to twice the former, and would not vary greatly from the American barrel of flour, which contains 196 pounds net.

The myriagram is rarely, if ever, used, but the kilogram is a unit which is found universally. Being the weight of a cubic decimeter of water it enables one instantly to determine the weight of a body whose volume and specific gravity are known, and for that reason is very convenient in calculation, such as to determine the weight of cut stone, etc. It is the unit most frequently employed in trade and industry for the sale of merchandise of all descriptions. By using the half kilogram there is a weight which approximates the pound, and being slightly larger there is an element in favor of the purchaser. Instead of using hectograms and decagrams it is found more convenient to express such quantities in terms of fractions of kilograms or as grams, and such is the usual practice. The gram is extensively employed in science, as by the chemist, and by those dealing in small and valuable materials, as jewellers and coiners. In multiples of ten it affords a convenient substitute for the ounce, 30 grams (28·3495 exactly) corresponding to one ounce avoirdupois. Its relation to the cubic centimeter of water makes it a useful unit for the physicist or chemist, and unless there is reason to the contrary it is always used to record and describe the results of his experimental and other work. As the gram is so constantly used for measures of weight of this nature by those having to do with masses of a size convenient for its use the adoption of this part of the metric system would work no hardship, as apothecaries' weight, which it would supplant, has few defenders, and is destined to disappear. Decigrams, centigrams, and milligrams are used in the form of fractions of the gram, though milligrams are employed to a certain extent, especially as the riders or smallest weights of a fine balance enable weighings to be made in milligrams and fractions of a milligram.

In the actual weights there is not only the diversity indicated by the table, but also others obtained by doubling or halving the various units there mentioned. The construction and design of these weights as also their accuracy depends upon the purpose for which they are intended, and vary from the platinum iridium and rock crystal copies of the international standard down to the cast-iron weights of the retail dealer. The cast-iron weights range from 50 kilograms to 50 grams or ½ hectogram, while the brass weights, which are usually cylindrical in shape, with the upper part fashioned into a knob for more convenient handling, range from 20 kilograms to 1 gram. Fractions of a gram are usually made of sheet metal, such as platinum, german silver, or aluminium, as in this shape they are more readily handled with the forceps employed to transfer them from their case to the pans of the balance. The very smallest or milligram weights are known as "riders," and are twisted loops of wire which may be placed at any desired position along the graduated beam of the balance, and thus enable the observer to read to fractions.

While there have been enumerated under each class of measures a number of units, yet it is necessary to state again that only a comparatively small number are employed. In this respect the metric system is similar to the United States monetary system, where there are mills, dimes, and eagles, as well as quarters and halves, in addition to dollars and cents, but in computation everything settles down to a dollars and cents basis. This is precisely the case with the metric system, and while the intermediate units appear in the tables we have taken care to explain how infrequently they are employed. In fact, it is a tendency in metrology to eliminate from use as many units as possible, and all existing measures are on a far less liberal scale in point of numbers than those of a century ago, not to speak of those of ancient times or of the middle ages. With the metric system this elimination can be done without any trouble, as it is the work of but a moment to change from one unit to another for any purpose whatsoever.

CHAPTER VI.

THE METRIC SYSTEM FOR COMMERCE.

FROM what has been said regarding the development and present conditions of the metric system, the advantages of its use by all nations would seem apparent; nevertheless, as its employment is not as yet universal, it would seem desirable here to deal first with the benefits to the commercial world at large of a single system of weights and measures, and second with the profit that would accrue to an individual nation from the adoption of the metric system. It is a mere truism to say that anything that enlarges the circle of exchange of either ideas or commodities works for the welfare of the world, and the happiest and most prosperous nations are those that have the advantages of such interchange with their fellows most firmly established. A striking example of this is seen when it is considered that the improvements in navigation following the application of steam have not redounded to the benefit of any one nation to the exclusion of others, but have stimulated trade and prosperity in all parts of the world. Likewise by means of the telegraph and submarine cable the exchange of ideas and rapid transaction of business between distant places have been made possible, and that again has brought about benefits confined to no single nation. Furthermore, international banking has also contributed to extend and develop trade, and here we find that through the pre-eminence of Great Britain in this field pounds sterling are adopted as a universal measure of value. Facilities have been supplied by the British merchant and banker which have resulted in no small profit to him, simply because he has been able to occupy the world with his commercial machinery and force the use of a standard of value adequate for a large part of the world's trade.

On the other hand, a result of international co-operation is the International Postal Union, where mails from all countries of the world are exchanged with equal and proportionate expense and advantage to all. Here, as we have seen,[1] it was necessary at the outset to find a common system of weights and measures to regulate the payments and the exchanges of mail, and it was found desirable to adopt the metric system, which has since been employed for many years with complete success even among non-metric nations. In general, wherever there has been international co-operation to secure uniformity in commerce, as in cable and telegraph conventions, treaties to establish uniform classifications and definitions, etc., the results have invariably resulted in promoting general prosperity and in increasing business. Furthermore, an international language, as well as an international currency, would serve to increase commerce and from many points of view would be an important benefit. However, international language and international currency are outside the province of the present consideration, but international weights and measures must be discussed, especially as the metric system is destined eventually to hold such a position, even in a fuller sense than at present. The reasons for this present pre-eminence, as we shall soon see, are obvious. First, in different contiguous countries, there was the realization of a need of a single system of measures that would conform to those of the other nations; and second, there was the natural desire for the best and most useful system. The result was that in every instance where a change was made, save that of Russia[2] in 1835, the metric weights and measures were adopted in preference to those of any other system, and in no case have they been given up, nor is the slightest desire for any change expressed.[3]

For the benefits of a single and international system of units, we have only to refer in passing to the electrical units which are subsequently discussed at some length.[4] For the measurement of electrical quantities throughout the world a single system

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[1] See *ante*, p. 127.

[2] Russia adopted as a unit of length 7 English feet, but neither multiples or submultiples were as in the British system. Furthermore the British pound was not adopted.

[3] See chapter iii. *ante*.

[4] See chapter ix.

of units is employed, and this system, based on the metric units, was developed in Great Britain, and has been adopted by scientists and engineers universally. When great industries were established to apply to the everyday uses of mankind the discoveries and inventions of men of science in this field, these same units were retained, and were later sanctioned by international agreements. No voice has ever been heard to dispute the advantages of such a system, and the result has been that there has been more progress in electricity through the interchange of ideas than in any other branch of applied science. When electrical congresses meet every communication is intelligible at once to every member so far as the expression of quantities goes. When tenders are asked for electrical machinery, materials, or apparatus, the manufacturers of every nation of the world are on the same footing as regards understanding the specifications and utilizing materials for a desired output. Accuracy in measurement is not restricted to any single nation or its scientific workers, as the work of the latter can be put immediately at the disposal of the world, and the highest precision can be secured by joint effort and co-operation. In fact, when the Physicalisch-Technische Reichsanstalt at Charlottenburg, near Berlin, was the only important governmental testing bureau and physical laboratory, it received apparatus and materials from many nations outside of Germany to be examined and standardized according to the common system. To-day electrical measuring instruments certified to by the Reichsanstalt, the Laboratoire Central d'Electricité at Paris, the National Physical Laboratory of England, or the U.S. Bureau of Standards, can be used for electrical measurements anywhere in the world, as the units employed depend for their derivation on the same definitions. In fact, so much a matter of course is the single system of electrical units that no one would think of proposing any other, and its existence is so taken for granted that its advantages are rarely spoken of or even considered until the possible chaos of substituting a number of systems in its place is mentioned. Indeed, while the various units are frequently criticized, no electrician or physicist would venture to propose the adoption of new units locally, despite the fact that universal reforms in units and standards are advocated before international congresses.

Looking at the question of weights and measures from a strictly commercial standpoint it is clear that, as commerce involves primarily the exchange of quantities of various commodities, the use of a simple and convenient method for the rapid calculation of weight, length, and capacity must promote ease and security of commercial intercourse. The metric system being decimal, and consequently the most easily grasped and applied, is therefore the best for commerce, and when to this is coupled the fact that its use is all but universal and is employed in the major portion of international commercial transactions, it is easy to see that a great saving of time in business operations must result from its adoption. That this saving of time and simplicity is real, and not the mere hope or opinions of reformers, can be demonstrated by reference to the reports of American and British consular and diplomatic officials who are acquainted with both the Anglo-Saxon and the metric systems. These reports, notable among which, as being most comprehensive and complete, are those presented to Parliament in 1900 and 1901,[1] to which reference has already been made, speak emphatically in this respect, and in a communication from Portugal appears the statement that "The large amount of time saved in commercial houses by the simplicity of the metric system, as well as by the uniformity now existing in place of the former chaos, is in itself a valuable factor in considering the advantages of the new system."[2]

The successful prosecution of foreign commerce requires a complete understanding between merchants in different countries as to each other's standing, methods of payment, and, most important, as to the goods themselves which form the subject of the transaction. Aside from standards of quality, quantities and dimensions must be considered, and it is here that universal measures and standards are needed. It is also of importance for both buyer and seller to know the quantity of the commodity in existence at different places, the quantity produced and consumed in previous years, and other statistical information. As regards

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[1] *English Parliamentary Accounts and Papers:* 1900, vol. xc.; *Reports from Her Majesty's Representatives in Europe on the Metric System:* 1901, vol. lxxx.; *Reports on Metric System*, part ii.

[2] *Ibid.* part i. p. 54.

the latter, it will readily be seen that the collection and diffusion of such knowledge would be facilitated if the same units were used in every country and port of the globe, and trade could then be carried on in a more intelligent manner, and with the elimination of speculative elements, while tariff laws and custom regulations, etc., could be more intelligently framed through the better and more uniform character of the statistical information. Such benefits accrue to trade throughout the world generally, and are generally recognized.

But with no uniform system of weights and measures which may be applied to the description of goods, it is inevitable that there is a lack of clear understanding between buyer and seller, and one of these parties is at a disadvantage. Especially is this true if there is a competitor who is ready to trade on a basis more readily understood. Thus, if a man is in doubt as to certain elements concerning goods which he desires to buy or sell, he naturally assumes that there are other points about which he is equally ignorant, and consequently he is unwilling to undertake the transaction. True, he may compute in his own system the quantities or dimensions of the article or articles, or may receive these figures in whole or in part from the other merchant or agent; but the basis of trade is unsatisfactory, and it is natural for men to buy or sell according to their usual measurements even if the goods must be imported from a greater distance. This, furthermore, is emphasized by the extensive use of standards which, at first designed for a single country and trade, have gradually crept abroad so that if either English or Continental goods, such as pipe or nuts and bolts, for example, have secured a foothold in a certain country, it is quite certain that in all subsequent orders they will be demanded, and a newcomer in the field will have to conform to styles and standards already established. Thus to compel trade in a large and unusual number of sizes is a most wasteful economic process, and results in forcing the manufacture into the hands of a comparatively small number of producers, who can so control their business as to occupy certain fields exclusively rather than to establish wholesome competition between all the manufacturers of the world.

A striking example of the evils attending lack of standardization in measures, materials, and machinery, is to be found in the mining districts of South Africa, where mining and other engineering operations are carried on in a cosmopolitan manner by engineers from various countries. Machinery and supplies are imported, for specific purposes, from all over the world, and consequently they vary in dimensions, often in parts that properly should be interchangeable.[1] The result is that considerable fitting is required in order to make the various parts of a plant work harmoniously. This of course involves time and expense without accompanying benefit to anyone, whereas by a system of international standards such waste would be avoided. Furthermore, a proper system of standardization would enable the specifications of machinery and supplies to be prepared in such a way that manufacturers and dealers would know exactly what was wanted, and make their bids accordingly, to the benefit of all concerned. If the standardization was universal a simple description of the desired articles could be circulated, and manufacturers and dealers all over the world could submit prices and estimates. Thus the whole world could participate in the competition, and not only would the supplies be cheaper to the purchaser, but manufacturing and commerce would be stimulated.

Now, the first principle of standardization is the defining of sizes in a regular and systematic manner, and conforming to a permanent standard, and this in the ultimate analysis must depend on a standard of length or mass. Consequently, if the dimensions of articles are referred to one and the same system, and that the international or metric system, it is comparatively simple to reach a point where all articles of a class are reduced to certain sizes determined by conference and mutual consent of the makers and consumers of the commodities in question. There is, in short, a survival of the fittest and most convenient sizes, and machinery and materials, involved in making the various articles, are soon conformed to these standards of size.[2] It will be seen, therefore, that the standardization which is a benefit, national or international in accordance with its scope, follows from a well-defined system of units, and when such a system is single and

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[1] See Presidential Address of R. M. Catlin before Mechanical Engineers' Association of the Witwatersrand, abstracted in *Engineering and Mining Journal* (New York), vol. lxxix. 1905.

[2] See p. 173, chap. vii.

universal there is bound to result a single set of standards in all important industries. Such a result is bound to promote commerce and industry by facilitating the manufacture and exchange of commodities, and the same benefits would be experienced by the world at large as have been realized in the United States where this policy has been followed in many lines.

International weights and measures soon would produce truly international standards, both of size and of quality, and the trade of the world would be on a far more wholesome and active basis, as there would not be material tied up in odd sizes, and consequently unavailable to other users except at increased expense, but there would be a common world stock. As trade would be stimulated and diversified a further division of labor would take place, and there would be greater general prosperity. To become thoroughly convinced of this, one has only to refer to the reports of American and British consuls, which are unanimous and constant in reiterating the assertion that the lack of an international system of weights and measures acts most strongly against the extension of trade between their home countries in those places in which they serve. This, of course, implies a reciprocal loss, as the wider the distribution of a nation's commerce the more extensive it must be, as also the more profitable.

That there is need of an international system of weights and measures which is universal and invariable is shown by the fact that the United States and Great Britain, which claim the same sources for their various weights and measures, now have units that figure constantly in trade relations which are quite unlike in value. For example, wheat and other grain from America is sold by a bushel which differs materially from the British bushel, as does also the gallon used in the measurement of petroleum, while the hundredweight of 112 pounds and quarter of 56 pounds are rarely used in America. These weights were abandoned in Liverpool in 1903 for a weight of 50 pounds, the use of which in trade was authorized by an Order in Council of October 9, 1903. Since that time a standard for this amount has been constructed and verified, and there is an increasing tendency towards using the cental of 100 lbs. as a commercial unit. Here are examples of the inconvenience where two countries employ measures and weights apparently the same, but which must be adjusted even for transactions between themselves, when by the adoption and use of the metric system they would be put on the same basis as regards one another as they would enjoy towards the rest of the world.

Foreign commerce presents many difficulties unknown to business between two parties in more or less proximity. There is the question of time and of freight, both important items in any commercial transaction, but especially so when weeks or months must elapse before a delivery can be effected. Misunderstandings or mistakes are most costly and cannot be rectified promptly; consequently there should be the most complete understanding between the parties to the transaction. This must involve an easy standard or basis of comparison, for the present differences in money and exchange are troublesome enough. The extent of this difficulty is best illustrated by modern methods of doing business where catalogues, price-lists, and other printed matter are used so extensively, and are such an important adjunct to the work of the salesman, who naturally is unable to carry with him a complete line of samples, even of agricultural tools, not to mention dynamos and steam engines. If these descriptions and prices are understood, and if the sellers have a good reputation, much has been done towards effecting a sale, as the prospective buyer can tell at a glance whether character, quality, and size are such as he desires and uses, and especially whether they will correspond in size with present or future stock or plant. Furthermore, in case of an immediate demand for the goods, business can be transacted satisfactorily by cable or telegraph. When, however, various articles are presented to a foreign purchaser described in strange units, the latter is compelled to employ conversion tables, and even then fails at a complete, not to speak of quick, comprehension of the goods. With a single system the case would be different, and no nation would enjoy any advantage over another in this respect, save in the actual merit of its goods, and the increased circulation and use of such catalogues would provoke keener competition, and would result in a higher grade of tools and other articles, as the world markets would be aimed at where general excellence and price would carry the day.

The question whether a country's export business would be helped by an international system of weights and measures must be considered, no matter whether that country is on a protection basis or enjoys free trade. In the latter case the advantages are obvious, but where there has been protection the result in many nations is that the product is often greater than the needs of the home market, consequently the manufacturer, in order to keep up his production on the largest, and therefore most economical scale, must seek to market his surplus in a foreign field. A glance at our table (page 105) will soon show that with the exception of Great Britain and its dependencies, Russia, Denmark, and China, the vast majority of nations are on the metric basis, and for reasons we have already advanced it is quite necessary that business with them should be done according to the international measures. That this is essential is shown by the fact that in the United States certain manufacturers, and the number is constantly increasing, not only describe their goods in metric measures, but so construct them, and stand ready to increase their business in this respect. If the surplus product is made so that it can be utilized in any country, it is of course obvious that the manufacturer has a far wider range of market, and is likely to secure better prices.

Possibly the best testimony as to the advantages to commerce of an international system of weights and measures should come from countries where the metric system has supplanted the local system or systems, though the latter still survive. Such is the following extract, which sums up the conditions in Spain, and which is typical of the enlightened opinion in nearly all metric countries: "The facility and security afforded to the sending of orders, owing to the amount ordered being subject to the same measure in the different countries, the conformity in transport, custom-house, and commission tariff, etc., attract, tighten, increase commercial relations."[1] This is the answer of the Spanish Geographical and Statistical Institute attached to the ministry of Public Instruction, Agriculture, Industry, and Public Works, in reply to a question as to how the adoption of the metric system had affected its commerce, and it is also the experience of other countries. The importance of the adoption of the metric system

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[1] *Report of Her Majesty's Representatives in Europe on the Metric System*, presented July, 1900, part i. p. 61; *Parliamentary Accounts and Papers*, 1900, vol. xc.

to international trade has been noted formally by various commercial and statistical conferences and conventions, but of a more official character was the action taken by the International American Conference which was held at Washington in 1890, where the following resolution was adopted: "Resolved that the International American Conference recommends the adoption of the metrical decimal system to the nations here represented which have not already adopted it." James G. Blaine, then Secretary of State, whose last important official work was towards the extension of American commerce through reciprocity treaties with the South American countries, urged upon the United States Government the adoption of that system for the customs service,[1] and his recommendations were concurred in by Secretary of the Treasury Windom (Report, Dec. 1, 1890), and by Secretary of State Foster, in his reports for 1891 and 1892. Likewise, in Great Britain there was a conference of Colonial Premiers at London in 1902, and a resolution was formally adopted favoring the use of the metric system for all the British colonies. Following up the matter the Colonial Office then communicated with the various Colonial governors, asking what action was likely to be taken with regard to this resolution. Mauritius and Seychelles already used the system, but the following colonies were reported as favorable to its adoption: Australia, New Zealand,[2] Cape of Good Hope, Transvaal, Orange River Colony, Southern Rhodesia, Gambia, Northern Nigeria, Gibraltar, British Guiana, Trinidad, Leeward Islands and Windward Islands. Sierra Leone, Southern Nigeria, Ceylon, and the Falklands stipulated that they were in favor of it if adopted by the United Kingdom or in the Empire generally. The Australian states, while favorably disposed, thought that the matter should be settled by the government of the commonwealth, while Jamaica and British Honduras required the adoption of the system by the United States. Fiji and British New Guinea would have to follow Australia, just as the Straits Settlements and Labuan were dependent on India. The Bechuanaland Protectorate would be compelled to be in harmony with the rest of South Africa. Opposition to the plans was evinced by St. Helena, Cyprus, Lagos,

[1] *Sen. Exec. Doc.*, No. 181, 51st Congress, 1st Session.

[2] Metric System adopted by New Zealand in 1905.

Wei-hai-wei, Barbados, and Bahamas, while the Gold Coast Colony and the State of Queensland were ready for the system, but anticipated inconvenience in its adoption. Natal reported that some definite general plan was necessary before an opinion could be expressed. Of the remaining colonies definite answers were not given by Newfoundland, Malta, or Bermuda, and no reply whatsoever was received from Canada, though it is sufficiently obvious that the latter country would be compelled to follow the example of the United States.

It will be seen from the foregoing that these colonies, widely scattered over the world, were for the most part alive to the advantages attending the adoption of the metric system, as by so doing the great trade of the British Empire would then be put on the same terms as that of the rest of the world. This, of course, leaves out of consideration the trade of the United States and its possessions, which, if brought into harmony with the above, would greatly facilitate in the development and prosecution of commerce.

An additional consideration is that new discoveries of mineral wealth and supplies of raw materials of one class or other have within comparatively few years greatly extended the range of commerce, and many nations once thought uncivilized and unproductive are becoming great consumers as well as producers, requiring the most varied supplies and machinery. These markets are destined to prove among the most valuable of the world, and to pre-empt them is the task of the highest wisdom. In South America and in all non-British colonies we find the metric system used, though with it are often various native or local nondescript units. It is the opinion of the consuls to these places—and they at least must be admitted to be competent judges—that the use of the metric system would greatly increase trade of these countries with America and Great Britain.

Having pointed out that the adoption of a single system of weights and measures throughout the world would be most advantageous, and would facilitate commerce, therefore benefiting each and every nation to a greater or less extent depending on its location and the amount of its foreign trade, it is now necessary to consider just what advantages a country not using the metric system would secure by its adoption, and what disadvantages, if any, are likely to be experienced. These advantages must be practical, especially in a country like the United States, and must appeal to the small shopkeeper and farmer, as well as to the professor of physics, the merchant, and the statistician. Large, as the question seems, it is possible to simplify it by eliminating a certain number of elements. Thus, we know that workers in science in America, Great Britain, and Russia have, for a long time, universally employed metric weights and measures in their daily work, and have urged their adoption for general use, confident of their great utility and superiority. Also, that other scientific men, whose work is of a more practical nature, such as electrical engineers, who constantly use the metric weights and measures in their work, have also urged their general adoption. Consequently, the change would be a distinct advantage to workers in this field, and there is no opposition to the step to be anticipated from them.

At the other end of the scale must be considered the average citizen who does business on a small scale, and who, with his household, uses weights and measures daily. In fact, looking at the question as a national one, this seems to be the most important aspect, and should be most carefully considered, both in the light of the experience of foreign countries and according to local conditions. Reflection, however, soon establishes the fact that most of these transactions take place where the actual goods are transferred in the presence of the buyer and seller, and some approximate idea of the measure desired is in the mind of both of the parties to the transaction. Thus a man buying sugar sees the amount he is receiving, and knows the price paid, so that with properly sealed weights there is no opportunity for injustice, as the man is free to buy sugar where he will, and at the most favorable price, the latter being governed by the law of supply and demand as modified by trade conditions. When his wife mixes the sugar to make cake her methods of measurement are purely relative, and neither ounces nor grams are employed, but approximate measures, such as tea-cups, which are quite independent of any laws of metrology. In fact, the question has been excellently summed up by one of the most distinguished opponents[1] of the introduction of the metric system into the

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[1] Dr. Coleman Sellers, *Cassier's Magazine*, vol. xvii. p. 365, 1900.

United States, as follows: "To the great bulk of mankind engaged in trade, in buying and selling, in bartering and exchanging, it matters little what system of weights and measures they adopt: it matters little whether they are obliged to use a yard-stick or a meter rod, pounds or kilograms, quarts or liters. The cost to them is the cost of the few devices needed in weighing and measuring; the *rationale* of the system may never enter into their thoughts." Thus, there is no reason why, so far as this class of people is concerned, a change should not be made if the new system supplied is superior for their purposes. This the metric system is, on account of its great simplicity, doing away as it does with all compound relations for the single ratio of ten, connecting weight and measures by the weight of a volume of water as a unit, thus eliminating all odd equivalents such as the fact that a cubic foot of water weighs 62½ pounds, and finally doing away with such anomalies as dry and liquid measures of capacity, avoirdupois, Troy, and apothecaries' weight, long tons and short tons, hundredweight of 112 pounds, and other weights and measures equally arbitrary, and not susceptible of being put into simple relation with other quantities.

Indeed, the full complexity and absurdity of the present "system," so called, is hardly realized until we stop to consider that in the United States copper is weighed by one standard, silver by another, medicines by a third, diamonds and other precious stones by a fourth, and platinum and chemicals by a fifth, none of which are interchangeable with one another except by means of fractions. Nor is the condition less striking in the case of the measures of capacity. One unit is used for wine, and bears the same name as a dissimilar one used for grain, while gas is measured by still a third unit. In fact, the condition as regards the last-named groups of units is summed up in the Anti-metric Argument of the committee of the American Society of Mechanical Engineers, where it is stated in a passage already quoted:[1] "There is no reason for the English system retaining the gallon and the bushel, except that they are in such common use." For convenience of computation it would be well if the gallon were 216 cubic inches, or the cube of 6 inches, and the

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[1] See pp. 145, 146 *ante*; *Transactions American Society of Mechanical Engineers*, vol. xxiv. 1902, No. 972, "Anti-Metric Argument," vii. p. 676.

bushel 1728 cubic inches, or 1 cubic foot. A few lines later in this interesting argument some comments on the various units of weight are concluded by the remark, "Both Troy weight and apothecaries' weight might be abandoned." Here, from a source unfriendly to the metric system, and opposed to any fundamental changes in the weights and measures, is to be found a frank admission that the measures of capacity are inconvenient, and could be greatly improved, and that no reason other than use exists for retaining the Troy and apothecaries' weight. Accordingly, they propose to reconstruct the measures of capacity into a new system which would occasion all the inconvenience attendant on a transition from one system to another, and yet would not yield the advantages of a decimal basis, and division, or relation between weights and measures of the metric system, nor would it have the least international value.

Likewise in England a society was formed in 1904 under the title of the British Weights and Measures Association, which had as it object "the defence, standardizing, and *simplifying* (italics ours) of British weights and measures," and to oppose the introduction of the meter as a British standard. Furthermore, this society proposed the introduction of "*simplified* and *scientifically related* weights and measures based upon existing British measures" (again italics ours). Now, with such an admission that the Anglo-Saxon weights and measures need "simplification" and to be "scientifically related," it is proposed to proceed on a new basis, and construct and try a system that has not been tested by actual use, as has the metric system, and which in addition must be pushed against the latter, despite the fact that it will doubtless contain neither the decimal basis nor the relation between measures of length and weight. In other words, there would be experienced all the inconvenience which would attend a change to the metric system, and at the same time the advantages obtained would be infinitely small in comparison with what would follow a decision to adopt the latter completely.

Moreover, such a proposition is by no means new, for we have seen how Sir John Riggs Miller, at the end of the eighteenth century, advocated a decimal division of the British weights and measures, while on October 27, 1863, Sir John

Herschel, the eminent scientist and astronomer, in an address before the Leeds Astronomical Society, advocated the readjustment of the British Imperial weights and measures on a decimal basis according to a plan that at least appeared scientific and methodical. He proposed to take as the standard of length the earth's polar axis, which in imperial inches was computed to be 500,482,296, and as a new, or as he termed it, "geometrical" inch, employ the $\frac{1}{500\,000\,000}$ part of this, which would differ by less than a thousandth from the customary inch, and be at the same time related to a natural quantity. The unit of weight would be a cubic foot of water, and would be approximately equal to 1000 ounces avoirdupois. Herschel says: "Thus the change, which would place our system of linear measure on a perfectly faultless basis, would at the same time rescue our weights and measures of capacity from their present utter confusion, and secure that other advantage, second only in importance to the former, of connecting them decimally with that system on a regular, intelligible, and easily remembered principle; and that by an alteration practically inperceptible in both cases, and interfering with no one of our usages or denominations."

It might be said in passing that the length of the polar radius, as calculated by Sir John Herschel, was no more accurate or permanent than the original determination of the length of the earth's quadrant by the founders of the metric system, while similar, though greater, errors have been found in his fundamental unit of weight. It is now conclusively recognized in metrology that no terrestrial dimensions can be relied upon to furnish an accurate standard of length.[1] Thus we see that a simple and albeit excellent step at reforming British weights and measure did not meet with any greater favor than the complete change to the metric system advocated about the same time, and it is quite probable that a like fate would to-day befall any similar proposition. So that the question seems to be not to reform weights and measures by gradual and slight improvements, but, if any changes can be made, to adopt the best possible system, notwithstanding the

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[1] See Mendenhall, "The Metric System," *Appleton's Popular Science Monthly*, October, 1896.

drawback of temporary inconvenience, and for the sake of the future benefits which must unmistakably follow.

Perhaps the most important question in connection with the adoption of the metric system is whether the change would occasion any temporary inconvenience or expense to the people at large. In the United States the great majority of the people have been educated in the public schools, in most of which since 1880 the metric system has been taught more or less effectively as an integral part of arithmetic. Everyone is used to the decimal system as employed in the national currency and coinage, and, furthermore, it must be granted that a higher standard of intelligence and adaptability prevails in the United States than in Germany and other European countries, where but little inconvenience was experienced and practically no injury was done at the time of the change. True, there would be in some cases the cost of new scales, weights, and measures, but it must be remembered that these are undergoing constant deterioration, and in constant use the life of scales and weights is only about two years. Therefore, any such expense would be in actuality practically negligible, and doubtless would result in distributing over the country weights and measures of increased accuracy. Indisputably some time would be required for the complete assimilation of metric measures and weights, as we have seen was the case in Europe, but at the same time the advantages attending their use would begin, and there would be employed tables of legal equivalents which would soon educate all to the necessary proficiency. Then, also, we would see for a few years before and after any legislative establishment of the metric system, all books for common use containing formulas, recipes, etc., printed with all quantities in both English and metric measures, so that the transition from one to the other either ideally or actually would be attended with no inconvenience.

In addition to the marked advantages in the actual measuring and weighing of everyday life, due to the simplicity of the metric system, there would be the great saving of time in the schools where the complete metric system taught in connection with decimals would require but a fraction of the time now given to compound numbers. In fact authorities on education have estimated that at least one year of the child's school course could be saved by the adoption of the metric system, as after its employment in our practical everyday life, the Anglo-Saxon measures would be of little more use than those of the Greeks and Romans, and would have scarcely more interest than the old measures of France have to-day.

It is not necessary here to refer to the great saving of time in making calculations involving quantities of produce of various kind, although it is by no means unimportant, for with the class of citizens we are now considering, while bookkeeping usually plays but a secondary part in their life, yet it is employed, and the farmer or petty shopkeeper will appreciate the saving of time as much as the clerk or accountant whom we will consider later. For the mechanic it is amply demonstrated that a change in measurements makes but little difference as foreign workmen educated to the metric system are able to work in the Anglo-Saxon system without any difficulty whatsoever and *vice versa*, ample testimony being forthcoming on both sides of this proposition.

In short, there are no serious drawbacks so far as the average man and woman are concerned why America and Great Britain should not adopt the metric system, and when it is recalled, how practically no inconvenience was experienced in Canada when the change was made from shillings and pence to dollars and cents, or in the early days of the United States when its system of currency was established on lines quite new, it is not reasonable to anticipate any embarrassment or difficulty.

We are then brought face to face with the question, how will the adoption of a metric system affect the internal commerce of a country using the term as referring to the exchange of commodities on a somewhat larger scale than we have discussed above. While such commerce depends for its prosperity on the individual purchaser, yet anything which facilitates it acts to the latter's benefit in reduction of prices and promptness of delivery and improvement of quality. This exchange is accomplished through an intricate system of machinery in which credits, banks, transportation, and other factors all enter to a large degree. Yet, with the extension of commerce constantly going on, there has been no backward step, and in its progress simplicity and accuracy in business transactions have been the chief essentials which have been aimed at and attained. Thus the use of banking facilities, and the telegraph, for the exchange of money have contributed to save time and trouble, which in business are definitely measured by money, while typewriter, telephone, calculating machines, and new methods of bookkeeping have played their part in releasing the mind of the business man to new and original activities, and to the extension of his business along such directions as his experience tells him are most profitable. With such innovations must be considered the adoption of the metric system, as a step in advance, since it will simplify all calculations and bookkeeping by the elimination of useless multiplications which are involved in the use of the compound numbers employed in the ordinary weights and measures. One immediate result would be the ease in determining errors and the decrease in their number through less multiplication. Undeniably, the simplest mathematical process for man is decimal multiplication, corresponding as it does to his fundamental notation, and this simplicity has been established uncontrovertibly in an experience of over a century with the decimal system of American money, where there has been demonstrated its applicability to all pecuniary transactions, both large and small, from the actual handling of the currency to the booking of credits and the computation of discounts, interest, etc., not to mention the ease with which such mental calculation as the determination of the price for a quantity from a price for an individual article or *vice versa* can be made.

Consequently there has resulted the widespread use of percentages and a decimal division wherever possible. Thus, it is a matter of convenience that railway and other shares shall be valued on a percentage basis, and still more convenient that the par value should be $100·00, and this practice has largely prevailed. For mining or other shares where a smaller par value is desired, it is usual to employ $10·00 or $1·00, while bonds are conveniently arranged on a basis of $1000·00 each. Likewise with such commodities as sugar and cotton,[1] where it is necessary to express intermediate values between even cents, it has been found desirable to give up common fraction and use a decimal

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[1] The Liverpool Cotton Association since October 1, 1902, has quoted cotton values in hundredths of a penny instead of sixty-fourths. A similar practice is observed in America.

division to facilitate computation and bookkeeping.[1] These changes have been the result of an evolution which has been independent of any theory, but which has considered merely the commercial availability of the method. For shop costs a decimal hour is often employed, and such clocks are used in some factories.

An instance of this in American weights and measures is found in the tendency to eliminate as many units as possible, and to use larger numerical figures, as 1000s of pounds instead of tons. Another example was the introduction of the short ton of 2000 pounds to facilitate calculation, and this unit soon came to be more extensively used than the long ton of 2240 pounds inherited from Great Britain. No difficulty was experienced in making the transition from the long to the short ton, in commercial usage, and there is no reason why any inconvenience should attend the change to the metric ton. In fact, in one of the largest chemical works in the United States,—that of the Solvay Process Company,—where the metric system is used exclusively, it is customary to weigh the coal and other supplies, when received, in metric units, despite the fact that they are bought and invoiced in ordinary weights and measures. This company has found it a distinct advantage in its internal economy to make use of the metric system, and employs it in all calculations, except for specifications of machinery and wood-work that must be constructed outside of their factory by people to whom the metric weights and measures are practically unknown. An interesting example of the superiority of the metric system for purposes of accounting and bookkeeping may be cited in the experience of the Brighton Railway in England, which for a number of years has employed the kilogram as its unit of weight for all its European business, and the French decimal monetary system for its accounts.[2] It is the opinion of the officials of this road that the keeping of all accounts would be simplified by using metric weights and measures. In the foreign business it would

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[1] The Stock Exchanges, however, still use common fractions and commissions are usually in eighths and sixteenths of a per cent.

[2] See testimony of Charles A. de Pury, chief accountant of Brighton Railway in Report by Select Committee on Weights and Measures (Metric System) Bill [H.L.] 1904, p. 25.

have been possible, of course, to have changed the French weights and currency to English, but the auditors of this corporation believed that the metric system would be the more convenient, and such it has proved in practice.

The elimination of the middleman is one of the tendencies of modern trade, and the more direct relation of consumer with producer requires that business should be done on the simplest possible basis by the contracting parties. Now the middleman in the past was the one who usually made the transformations of weights and measures, buying by one system and selling by another. Inasmuch as often now he is considered superfluous, in many transactions where the buyer and seller come together directly, it is essential that a single system, which must also be the simplest, should be employed. Thus there is no reason why coal should be sold at wholesale by the long ton and retailed by the short ton of 2000 pounds, or that the dealer in drugs and chemicals imported by metric weights should dispose of them by avoirdupois or apothecaries pounds. In fact, transformations of weights and measures, or the use of double systems, are and always have been a fruitful source of complaint and controversy. Indeed, it was well said by a British diplomatic official in speaking of conditions in Belgium, "The disputes which were formerly so numerous, and which rendered long and complicated calculations necessary, have become few and far between. In short, the adoption of the metric system has done much to ensure honesty in commercial transactions."[1]

With the decimal system can be used such important labor saving device as slide-rules and calculating machines, the latter in particular now being a feature of every well equipped office, and resulting in increased accuracy and speed of operation. So that the way is in part prepared for the introduction of the metric system to denote units of quantity on account of its decimal features, which would fit in completely with modern business computation, and America could make the change with greater facility than Great Britain, or even than that experienced by any foreign country, on account of its simple currency system. With the advent of the metric system would come the release

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[1] *Reports from Her Majesty's Representatives in Europe on the Metric System*, part i. p. 8; *English Parliamentary Accounts and Papers*, 1900, vol. xc.

from the various heterogeneous arrangements of tables of length, surface, volume, capacity, and mass in which binary, duodecimal, and other relations are maintained and abandoned in accordance with no consistent theory or system, constantly requiring reference to unwieldy tables and tedious calculation. Not only is there saving in the time required to learn the metric system over all others (and it is safe to say that any clerk working at a new task where quantities or dimensions of a substance were involved would have to brush up his knowledge of compound numbers and tables, or proceed with extreme slowness and caution), but in its application there is a most important gain of time. The result is that more business can be transacted with a smaller office force, and that the activity of clerks and computers can be turned in other directions.

The disadvantages attending the introduction of the metric system will be entirely of a temporary character, and if we may take the experience of Germany as a guide, will prove far less than is feared by the timid. The time lost by making transformation from the old into the new weights and measures will in reality prove much less than is anticipated, as such operations doubtless will be performed with the aid of tables, such as will be found in the appendix, which not only the government but every industry doubtless will prepare to facilitate such work, while for new calculations employing metric weights and measures throughout there will be a great saving.

The difficulty of minds learning to think in a new system of weights and measures is not so easily disposed of, but we have seen how convenient and easily applied are some of the approximations, and we have only for most purposes to consider a yard equal to $\frac{9}{10}$ of a meter, two pounds equal to ·9 kilogram, a liter a quart, a long ton equivalent to a metric ton, etc. The relation between volume and capacity should be appreciated greatly in commercial work, as the capacity of a tank, reservoir, bin, or car in appropriate units can readily be computed from its dimensions, and then, knowing the specific gravity, by simple multiplication the weight of its contents can be ascertained.

With all the inconveniences of the Anglo-Saxon systems of weights and measures we are forced to consider a still more serious difficulty, namely the growth of a dual system due to the increased use of the metric system as permitted by statute. It cannot be denied that the metric system has made great progress, and that by the close connection of science with industry that it is destined to be even more widely employed. Both systems being legal, and the metric measures coming into more wide spread use, there would result the perpetual necessity of converting from one to the other in commercial transactions, and while the nation was waiting for the ultimate survival of the fittest system, or the birth of an ideal scheme, incalculable inconvenience and damage would ensue, as has been shown many times in the past where a nation at other times than at a transition period has employed a double standard.

CHAPTER VII.

THE METRIC SYSTEM IN MANUFACTURING AND ENGINEERING.

The application of the metric system to manufacturing and mechanical and other forms of constructive engineering, where there has been long use of units of other systems, presents confessedly the most serious aspect of the question of adopting the international weights and measures. These branches of human activity, it must be remembered, had their beginnings in most humble and commonplace sources, such as the village smith, the local carpenter, or even the aboriginal savage with his primitive loom. In this respect they differ from electrical and civil engineering, and applied chemistry, where the applications of science and discovery have resulted in vast industries and important technical professions. From their very inception these latter have been dependent on the work of scientific men, using the term broadly, and it has been possible to use such units and measurements as they have recommended. That these units can be developed rationally and systematically, as well as with extreme simplicity we can see from the electrical units which will be discussed in a subsequent chapter. But in mechanical engineering and manufacturing simple processes and methods have gradually been developed by the aid of scientific men, and by applying their discoveries to every-day work, consequently the engineers have been forced to use the units and measures of the people rather than to develop and rationalize such systems as would best commend themselves to their judgment.

Improved methods of manufacturing, however, have brought about machinery and processes marked by simplicity and efficiency, and while the advantages that will ensue ultimately from the adoption of international weights and measures will more than compensate for any temporary inconvenience, nevertheless, it must be admitted that the transition will involve some serious problems and expense. Inasmuch as comparatively few manufacturing processes, or at least individual plants, remain stationary, but are constantly undergoing improvements either of method or machinery, the possibility of adjustment to new conditions, such as a new system of weights and measures, is not so difficult as might at first be imagined. Oftentimes changes of styles or classes of product are made that are far more fundamental than any changes that would be involved by new measures, and natural wear and tear to machinery require constant renewals and substitutions at intervals, and in many shops it is considered good economy to strive for a maximum output at the expense of individual machines and tools. Furthermore, conformation to standards, so necessary for successful manufacturing, does not involve the blind adherence to such standards, however honored and however universally observed, after better standards have been evolved. That such a change in units or standards can readily be made we know from numerous instances in the past where various gauges, screw threads, screws, etc., have been changed without undue confusion and expense. A notable instance, inasmuch as the change was radical and fundamental, was made by the printers of the United States in 1883, when the nomenclature of the different sizes of type was changed, and a system of measuring by points adopted to take the place of names in use for years. In fact, the adoption of various screw threads in different countries, either in the interest of standardization or to obtain a better screw, and even their modification, has worked no great hardship, and such changes in car coupling and other devices recommended from time to time in the United States by the Master Car Builders' Association, involving as they often do marked departures from sizes or styles in use by different railroads, seem to be made speedily and effectively, and without such expense as would occasion objection from controlling officials.

Numerous instances where changes of systems and standards dealing with actual concrete things may be cited to show how readily changes in manufacturing and mechanical engineering have been brought about, proving that it is not only under ideal conditions, such as the change from local to standard time, or in an improved calendar, that scientific reforms can be effected. Once the people concerned are convinced of the need of the change and the superiority of a new system, history shows that the change can be made effectively and expeditiously, so that at present it remains for the adherents of the metric system to convince the manufacturing public by demonstrating its superiority for their work, and to show how it may be adopted with the smallest amount of inconvenience. Possibly this will best be understood by considering briefly the relation of weights and measures to manufacturing and constructive engineering. If a single piece of machinery or a single fabric is to be produced, it is of little moment what units of weight and measures are employed by the designer, and what are used by the maker, provided that both can understand each other, and provided that time and expense are subordinate. That this is true is shown by the ease with which American and English workmen can and do work from continental designs prepared according to the metric measures and *vice versa* on special orders. But when thousands of the manufactured article are required, and time and economy must be considered, or in other words, when the commercial conditions of successful manufacturing have to be met, then the influence of weights and measures as reflected in standards, processes, and in numerous more or less direct ways, is felt.

We may start with the raw material, which may be in bulk as in the case of ore, pig iron, crude chemicals, baled cotton or wool, logs, etc., to cite but a few examples, or we may consider as raw material, wire, sheet metal, structural shapes from the rolling mill, yarn, boards, and other sawed or milled timber, to mention some of the innumerable articles that enter into manufacturing processes. In the case of the former class we have to consider the same principles discussed in the last chapter, as the purchase of the materials would be greatly simplified by having all invoices and calculations of prices made in the metric system, consequently there would be a saving of time to the office. The actual weighing would be the same under any system, though easier with metric weights, but for the computations involved in mixing or otherwise treating raw materials there would be a great saving effected by using the metric system, as it would avoid the employment of different classes of units, and would be throughout on a strictly decimal basis. However in this no particularly serious questions arise, but with the other class of raw materials used in manufacturing, experience has shown and convenience enforces the demand that they must be supplied of certain dimensions which must be of sufficient variety to fill all reasonable needs, prepared according to certain standards, and packed in certain quantities. The dimensions or weights are taken, of course, in conventional units, and the law of supply and demand, modified by co-operative action and trade customs among manufacturers, consumers, and dealers, has resulted in the establishment of certain standard sizes which not only are regularly carried in stock, but for which have been calculated many tables dealing with their weight, strength, elasticity, resistance, and other characteristics useful to designer and maker alike. As a result the majority of articles used in manufacturing and construction are made only in standard sizes, for making which special machinery has been prepared and adjusted, while articles of other dimensions must be specially made at considerably greater expense.

This policy of making articles in standard sizes has been productive of the highest benefit to the manufacturer, and the specialization that has been brought about in American works and factories has contributed in no small degree to the position in manufacturing that the United States now occupies among the nations of the world. This system of standardization is also advantageous to the consumer, who in turn may be just as important a manufacturer, only turning out a more finished or more complex article. Let us see how the metric system would apply here. First, let us take the purely arbitrary standards which have no even dimensions. For example, flour is manufactured and usually sold 196 pounds net to the barrel, yet there is no particular reason for this quantity, since flour sold in sacks for export, where it may be stowed the more readily in a vessel's hold, usually is packed 140 pounds to a sack. Now, if there was any reason for preserving these particular quantities they could be used in metric weights just as readily as at present, but appreciate the convenience if barrels of 100 kilograms and sacks of exactly half that amount were employed. True, the miller would have to adjust his automatic scales for weighing his flour, but the product would be turned out in even quantities, and the weight of carload or cargo would be told at a glance from the number of barrels or sacks. Every transaction from the time that the flour left the mill until it was divided by the retail grocer into 10 kilogram lots would be facilitated.

Then let us consider wire and sheet metals for which there have been a number of gauges. These, for the most part, have been and are, not only arbitrary but irregular and inconsistent, and have stated the thickness in decimal fractions of inches, some of which are expressed to the fifth or sixth place. If these numbers are to be retained it is certainly just as easy to express the thicknesses in fractions of a millimeter as of an inch, and in fact this was officially done in the Act of March 3, 1893, when a standard gauge for sheet and plate iron and steel was established by Congress[1] in which the numbers were defined by equivalent values in inches and millimeters. Consequently, under the existing legal gauge, the adoption of the metric system would cause no difference whatever in the making of sheet iron and steel, and the customer would find the same legal sizes under the metric system as before. While no wire gauge has been legalized, yet, if any of the standard gauges is to be used, it is quite as easy to consider the metric as the inch values since the decimal fractions are no greater. The gauge system at best is bad in its general aspect as it always requires an act of memory, and in practice so inexact and unsatisfactory that certain large consumers in the United States, notably the Great Electric Companies, have instructed their draughting rooms and purchasing departments to always specify by actual dimensions in thousandths of an inch expressed decimally. But so long as gauges are generally used, it is necessary to consider just what they signify and what part they play in mechanical operations. Formed as they are of plates of sheet steel or other metal, with holes or openings with which to test the various samples of

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[1] C. 221, Sec. 1, 27 Stat., 746, R.S. 3570.

materials, they are in practice often at the outset very inexact in their graduations, and in any event they sooner or later become so by the wear of constant use. As regards their graduation and division the various standard gauges differ widely from one another, and in individual cases, as has been said, they are hardly ever arranged systematically or methodically. This can readily be appreciated by examining the tables in almost any standard engineer's reference or so-called pocket book, but a hint can be given by the following list, which shows the dimensions in decimal parts of an inch for the same number (No. 2) of the various gauges that are all in use in the United States.

Dimensions of No. 2 gauge according to different standards:

	Inch.
American or Brown & Sharpe,	·25763
Birmingham or Stubs' Wire,	·284
Washburn & Moen M'fg Co., Worcester, Mass.,	·2625
Imperial Wire Gauge,	·276
Stubs' Steel Wire,	·219
U.S. Standard for Plate,	·265625
Twist Drill and Steel Wire Gauge,	·221
Screw Gauge for Machine and Wood Screws,	·08416

Thus it will be seen that material made according to any of the above gauges is not suitable to be used with that made by another gauge, as for example there is no correspondence between the gauge sizes of wire and the twist drill which would make the hole in which the wire might be inserted, or the size of the wire and the wood or machine screw into which it might be made. Consequently the present tendency is to abandon all arbitrary gauges and work to decimal parts of an inch requiring all materials to be furnished of such dimensions, a condition which can be easily determined with great exactness by a micrometer caliper of low cost. Now, the use of decimals presents no inconvenience whatsoever to the average mechanic, so that at such a transition period as regards standard sizes of materials, there is every reason for adopting the metric system rather than waiting until further standardization on an inch basis shall have occurred. Instead of arbitrary gauge numbers millimeters and decimal fractions could be employed, and there would be the advantage of having a larger number of integral numbers and division by tenths and hundredths, amply sufficing for all ordinary mechanical work. The workmen, in their measurements, would employ the same form of micrometer, the reading of which would be even more simple, and much greater interchangeability would result as soon as materials were furnished in a smaller number, but standard sizes.

The tendency would be towards a more exact arrangement on a metric basis. Such a movement would be gradual, and there would be few occasions where any difficulty would be experienced. Metric wire gauges were introduced in France in 1894, and have proved satisfactory, their use increasing very rapidly. In fact, in much work done with such materials, as sheet metal and wire, as well as with other material, it is rarely necessary to look for the strictest exactness in conforming to a certain gauge as the purpose can be satisfied by an approximation, and the customary method of payment being made on a basis of weight prevents any imposition or injustice. As, however, new dies or rolls were required, these would be carefully adjusted to metric gauge, and the older sizes would gradually become obsolete, unless there arose some special demand, while in the case of sheet metal it would only be necessary to have a new setting of the rolls. It is impossible to conceive of any injury being done the manufacturer, for at the worst he has only to provide himself with a few new adjuncts to his larger tools and a limited number of smaller tools, which are constantly being replaced.

Then take the case of the lumber mill, where planks, boards, joists, etc., are turned out on an inch basis. How near do these dimensions correspond in reality with the sizes they are sold for? In fact, in many instances planed boards of a certain dimension do not gauge that dimension at all, but represent what remains after a board sawed approximately to that thickness has been planed. The carpenter and the cabinetmaker do not demand so high a degree of precision from the lumber dealer that the ·4 of a millimeter, between 25 millimeters and an inch (25·4 mm.) cannot be disregarded, and here again it is found that most standard sizes of lumber can be readily described in metric measures without the use of decimal fractions, and no new machinery will be required except as new styles or sizes are demanded.

In actual manufacturing, after the adoption of the metric system, the first step would be the provision of facilities for making various articles, such as sheet metal, paper, wire, cloth, etc., according to metric dimensions. This would be to meet the requirements of the government and other consumers, who desired goods according to metric specifications. In other words, the same process would be gone through with as occurs when a large new or special order is received. As these orders would be in metric sizes, and conformable approximately to those that experience had taught were most serviceable for the particular use for which they were designed, they would gradually become standards, and would supplant the older sizes. In many cases where materials are sold by weight, as paper and wire, the effect of a change of dimensions would have no effect on the price, while a minute change sufficient to adapt the material to a regular metric dimension would in no way affect its usefulness to the consumer, and should there be a slight increase in some instances it would be balanced by a slight decrease in others. Indeed, in many instances only the trimming or finishing would be involved, and here it is probable that the waste material would just as likely be less than the amount produced in making the present sizes as it would be greater, and at any rate it could doubtless be worked or utilized in some way, the difficulties can hardly be called serious.

Linear measures and standards play a prominent part in all mechanical operations, and here the superiority of the metric system and its ready applicability may be shown. It has been the practice to measure by successively halving the unit, and in the case of the inch this has brought us down to such fractions as $\frac{1}{32}$ and $\frac{1}{64}$, which are awkward both for computation and observation on a scale. While it is quite natural to halve or quarter a unit, yet to pursue this policy of binary subdivision too far is extremely inconvenient. With the metric system in linear as in other measurements it is possible to make use of any decimal multiple or submultiple of the meter from the micron to the myriameter as the base, according to the nature of the measurement involved, and it is quite possible to use the half of it simply by writing ·5, or the quarter by writing ·25, both expressions requiring no more figures than the corresponding common fractions, and involving no difficulty in case it is desired to transpose to a higher or lower unit. Now, it has been found better in actual experience when other fractions than a half or quarter are desired, to divide decimally, and where accurate work is demanded it has become the almost universal custom in the United States among engineers and machinists to work in hundredths and thousandths of inches, the practice being followed from draughting room to shop. This practice involves the expression of all quantities in terms of a single unit, such as feet, inches, or pounds, with the appropriate decimal fraction, and demonstrates the availability of the decimal system for such practical work, as well as for mere computation. This practice is rapidly on the increase, due largely to the use of calipers and gauges thus divided, so that the matter of decimal fractions presents no disadvantage, but rather a convenience, to the workman who has to make measurements.

As regards the linear units themselves; if the workman employs millimeters he has a unit which is a whole number, and is superior to $\frac{1}{16}$, as the latter is too large, and represents coarse measurement and work. On the other hand $\frac{1}{32}$ is too fine a division for an ordinary scale, especially for a draughtsman, and is only useful on a steel scale, with which few mechanics are equipped, consequently the centimeter and millimeter are quite as convenient as the inch, while the foot, which is rarely used in modern mechanical engineering, is in no way missed. Even if we consider the inch as the principal unit we are forced to use, either its sixteenth part, or its tenth, hundredth, or thousandth, and in reality we make such a fractional part our standard unit, and we have the odd relation between such units and the greater ones, the inch, and the foot, as compared with the simple decimal relation of the metric linear measures. The yard and the meter wherever desired are units of the same class, and what can be done with one is equally possible with the other, not to mention, of course, the advantage of the decimal relation of the meter to its sub-multiples. But the great gain is that all calculations are made in the same unit as the original measurement, and no reductions, save the transfer of a decimal point, are ever necessary. Contrast this with the English system where measurements made in inches must be changed to feet or yards for use with tables or *vice versa.*

But in most manufacturing there is comparatively little or no measuring for the workman to do, inasmuch as he is required merely to make his work according to gauges, or templates, or jigs, which are supplied to him by the tool room, where they have been carefully worked out from the specifications of the draughting room. Holes are bored and reamed to a certain gauge, drills are set so that several will come down on the piece of work at places previously determined by the jig, and planers, shapers, milling machines, etc., are all operated in the same way. But there must be some consideration of standards and units in the draughting room and tool room, is the suggestion immediately made, and here possibly would be one of the points where difficulty might be encountered. It has been shown in actual experience that the work of the draughtsman in preparing plans according to metric measures is not only no harder, but is facilitated considerably in actual drawing, and immeasurably so if there are computations to be made. Now, in the construction of gauges and tools the highest intelligence of the mechanical force is employed, and here there are men not only having a knowledge of current sizes and standards, but perfectly capable of working in any kind of measures. In fact, the dimensions of many gauges are merely nominal, and there is a greater or less deviation from the stated dimensions, but which concern neither draughtsman nor workman if all tools and gauges are harmonized as they must be to these dimensions throughout the work. This, of course, involves the use of micrometers and other adjuncts to fine measuring, and this class of work can be done with greater facility in the metric system, as is shown by its adoption by makers of instruments of precision, opticians, and watchmakers universally.[1] If tools and gauges in the factory are to remain as before the introduction of the metric measures, as they can be

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[1] The Swiss watchmakers were the first to employ a metric thread for small screws, and the basis of the system was to start with a pitch or distance between threads of one millimeter, and to decrease the pitch of each succeeding size by ten per cent. In 1869 not only were metric threads adopted by the American Watch Company for watches, but also throughout their factory, and all their watchmaking machinery has been constructed on that basis. In Great Britain a Committee of the British Association for the Advancement of Science appointed to determine a gauge for small screws used in telegraph and electrical apparatus reported in favor of the Swiss series of small screws, and the same was adopted.

without the slightest inconvenience, it is only necessary to designate them by their metric values for purpose of computation, and to continue employing them with their various shop numbers as before. Where new standards and gauges are to be constructed, as they must be from time to time, then it would prove desirable to use the metric measures, and the tendency will be to work toward even dimensions and universal standards. Such a tendency will be general, and if the manufacturer need tools, which he must buy, he will soon find that the new ones carefully standardized will be forthcoming in metric sizes, wherever any changes are made from existing patterns and numbers. To such a degree of exactness is this work now carried on in well-organized American shops, that the highly skilled man in charge of the tools will find little trouble in adopting the metric dimensions.

Making the supposition now that a machine shop or factory is required to work to actual correct dimensions in the metric system, which, of course, is not contemplated by any movement for the introduction of the new system, it does not mean that a new equipment of tools must be procured. None of the larger tools would be changed, as even in the case of the lathes a single gear wheel connected to the lead screw enables metric threads to be cut on an ordinary lathe with an inch lead screw and *vice versa*, while the only important changes would be such small tools as drills, reamers, taps, dies, etc., where in certain dimensions a new size might be demanded, and these, if not already made and in stock, as are gear cutters for cutting metric pitches[1] at the present time in the United States and England, would soon be provided by tool makers.

In this connection the cutting of screws may be discussed more at length, as it is one of the principal undertakings in a machine shop, and involves the greatest care in order to secure high precision and interchangeability. Screw threads originally are made upon a lathe where a cutting tool is given a lateral motion by means of a screw known as a lead screw which revolves in a nut attached to the tool carriage, and thus gives a lateral motion to the tool. The object on which the screw is being cut is also revolved, and the proper ratio of revolution

[1] Bevel gears can be cut to metric pitch with the usual tools.

between the two is maintained by suitable gearing. In the United States and England lathes are usually designed to work on an inch basis, and consequently the lead screw is so divided and the corresponding gears furnished. But, by the use of one change wheel with 127 teeth[1] it is possible to arrange a lathe so that with a lead screw divided on an inch basis metric threads may be cut with an error that can only be detected by the most refined methods, if at all, and such screws are entirely suitable for all ordinary use, being correct to one part in 6350. By such means are made the taps of hard steel with which holes are threaded, and the dies that are used for the more rapid cutting of threads on a large scale in the actual manufacture of screws in quantities.

While the adoption of the metric system does not necessarily involve the doing away with the present systems of screw threads in the United States and England, which, however, are purely arbitrary, and could be measured in millimeters with equal facility, yet there is a metric thread which was approved at a congress of engineering societies held at Zurich in October, 1898, and again at an international conference held in October, 1900, at Paris, delegates being present from all the important metric nations of the Continent, including France, Germany, Switzerland, and Italy. This form of thread was evolved by the Société d'Encouragement pour l'Industrie Nationale of France, having been devised by M. Ed. Sauvage, and used for a number of years on the French railways previous to its adoption by the society. With slight modifications it was adopted as an international standard for shape of thread and pitch, and is now known as the Système International, abbreviated to S.I. or S.J. The shape of this thread is practically the same as that of the U.S. standard adopted by the U.S. Navy Department in 1868, and also known as the Franklin Institute or Sellers Standard, from the name of its inventor, William Sellers. The thread of the bolt or screw consists in cross section of an equilateral triangle, giving an angle of 60 degrees as compared with 55 degrees in the Whitworth (British) standard, and the edges and bottom of the thread are flattened by an amount equal to $\frac{1}{8}$ the height. A modification and improvement over the Sellers thread, as well as over the

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[1] This represents five times the ratio of the inch to the millimeter.

Whitworth thread, consists in allowing for clearance between the base of a nut thread and the top of a bolt thread, though in American machine shop practice it has been usual so to make

Common Sizes of Screw Threads.

Whitworth. (Inches.)			S.I. (mm.)		
Diam.	Thds. per inch.	Diam. Increment.	Diam.	Pitch.	Diam. Increment.
$\frac{1}{4}$	20	$\frac{1}{8}$	6	1	2
$\frac{3}{8}$	16	$\frac{1}{8}$	8	1·25	2
$\frac{1}{2}$	12	$\frac{1}{8}$	10	1·5	2
$\frac{5}{8}$	11	$\frac{1}{8}$	12	1·75	4
$\frac{3}{4}$	10	$\frac{1}{8}$	16	2·	4
$\frac{7}{8}$	9	$\frac{1}{8}$	20	2·5	4
1	8	$\frac{1}{8}$	24	3·	6
$1\frac{1}{8}$	7	$\frac{1}{4}$	30	3·5	6
$1\frac{1}{4}$	7	$\frac{1}{4}$	36	4·	6
$1\frac{1}{2}$	6	$\frac{1}{4}$	42	4·5	6
$1\frac{3}{4}$	5	$\frac{1}{4}$	48	5	8
2	$4\frac{1}{2}$	$\frac{1}{4}$	56	5·5	8
$2\frac{1}{4}$	4	$\frac{1}{2}$	64	6	8
$2\frac{1}{2}$	4	$\frac{1}{4}$	72	6·5	8
$2\frac{3}{4}$	$3\frac{1}{2}$		80	7·	
3	$3\frac{1}{2}$				

the thread that there is such a clearance, the sides of the thread and nut receiving the fit. In the S.I. thread this clearance amounts to $\frac{1}{16}$ of the thread in the form of a circular fillet tangent to the thread's side, while the thread itself has a flat top. The pitches or distances between the threads increase regularly by a half millimeter, with a ·25 millimeter interval in some cases, as between 1 and 2 millimeters. The rate of increase is much more regular and simpler than in the case of the United States standard thread, where in many places awkward fractions are introduced. The pitch of the latter is finer, thus making a bolt constructed on the Système International a trifle weaker, but the difference is not serious, and no disastrous effects have been experienced in actual use. The underlying symmetry and the regularity are, however, features of great value, and the system at the time of its adoption was thought worthy of widespread use, even to supplant the Whitworth thread, which despite its English basis has been in wide use for years even in metric countries.[1]

In watchmaking the metric thread is employed universally, the Swiss system being taken as the standard; while for small machine screws used in electrical and other apparatus there is the B.A. (British Association) standard, which is also metric. The latter thread was devised by a committee of distinguished electricians and experimental physicists, and since its adoption the regularity and symmetry of its divisions have been thoroughly appreciated.

The change to the Sellers thread in the United States was made without any paralysis of manufacturing industries or serious injury to machine work, and the same was true when the railroads adopted a standard screw thread and gauge on the recommendation of a committee of the Master Car Builders' Association, which reported in 1882. This report[2] shows the advantages to be gained by adopting and adhering to one system, and outlines the problem that was solved by the late Professor William A. Rogers and the Pratt and Whitney Company in preparing suitable standards for adoption by all railroads. This change was made in the course of a few years without undue difficulty or expense, and since has been found amply justified, illustrating most strikingly the advantages of a common standard in a single industry.

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[1] Henry Hess, "The S.J. Standard Metric Thread in Continental Europe," *American Machinist*, p. 422, vol. xxiii. No. 18, May 3, 1900.

[2] M. N. Forney, Chairman, *Railroad Gazette* (New York), July 7, 1882, vol. xiv. p. 407.

The adoption of the metric system, however, does not necessarily involve the changing of the present excellent screw system of the United States, as it is perfectly possible to get along with arbitrary names and gauges based on original standards, and well defined in terms of metric as well as the old measures. Just as "tenpenny" nails are now spoken of, so screws could be defined by number even if they were based on obsolete linear measures and standards. On the other hand, if the tendency should be towards a new international gauge it will come gradually, and without undue inconvenience, as similar changes have been made in the past.

In Great Britain, where possibly the standardizing of screws and screw threads has not been developed so highly as in the United States, the situation has been most excellently summed up by Alexander Siemens, the well-known electrical engineer and manufacturer. In his Presidential Address[1] before the (British) Institution of Electrical Engineers, delivered November 10, 1904, he said:

"As a last resort the expense of changing the screw threads is urged against the change to the Metric System, and the Continental practice of calling their system 'Whitworth thread' is considered an incontrovertible proof that the metrical screw thread is impracticable. If all taps and dies and leading screws had to be exchanged at once, it would certainly be a costly affair, but such a measure is not likely to be adopted, as no advantage could result from it. For the real difficulty with screw threads is that giving dimensions on paper is not sufficient to ensure that the screws, manufactured according to such instructions in different works, are really interchangeable. This subject has been investigated by a committee from the War Office, and their conclusions throw a very interesting light on the controversy. In their opinion it is only possible to obtain interchangeable screws, if the leading screws by which they are made have all been cut on the same screw-cutting lathe, or are at least cut on benches which are fitted with a leading screw manufactured on the same original bench. If another link is interposed, differences in the screws turned out become perceptible. As a consequence of the finding of the committee a screw-cutting lathe has been set

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[1] *Electrician* (London), Nov. 11, 1904, p. 149.

up at the National Physical Laboratory, where leading screws for screw-cutting lathes are to be manufactured.[1] The same experience has been had in other countries, where nominally 'Whitworth's threads' are used. It is not possible to make screws interchangeable by prescribing their dimensions, the only way is to obtain taps and dies or leading spindles cut by the same tools. If it is a case of extreme accuracy, there is no difficulty in cutting English thread by means of a metric lathe, or *vice versa.*"

To appreciate just what would be the immediate effects of the adoption of the metric system in mechanical engineering it is interesting to study the experience of a large engine works and machine shop in England—Messrs. Willans and Robinson, of Rugby—which enjoys a reputation for extremely accurate work together with progressive ideas associated with the best engineering practice. This firm employs in its works the metric measures of length, and not only are they preferred by their draughtsmen and engineers, but also by the workmen in the shops, who did not experience the slightest difficulty in accustoming themselves to the new system or to employing it interchangeably with the customary measures. Inasmuch as this shop has been and is now experiencing some of the conditions attendant on a transition period from the customary to the metric measures its experiences are of interest. They employ bolts whose diameter is turned to the nearest even millimeter larger than the size of thread and on them cut a thread of the standard Whitworth pattern. One of their engineers, Mr. Ernest R. Briggs, in describing the use of the metric system in the shop's work has written:[2] "I have seen new machines built in the metric system side by side with existing lines built in the English system, and I have seen standard parts of one set of machines made to work in with standard parts of the other set, and I have also made and sent into the shops drawings in which a single large and complicated casting has been figured in each system. I can make no defence for

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[1] The screw of this lathe is six feet in length, and is made of compressed steel, the thread being cut with such accuracy that it is said to be correct to $\frac{1}{10000}$ of an inch at 60° Fahrenheit. The lathe is installed in a constant temperature room at Bushy House. [Authors.]

[2] Ernest R. Briggs, p. 450, vol. xxv. *American Machinist*, 1902; also a second paper by the same author on p. 1347 of the same volume.

this latter, but it shows what can be done in working the two systems side by side during the transition period."

In England there is at present the beginning of a lack of uniformity, as during recent years much improved machinery has been imported from the United States and from Germany and Switzerland. The former has screws cut to the Sellers thread, while in the latter the S.I. system is being widely and increasingly used. Consequently, so long as English engineers will go into the market for the best machinery irrespective of its source, as is now the tendency of the best and most progressive manufacturers, there is bound to be an increasing lack of uniformity in screws and screw-threads.

As to the effect of the introduction of the metric system into the manufacture of machinery, we cannot do better than conclude by quoting from the remarks of Mr. S. M. Vauclain, the superintendent of the Baldwin Locomotive Works of Philadelphia, Pa. Mr. Vauclain's testimony is not only interesting and most valuable from his high reputation as a mechanical engineer, but from the position that his company enjoys in the manufacturing world. Locomotives from its works have been shipped all over the world, while the actual manufacture has been systematized and specialized to such an extent that unrivalled speed of construction as well as largeness of output has been attained. Mr. Vauclain says:[1] "So far as the metric system is concerned from a manufacturer's standpoint, it certainly should have no terrors. Where—in what workshop—can you find a dozen men who will measure the same piece of work and find the same result with the ordinary 2-foot rule, or such scales as are ordinarily provided for their use? Could any manufacturer in America to-day rely upon the accuracy of the measurement of its employees in its products? Instead of having first-class fits and interchangeability he would have first-class misfits and ruination of his trade." Referring to the vast amount of fitting involved at the Baldwin Works, where there is an output of five locomotives daily and a force of workmen aggregating 11,500, Mr. Vauclain goes on to say, ". . . it can readily be understood how poorly these locomotives would be fitted together if we relied upon each and every one of these 11,500 men to do the measuring necessary

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[1] S. M. Vauclain, p. 414, vol. cliii. *Journal of Franklin Institute*, 1902.

to fit these parts together with the drawings furnished by the draughtsmen in their hands."

Discussing the actual relation of the measures to the work of designing and construction, he says: "What is the natural proceeding, then, in a workshop of this kind; you receive the drawings from the drawing room; they are all made to, we will say, the English measure—12 inches to the foot, 3 feet to the yard, or whatever you please—no matter how you may see fit to speak of it; but really and truly these drawings are not made to the ordinary English measure: they are made to a scale which is adopted, and which represents 12 inches to the foot, or 3 feet to the yard, or so many sixteenths inches to an inch. The scale that we have adopted in our draughting room is a scale of 2 inches to the foot, and in comparing everything that we look at, we do not consider the foot at all: but if it is 2 inches long it is a foot long."

"When a change of this kind would commence in any manufacturing establishment, it would first commence in the drawing-room (because unless the drawings were made in accordance with the metric system, the men in the shop could never work to it), and there would be very few gauges in use in the shop that would have to be changed, because the gauges do not depend upon the figured dimensions on the drawings; the drawings would all be figured for the gauges. A certain gauge would be called for instead of a certain dimension. In our works to-day there is not a single hole drilled in a connecting rod where the straps are fitted on the stub ends of the rods, that is drilled to a dimension; the drawings do not refer to any dimensions; we have no use for dimensions, but we have for gauges. They are marked to be drilled with a certain gauge and a certain bushing piece. You could not use an inch and a quarter drill in a inch and an eighth bushing. Whatever bushing you use determines the size of the drill you are going to use; and whatever gauge you use determines the distance apart the holes may be and the number of them, and the distance they are from the end to the stub. The workman goes ahead and drills regardless of the consequences in accordance with the gauge that is ordered on the drawing; and the result is that these parts are perfectly interchangeable, and hundreds and thousands of these parts are duplicated from time to time and shipped to almost every country on the face of the earth, and that without a single dimension either metric or English on the card—simply the gauge number calling for that part. This may be met with the remark that those people who do not do their work with gauges would not find it so easy to change; but that is easily confronted by stating that no first-class shop, or any shop, no matter how small it might be, that desired to enter into competition with the world would ever do its work in any other way and expect to succeed; it would die a natural death sooner from the fact that it failed to use gauges or jigs for the output of its work—even though it had only one of a kind to make—much sooner than it would if it undertook to use the metric system."[1]

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[1] S. M. Vauclain, p. 417, vol. cliii. *Journal of the Franklin Institute.*

CHAPTER VIII.

METRIC SYSTEM IN MEDICINE AND PHARMACY.

In no branches of scientific work is there greater need for uniformity of weights and measures than in pharmacy and medicine, where the entire world is drawn upon for drugs and chemicals for therapeutic purposes, and where the latest discoveries of such agents, or new methods of their use, are immediately communicated to the medical profession in every civilized country. With uniformity of measures there would result uniformity of treatment, and the ability to compare various methods in different cases. In fact, there is no reason why the medical profession should not be able to write and speak in the same language as concerns their weights and measures throughout the world just as much as the chemist and other workers in pure and applied science; such a condition would also facilitate the exchange of scientific information, which in the case of medical intelligence would be of incalculable value. In addition to this must be considered the commercial advantages to the general wholesale drug trade, the manufacturing chemist, and the retail pharmacist, due to the fact that many drugs are produced in metric-using countries, and are there sold and exported according to such measures. These same drugs, when they reach English-speaking countries, customarily are sold according to avoirdupois weight, and are then compounded according to apothecaries' weight—a system which is a survival from mediaeval times, and which finds few, if any, defenders on grounds other than its customary usage. The fact, however, must be considered that the manufacture and distribution of pharmaceutical products is a trade that is selfcontained, as it were, and we do not find the retail consumption of drugs and chemicals save for medicinal purposes, where the measurements are by spoonfuls or similar devices, and are usually at the direction of a physician, a matter of great interest in the daily life of the public. In other words, the buying, selling, and compounding of drugs and chemicals concerns the physician and pharmacist rather than the general public, who, however, are the ultimate consumers, but whose wants are not such as to require the use of any particular system of weights and measures, much less to insist upon it. The use of the metric system among the manufacturers and dealers in drugs and chemicals has been constantly on the increase, in fact some of them furnish their products altogether according to metric units. On the other hand, the European chemical manufacturer must provide special containers for all of his products intended for the American market. Therefore, it is a fact that manufacturers and dealers in drugs and chemicals are more than willing to adopt metric weights and measures exclusively, if they are not already in use. Furthermore, we know that the pharmacist is convinced of the availability of the metric system inasmuch as it has been adopted universally in continental Europe (in Germany since 1858), and figures exclusively in the United States Pharmacopoeia, and conjointly in the British Pharmacopoeia of 1898. This brings us to the medical profession, and here we find that in English-speaking countries there has been great progress in the use of metric weights and measures in writing prescriptions, but that owing to the conservative tendencies of medical colleges it is by no means general, and while the majority of pharmacists stand ready to compound metric prescriptions, comparatively few American practitioners write them. That there is no difficulty involved is shown by the ease with which the system was adopted by the United States Marine Hospital Service, the Medical Department of the United States Army, and the Medical Department of the United States Navy, as will be further explained below; while the fact that it is eminently desirable is demonstrated not only from the testimony of those that have used it, but from resolutions adopted at various times by representative national organizations of physicians and surgeons. Despite the fact that there has been no active campaign in behalf of the metric system waged among physicians there has been great progress, and when its advantages are more thoroughly realized it is believed there will be little opposition to completely dropping the absurd antiquated apothecaries' weights. The science of medicine to-day is closely connected with chemistry, physiology, biology, microscopy, and other sciences in which measurement plays a most important part. For example, in all experimental medicine the doses given to animals are measured in metric measures, in pathology the dimensions of an organ or any part of it are always stated in centimeters or millimeters, while the oculist employs metric measures in all his measures of focal length. In short, wherever medicine comes into contact with natural or exact science we find that the metric system is employed, and there is no reason why it should not be used universally. The only excuse advanced is that the practitioner has learned all his doses on the basis of the old measures, and that any change not only might result in inconvenience but in possible danger to the patient, inasmuch as a mistake that might prove fatal could be made in writing out the quantities. This is indeed a very weak objection, as the pharmacist or his clerk is constantly on the lookout for errors of this or any other kind in prescriptions. Furthermore, the more advanced physician is constantly reading in medical journals of new methods of treatment employed in Europe, where of course the metric weights and measures are altogether employed, and desiring to adopt such remedies in his own practice he must either employ the metric measures, or translate them into English, either operation requiring a knowledge of the metric system.

In pharmacy there are two different methods of compounding prescriptions according to the metric system, which, while fundamentally different, in their actual results do not occasion any very serious discrepancies. In Continental Europe and in countries where the metric system is exclusively used, it is the practice to measure all substances entering into a prescription, whether solid or liquid, by weight, and this consequently is known as the gravimetric method. That is, the quantities are denoted by grams, and in Germany no designation of the unit follows the number, grams being understood in every case, as no other units are employed for this purpose. This, of course, furnishes a very accurate method; but in the United States and

Great Britain, where the metric system is used it is customary to employ what is termed the volumetric method, where the fluids are measured by volume or capacity measure, the quantities being indicated in cubic centimeters. The solids, of course, are weighed in grams, and it is usual to write after the number the abbreviation *gm.* to distinguish from *gr.* denoting grains, as used in the older system. Inasmuch as the specific gravity of water is taken as unity, and one cubic centimeter of water at its temperature of maximum density weighs one gram, it will be seen that for water and other liquids of approximately the same specific gravity there is no difference between the two methods, and the majority of the liquids used in compounding prescriptions are so near to water in specific gravity that little trouble is occasioned; but there are a few instances in which this difference is material, according as the liquid is either considerably lighter or heavier than water. These few should be borne in mind in comparing formulae on the gravimetric system with those on the volumetric. Of the substances lighter than water the most important are ether, whose specific gravity is ·736 at 0°C. and spirits of nitrous ether, whose specific gravity is ·837. Consequently, speaking approximately, four parts by weight of these liquids will occupy an equivalent space to five parts by weight of water. Alcohol (proof spirit) sp. gr. 0·79 at 20° Centigrade is another substance similar in this respect. On the other hand, dealing with liquids heavier than water, we find that glycerin stands in such a ratio that five parts by weight of it occupy the same space as four parts of water, while with syrup this ratio is four to three, and with chloroform three to two. It is, of course, possible to indicate on the prescription that the quantities are to be taken by weight; but except in such cases as above noted, or in those of an extraordinary character, the volumetric method is employed, and not only corresponds more closely with the older method, but also is much more expeditious, as the fluids may be poured from graduated measuring glasses in much less time than they could be weighed.

The profession at large was not so quick to see the advantages of the metric system as the medical departments of the United States Government, and the first of these to adopt the innovation was the Marine Hospital Service, where, in accordance with Department Circular 39, dated April 27th, 1878, it was ordered that "The Medical Officers of the Marine Hospital Service will hereafter, for all official, medical and pharmaceutical purposes, make use of the Metric System of Weights and Measures."

This action, which was the first Government order issued in the United States to make the use of the metric system obligatory for any purpose whatever,[1] followed the report made to Surgeon-General John M. Woodworth, which was prepared by Oscar Oldberg, Phar.D., then Chief Clerk and Acting Medical Purveyor, U.S. Marine Hospital Service, in which he called attention to the advantages of the metric system, and provided the necessary rules for expressing quantities in that system, and also described the necessary methods to be followed in writing metric prescriptions.

In 1881 the Bureau of Medicine and Surgery in the U.S. Navy adopted the system, as on April 15th of that year there was approved by Secretary William H. Hunt a small volume entitled, *Instructions for Medical Officers of the United States Navy*, prepared by Medical Director Philip S. Wales, U.S.N. On page 10, Article 2, Section 1, was the official direction that "the Metric System of Weights and Measures shall hereafter be employed in the Medical Department of the Navy." Accordingly, the "Supply Table" in this volume was prepared on a metric basis, and supplies have since been issued in accordance with this system.

In 1894 the metric system was adopted by the medical department of the United States Army, and was put into operation under the provisions of the accompanying order.

WAR DEPARTMENT,
SURGEON GENERAL'S OFFICE,
WASHINGTON, *April* 13, 1894.

CIRCULAR:

Upon the publication of the new Supply Table and receipt of the new forms, all requisitions, invoices, receipts, and returns pertaining to medical supplies will be in accordance with the metric system of weights and measures.

After the 30th day of June, 1894, the use of this system in writing

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[1] See Oldberg, *Weights, Measures and Specific Gravity*, Chicago, 1888, p. 18.

official prescriptions is desired; on and after the 1st day of January, 1895, such use is hereby ordered.

Metric measures, weights, and prescription blanks will soon be issued to all posts without requisition.

Until medical supplies now in stock in troy and avoirdupois weights are exhausted, the following approximate values may be considered as equivalent in transferring original packages:

1 ounce = 30 grammes.
1 pound = ½ kilogram.
1 fluid ounce = 30 cubic centimeters.
1 pint = 500 cubic centimeters.
1 quart = 1 liter.
1 yard = 1 meter.

GEO. M. STERNBERG,
Surgeon General, U.S. Army.

Approved:
Daniel S. Lamont,
Secretary of War.

This order was promptly carried out on the dates specified, and all supplies were not only handled within the department, but were purchased from dealers according to metric weights and dimensions. In addition, the army surgeons began writing their prescriptions on the metric basis without protest or difficulty, and the system was soon in successful operation, and in 1902 was pronounced by Surgeon-General Sternberg as eminently satisfactory, the General testifying before the Committee on Coinage, Weights and Measures, Congress, February 15, 1902, when asked why he would not go back to the old system:

"Because it (the metric system) is so decidedly superior. It is working smoothly, and we have no difficulty whatever—no protests on the part of the people we deal with, from whom we purchase. The wholesale druggist must necessarily be familiar with it."[1]

General Sternberg also said that the principal reason for the adoption of the system was the greater simplicity of the decimal system, and furthermore it was successfully used in other countries, and was a better system than the one in use. An important test came in the Spanish-American War, when the

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[1] Page 83, *The Metric System of Weights and Measures.* Committee on Coinage, Weights and Measures (Hearing), February 15, 1902.

medical department was increased by a number of volunteer and contract surgeons; but the latter experienced no difficulty in conforming to the regulations.

In England the feeling of the advanced members of the medical profession has been most favourable to the metric system, and in 1904 the General Medical Council adopted the following resolution in reference to the Bill then before the House of Lords: "That the President (with the Chairman of the Pharmacopoean Committee) be requested to inform the Lord President of the Privy Council that in the opinion of the Council it is desirable that, after a sufficient period to be fixed by law, the metric system of weights and measures should become the one legal system for the preparation and dispensing of drugs and medicines; that the Council would view with favour the passing into law of a Bill such as that now before Parliament, entitled the 'Weights and Measures (Metric System) Bill'; and that in that event the Council would be prepared to take all necessary steps to give effect to the law by making the proper modifications in the British Pharmacopoeia."

The correctness of the prescription when written in metric units is much more likely to be ensured, as there is no possibility of mistaking the various units, since but two are used —the gram for solids, and the cubic centimeter for liquids. In a prescription written in apothecaries' weights and measures, on the other hand, not only are there numerous units—as pounds, ounces, drachms, scruples, grains, minims, etc.—but these are denoted by alchemistic characters which, at least in the case of ounces and drachms, are susceptible of confusion. Thus, not only is there the danger of errors in figures which is common to both methods, but in the case of the older system there are also the characters. Furthermore, with apothecaries' weights it is customary to denote the quantities by Roman figures or letters, which are much more readily confused than the Arabic figures employed in metric prescriptions. If the decimal line is used, as in a cash account, the danger of a misplaced decimal point, or of an occasional dot being taken as a point, is obviated. In fact, these possible errors attributed to the metric system have been found by experience to be altogether imaginary, for a misplaced decimal point decreases or increases a dose *ten-fold.* The dispenser would therefore detect the error at a glance. Then there is the further advantage that it is possible to send by telegraph a metric prescription with far greater facility than one where the Roman characters are employed.

While the gravimetric method may be the most scientific and exact, yet it must be remembered that the dose cannot be administered to the patient in the great majority of cases with anything like scientific accuracy, and it is usual to employ various domestic glasses and spoons, which of course give a volumetric measurement. In general certain rough equivalents amply suffice, and the following measurements are used in the United States and France:

A tea-spoonful	= 1 fluid drachm,	= 5 grams of water
A dessert-spoonful	= 2 fluid drachms,	= 10 „ „
A table-spoonful	= ½ fluid ounce,	= 15 „ „
A tumblerful	= 8 fluid ounces,	= 240 „ „
A wine glass (U.S.A.)	= 2 „ „	= 60 „ „
A wine glass (French)	= 5 „ „	= 150 „ „

CHAPTER IX.

INTERNATIONAL ELECTRICAL UNITS.

Beside the units incident to our every-day life which we have already discussed, it is possible to derive from the metric system in connection with the ordinary unit for the measurement of time employed throughout the civilized world, a complete system of units that will answer for the measurement of any and all physical quantities. For such a system it is necessary to have as the bases certain fundamental units, and with them we may build up and extend the system as occasion demands. It has been found that, starting with units of length, mass, and time, a satisfactory system can be evolved; and though there have been several such systems proposed, yet the one founded on the centimeter as the unit of length, the gram as the unit of mass, and the second as the unit of time, has met with the greatest favour. It has for many years been the only one employed in scientific work, and has served as a basis for other and practical units when such have been required or desired. As the units mentioned have been adopted for most scientific work, being as small as were convenient to employ in ordinary measuring processes, it is easy to see why they were chosen eventually as the basis of a system of units that should be complete and symmetrical. From the names of the fundamental units this system is known as the C.G.S. system, and it is our purpose to outline briefly its development in order that we may trace the derivation of some of the ordinary electrical units now in every-day use, and which are essentially metric in their origin. The first suggestion of such a system of units was due to Carl Friedrich Gauss, who in 1832 proposed a system of so-called absolute units, which had as its base the fundamental units of length, mass, and time. This system was devised by Gauss while engaged in the study of terrestrial magnetism, in which the intensity of the earth's magnetism, as well as the declination and dip, was to be measured at different points in Europe. For this purpose a German Magnetic Union had been organized by Gauss and Alexander Von Humboldt, and was actively engaged in magnetic studies from about 1834 to 1842. Previously there had been no unit for the intensity of magnetism, and English physicists had taken the intensity at London as the standard. Gauss believed that it would be more scientific, as well as more practical, if a system were devised which would be independent of season or place, as well as of instruments and external conditions. Accordingly, as the system which he proposed in 1832 was based merely on the three fundamental units mentioned, he termed it the Absolute System. In this system it was possible to derive all necessary units from the three selected as fundamental; thus a unit of velocity was obtained by defining it as such a velocity as a body would have in travelling unit distance in unit time. Unit acceleration was the acceleration that a body would experience when it gained or lost unit velocity in unit time. Then, for the unit of force, it was only necessary to take such a force as would impart unit velocity to unit mass in unit time—that is, the unit acceleration. Consequently, when it came to defining a unit of intensity of magnetism, Gauss took such a quantity of magnetism as would exert unit force on a similar quantity at unit distance.[1] Now, as magnetic force was manifested by the attraction or repulsion of a magnetic pole when placed in a magnetic fluid, it would be possible to measure the force by mechanical methods, and for this he deduced the necessary equations.

In this way, by mathematical processes which are interesting but

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[1] *Resultate aus den Beobachtungen des Magnetischen Vereins*, 1836-1842; *Soc. Gott.* viii. 1832-1837; *Pogg. Ann.* xxviii. §§ 241, 591 (1833); Gauss, *Werke*, v. § 79-118.

need not be discussed here, it was possible for Gauss to determine the intensity of the earth's magnetic field at any given point on its surface. While the process of derivation was the same as for the modern C.G.S. system, yet Gauss employed as the fundamental units in his Absolute System the millimeter as the unit of length, the milligram as the unit of mass, and the second as the unit of time. By similar reasoning, it was possible to define the unit charge of electricity as such a charge as would act on a similar charge at unit distance with unit force. So useful was this idea of absolute measurement that it was straightway adopted by Wilhelm Weber, (1804-1891) and found application in his experiments to measure the intensity of an electric current, the intensity of electromotive force and of resistance; the latter investigation being further developed by Rudolf Kohlrausch (1809-1858) in some most valuable investigations. Weber's work[1] is remarkable not only for the fact that he applied absolute measurements in electricity, but for his showing that electricity was but a manifestation of mechanical energy, and consequently could be measured in terms of length, mass, and time. There was, however, an important difference, in that it was not possible to measure directly quantities of electricity, but it was necessary to make such measurements by the effect on some external object. For example, when Weber came to determine the intensity of an electric current in absolute measurement, he found three ways open to him. The first was to determine the strength of current by its chemical or electrolytic effect. In other words, a unit current would be that which decomposed a unit mass of water into its chemical elements in unit time. Secondly, the magnetic effect of the electric current also served as a basis for measuring a current of electricity, and a unit of intensity of current he defined as such a current as would exert, upon a magnet pole, the same force as an infinitely small magnet of unit moment, placed at the center of a closed circuit of unit area around which the current should flow, and perpendicular to its plane. In other words, he defined his unit of current according to the measurements which could be made with a tangent galvanometer, as will be described below. Then thirdly, the intensity of current could

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[1] Rosenberger, *Geschichte der Physik*, vol. iii. pp. 302, 514-519. Braunschweig, 1890. Weber, *Pogg. Ann.* xcix, p. 11, 1855.

QUANTITY.	C.G.S. UNITS.			PRACTICAL UNITS.		
	Name.	Symbol.	Definition.	Name.	Symbol.	$\frac{\text{Practical.}}{\text{C.G.S.}}$
Length	Centimeter	cm.	One hundredth of the international meter	Centimeter	cm.	1
Mass	Gram	gr.	Mass of one cubic centimeter of water at temperature of maximum density	Kilogram	kgr.	1000
Time	Second	sec.	1 second mean solar time (Solar year is 365 days, 5 hours, 48 minutes, and 46 seconds.)	Second	sec.	1
Volume	Cubic centimeter	c.c.	A cube of water at maximum density whose mass is 1 gram	Liter	l.	1000
Velocity	None	None	1 centimeter per second	None	None	1
Acceleration	None	None	Change of velocity of a unit per second	None	None	1
Force	Dyne	None	Imparts unit acceleration to unit mass	Megadyne	None	10^6
Work Energy	Erg Erg	None	A dyne acting through one centimeter	Joule	None	10^7
Power	None	None	One erg per second	Watt	None	10^7
Angle	Radian	None	The arc is equal to the radius	Degree	°	$\frac{1}{57{\cdot}2958}$
Angular Velocity	None	None	Radian per second	360° per minute	r.p.m.	$\frac{1}{9{\cdot}5493}$
Angular Acceleration	None	None	Change of angular velocity of unit per second	None	None	1
Moment of Rotation	None	None	A force of 1 dyne on a lever arm of one centimeter	None	None	1
Torque						
Directive force						
Momentum	None	None	One gram with unit velocity	None	None	1
Curvature	None	None	Direction is changed by the unit angle in the centimeter of length	None	None	1
Tortuosity						
Solid Angle	None	None				
Pressure	None	None	One dyne per square centimeter	Barie	None	10^6
Magnetic Pole	None	None	A unit pole acting upon an equal pole at one centimeter distance exerts a force of one dyne	None	None	1
Magnet	None	None	A unit pole at each end a centimeter apart	None	None	1
Intensity of Magnetization	None	None	A unit magnet per cubic centimeter of volume	None	None	1

QUANTITY.	C.G.S. UNITS.			PRACTICAL UNITS.		
	Name.	Symbol.	Definition.	Name.	Symbol.	Practical. C.G.S.
Magnetic field, or flux density	Gauss	H or $\mathfrak{H}$	A field which exerts one dyne force upon a unit magnetic pole. It has one Faraday line of force per square cm.	Gauss Kilogauss	None None	1 10^3
Flux of Induction	Maxwell	B or $\mathfrak{B}$	A flux of one Faraday line of force - - -	Maxwell	None	1
Permeability	None	μ	When unit field produces unit flux of induction. B divided by H	None	None	1
Susceptibility	None	K	When unit field produces unit intensity of magnetization. I divided by H	None	None	1
Electric Current	None	C	A unit current one centimeter long exerts a force of one dyne upon a unit magnet pole one centimeter distant	Ampere	None	$\frac{1}{10}$
Electromotive force, potential difference	None	$E.M.F.$	Is produced when a conductor cuts one Faraday line of force per second	Volt	None	10^8
Resistance -	None	R	Such that a unit of electo-motive force will produce the unit current through it.	Ohm	ω	10^9
Quantity of Electricity	None		The quantity flowing per second in a unit current	Coulomb	None	$\frac{1}{10}$
Capacity -	None		Such as will hold unit quantity when charged to unit potential difference.	Farad Microfarad	None None	10^{-9} 10^{-3}
			ELECTROSTATIC SYSTEM.			
Quantity of Electricity	None		Such that it will exert a force of one dyne upon an equal quantity at one centimeter	Coulomb	None	3×10^9
Potential Difference	None	$P.D.$	Exists between two points when unit work (erg) is involved in moving unit quantity of electricity from one point to the other	Volt	None	$\frac{1}{3} \times 10^{-2}$
Current -	None		When unit quantity flows per second - - -	Ampere	None	3×10^9

also be measured by the effect of two currents flowing along parallel conductors distant from each other by a unit length.

Following out these three methods, Weber made a series of absolute measurements and found that they possessed a certain ratio to each other. He also found that, with the galvanometer, he was able to measure the quantity of electricity with which a conductor was statically charged, by allowing it to be discharged or flow to the earth through the galvanometer. Having thus been able to measure the intensity of current in absolute units, which (following the example of Gauss) were based on the millimeter, milligram, and second, Weber then proceeded to make absolute measurements of electromotive force. The absolute unit of electromotive force he defined as that induced by unit magnetic force in a circular conductor of unit area, if this circular conductor were turned from a position parallel to the direction of the magnetic force into one perpendicular to it in the time of one second.[1] Inasmuch as he was able to use the magnetic field of the earth, whose intensity could be measured accurately, and as by his previous experiments he was able to measure the intensity of the current, using the apparatus known as the earth inductor, he was soon able to make a direct measurement of electromotive force. The earth inductor, it may be said in passing, consisted of a large coil of wire whose axis of revolution was perpendicular to the lines of magnetic force, so that when the coil was revolved a current was induced in it which could be measured by the galvanometer.

With methods for the absolute measurement of current and electromotive force already known and defined, it only remained to measure the resistance in absolute units, and this, of course, followed from Ohm's law, which had been known since 1827. According to this statement, the current was equal to the electromotive force divided by the resistance, and consequently it followed that a unit of resistance would be that through which unit electromotive force would produce unit current. This determination of the unit of resistance involved most elaborate experiments,

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[1] Rosenberger, vol. iii. p. 517; "Electrodynamische Massbestimmungen ins besondere Widertandsmessen," *Abhandl. der K. S. Gesellsch.* I. § 197, 1852; *Pogg. Ann.* lxxxii. § 337. Weber, *Abhandl. bei Begründung der K. S. Gesellschaft der Wissenschaft*, 1846; *Abhandl. der K. S. Gesellschaft d. Wissenschaft*, I. 1852.

which are among the most celebrated in all experimental physics, and their result was firmly to establish the absolute system on a thoroughly scientific basis.

There were, previous to this, various arbitrary electrical units suggested, and in more or less limited use.[1] Thus various lengths of copper, iron, or German silver wire of specified length, weight, and cross-section were suggested and employed as units. Perhaps the most conspicuous of these was the copper wire of prescribed dimensions and weight which was recommended by Jacobi,[2] of St. Petersburg, in 1846, to the physicists of Europe as the standard of normal resistance. This standard was determined in absolute units of resistance by Weber, but it did not prove entirely acceptable, owing to the changes taking place in the copper with time, and owing to the difficulties experienced in obtaining standard conditions. Accordingly, Werner Siemens, of Berlin, proposed, in 1860, following the suggestion of Marié-Davy made in 1843, to use mercury in defining the unit of resistance, and as a standard, a column of this substance one meter in length and one square millimeter in cross-section, measured at 0°C.[3] This also was measured by Weber in 1861, and later by Kohlrausch.

For electromotive force, it was customary at this time to employ the electromotive force of a constant battery, such as the Daniell cell, and in the case of a current, to make use of various arbitrary units. With the increase in the scientific knowledge of electricity, as well as in its industrial applications, such as the telegraph and submarine cable, it was realized that, for practical use, there should be a systematic and comprehensive system of electrical units, which would be based on certain fixed standards, and would be universally employed by electricians. This subject was accordingly taken up in Great Britain by the British Association for the Advancement of Science, and in 1861 a strong committee, composed of leading physicists and electricians, was appointed to investigate the subject and to report on suitable units. The subject was discussed in all its many bearings by

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[1] For a list with bibliography, see Rosenberger, *Geschichte der Physik*, vol. iii. pp. 519-520.

[2] Jacobi, *Comptes Rendus* (Paris), p. 277, vol. xxxiii.

[3] W. Siemens, *Poggendorff's Annalen*, cx. p. 1, 1860.

this committee, Weber's and other experiments were repeated, and the result was that an absolute system was adopted, only the centimeter, gram, and second were employed as the fundamental units in place of the millimeter, milligram, and second of Gauss and Weber. This committee not only reported in favor of the establishment of the C.G.S. system, but also fixed a certain number of so-called practical units, which, with slight modifications, are now in universal use.

The reason for this was that a number of the C.G.S. absolute units are either too large or too small to be employed in practical work. For example, the electromotive force of an ordinary Daniell cell would represent about 10^8 absolute units, and as the electrician of that time dealt with electromotive forces of this magnitude, rather than with those represented by a quantity so much smaller, it was convenient to multiply the absolute unit by 10^8 to obtain a convenient practical unit, which was designated by the name *volt.* Likewise with the *ohm,* or practical unit of resistance, which represented 10^9 absolute units. But in the case of the *ampere,* or unit of current, which, as we have seen, must follow from Ohm's law, the difference was not so large, and the absolute unit had merely to be divided by 10 to give the practical unit. This Commission decided on the *coulomb* as the unit of quantity, being 10^{-1} absolute units, and being the quantity of electricity conveyed by one ampere in one second. As a unit of capacity, the *farad,* or 10^{-9} absolute units, was taken, and measured the capacity of a condenser charged to a potential of one volt by one coulomb. As a more useful unit still, the *micro-farad,* or 10^{-6} part of a farad, was also established. For work, the *joule* was taken, representing 10^7 *ergs* or absolute units of work, and equivalent to the energy expended in one second by one ampere flowing through a resistance of one ohm. As a unit of power, the *watt,* or 10^7 ergs per second, represented the power of a current of one ampere flowing under a pressure of one volt, or one joule per second, and when multiplied by 1000 it gives the *kilowatt,* which soon became common in electrical work in place of the old familiar horse-power.[1]

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[1] For an interesting historical presentation which includes the text of recent legislation, see Wolff, "The So-called International Electrical Units," a paper presented at the International Congresses of Electricians at St. Louis, 1904.

In 1865 this committee made a determination of the ohm, and constructed a standard of platinum-silver to represent its value. This standard, by law, represented the legal unit of resistance in Great Britain, and was also known for many years as the B.A. (British Association) unit; in fact, holding its own, especially in English-speaking countries, until the adoption of the international ohm by the Chicago Congress of 1893.

Soon after this, the invention by Latimer Clark, in 1873, of a constant cell, which was found to have, under certain conditions, an electromotive force of 1·434 volts, furnished a standard of electromotive force which, while not legally defined until some years later, became widely used, and figured in many determinations.

So thoroughly was the C.G.S. system thought out by the British Association Committee, and so systematically were the practical units determined and defined that, despite minor inaccuracies, as shown by the experiments of German physicists, the system was favorably considered at the International Congress of Electricians held in Paris in 1881, and resolutions were adopted in which the C.G.S. electro-magnetic units were chosen as the fundamental units in terms of which the practical units should be defined. At a meeting held in 1884 an international commission decided on the length of the column of mercury for the standard ohm, and the legal ohm was defined as the resistance of a column of mercury of one square millimeter section, and of 106 centimeters length at a temperature of melting ice.

The ampere was defined as a current corresponding to 10^{-1} absolute C.G.S. electro-magnetic units, while the volt was defined as an electromotive force which produced a current of one ampere in a conductor whose resistance was a legal ohm. This definition of the ohm did not carry with it universal acceptance, and the legal ohm was not made legal in Great Britain or in the United States; but in the meantime a number of prominent physicists, including Professor Henry A. Rowland in America and Lord Rayleigh in England, carried on further investigations to evaluate the true ohm, with the result that the length of the mercury column was found to be nearly 106·3 centimeters, which

Reprinted in *Bulletin* No. 1, Bureau of Standards, Washington, D.C. See *British Association Reports on Electrical Standards* (London, 1873).

accordingly was adopted by the British Association Committee in 1892, together with the definition of the column in length and mass, rather than by length and cross-section.

Meanwhile, in 1889, another international congress of electricians was held at Paris, at which, in addition to a number of decisions involving nomenclature, definitions of units of energy, power, and inductance were adopted. The *joule* was selected as the practical unit of energy and was defined as equal to 10^7 C.G.S. units, being equivalent to the energy disengaged as heat in one second by a current of one ampere flowing through a resistance of one ohm. As a practical unit of power the *watt* was taken, and was equal to 10^7 C.G.S. units, being the power of one joule per second. For inductance the *quadrant* was chosen as the practical unit, and was defined as equal to 10^9 centimeters. This congress also took the important step of recommending that the power of various electric machines, such as dynamos, motors, transformers, etc., should be rated in watts and kilowatts instead of horse-power, and this practice has generally prevailed even in non-metric countries such as Great Britain and America.

In 1893, in connection with the World's Columbian Exposition at Chicago, an International Congress of Electricians was held, and a Chamber of Delegates, composed of officials appointed by the various Governments, proceeded to define and name the various electrical units. By this time, owing to the increased use of electric lighting, various forms of power transmission, electric railways, and other important applications of electricity, the subject was one of prime interest, and required the most careful consideration of the Chamber of Delegates, which consisted of many of the world's most eminent physicists and electrical engineers. Its deliberations resulted in a series of recommendations which were reported to the Congress, and referred to the various nations of the world, by many of whom they were subsequently embodied to a greater or less extent in legal enactments making the use of the new units obligatory. In the United States such an Act was passed and approved, July 12, 1894.[1] These resolutions contained the following recommendations:

" *Resolved,*—That the several Governments represented by the delegates of this International Congress of Electricians be, and

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[1] *Revised Statutes of the United States, Supplement*, vol. ii. chap. 131, 1894.

they are hereby, recommended to formally adopt as legal units of electrical measure the following: As a unit of resistance, the *international ohm*, which is based upon the ohm, equal to 10^9 units of resistance of the Centimeter-Gramme-Second System of electro-magnetic units, and is represented by the resistance offered to an unvarying electric current by a column of mercury at the temperature of melting ice 14·4521 grammes in mass, of a constant cross-sectional area, and of the length of 106·3 centimeters.

"As a unit of current, the *international ampere*, which is one-tenth of the unit of current of the C.G.S. system of electro-magnetic units, and which is represented sufficiently well for practical use by the unvarying current which, when passed through a solution of nitrate of silver in water, and in accordance with accompanying specifications deposits silver at the rate of 0·001118 of a gram per second.

"As a unit of electromotive force, the *international volt*, which is the electromotive force that, steadily applied to a conductor whose resistance is one international ohm, will produce a current of one international ampere, and which is represented sufficiently well for practical use by $\frac{1000}{1434}$ of the electromotive force between the poles or electrodes of the voltaic cell known as Clark's cell, at a temperature of 15° C., and prepared in the manner described in the accompanying specification.[1]

"As a unit of quantity, the *international coulomb*, which is the quantity of electricity transferred by a current of one international ampere in one second.

"As a unit of capacity, the *international farad*, which is the capacity of a condenser charged to a potential of one international volt by one international coulomb of electricity.

"As a unit of work, the *joule*, which is equal to 10^7 units of work in the C.G.S. system, and which is represented sufficiently well for practical use by the energy expended in one second by an international ampere in an international ohm.

"As a unit of power, the *watt*, which is equal to 10^7 units of power in the C.G.S. system, and which is represented sufficiently well for practical use by work done at the rate of one joule per second.

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[1] No report was ever made by the committee to which the preparation of the specifications was entrusted. Its members were Professors Helmholtz, Ayrton, and Carhart, but the death of the first prevented the work.

"As a unit of induction, the *henry*, which is the induction in a circuit when the electromotive force induced in this circuit is one international volt, while the inducing current varies at the rate of one ampere per second."

Specifications for Construction and Use of the Silver Voltameter.

In the following specifications the term silver voltameter means the arrangement of apparatus by means of which an electric current is passed through a solution of nitrate of silver in water. The silver voltameter measures the total electrical quantity which has passed during the time of the experiment, and by noting this time the time average of the current, or if the current has been kept constant, the current itself, can be deduced.

In employing the silver voltameter to measure currents of about one ampere the following arrangements should be adopted:

The kathode on which the silver is to be deposited should take the form of a platinum bowl not less than 10 cms. in diameter and from 4 to 5 cms. in depth.

The anode should be a plate of pure silver some 30 sq. cms. in area and 2 or 3 mms. in thickness.

This is supported horizontally in the liquid near the top of the solution by a platinum wire passed through holes in the plate at opposite corners. To prevent the disintegrated silver which is formed on the anode from falling on to the kathode, the anode should be wrapped round with pure filter paper, secured at the back with sealing wax.

The liquid should consist of a neutral solution of pure silver nitrate, containing about 15 parts by weight of the nitrate to 85 parts of water.

The resistance of the voltameter changes somewhat as the current passes. To prevent these changes having too great an effect on the current, some resistance besides that of the voltameter should be inserted in the circuit. The total metallic resistance of the circuit should not be less than 10 ohms.

In the United States the foregoing recommendations were duly given force of law by an Act of Congress approved July 12, 1894, one section of which provided that the National

Academy of Sciences should prepare detailed specifications for the practical application of the definitions of the ampere and volt. Such specifications were accordingly prepared by a committee[1] of the Academy, and were adopted by that body on February 9, 1895. They are given in full below.

REPORT.

In the preparation of this report, in order to have the specifications accord with international usage, free use has been made of the English Government specifications and of certain papers prepared by Dr. K. Kahle of Germany, and Prof. H. S. Carhart of this country.

SPECIFICATIONS FOR THE PRACTICAL APPLICATION OF THE DEFINITIONS OF THE AMPERE AND VOLT.

SPECIFICATION A.—*The Ampere.*

In employing the silver voltameter to measure currents of about 1 ampere, the following arrangements shall be adopted:

The kathode on which the silver is to be deposited shall take the form of a platinum bowl not less than 10 centimeters in diameter, and from 4 to 5 centimeters in depth.

The anode shall be a disk or plate of pure silver some 30 square centimeters in area and 2 or 3 millimeters in thickness.

This shall be supported horizontally in the liquid near the top of the solution by a *silver rod riveted through its center.* To prevent the disintegrated silver which is formed on the anode from falling upon the kathode, the anode shall be wrapped around with pure filter paper, secured at the back by suitable folding.

The liquid shall consist of a neutral solution of pure silver nitrate, containing about 15 parts by weight of the nitrate to 85 parts of water.

The resistance of the voltameter changes somewhat as the current passes. To prevent these changes having too great an effect on the current, some resistance besides that of the voltameter should be inserted in the circuit. The total metallic resistance of the circuit should not be less than 10 ohms.

Method of making a measurement.—The platinum bowl is to be washed consecutively with nitric acid, distilled water, and absolute alcohol; it is then to be dried at 160° C., and left to cool in a desiccator. When thoroughly cool it is to be weighed carefully.

It is to be nearly filled with the solution and connected to the rest of the circuit by being placed on a clean insulated copper support to which a binding screw is attached.

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[1] Henry A. Rowland, Chairman; Henry L. Abbot, George F. Barker, Charles S. Hastings, Albert A. Michelson, John Trowbridge, Carl Barus.

The anode is then to be immersed in the solution so as to be well covered by it and supported in that position; the connections to the rest of the circuit are then to be made.

Contact is to be made at the key, noting the time. The current is to be allowed to pass for not less than half an hour, and the time of breaking contact observed.

The solution is now to be removed from the bowl and the deposit washed with distilled water and left to soak for at least six hours. It is then to be rinsed successively with distilled water and absolute alcohol and dried in a hot-air bath at a temperature of about 160° C. After cooling in a desiccator it is to be weighed again. The gain in mass gives the silver deposited.

To find the time average of the current in amperes, this mass, expressed in grams, must be divided by the number of seconds during which the current has passed and by 0·001118.

In determining the constant of an instrument by this method, the current should be kept as nearly uniform as possible, and the readings of the instrument observed at frequent intervals of time. These observations give a curve from which the reading corresponding to the mean current (time-average of the current) can be found. The current, as calculated from the voltameter results, corresponds to this reading.

The current used in this experiment must be obtained from a battery, and not from a dynamo, especially when the instrument to be calibrated is an electrodynamometer.

SPECIFICATION B.—*The Volt.*

Definition and properties of the cell.—The cell has for its positive electrode, mercury, and for its negative electrode, amalgamated zinc; the electrolyte consists of a saturated solution of zinc sulphate and mercurous sulphate. The electromotive force is 1·434 volts at 15° C., and between 10° C. and 25° C., by the increase of 1° C. in temperature, the electromotive force decreases by 0·00115 of a volt.

1. *Preparation of the mercury.*—To secure purity, it should be first treated with acid in the usual manner and subsequently distilled in vacuo.

2. *Preparation of the zinc amalgam.*—The zinc designated in commerce as "commercially pure" can be used without further preparation. For the preparation of the amalgam, 1 part by weight of zinc is to be added to 9 parts by weight of mercury, and both are to be heated in a porcelain dish at 100° C., with moderate stirring until the zinc has been fully dissolved in the mercury.

3. *Preparation of the mercurous sulphate.*—Take mercurous sulphate, purchased as pure; mix with it a small quantity of pure mercury, and wash the whole thoroughly with cold distilled water by agitation in a bottle; drain off the water and repeat the process at least twice. After the last washing,

drain off as much of the water as possible. (For further details of purification, see Note A.)

4. *Preparation of the zinc sulphate solution.*—Prepare a neutral saturated solution of pure recrystallized zinc sulphate, free from iron, by mixing distilled water with nearly twice its weight of crystals of pure zinc sulphate and adding zinc oxide in the proportion of about 2 per cent. by weight of the zinc sulphate crystals to neutralize any free acid. The crystals should be dissolved with the aid of gentle heat, but the temperature to which the solution is raised must not exceed 30° C. Mercurous sulphate, treated as described in 3, shall be added in the proportion of about 12 per cent. by weight of the zinc sulphate crystals to neutralize the free zinc oxide remaining, and then the solution filtered, while still warm, into a stock bottle. Crystals should form as it cools.

5. *Preparation of the mercurous sulphate and zinc sulphate paste.*—For making the paste, 2 or 3 parts by weight of mercurous sulphate are to be added to 1 by weight of mercury. If the sulphate be dry, it is to be mixed with a paste consisting of zinc sulphate crystals and a concentrated zinc sulphate solution, so that the whole constitutes a stiff mass, which is permeated throughout by zinc sulphate crystals and globules of mercury. If the sulphate, however, be moist, only zinc sulphate crystals are to be added; care must, however, be taken that these occur in excess and are not dissolved after continued standing. The mercury must, in this case also, permeate the paste in little globules. It is advantageous to crush the zinc sulphate crystals before using, since the paste can then be better manipulated.

To set up the cell.—The containing glass vessel, . . . shall consist of two limbs closed at the bottom and joined above to a common neck fitted with a ground-glass stopper. The diameter of the limbs should be at least 2 centimeters and their length at least 3 centimeters. The neck should be not less than 1·5 centimeters in diameter. At the bottom of each limb a platinum wire of about 0·4 millimeter diameter is sealed through the glass.

To set up the cell, place in one limb pure mercury and in the other hot liquid amalgam, containing 90 parts mercury and 10 parts zinc. The platinum wires at the bottom must be completely covered by the mercury and the amalgam respectively. On the mercury place a layer 1 centimeter thick of the zinc and mercurous sulphate paste described in 5. Both this paste and the zinc amalgam must then be covered with a layer of the neutral zinc sulphate crystals 1 centimeter thick. The whole vessel must then be filled with the saturated zinc sulphate solution, and the stopper inserted so that it shall just touch it, leaving, however, a small bubble to guard against breakage when the temperature rises.

Before finally inserting the glass stopper it is to be brushed around its upper edge with a strong alcoholic solution of shellac and pressed firmly in place. (For details of filling the cell, see Note B.)

NOTES TO THE SPECIFICATIONS.

(A) *The mercurous sulphate.*—The treatment of the mercurous sulphate has for its object the removal of any mercuric sulphate which is often present as an impurity.

Mercuric sulphate decomposes in the presence of water into an acid and a basic sulphate. The latter is a yellow substance—turpeth mineral—practically insoluble in water; its presence, at any rate in moderate quantities, has no effect on the cell. If, however, it be formed, the acid sulphate is also formed. This is soluble in water, and the acid produced affects the electromotive force. The object of the washings is to dissolve and remove this acid sulphate, and for this purpose the three washings described in the specification will suffice in nearly all cases. If, however, much of the turpeth mineral be formed, it shows that there is a great deal of the acid sulphate present, and it will then be wiser to obtain a fresh sample of mercurous sulphate, rather than to try by repeated washings to get rid of all the acid.

The free mercury helps in the process of removing the acid, for the acid mercuric sulphate attacks it, forming mercurous sulphate.

Pure mercurous sulphate, when quite free from acid, shows on repeated washing a faint yellow tinge, which is due to the formation of a basic mercurous salt distinct from the turpeth mineral, or basic mercuric sulphate. The appearance of this primrose-yellow tint may be taken as an indication that all the acid has been removed; the washing may with advantage be continued until this tint appears.

(B) *Filling the cell.*—After thoroughly cleaning and drying the glass vessel, place it in a hot-water bath. Then pass through the neck of the vessel a thin glass tube reaching to the bottom, to serve for the introduction of the amalgam. This tube should be as large as the glass vessel will admit. It serves to protect the upper part of the cell from being soiled with the amalgam. To fill in the amalgam, a clean dropping tube about 10 centimeters long, drawn out to a fine point, should be used. Its lower end is brought under the surface of the amalgam, heated in a porcelain dish, and some of the amalgam is drawn into the tube by means of the rubber bulb. The point is then quickly cleaned of dross with filter paper, and is passed through the wider tube to the bottom and emptied by pressing the bulb. The point of the tube must be so fine that the amalgam will come out only on squeezing the bulb. This process is repeated until the limb contains the desired quantity of amalgam. The vessel is then removed from the water bath. After cooling, the amalgam must adhere to the glass, and must show a clean surface with a metallic luster.

For insertion of the mercury, a dropping tube with a long stem will be found convenient. The paste may be poured in through a wide tube reaching nearly down to the mercury and having a funnel-shaped top. If the paste does not move down freely it may be pushed down with a small glass rod. The paste and the amalgam are then both covered with the zinc sulphate crystals before the concentrated zinc sulphate solution is poured in. This should be added through a small funnel, so as to leave the neck of the vessel clean and dry.

For convenience and security in handling, the cell may be mounted in a suitable case, so as to be at all times open to inspection.

In using the cell, sudden variations of temperature should, as far as possible, be avoided, since the changes in electromotive force lag behind those of temperature.

Somewhat similar specifications were prepared by the Board of Trade of Great Britain and were promulgated in an Order in Council, August 23, 1894. The chief points of difference besides phraseology were in the specifications for the Clark cell, but these were in no way radical. Canada also adopted regulations essentially in harmony with the above, as did France, Austria, and Belgium; while in Germany the measure of current was made of prime importance, and the specifications for the silver voltameter and the method of measurement are somewhat modified.[1]

At the Paris International Electrical Congress of 1900 it was decided to give the name of Gauss to the C.G.S. unit of magnetic field intensity, or to such a field as would be produced by the unit of magnetism at the distance of one centimeter, or, in other words, such a field as would act on a unit pole with the force of one dyne. Likewise the same congress gave sanction to the name of Maxwell to denote the C.G.S. unit of magnetic flux or the number of magnetic lines within a tube of force. The magnetic flux would consequently be equal to the product of the intensity of the field by the area, and the unit would be a single magnetic line. Thus magnetic flux would correspond to current, being dependent on the magnetomotive force and the magnetic reluctance. This step was taken as these C.G.S. units were employed in actual practice and apparatus was in common use by means of which field intensities could be measured directly. The name *kilogauss* is also employed to denote a thousand times the unit. Other propositions have been made for names for the C.G.S. magnetic units, but they have not yet been adopted legally

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[1] The full text of the various laws and regulations will be found in the Appendix to Wolff's paper on the "So-called International Electrical Units," *Bulletin of the Bureau of Standards* (Washington, 1901), No. 1, vol. 1, pp. 61-76.

as they have not been considered essential, though strenuously urged by many prominent electricians.

After the adoption of the resolution defining the electrical units, at the Electrical Congress held at Chicago in 1893, and their subsequent ratification, either in whole or in part, by various governments, it was found that there were slight errors in these definitions, especially in the electromotive force of the Clark cell, which has been found to be nearer 1·433 volts than 1·434 as defined. It was stated by some physicists that a cadmium (Weston) cell[1] was more constant, had a lower temperature coefficient, and could be defined with greater accuracy, while further researches on the Clark cell itself gave a value for its electromotive force somewhat different from that stated in the resolutions; and, in fact, in Germany the value 1·4328 volts was adopted as corresponding to the realized value of the ohm and ampere. There was also a demand for new units, and for changes in the nomenclature in the existing units. Consequently, at the Electrical Congress held in connection with the St. Louis Exposition, 1904, a chamber of representatives of various governments was in session to pass upon these propositions. It was the opinion of the Chamber of Delegates that these propositions were of sufficient character to warrant a thorough discussion, but, at the same time, the delegates did not seem to be of the opinion that they should be settled at such a meeting. Accordingly, they resolved that a permanent Commission, consisting of representatives from various governments, should be convened, and that to such an International Commission should be entrusted the decision of the matter. Such an international body would have much the same duties as the International Commission of Weights and Measures, and, without doubt, its deliberations and decisions would be equally acceptable and important to electricians and physicists.

In concluding this chapter on electrical units it is hardly necessary to more than call attention to the great benefits that

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[1] The Weston cell has for its electrodes cadmium amalgam covered with a layer of crystals of cadmium sulphate, and pure mercury in contact with a paste of mercurous sulphate, cadmium sulphate crystals, and metallic mercury, while the electrolyte is a saturated aqueous solution of zinc sulphate and mercurous sulphate.

have been conferred on the electrical industry throughout the world by the employment, in all countries, of one and the same system of units of measurement. In fact, this condition has been advanced as one of the reasons for the rapid growth of the industry, and while various modifications of units have been demanded and discussed, they have only been adopted after they have been determined by an International Congress. No nation or group of electricians or engineers has ever found fault with the extensive use of the decimal system, and by the close connection of electrical units with the metric system such workers have been enabled to appreciate the advantages of the latter, so that in non-metric countries the electrical professions unanimously are found eagerly demanding its adoption. In fact, it has been truly said by a British electrical engineer,[1] than whom there is no one more competent to discuss the subject in its many aspects, that "so far as I am aware nobody has ever suggested that it would be to the advantage of any country to start a system of electrical units of its own."

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[1] Alexander Siemens, Presidential Address before the Institution of Electrical Engineers of Great Britain, Nov. 10, 1904, *Electrician* (London), Nov. 11, 1904, p. 149.

CHAPTER X.

STANDARDS AND COMPARISON.

In all systems of weights and measures based on one or more arbitrary fundamental units, the concrete representation of the unit in the form of a standard is necessary, and the construction and preservation of such a standard is a matter of primary importance. The reference of all measures to an original standard is essential for their correctness, and such a standard must be maintained and preserved in its integrity for purposes of comparison by some responsible authority, which is thus able to provide against the use of false weights and measures. Accordingly, from earliest times, standards were constructed and preserved under the direction of kings and priests, and the temples were a favorite place for their deposit. Later, this duty was assumed by the government, and to-day in addition we find the integrity of standards of weights and measures safeguarded by international agreement.

The progress of the science of metrology is not only well exemplified in these actual representations of various units, but is intimately connected with the construction of the prototypes of the fundamental standards. The mechanical processes and other features involved in their construction have so improved with time and with the growth of physical science, especially as it involves a constantly increasing degree of exactness in measuring, that the subject is one which warrants attention in even a brief treatise on weights and measures. In fact, metrology has been defined as: "That part of the science of measures which applies itself specially to the determinations of prototypes representative of the fundamental units of dimensions and of mass, of the standards of the first order which are derived from the same, and are employed in experimental researches, aiming at a high exactitude, as well as to the operations of diverse natures which are the necessary corollaries."[1]

That a standard should exactly represent a unit is of course obvious, and what is usually the case, the definition of the unit is derived from the standard, as is the definition of the British imperial yard or the modern definition of the meter. Therefore it is essential that the standard should be so constructed as to be as nearly permanent and invariable as human ingenuity can contrive. As an example of the lack of permanence experienced in standards, attention might be called to the fact that the secondary standards of the British yard of 1855, which were distributed to the various nations and laboratories, have since undergone careful comparisons and remeasurements, and it is believed that in many cases their lengths are not the same as when they were first constructed.[2]

While it is physically impossible to secure absolute invariability in standards, yet in their construction a material should be chosen whose variations are well-determined functions of one or more independent variables easy to measure. In practice, these variations themselves ought to be very small, and the variables upon which they depend susceptible of being determined with high precision. The realization of these conditions represents essentially what has been accomplished by the advance of metrological science so far as exactness in standards is involved. In the past, as we have seen, an extreme degree of precision in measurement was not essential, nor could it be obtained with the means at the disposal of the scientist or mechanician, but improvements in this branch of science have been made to such an extent that within two centuries the precision of standards of length has been increased nearly a thousand fold. With the growth of knowledge, it was realized that matter varied to a marked degree under the influences of temperature, pressure, time, and other conditions, so that in consequence, not only a unit must be defined precisely, but the appropriate standard and its copies be so con-

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[1] J. René Benoît, "De la Précision dans la Détermination des Longuers en Métrologie," p. 31, *Rapports présentés au Congrès International de Physique*, tome 1, Paris, 1900.

[2] See *Report, Superintendent U.S. Coast and Geodetic Survey*, 1877. Appendix 12, pp. 180-181.

structed that they would be permanent, invariable and exact. In designing and constructing a standard to fill these demands there would be, consequently, a number of conditions to be satisfied. First, there would be the natural wear of time, which would alter easily the length of a measure or the mass of a weight, and could only be guarded against by selecting a hard and durable material which would resist abrasion. Then, there would be the question of temperature effects, most important in all metrological work, but hardly realized before the beginning of the 18th century. For it will be remembered that, at different temperatures, a body varies in length and volume, so that a standard of length, for example, is only of unit length at one stated and defined temperature, being too long at a higher temperature and too short at a lower temperature. Consequently, it is desirable that a standard should be of a material affected as little as possible by heat, or, in scientific language, having a low and regular coefficient of expansion, and it is essential that this amount of expansion should be known accurately, so that in case the standard is used at other temperatures than that of the definition, the amount that it is too large or too small may be taken into consideration and allowed for, as by knowing accurately and applying the factor which represents the variation in length, a measurement may be made as exact as the original measurement on which the standard is based. It is therefore necessary to exclude from consideration materials having coefficients of expansion which vary considerably at different temperatures, or which expand at a different rate from that with which they contract.

The prime condition of a standard of length, and the same is essentially true of standards of mass, is that it should consist of a single bar, or piece of a single material, avoiding any joining of several elements, such as by screws or by soldering. In fact, the method used at the beginning of the 19th century, whereby a strip of silver was inlaid on a brass bar, as in the Troughton scale, after the fashion of the graduated circles of various modern instruments, was soon found unsuitable for the standards of higher precision which were demanded. The material selected should not only be hard and highly elastic, but should have a surface that can be polished readily, and engraved with the marks of terminal limits, or of the divisions of the unit. For many years it was customary to construct the standards of iron or of brass—materials which were easily oxidizable, and which were with difficulty obtained in a pure and constant condition. For the standard of the meter, known as the Meter of the Archives, platinum was used; but later, the material best suited for a standard was found to be an alloy of platinum and iridium, and such was used for the international prototype meter and kilogram and the national standards copied therefrom. This material, however, being extremely expensive, cannot be used generally where secondary standards for ordinary exact measurements are desired, nor can rock crystal of which a few standards of mass have been constructed.

A recent study of alloys, however, has resulted in finding materials which possess many of the desired properties, such as hardness and durability, and at the same time have a low coefficient of expansion. One of the most recent of these, known as *invar*, has resulted from experiments carried on at the International Bureau of Weights and Measures, and has been developed to a high degree of usefulness by M. Guillaume. This metal, which consists of 36 parts of nickel to 64 of steel, has been found available for measuring rods and wires for use in geodetic operations, and seems destined to occupy a much wider field in the future. Wires for measuring base lines made of this alloy have been found to possess a coefficient of expansion in some cases as low as ·0000001 for a degree centigrade.[1] In 1900 invar standards and gauges were put on the market, and for all practical purposes permitted the disregarding of temperature effects. In fact, it has been proposed to employ a heavy bar of this material as the support of the observing microscopes in a comparator. Invar, however, is not quite steady and constant and cannot be used for primary standards. In accurate surveying such standards should be determined just before and after using in the field.

From the early standards of length rectangular or cylindrical in form, much improvement has been made and care is now taken that the cross-section of the bar shall be of such design

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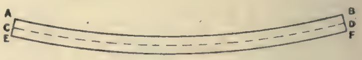
[1] See Guillaume, "Les Procédés Rapides de la Géodésie Moderne," *La Nature* (Paris), 1904, No. 1640, p. 339, and No. 1643, p. 395; id., *Les Applications des Aciers au Nickel, avec un Appendice sur la Théorie des Aciers au Nickel* (Paris, 1904); id., *La Convention du Mètre* (Paris, 1902), pp. 127 and 233.

that not only it shall possess maximum strength, but especially that it will resist deformation by bending, which in accurate measurements may cause considerable error. Thus in a linear scale of considerable length as compared with its breadth and thickness and, let us say, of rectangular section, where the divisions are on the upper surface, it will be obvious that if it is so supported that the ends hang lower than the centre, the upper surface will form a convex curve, and the particles of the material lying in such a surface will be stretched apart, and the distance *A* to *B* will be greater than when the bar is straight as under normal conditions.



If the ends of the scale were supported, rather than the centre, the opposite conditions would prevail, and the marked distance will be too short. This was recognised by Captain Kater, who proposed the employment of a scale of small thickness which was placed on a base whose surface was perfectly plane.[1] A better solution of the difficulty was to use the neutral fibres, as shown by the dotted line *CD*, and for this purpose the British standard of 1855 was constructed, as shown on pages 245 and 246, where the unit distance is measured between lines on polished gold plugs, set in two holes or wells, so that they lie in this so-called neutral plane. This idea was more perfectly carried out in the standards of the International Metric Commission, having the X-section as shown on page 254, where the construction is such that the bar possesses maximum rigidity with the minimum material and the neutral plane in the line standard is easily accessible for measurements throughout its length. In standards for small lengths, such as the decimeter, such considerations as a desirable type of cross-section and the placing of the divisions in a neutral plane, naturally do not require careful consideration and can practically

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[1] See Kater, "Investigation of the Curvature of Bars, produced by the Inequalities of the supporting surface," *Phil. Trans.*, 1830, p. 359. See also W. A. Rogers, *Proc. Amer. Acad. Arts and Sciences*, vol. xv. 1879-80, p. 292.

be neglected, but in meter or yard standards it is an important consideration.

Then, as regards the actual means of denoting the distance, we may have end standards (*étalon à bouts*) and line standards (*étalon à traits*). The end standard represents the given unit by the distance between the extreme boundary surfaces, as in the case of any ordinary rule, or in the case of the inside measure,—the distance between the interior surfaces of two extended arms,—the object being to secure better protection for the surfaces employed for measurement, and at the same time, to furnish a ready means of comparing end measures with a standard, by simply bringing them within the space included between the terminal arms. With the other form of standard, the limits of the distance are indicated by lines or sometimes dots. The line standard, of course, can be used with a microscope with cross-hairs, or a micrometer microscope, much more readily than an end standard, as it is possible to effect an exact setting on even a coarse line with much greater accuracy than on an edge, which though imperceptibly worn to the naked eye, would appear rough and indistinct when magnified by the microscope.

The line standard possesses a distinct advantage, where it is divided throughout its whole length, as is usually the case, since it is readily comparable with its own sub-divisions and with smaller standards. On the other hand, the end standard constitutes merely a standard for a single length, and does not lend itself to direct comparisons with the ordinary standards of other lengths in the laboratory or testing bureau, which in the case of metric scales are usually divided into millimeters, with the centimeters and decimeters suitably marked. With a standard so divided, standards of measure for other distances besides the greatest one marked on its surface must be supplied.

In spite of the general tendency to use a line standard, rather than an end standard, Bessel, in 1835, when he was preparing a standard based on the seconds pendulum at Koenigsberg, used a steel bar with sapphires set in its ends, to form a standard of length. This standard of Koenigsberg was used as a basis for numerous measurements of base lines in geodetic surveys in Europe.[1]

Though the line standard forms the most suitable, and in

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[1] P. 9, Guillaume, *La Convention du Mètre.*

fact the only, standard for a modern prototype, and even for secondary purposes, there are nevertheless occasions where standards of the end type can be conveniently used. Especially is this the case in mechanical engineering, where various gauges and shop standards must be constructed so as to be used readily in the tool-room or machine shop for accurate measurements. The methods of comparison are essentially similar to those employed in comparing line standards. However, certain variations of methods have been introduced, since it is necessary to consider the terminal faces, which are susceptible of wear and must be protected carefully. In addition to the use of the microscope comparator, which is described below, in connection with line standards, there are three methods which can be used for this purpose, as follows:

First, the method of direct contact, which, while the simplest, can also be made very accurate if properly used.

Second, by reflection of an object at the terminal surface.

Third, by interference fringes which are produced at the ends of the scale to be measured.

In the method of contact, which is ordinarily employed where a high degree of precision is unnecessary, it is usual to employ such simple measuring devices as a screw micrometer, or a spherometer, or some less accurate form of instrument, such as calipers or a beam compass. The second and third methods are optical, and must be executed by a trained physicist; but they increase materially the range of precision, and can afford results more accurate than are obtained in comparing line standards.

The method of reflection was employed in comparing the Meter of the Archives, an end standard, with the provisional meter for the construction of the international prototype, and also subsequently in the standardizing of certain end standards of platinum-iridium, which were given to such nations as had ordered them. This method consisted in observing the displacement of the reflection of a line at the terminal surface of the bar; and while under certain circumstances it was exact, it required a study of the objectives of the microscope and other features in order to insure its accuracy.

Employing this method, in 1881-82, a series of comparisons of the new standards was made at the Conservatoire des Arts et Métiers with the Meter of the Archives, taking into consideration most carefully the question of temperature. It was found that these comparisons, when reduced to 0 degrees C., gave an accuracy of ·6 of a micron for each standard.

In the method of interference use is made of the phenomenon of Newton's rings, whereby interference of light follows differences in the path of a beam, such as may be produced by reflection from two different surfaces. It is necessary to have a fixed and determined surface as a plane of reference, and then to consider the difference in the fringes that are produced by light falling on two other surfaces at different times.

Considering now a line standard constructed, of approved material and cross-section, it is naturally of primary importance to provide the marks accurately limiting the distance. These marks or traces are usually made with a diamond, and are transverse to the axis of the bar. The method employed is to place the bar, with the standard by which it is graduated, on the carriage of a special piece of apparatus, such as a comparator or dividing engine, which will be described below more fully, with the cross-hairs of one of the microscopes accurately over the line of the standard scale. After a mark is made on the scale to be graduated, both scales are moved until the second mark of the standard scale is under the cross-hairs, and another ruling is then made by the diamond. Or the scales may remain stationary and the microscope and tracing device be moved.

To divide a scale into millimeters or other divisions the dividing engine is employed, an instrument in which the essential feature consists of an accurately constructed screw, whose pitch (*i.e.* distance between threads), as well as its constant and periodic errors, are known to a high degree of precision. This screw, working in a suitable nut, moves a table along a heavy metal supporting bench, and a metal or glass bar on this table can be moved forward by regular and successive intervals of length. Above the table is a tracing device operating in a fixed vertical plane, and by this means the desired divisions may be inscribed on the bar. Apparatus of this kind has been constructed which is entirely automatic in its movements, and which is able to mark the divisions in millimeters on a scale a meter in length. Such machines have means of correcting the errors in the screw, whether they are constant or occur at different intervals of its length, and also devices permitting corrections for temperature. Often these machines are driven by an electric motor, and even the differences in length of the marks denoting divisions of the scale—as, for example, at every tenth millimeter—are made longer automatically. A meter scale divided into millimeters can be ruled with a machine of this description in the International Bureau of Weights and Measures, in about sixteen hours, with an accuracy of two or three microns for each division.[1]

With the dividing engine or ruling machine of the late Professor H. A. Rowland of the Johns Hopkins University, designed for constructing diffraction gratings for spectroscopic work rather than for making linear scales, as many as 20,000 lines to the inch, 787·5 to the millimeter, could be ruled on speculum metal, and gratings having as many as 120,000 lines have been made where the estimated error between any two lines was not thought to exceed $\frac{1}{2000000}$ of an inch, or nearly the $\frac{1}{80000}$ of a millimeter.[2]

To secure the best results, the surface of the standard or scale on which the lines are traced should be highly polished, and great care should be taken, not only in the choice of the diamond or tracing-tool, but in the actual operation. The line made should be clear and sharp, not broader than is absolutely necessary, and not appearing rough and indistinct when seen under the microscope. In the national standard prototypes of the meter this line measures from 6 to 8 microns in width, but after it had been ruled, it was thought that a much narrower line, say 2 or 3 microns, could have been used with advantage,—securing, of course, a sufficient depth to insure the permanent preservation of the line. On both sides of the line at a distance of ·5 mm. are two parallel and similar lines, the distance between them

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[1] M. Guillaume says, "It is essential in order to get very good lines to trace very slowly, and in the studies made at the Bureau International it has been found useful to trace the 1000 lines of the meter in millimeters in about 16 hours. The inaccuracy in the position of either end line does not exceed two or three microns, but of course the error of every interval of 1 mm. is much smaller."

[2] See *The Physical Papers of Henry A. Rowland* (Baltimore, 1902), pp. 506-511, 691-697.

forming a standard millimeter at each end of the scale, which furnishes a check on the micrometer of the microscopes of the comparator used to compare the scales. These transverse lines are crossed by two longitudinal lines parallel to the axis of the bar, and distant from each other ·2 of a millimeter. Between the intersections of these lines with the transverse lines is where the standard distance is measured.

The important part played by temperature in exact determinations and comparisons of standards of length, as well as of mass, of course involves a means of measuring such temperatures. This subject has received increasing attention in the course of time, and it has been realized that exactitude in constructing standards of length is only possible where the most accurate methods of temperature measurements are employed, as the changes in length or volume with temperature of course produces marked variations from the standard unit. Since a linear unit is represented by the length of a standard or bar of metal at a fixed and defined temperature, at no other temperature will this bar have the standard length, and consequently its exact length at such other temperature can only be ascertained by knowing the amount that it expands for a unit (degree) of temperature, and the precise temperature at which the measurement is made. Accordingly, two thermometric measurements of great precision are involved, one in determining the expansion of the material forming the standard, or obtaining the coefficient of expansion of the bar, and the other, in measuring the temperature at which the bar is used. Now as the coefficient of expansion enters as a direct factor in determining the exact length of a standard, it is necessary to consider how far we can depend upon its accuracy, and to realize that if this factor cannot be trusted beyond a certain figure of decimals, then refinement of measuring with the micrometer is quite superfluous.

In the first attempts at accurate measurement and comparison of standards, as soon as temperature effects began to be considered, mercury-in-glass thermometers were used, and in them for many years a confidence was placed, which has been since found entirely unwarranted. The gravity of this matter was realized by physicists toward the middle of the 19th century, and at the time of the construction of the international standards, it was considered necessary to undertake a complete study of the mercury-in-glass thermometer, and find within what limits its accuracy could be trusted. So many sources of error were found in the instruments as then constructed, due to the material used, and to differences in its behaviour at different temperatures, as well as to the difference in the coefficient of expansion of mercury at different temperatures, that it was found necessary, after a most thorough investigation, to adopt a gas thermometer in which hydrogen was used as the expanding fluid. In this the expansion of the gas indicates the temperature, and within certain limits it is far more accurate than the mercurial thermometer. The latter, however, when carefully studied and calibrated, can be referred to the hydrogen scale with sufficient exactness for use at ordinary temperatures. For purposes of standardizing, it has been found necessary to refer all temperature measurements to the hydrogen thermometer, and the study of exact thermometry made at the International Bureau of Weights and Measures, has been one of its most important scientific works. It has served to increase the accuracy of the present standard of length and of mass, as well as to raise materially the degree of precision in all measurements in science in which temperature enters as a factor.[1]

Fundamental standards or prototypes are of course not available for general work, even where high precision is demanded, but they must serve only as a basis for the construction and testing of secondary standards which are divided throughout their entire length. These are necessary for many purposes, and can be used under conditions involving more or less wear.

The question of the permanence of these fundamental standards, or more particularly that of the international prototype meter is of primary importance. New methods involving greater exactness in measurements and comparisons would avail little if

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[1] Good modern mercury thermometers made of hard glass alloy are of great accuracy at moderately high temperatures, but their scale though very well defined and reproducible is an arbitrary one and has no fixed relation with theoretical phenomena, as is the case with the gas thermometer—Guillaume. See Benoît, p. 75, *Rapports Congrès International de Physique*, tome i. Paris, 1900. Guillaume, *La Convention du Mètre*, Paris, 1902, p. 26, etc., for résumé of thermometric studies at the International Bureau of Weights and Measures; *Traité de la Thermométrie de Précision.* Paris, 1889. *Travaux et Mémoires, Bureau International des Poids et Mesures*, vol. i.-vi., x., xii., xiii.

changes were taking place in the material of the standard bar which would produce variations in its length. Evidence that has accumulated in almost twenty years' experience with the national standard meter bars does not indicate any substantial changes that should give cause for anxiety in this respect, but at the same time, the physicist is hardly in a position to guarantee this permanence for a longer period of time, such as a century. Recourse must be had, therefore, to a series of comparisons of other standards among themselves and of providing new means by which the integrity of the standard may be safeguarded. The most satisfactory of these auxiliary means of protection is the reference of the standard meter to a wave-length of light, according to the method devised by Professor A. A. Michelson and applied at the Bureau International des Poids et Mesures, to which reference will be made in the course of a few pages. Thus to-day the permanence of the meter is assured in that it is defined in terms of a wave-length of cadmium light, with an exactitude of one part in 1,000,000 or, in other words, of a micron.[1]

In comparing standards of length the earliest scientific device employed was the use of some form of calipers or beam compass. Thus in comparing an outside end standard with an inside end standard, by placing the former between the projecting ends of the latter, a measurement could readily be made. For comparisons of this kind, the inside end standards constructed of metal were frequently embedded in a masonry wall at some central and convenient point in a city. In comparing the toise of Peru with that of the Grand Châtelet, we are told by the Astronomer Lalande that the microscope, in connection with a beam compass having very fine points, was used as early as 1735, and we also know that a similar device where the jaws or points were moved by micrometer screws with divided heads was employed in England by Graham, in 1742, in making his comparison of standards of length.[2] In the earliest comparisons involved in the original determination of the meter and the construction of the standard bars used for measuring

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[1] Benoît, p. 68, *Rapports Congrès International de Physique*, vol. i. Paris, 1900.

[2] See "Description of Standards and Use of Beam Compasses," *Philosophical Transactions*, 1742-1743, vol. xlii. London.

the bases, the various scales to be measured and compared were placed on a long plate of brass, having a fixed terminal piece at one end, with which the ends of the scales were placed in contact. Differences of length were determined by means of a moving contact block and a small scale carefully divided. This device, known as the rule of comparison, or the comparator of Borda and also of Lenoir, which was believed for many years to have been lost, was discovered by M. Wolf,[1] and is now preserved in the Observatory of Paris. It consists of a heavy strip of copper, some 13 pieds (4·225 meters) long, 30 lignes (6·78 centimeters) in width, and 4 lignes (·9 centimeter) in thickness. The movable piece is a smaller scale of copper, about 6 feet in length, and divided into ten thousandths of a toise. It was movable along the copper bar, and with it an exact reading of the length of the scales to be compared could be made. There were verniers ruled on the copper bar at different points, such as 12 pieds from the extremity, for the comparison of geodetic base bars of 2 toises length; at 6 pieds for the comparison of toise standards; at 3 pieds for the comparison of meters, etc. The verniers were divided to read to tenths, so that it was possible to obtain the $\frac{1}{100}$ part of the length of a toise.[2]

In this way a degree of precision equal to about $\frac{1}{200}$ of a ligne (·01 mm.) was obtained, which was practically ten times that attained in the comparisons of the toise of Peru and that of the Grand Châtelet half a century before. However, even greater precision was demanded at this time, and accordingly, a lever comparator was constructed by Lenoir, in which the long arm of a lever magnified the distance traversed by a movable contact piece in connection with a shorter arm, with the result that it was possible to read even smaller differences than those mentioned above.[3]

The next step marking progress and increased accuracy in the comparison of standards was the use of the micrometer-microscope which was devised by Troughton, of London, and was first employed by Sir George Shuckburgh, in 1796-8, in the measurement of some line standards, which were then beginning to be employed

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[1] See *Annales de l'Observatoire de Paris; Mémoires*, vol. 17, p. C 32.

[2] Bigourdan, p. 86, *Le Système Métrique*, Paris, 1901.

[3] Benoît, p. 34, *Rapports présentés au Congrès International de Physique*, vol. i. Paris, 1900.

in metrology.[1] This device has since played an important part in all such comparisons, and the micrometer-microscope, in improved form, figures in many instruments for this purpose. In Shuckburgh's comparator, the two microscopes were arranged vertically on a metallic bar, and in one there were fixed cross-hairs, and in the other, a movable system of cross-hairs connected with the screw of a micrometer. The divisions of the head of this screw corresponded to ten thousandths of an English inch. The method of operating was to adjust one of the scales so that the image of its line should appear at the cross-hairs of one of the microscopes, the cross-hairs being set at the focus of the objective. The other microscope would be so adjusted that its cross-hairs would coincide with the image of the line at the opposite end of the scale, or in case of a comparison with end standards, the cross-hair would be set on the ends themselves. In making a comparison, a second scale was substituted for the first, and was placed under the microscopes in the same position, one of the lines, or the extremity of the scale (in case it were an end standard) being made to take a position so that its image would correspond with the cross-hairs of the first microscope. If the other division were exactly equivalent to that of the first scale, it would occupy the same position in the field of the second microscope, but, in case there was a difference, this difference could be measured by moving the movable cross-hairs with the micrometer screw. The micrometer-microscope of Sir George Shuckburgh was capable of reading to ·0001 of an inch, or the $\frac{1}{40}$ of a millimeter, and with this apparatus he made, in 1802, a comparison between the British and French standards.

This idea for a comparator underwent subsequent improvements about 1804 at the hands of Baily, also of England, who employed in his apparatus, two microscopes, each provided with a micrometer and with an achromatic objective, by means of which the image was made clearer and the magnification increased. He also devised a method whereby the scales could be slid under the microscopes, without touching them with the hands, by arranging a carriage on a frame independent of the microscopes. While this apparatus contained important improvements, nevertheless, in its construction, it lacked in solidity, and at the

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[1] *Philosophical Transactions* (London), 1798, p. 137.

same time was without adequate means of preserving the temperature of the rules constant. Accordingly, the commission charged with the construction of the British Imperial Standards, in 1843, made important improvements in the comparator, supplying the desired rigidity and strength by means of a solid foundation for the microscopes, and providing for enclosing the rules to be compared in a double-lined box, whose temperature was maintained constant at the desired temperature by a circulation of water.

In France, also, the work of constructing and comparing standards of length developed, and the progress towards exactness made in that country during the nineteenth century, was due in large part to the placing the service of weights and measures in charge of the Conservatoire des Arts et Métiers. There was constructed for this institution, by Gambey, a comparator with longitudinal displacement, which permitted the comparison of both end and line standards, and at the same time allowed the defining lines to be marked upon them. The result of improvements and the activity of this establishment was that much was accomplished in the semi-scientific and industrial application of exact measurements, and the weights and measures of France were brought to a higher degree of precision.

In the United States, also, important comparisons were made of the various scales presented by the French and British Governments, with those in the Coast and Geodetic Survey. But neither instruments nor methods represented any striking departures from European practice, though the work itself was up to the high scientific standard maintained by this bureau and was favorably commented on abroad. A useful and accurate comparator, still in use, was constructed by Saxton and was employed in making the early standards of length.[1]

While there have been no fundamental improvements in the idea underlying the operation of comparing standards, within the last half-century, nevertheless by various mechanical improvements and refinements, the range of accuracy has been notably increased, so that to-day the modern comparator represents an instrument susceptible of great precision in the

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[1] *Executive Doc.* 27, 34th Congress, 3rd Session.

hands of a competent observer. The prime requisite of a comparator designed for such purposes as the comparison of a prototype with national or other standards, is its stability, and for that purpose the instrument is generally mounted on piers of solid masonry, which are independent of the structural walls of the building in which it is placed. It is essential that such a building should be located in a place free from vibrations and disturbances, such as would be produced by the traffic of a busy street, or by machinery, or by a railway. The micrometer-microscopes are mounted on heavy castings, set on separate piers placed at approximate distances, if the comparator is to be used for the comparison of standards of a single unit, as, for example, meter-bars. If, on the other hand, the comparator is of a universal character, and must be used in the comparison of various lengths, then the microscopes must be mounted on solid carriages, which are capable of being moved along some sort of a solid frame-work or firmly mounted beam. Equally important with the microscopes is the arrangement for carrying the scales which are to be compared. Some means must be provided to place them successively in the same position beneath the microscopes, so that the difference in their length may be determined by means of the micrometers. These scales must be maintained at the same temperature, and must be examined under practically the same conditions. This involves, first, the absolute uniformity of the temperature of the apparatus itself, and for this purpose it should be installed in a room where direct sunlight cannot penetrate and be surrounded by corridors, enabling a constant temperature to be maintained. This requires, naturally, an apartment of a considerable extent, provided with thick walls, and specially designed doors and windows, as well as various devices for maintaining automatically the desired degree of temperature. The entire instrument may be surrounded by a box through which penetrate only the eye-pieces of the microscopes and the handles controlling the various parts of the mechanism.

To keep the scales at the same temperature there is a movable carriage which carries a double-walled box containing water. In this box the scales are placed and the water is kept in constant circulation by means of small agitators electrically driven and in motion except at the moment of reading. A number of thermometers arranged in close proximity to the scales enable a series of accurate readings of the temperature to be made with microscopes placed above for that purpose. It will readily be seen that by changing the temperature of the surrounding water, the amount of expansion of a scale can be measured.[1]

Improvements have been made in the micrometer-microscope as well as in the rest of the apparatus, and particularly in the screws which form the basis for moving the cross-hairs and for measuring the amount of motion. These improvements consist essentially of a frame carrying several sets of cross-wires in pairs, which occupy a vertical position in the field of view of the microscope. This frame is set at the focal plane of the objective, and can be moved laterally by means of a screw with a graduated head and handle. Such screws are so constructed that they are practically free from constant or periodic error, and by means of a spring, any "back-lash" or lost motion between the screw and nut is guarded against. The head of the screw is graduated to a certain number of divisions, usually 100, so that a fractional part of the revolution of the screw can be determined accurately. For example, if a pair of cross-wires are focussed over a line of a scale, it is possible, by noting the number of revolutions of the screw, to bring those cross-wires over the next line, to determine the value of a single revolution of the screw, and by means of its divided head and a vernier, of minute fractions of a single revolution. Where cross-wires of the ordinary or X type were once employed and a setting made on the centre of the magnified division, it is now usual to employ two vertical cross-wires, following a plan proposed by Kupffer when preparing the Russian standards, and to arrange the setting with respect to the edges of the engraved line. This lends itself to greater accuracy, as by means of the bright borders of the image of the line a much sharper setting can be made than where the magnified line was bisected by a single cross-wire. The magnifying power of the microscope for accurate comparisons ranges from 80 to 250 times, and in some few rare cases even higher, the most serviceable power being determined

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[1] A description of the Brunner Comparator of the International Bureau will be found in *Travaux et Mémoires du Bureau International des Poids et Mesures*, vol. 4.

after considering the conditions, as, under many circumstances, increased magnification introduces errors and does not result in as satisfactory results as with the use of a lower power.[1]

There must also be considered the illumination of the face of the rule, and it is now usual to provide direct illumination, rather than oblique. This is accomplished by the use of a prism which will reflect light from a distant source, such as an incandescent lamp with a ground glass globe, to the scale and then to the objective of the microscope. A transparent plate of plane glass placed in the tube of the microscope at an angle of 45 degrees to the axis, will also produce the same result, and is preferred by some observers.

As regards the manner in which the adjustment of the scale is accomplished, two main divisions of comparators can be made,—those which give the transverse movement of the scales, and those in which the scales are moved longitudinally. A longitudinal comparator is so arranged that the divisions of a standard can be studied accurately; for example, throughout the entire length; or standards of different lengths, whose differences exceed the diameter of the field of the microscopes, can be measured with facility. Thus from a standard meter, a bar or tape of several times this length for use in measuring a base line or in surveying, can be standardized. In a comparator of this kind the scales must be so adjusted that they lie with their axis either in a perfectly straight line or exactly parallel.

In the comparators where the scales have a transverse movement, as is the case with an instrument designed for comparing two scales of the same length, the microscopes are mounted at a fixed distance, and the scales are adjusted so that their axes are parallel to a line connecting the two microscopes. The two scales should rest in a carriage protected from changes of temperature by means already described, and so arranged that after being adjusted parallel to each other, they can be moved under the two microscopes. Such an arrangement enables one to study the relative expansion of scales of different materials, as the measurement of the differences of length at a certain temperature

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[1] See W. A. Rogers, "On the Present State of the Question of Standards of Length," *Proceedings American Academy of Arts and Sciences*, vol. xv. 1879-80, pp. 290-291.

can be made, and then, at a second temperature, obtained by varying the warmth of the circulating water.

With standards of mass, the material of which they are composed is of primary importance. Not only must the standard be of a permanent character, hard and able to resist abrasion in actual use, but it must be such that it will not be affected by the oxygen of the air, or, in other words, have its surface oxidized and the weight increased. Other and more subtle chemical changes must also be provided against. On this account, platinum and rock crystal have been found to be the most useful materials, and the former posesses the merit of having a high specific gravity, so that when weighed in air the amount displaced is a minimum. Furthermore, the shape must be such that the volume can be measured with a high degree of exactitude, as on the volume depends the effect of buoyancy, and of temperature. Such corrections are often very small; in fact, much less than in the case of a standard of length, but in constructing and using a standard of mass, the barometric pressure, temperature, and the humidity should be determined, as the density of the air must be known accurately and duly considered.

In addition to possessing a geometrical figure easily measured, the standard should be so designed that there are no grooves or cavities to collect dust, and that when used in a balance it will conform to the needs of the mechanism used for changing the weights in the scale-pans. Taking all things into consideration, the cylindrical shape with round edges serves the best, and such is the form of the Kilogram of the Archives and of the International Prototype and its copies.

For determining standards of mass, the modern physicist has recourse to the same instrument which was employed thousands of years ago by the ancients, viz. the balance with equal arms. But he has effected such improvements in its mechanical construction and operation that this instrument is now entitled to rank with the apparatus of precision of the first order. For accurate weighing, the balance must be of the finest and most accurate workmanship, and also there must be employed various methods and corrections evolved largely from mathematical considerations.

In comparing standards of mass, and in all accurate weighings with a balance, it is necessary to take into consideration the buoyant effect of the displaced air, as conditions are quite different from those obtained when a body is weighed in a vacuum. This correction is especially necessary in making an absolute determination, but in cases where the standard and the weights with which it is compared are of the same material, the effect is the same in both cases and does not enter into consideration at all.

For accurate weighing it is possible to employ the method of double weighing of Borda, where the two objects whose masses are to be compared are successively placed in the same scale-pan and are counterpoised by weights on the opposite side, or the interchange of the weights on the scale-pans, as devised by Gauss. There must be considered, also, the effect of temperature, which can change the condition of balances and weights, just as much as in other physical operations, and it is accordingly necessary to have such a balance placed in a room with constant temperature, and to provide against currents of air, by means of a suitable case. Even the influence of the temperature of the observer's body has its effect, and he must be placed as far as possible from the balance, observing the oscillation of the beam with a small telescope, and changing the weights, setting the beam in motion and bringing it to rest, and performing other necessary operations by suitable mechanical devices, which can be operated at a distance, without opening the casing of the balance.

These conditions are realized in the balances used at the Bureau International, as well as at various governmental Bureaus of Standards, physical laboratories and like institutions. Typical, perhaps, as involving the greatest refinements, are the balances of the Bureau International, two forms of which are described in outline below.

Of these perhaps the simplest is the Ruprecht type of balance, which consists of a balance with equal arms carrying two scale-pans in which an opening is cut in the form of a cross, the edge being cut away at one of the branches. Beneath this is an axis carrying a cross-shaped piece of somewhat smaller dimensions than the opening in the scale-pan. Two supports similar in shape to the scale-pans and provided with like openings are attached to the central column supporting the balance. When a weight is placed on the scale-pan by means of mechanism operated from a distance of over four meters, it is possible for the cross-shaped piece below to be raised, thus carrying the weight clear of the scale-pan, and then to be swung out through the opening clear of the latter, and into the plate placed on the central column where the weight may be deposited. The standard carrying the cross-shaped piece is then lowered and the weight is left on the rest. The weights can then be revolved around the central column carrying the beam and by the apparatus just mentioned placed on opposite pans from their original position. This operation is accomplished by means of gears and shafts, and is carried on simultaneously for both pans of the balance. Mechanism is also provided, so that the observer may release the pans and also the beam, by turning suitable cranks, and there is a telescope, whereby he may observe the deflections of the beam by means of a mirror and divided scale.[1]

The Bunge balance, at the Bureau International des Poids et Mesures, contains several features leading to further refinements. It is enclosed in a copper case, from which the air may be exhausted, so that the weights may be compared in vacuo. In addition to the means of changing the weights, and for releasing and arresting the scale-pans and beam, mechanism is provided whereby small additional weights can be added to one side or the other of the beam, as is found necessary. All of the controlling devices are so arranged that they may be operated by the observer from a distance of several meters, and with this balance the most accurate results may be obtained.

In the determination of standards of mass, it is necessary to determine their specific gravity and the amount of water that they displace when immersed. For this hydrostatic balances are used, which, in their essential features, correspond with the balances of precision just described. The vessel containing the water in which the weight is immersed is placed directly below

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[1] Guillaume's *La Convention du Mètre*, p. 111. The balances have been provided with suitable mechanism to add small differential weights, *i.e.* at the same time two weights say of 100 and 100·5 milligrams respectively, which give a new position of equilibrium and allow the determination of the sensitiveness. This addition of small weights can be made without arresting the balance which constitutes a great saving of time.—Ch. Ed. Guillaume.

the point of support of one of the arms of the balance. There is also provided a scale-pan, in which the body to be measured is placed, and connected with it—a device by which it can be supported when immersed in water—the whole forming a continuous arrangement supported from one arm. The body is first placed in the upper pan and counterbalanced by weights on the opposite side of the balance. It is then removed and weights are added in its place until the equilibrium of the balance is secured. The sum of the weights so added gives, of course, the actual weight of the body. It is then immersed in water, and the same process is gone through with, the temperature of the water being noted by a carefully calibrated thermometer. Various devices are employed to secure a uniform temperature of the water, to diminish the effects of friction and capillarity, and to facilitate the handling of the body when immersed.

The sensibility of an accurate balance depends on the load, and in making a weighing, this factor must be determined accurately, and it is likely to vary under different conditions. With the balances employed in comparing the standard kilograms, it is usual to have the sensibility equal to 25 to 50 divisions for a milligram, or, in other words, an addition of weight equal to a milligram produces a deflection of the beam corresponding to this amount. This is useful, inasmuch as the differences of weight between the two standards compared are usually so small as to be measured only by the deflection, and not requiring the addition of the smaller weights to either scale-pan.

In some cases, a reading of a tenth of a division of the deflection in either direction may correspond to some thousandths of a milligram. Thus, in comparisons of standard kilograms, the ·01 of a milligram would be equal to a ·000,000,01 of the mass measured, but other considerations do not permit this degree of precision to be maintained. Nevertheless, this represents a substantial gain in accuracy, as the fine balance used at the London Mint by Harris in 1743 was able to indicate only $\frac{1}{8}$ of a grain on a Troy pound, or about one part in 50,000, while in adjusting the Kilogram of the Archives in 1779, Fortin employed a balance sensitive to one part in a million.

As units of capacity are defined in terms either of linear measures or of mass, the construction of suitable standards does not present any particular difficulty, nor is any high degree of precision required, save in a few cases. In fact, standard measures of capacity are usually adjusted by means of the weight of a liquid such as water, taken at a certain temperature. As these measures are used in few experiments or determinations where extreme accuracy is called for, there is no need of observing particular precautions, either in their construction or their calibration. The standards are usually of some metal, such as bronze or gun-metal, of a regular geometrical shape, and are adjusted with water at a certain temperature. The purpose for which a measure of capacity is to be used is borne in mind in determining its shape, as with liquids it is not necessary to take into consideration the question of compressibility or of heaping the measure which would be involved in the measurement of grain or vegetables. This, of course, does not affect the actual cubical contents of the measure, but merely considers its actual application in commerce. Thus, in Great Britain there have been various shapes adopted for standards for the liquid and dry gallon, and for the coal bushel, and for other measures, the exact dimensions of which are defined. In view of the great inaccuracy in measuring goods by capacity measures being unavoidable, it is the present tendency of metrology to use capacity measures as little as possible, and to recommend the use of weights, especially in business dealings. In Europe this practice is rapidly increasing among the metric countries, and in some of them nearly all articles of food and other necessities for daily life, even liquids such as oil, are bought and sold by weight.

There is, however, one kind of standard of capacity where accuracy is important, namely, flasks, burettes, or other vessels of glass employed in physical or chemical experiments. These are calibrated carefully with water or mercury, whose volume at any specified temperature is known with exactness. Such standards, however, are not specially and exclusively maintained by national bureaus and direct comparisons made with them, but as their calibration involves little difficulty to the trained physicist or chemist,[1]

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[1] The calibration of chemical and other graduated glass-ware is one of the regular routine duties of the National Bureau of Standards at Washington, and is done for the technical public at reasonable and established fees.

they are usually constructed in any laboratory where their use is desired.

In the case of other standards, such as those of electricity, the most important are the ohm and the standard cell, which involve the realization of the international definitions[1] by careful scientific work. These definitions for practical purposes are so exact and the modes of construction so well understood by physicists that such standards can be constructed at national or other physical laboratories and bureaus of standards by trained investigators, and the results represent refined methods of manipulation and the use of specific apparatus rather than scientific work of such character as was involved in the construction of the international standards of length and mass. It should not be understood, however, that from the purely scientific point of view that electrical engineers and physicists are altogether satisfied with the present definitions. Consequently there is at present much important investigation in progress which has as its object the determination of new standards or new definitions, and at the Electrical Congress held at St. Louis in 1904 it was decided that steps should be taken to form an international electrical commission composed of official representatives, much after the fashion of the International Commission of Weights and Measures. The call for a preliminary meeting of delegates has been issued and the formation of this international commission in the near future is probable. From the discussion of the electrical units in the last chapter their independence on each other will be appreciated, so that it is necessary to determine whether the voltameter operating under standard conditions shall give the unit of current from which, with the ohm, may be derived the unit of electromotive force, or whether the unit of electromotive force as given by a standard cell shall be considered the fundamental source of the standards.

There have been constructed by the Physikalisch-Technische Reichsanstalt at Berlin and the English National Physical Laboratory, primary mercurial standards of resistance in which the international definition of the ohm has been realized and the apparatus of these two laboratories shows substantial agreement of measurement, being in harmony to a few parts in

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[1] See chapter ix. *ante.*

100,000.[1] Furthermore there are in England, preserved at the Board of Trade Electrical Standardizing Laboratory in London, actual standards of resistance, current and electrical pressure which have been duly legalized (Order in Council, August 23, 1894). Thus the standard ohm is the resistance between the copper terminals of the platinum-silver coil marked "Board of Trade Ohm Standard, verified 1894," to the passage of an unvarying electrical current, when the coil of insulated wire forming part of the aforesaid instrument and connected to the aforesaid terminals is in all parts at a temperature of 15·4 degrees Centigrade.

The standard ampere is the current which passes in and through the coils of wire of the standard ampere balance, marked "Board of Trade Ampere Standard, verified 1894," when on reversing the current in the fixed coils the change in the forces acting upon the suspended coil in its sighted position is exactly balanced by the force exerted by gravity in Westminster upon the iridio-platinum weight marked "A" and forming part of said instrument.

The British standard volt is one-hundredth part of the pressure which, when applied between the terminals of a Kelvin electrostatic voltmeter of the multicellular type marked "Board of Trade Standard, verified 1894," causes a certain exactly specified amount of rotation of the suspended part of the instrument.

While various other standards are of course possessed by the different national laboratories and testing bureaus, yet they aim rather at representing specifically the definitions of the various units, than, as in the case of the British Board of Trade, employing as national standards the mere concrete apparatus. The same holds true for standard barometers, thermometers, polariscopes, and other instruments of precision which are used for standardizing similar instruments used in science and industry.

Having considered the general principles underlying standards and their construction and comparison, it may be advantageous to discuss briefly the weights and measures that have served this purpose in France and England, as well as the present metric standards. While it was legally possible to establish the inch by taking "three barley corns round and dry" as was provided by the statute of Edward II. and to raise a pound from 7680 grains

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[1] The first standard ohm was constructed privately by M. Benoit of the Bureau International.

of wheat as was enacted by the statute of the Assize of Bread and Ale (51 Henry III., stat. 1, 1266), yet such means on their very face were manifestly lacking in accuracy, as there was nothing to ensure that the corns or grains would conform to a uniform standard. Consequently as early as the fourteenth year of the reign of Edward III. (1340) a royal edict was published ordering "standard weights and measures to be made of brass, and sent into every city and town in the kingdom." This necessary and excellent law, however, merely followed the precedent made by Richard I. who ordered that standard measures of length should be made of iron and that those for capacity should have iron brims, and that standard measures of every kind should be kept by the sheriffs and magistrates of towns. While it cannot be said that this law was enforced, yet it shows that the government was alive to the necessity of proper standards in order to secure the desired uniformity and that their construction was constantly in mind.

The earliest English standard of length extant is the Exchequer standard yard of Henry VII., which dates back to 1496. It is a brass bar of octagonal cross section whose length furnished the standard distance, and which is divided both into inches and also into sixteen equal parts on the basis of binary division. It was used until 1588, when in the reign of Queen Elizabeth a new standard yard, also of brass, was constructed, which is still in existence after having served for a long period as an original standard. It is a rectangular bar one yard in length, on which are indicated the divisions of a yard and also a similar bar forming an ell of 45 inches (exact length 45·04 inches), there being a third and larger bar with two beds or matrixes into which both of the end standard bars could fit, and having at one end of the yard bed a subdivision into inches and half inches. It may be said in passing that both the standards of Henry VII. and of Elizabeth are essentially of the same length, and they are only about ·01 inch shorter than the present British imperial standard. The Elizabethan standard did duty until well into the nineteenth century, in spite of the fact that some time between 1760 and 1819 it had been broken and mended by means of a dovetail joint in a rather crude fashion. In fact this ancient standard has been spoken of most contemptuously by F. Baily, who examined it in 1836, he even going as far as to call it disgraceful for the British government to issue certificates and construct copies based on it as representing the English standard.[1]

A line standard constructed by Bird in 1760, under the authorization of the Committee on Weights and Measures of the House of Commons, was based upon a standard made by the same maker in 1742 for the Royal Society, and on a line standard which he constructed in 1758. The former has been pronounced by H. W. Chisholm, an authority on British metrology, to be "the first scientifically constructed measure of length in this country" (England).[2] The Bird standard of 1760 was approved by the Committee, and, though not at that time legally established, formed a basis for a number of secondary standards. It was eventually adopted as the legal standard of Great Britain by an Act of Parliament promulgated June 17, 1824, and served as such until its destruction in the fire which consumed the Houses of Parliament in 1834. The adoption of this standard, however, at this time was hardly warranted in view of the state of scientific knowledge, or by the actual character of the standard itself. It was a brass bar, 1·05 inch square and 39·73 inches in length, with gold plugs near the ends, on which were points or dots, the distance between which at the temperature of 62 degrees Fahrenheit (16·7 degrees Centigrade) represented the standard yard. This standard bar, however, in addition to being of comparatively crude construction, even at the time of its legal adoption had become badly worn by rough treatment. By the use of beam-compasses, and in various rough comparisons, the dots had become worn, so that under the microscope they were seen to appear like the craters of small volcanoes, and consequently rendered the bar quite unsuitable for exact scientific work. In the Act by which this standard was established it is clear that the idea of a natural standard was still cherished, since it provided that in the event of the loss of the standard yard it should be restored by means of a reference

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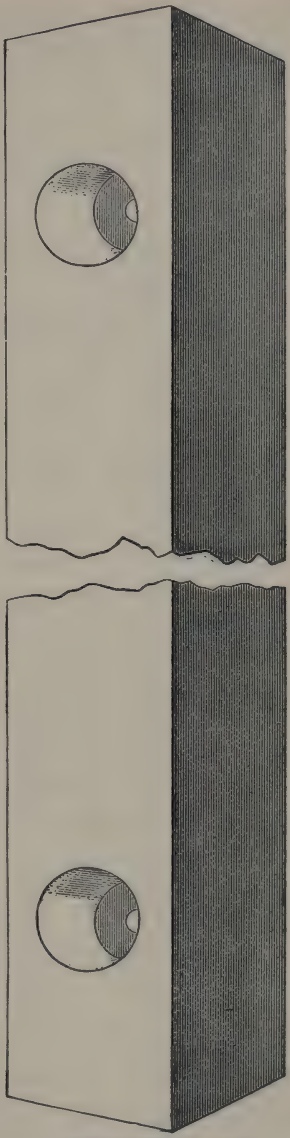
[1] See H. W. Chisholm, "Seventh Annual Report of the Warden of the Standards," 1872-3, *English Parliamentary Papers, Reports from Commissioners*, 1873, vol. xxxviii. pp. 25 and 34; also *id.* "Weighing and Measuring" (London, 1877), pp. 50-54. See also footnote, p. 36, *ante*.

[2] See Chisholm in same Report, p. 10, for full description of this and other standards.



BRITISH IMPERIAL YARD.

to a pendulum beating seconds in a vacuum, at the latitude of London and reduced to sea level, which would have the relation to the yard of 39·1393 to 36; but in spite of this statutory provision, when the standard yard was destroyed ten years later no recourse was had to the seconds' pendulum, as that method seemed then incapable of furnishing the standard with sufficient exactness, and the standard yard was reconstructed from other standards in the possession of the Government and scientific societies which had been compared with the standard of 1760. These included the five-foot brass standard scale of Sir George Shuckburgh which was made by Troughton, of London, in 1796, two iron standards made for the Ordnance Survey in 1826-7, the brass tubular scale of the Royal Astronomical Society, and the standard yard of the Royal Society constructed under Captain Kater's direction in 1831. The Shuckburgh scale was based on a five-foot scale made and used by Troughton, which in turn was constructed from an accurate 90-inch brass scale made by Bird.[1]

This imperial standard yard, as well as the imperial standard prepared under the direction of a Parliamentary Committee appointed in 1843, were

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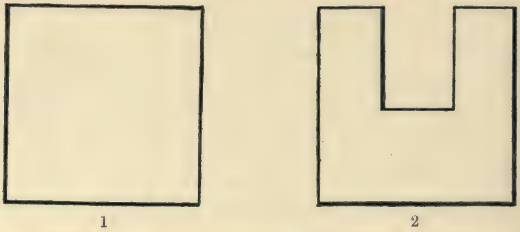
[1] See W. Harkness, "Progress of Science as Exemplified in the Art of Weighing and Measuring," *Bulletin, Philosophical Society of Washington, D.C.*, vol. x.; *Smithsonian Miscellaneous Collection*, vol. xxxiii. 1888, pp. 43 *et seq.* Also W. A. Rogers, "On the Present State of the Question of Standards of Length," *Proceedings, American Academy of Arts and Sciences*, vol. xv. 1879-80, pp. 273 *et seq.*

duly legalized in 1855 (18 and 19 Vict. c. 72) by an Act known as the Standards Acts, whose provisions as regards these standards were re-enacted in the Weights and Measures Act of 1878. These standards, as they represent the best practice of the time of their construction, and as they are the present standards of Great Britain, may be briefly described.[1] The imperial standard yard is a solid square bar of a special bronze or gun-metal known as Baily's metal, composed of copper 16 parts by weight, tin $2\frac{1}{2}$, and zinc 1. It is 38 inches in length, with a cross section one inch square, and has near its ends two circular holes or wells sunk to a point midway the depth of the bar. In these wells are inserted two gold studs, on which the fiducial lines are engraved, the distance between them forming the imperial standard yard of 36 inches at a temperature of 62 degrees Fahrenheit ($16\frac{2}{3}$° C.). This imperial standard, as also the imperial standard pound, is preserved in a strong fire-proof room at the Standards Office in Old Palace Yard, Westminster, and copies are deposited at



British Imperial Standard Yard. Cross-section. (Exact size.)
1.—Section of Bar. 2.—Section through holes.

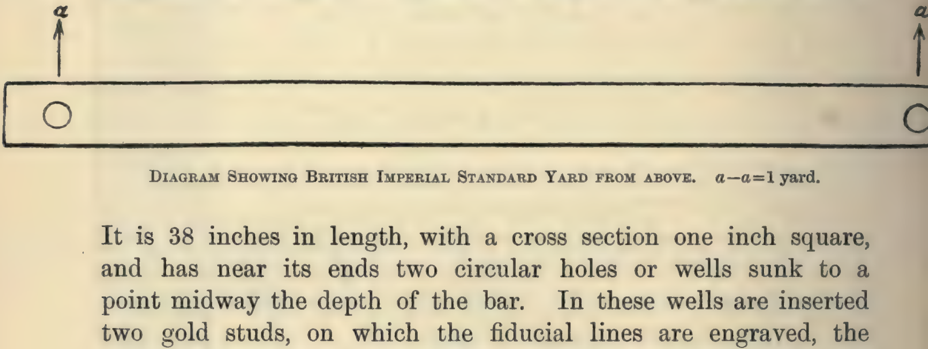


Diagram Showing British Imperial Standard Yard from above. $a-a$=1 yard.

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[1] G. Airy, "Account of the Construction of the New National Standards of Length, and of its Principal Copies," *Philosophical Transactions* (London), 18th June, 1857.

the Royal Observatory, Greenwich, the Royal Mint, the Royal Society, and the Houses of Parliament. The latter are specially designated by statute as Parliamentary copies, and must be compared with the imperial standard once in every ten years, since in the event of the possible destruction of the latter they would furnish the source from which a new standard would be derived. There were in addition thirty-five other standards made of the same size and of the same material, which were duly compared with the prototype, and were distributed to the various nations of the world and to scientific institutions in Great Britain and elsewhere. One of these standard bars, by Act of Parliament, June 30, 1855, was presented to the United States Government, and was known as "Bronze Standard No. 11." It is ·000088 inch shorter than Bronze Standard No. 1, which was chosen as the imperial standard. It was accompanied by a malleable (Low Moor) iron standard of length, No. 57, and standard weight No. 5, the correction for each standard being given over the signature of G. B. Airy, Astronomer-Royal.[1]

These two yards, particularly the bronze standard, were so much superior to the Troughton scale that they were accepted by the United States Office of Weights and Measures as the standards of the United States, and in this way comparisons of American measures of length were made with the imperial yard. In 1876, and again in 1888, they were taken to England and were compared with the British standards.

In 1904, the late H. J. Chany, Warden of the Standards, caused to be constructed and standardized at the International Bureau a platinum-iridium bar similar in composition and section to the international meter, and while this has not as yet any legal standing, it is perhaps the best representative of the British yard.

The oldest authenticated British standards of weight date from the reign of Queen Elizabeth, and consist of three distinct sets. The first of these are bell-shaped standards of bronze for the heavier weights, and range from 56 lbs. to 1 lb. inclusive. They are of importance, as from the time of their construction in 1588 until 1824 they were the standards of the kingdom. Then there

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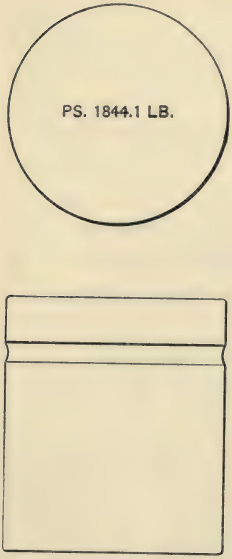
[1] See *Report, Superintendent U.S. Coast and Geodetic Survey*, 1877, Appendix 12, p. 154, for description of these standards of length. See also *Executive Document* 27, 34th Congress, 3rd Session, p. 17.

is a series of flat circular avoirdupois weights from 8 lbs. to $\frac{1}{16}$ of an ounce, and a set of cup-shaped Troy weights which, with the exception of the very small weights, fitted into each other. These standards had been prepared under the direction of a committee of merchants and goldsmiths, who employed as the basis for avoirdupois weight a 56 lb. standard of the Exchequer dating from Edward III., and for Troy weight the ancient standard of the Goldsmiths' Hall.



British Imperial Standard Pound. (Exact size.)

About 1758 the Parliamentary Committee, to which we have before referred, caused to be constructed three standard Troy pound weights, but like the yard of the same period none of these was legalized until 1824, when one of the weights was chosen as the government standard, only to be destroyed by the fire of ten years later. On the recommendation of the Standards Committee of Parliament, made in a report submitted December 21, 1841, the British imperial standard of weight was changed from a Troy pound of 5760 grains to an avoirdupois pound of 7000 grains, and a standard representing the latter was constructed in 1844 and duly legalized in 1855. After much discussion and a careful examination of existing standards it was found necessary to use almost exclusively two platinum weights, one belonging to the Royal Society and the other to Professor Schumacher, whose values were accurately known in terms of the lost standard. The new standard, which is indeed the present imperial standard, is of platinum, cylindrical in form, 1·35 inches in height, and 1·15 inches in diameter. Its density as compared with distilled water is 21·1572, and it displaces ·403 grains of air under standard conditions.[1] It has a slight groove or channel near its upper surface by which it may be moved with a fork of ivory, and

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[1] W. H. Miller, "On the Construction of the New Imperial Standard Pound, etc.," *Philosophical Transactions* (London), 1st June, 1856. H. W. Chisholm, *Weighing and Measuring* (London, 1877).

bears on its upper surface the inscription "P.S. 1844, 1 lb.," the letters signifying Parliamentary Standard. Copy No. 5 was presented to the United States in 1856. The British units of capacity, the gallon and the bushel, are based on the fact that an imperial gallon represents the volume occupied by ten imperial pounds of distilled water at 62 degrees Fahrenheit and a barometric pressure of 30 inches, while the bushel is eight gallons.[1] The imperial standard gallon bears the date of 1828 and is of brass, with a diameter equal to its depth. The imperial bushel standard is of gun-metal, with a diameter twice that of the depth, these latter dimensions being selected on account of the applicability to the use for the measure of grain. It dates from 1824, and was verified in the following year.

The French standard of length previous to the completion of the Meter of the Archives was the Toise de Perou, to which reference has already been made. It was constructed for use in making the base measurements for determining the length of the Peruvian arc of the meridian and the verification of the arc passing through Paris, being derived from the Toise du Grand Châtelet, which dated back to 1668. This latter standard was a bar of iron which was fixed in the wall of the Grand Châtelet, forming an inside end standard by which all scales could be tested by simply placing them between the limiting ends. This naturally deteriorated from exposure and wear, and, as a result, the Toise de Perou was substituted for the Toise du Grand Châtelet, as the French standard of length, in 1766, and is now preserved at the Observatory in Paris. It is an end standard of polished iron, somewhat greater than a toise in length and of rectangular section, 17 lignes in breadth and 4½ lignes in thickness. At each end of the bar a rectangular portion extending to a line midway of the breadth was removed, and the standard distance was taken between the edges of the remaining portion of the bar, at a point about one ligne from the median line. On the longer part of the bar two lines were traced, with points marked at their centers, so that the distance between them was exactly a toise, with the result that an end standard was combined in the same metal bar with the more exact line standard,—there being, however, a difference

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[1] Henry Kater, "Verification of Standard Gallon," *Philosophical Transactions* (London), 1826.

between the two scales of about ·1 of a millimeter, a quantity which was readily negligible in the metrology of those days. The bar was standard at a temperature of 13° Reaumur (16°·25 C. or 61°·25 F.) and has been found equal to 1·949036 meter at 0° C.

The French standards of weight were a series of weights known as the Pile of Charlemagne, and dating back to the reign of that king (about 789). Together they aggregated 50 marcs, as the unit of the series was termed, or 25 livres poids de marc (pounds), and in standardizing weights the sum of the pile was usually taken as the standard. These weights are now preserved in the Conservatoire des Arts et Métiers at Paris, and have figured in many comparisons.[1]

With the experience which the French scientists had gained in their brilliant geodetic work during the 18th century, it was possible to employ new and more accurate standards of length in the measurements of the base lines. Accordingly, for the purpose of making this fundamental measurement in determining the length of the earth's quadrant, four compound standard bars of novel form were designed and constructed by Borda, each of which was two toises in length, six lignes in width and almost one ligne in thickness.[2] Each bar consisted of a strip of platinum connected permanently at one end with a strip of copper, which otherwise was free to move longitudinally as it expanded or contracted. At the opposite end the copper was cut away for a short distance and a movable rod of platinum was provided, so that an exact and variable setting could be made by means of a divided scale and vernier. As the two metals had unequal coefficients of expansion, it was possible, by determining their relative expansion, as indicated by a graduated scale and vernier, to obtain not only a true measure of length, but also the temperature of the bar. This was accomplished by first standardizing the bars in the laboratory and measuring the relative expansion corresponding to a certain number of degrees.[3] In

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[1] See C. Mauss, *La Pile de Charlemagne* (Paris, 1897). A mathematical discussion of these weights.

[2] See Borda, "Expériences sur les règles destinées à la mesure des bases de l'arc terrestre," Delambre and Méchain, *Base du Système Métrique*, vol. iii. p. 313.

[3] These bars of Borda were studied and standardized by Lavoisier. See Chisholm in *Nature* (London), vol. ix. p. 185, Jan. 8, 1874. See also Dumas, *Works of Lavoisier*, vol. v.

use in the field, these bars were placed end to end and were carefully levelled. One of them was considered as a standard, and to this all measurements were referred, including that of the seconds' pendulum, and when the length of the meter was evaluated, it was obtained in terms of the fraction (·256537) of this modulus.[1]

Compensated bars of this form found increased use in the measurement of base lines in geodetic surveys until well into the 19th century, though they have been largely displaced by the employment of bars of a single material, or steel tapes or wires whose temperature coefficients are accurately known. In the case of the metallic bars, in one of the most accurate base measurements to which reference has already been made, viz., that at Holton, Mich., which was made in connection with the transcontinental survey of the United States, the distance was measured by means of a bar carried in a trough of melting ice.[2]

In passing from these standards of Borda to the meter, use was made of the comparator of the Committee, and that of Lenoir, already described. A provisional standard of brass, first constructed, served as a means of connecting the two measurements. Finally, when sufficient data had been obtained and computed to justify the construction of a definite standard, it was made from a mass of platinum as nearly pure as possible and of a rectangular section. It was an end standard 4 millimeters in thickness and 25 millimeters in breadth becoming the Meter of the Archives.[3] From the same material and at the same time were constructed two other standards, which differed only in having a thickness of 3·5 millimeters. These have since been known as the Meter of the Conservatory and the Meter of the Observatory.[4]

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[1] Benoît, "De la Précision dans la Détermination des Longueurs en Métrologie," *Rapports presented au Congrès International de Physique* (Paris, 1900), vol. i. p. 34. Bigourdan, *Le Système Métrique* (Paris, 1900), p. 83. C. Wolf, "Recherches historiques sur les étalons des poids et mesures de l'Observatoire," *Annales de l'Observatoire* (*Mémoires*), Paris, vol. xvii. p. C 36 *et seq.*

[2] See note *ante*, p. 141, chapter v.

[3] For Cross-section see illustration on p. 252. No. 1 is the Meter of the Archives.

[4] C. Wolf, "Recherches historiques sur les étalons des poids et mesures de l'Observatoire," *Annales de l'Observatoire* (*Mémoires*), vol. xvii. p. 52.

The construction of the actual meter was accomplished by using a number of auxiliary rules, which being placed end to end and compared both among themselves and with the modulus, enabled the true length of the meter to be obtained. This proceeding involved considerable careful mathematical work as well as manipulative skill, and was accomplished with a remarkable degree of precision, considering the apparatus at the disposal of the investigators. In fact, it is fair to say that modern work of this character is more exact only through the improved instruments that an advance in mechanical and scientific knowledge has made possible, rather than in any greater skill and carefulness on the part of the observers.

Although a large number of standards of a secondary character were constructed by the different bureaus established for this purpose by the French Government as well as by instrument makers, but little advance was made as regards their form and general character. In most of them the rectangular shape was preserved, and though, by the use of the microscope, a more accurate division was possible, yet no standards of high precision were attempted. When, however, the custody of the standards and their verification was assigned to the Conservatoire des Arts et Métiers, more interest was taken in this work, and with the installation of new comparators, the scientific staff of that institution began researches which led to substantial improvements. It was due to M. Tresca, who was Assistant Director, that a thorough study of the shape and material of standards was undertaken, the results of which were placed at the service of the International Commission, when it assembled in 1870.[1]

The French Committee, of which he was a member, recommended in preparing the specification for the international meter, that the new standard should be a line standard, having a cross-section sufficient in form and dimensions to preserve accurately the shape of the bar, and that its coefficient of expansion should be as nearly as possible that of the meter of the Archives. The platinum which went to make up this original standard contained also iridium, together with a small amount of palladium, and it was deemed desirable, in constructing a new prototype, to

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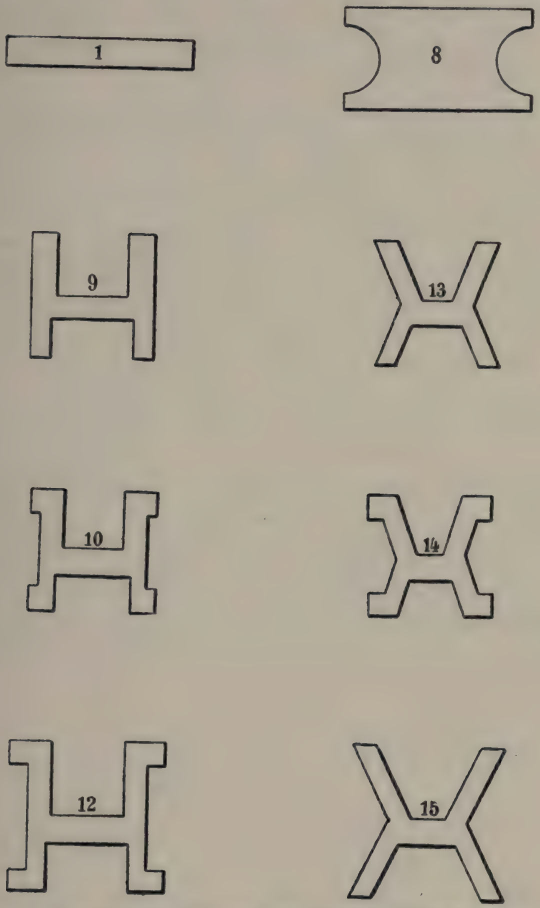
[1] See Tresca, Appendix 7, *Annales du Conservatoire des Arts et Métiers*, vol. x. 1873.

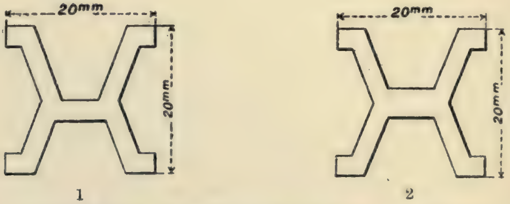
employ an alloy of platinum, with one-tenth part of iridium, as devised by H. Sainte-Claire Deville, since as such a combination filled the required conditions of inalterability, homogeneity, durability, and small expansibility under the influence of temperature. In addition, it was susceptible of taking a high polish, and possessed numerous other physical and chemical advantages which made it particularly suitable for this purpose.[1]



Cross-Sections of Standards (Studied by Tresca).
1.—Meter of the Archives. 8.—Provisional Standard of Platinum Iridium.
9, 10, 12.—H Standards. 13, 14, 15.—X Standards.

[1] Bigourdan, *Le Système Métrique*, p. 274.

In preparing the standards of length, it was realized by the Commission at the outset that two essential conditions must be fulfilled, viz., that the metal bars should be as rigid as possible, without employing such a quantity of the platinum alloy as would make their cost prohibitive, and, secondly, that the lines marking the divisions must be placed in the plane of the neutral fibres. M. Tresca, who had given the subject of standards careful study, reported to the Commission on their form, and stated the essentials which must be observed in the construction of a new standard meter. He called attention to the fact that it was necessary that the distance between the two limiting lines should lie entirely in a plane which would contain the various centres of gravity, and this condition could only be obtained by making the bar of such cross-section that it would have the greatest rigidity. He also deemed it essential that the cross-section should be uniform throughout the length of the bar, and that the median plane on which the lines were traced should be available for tracing the necessary divisions, and for observation with the microscope of the comparator. M. Tresca carried on a series of experiments and investigations with bars of different cross-sections for which he calculated the mechanical constants, and, as a result of the studies, he came to the conclusion that the most suitable form for the standards of length was the bar of X section, as shown in the accompanying figures.



Cross-Section of Standard Meter Bars. (Exact size.)
1.—Line Standard. 2.—End Standard.

It will be seen from the illustration that the median plane, or plane of the neutral fibres, lies exactly in the center of the bar, and is available for marking any necessary lines or divisions. This is the case with the line standard. For the end standard he adopted a somewhat similar section, but with the cross-bar relatively higher, so that the median plane passed through its center instead of being situated in its upper surface, as in the case of the line standard. The section in either case would be included in a square 20 mm. on each side, and the diagram represents accurately the actual size and figure of the section.[1]

As compared with the Meter of the Archives, the new standard proposed by Tresca had a profile 1·509 times as great, so that the actual quantity of material involved was but slightly more than a third, but the form of construction made possible far greater strength and rigidity, while at the same time the standard distance was measured in the neutral plane. These recommendations were duly adopted, the material was prepared according to the above specifications, and the bars were delivered to the Conservatoire des Arts et Métiers, where the standards were constructed by the French section under the terms of the international agreement.

In the comparison of the prototype meters among themselves and with the international standard, the first step was to construct a provisional meter, whose constants were determined directly in terms of the Meter of the Archives. For this purpose a comparator with a transverse movement was employed, while for making the definitive marks on the bars a longitudinal comparator was used. The comparisons between the Meter of the Archives and the provisional meter were made at the Conservatoire des Arts et Métiers. The standard bars were taken to the Bureau International, where was made a series of comparisons which established their relations to each other, as well as to the international prototype.[2] Of the thirty bars thus examined, the one that approached most nearly the length of the Meter of the Archives was selected as the international prototype, and a new scale was chosen to take its place in the series of

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[1] Guillaume, *La Convention du Mètre* (Paris, 1902), pp. 15-18; Benoit, "De la Précision dans la Détermination des Longueurs en Métrologie," *Rapports, Congrès de Physique* (Paris, 1900), tome i. p. 48.

[2] See *U.S. Coast and Geodetic Survey Report*, 1890, Appendix 18, pp. 743 *et seq.*, for a description of the construction of the standard meter bars; also Bigourdan, *Le Système Métrique*.

comparisons. As a result of these comparisons, the probable error of a single comparison was stated at ±0·12 μ—the probable error in the length of any one of the standards being stated at ±0·04 μ.[1] From the result of many years of comparison at the Bureau International, the conclusion is reached that the length of a standard can be absolutely guaranteed to an exactitude of about ·2 micron at all usual temperatures.[2]

In the construction of standards of weights, the instrument makers of the eighteenth century had gradually become more proficient, and their work partook of greater precision, both in the weights themselves and in the balances. Nevertheless, no particular features are worthy of note until the kilogram of the Archives was constructed. This unit of weight, as we have seen, was defined as the "weight of a cubic decimeter of distilled water, taken at its maximum density and weighed in a vacuum." To realize such a definition in a standard would apparently involve the construction of a cubic vessel whose side was exactly a decimeter, and then ascertaining the weight of water contained therein. A measurement of this kind could be made by taking a vessel of regular form and known interior dimensions, but to determine its volume accurately by any process of measuring was a difficult, if not an impossible proceeding. Recourse was had, accordingly, to the law of Archimedes, which states that a body immersed in a fluid loses an amount of weight equal to the weight of the volume of the fluid which it displaces. Consequently, in order to determine the weight of the displaced water, it was necessary to weigh a solid body of regular form, first in air, reducing to vacuum, and then in water, making suitable provision or correction for its temperature. In order to determine exactly the volume of such a body, it must be constructed in a regular geometric form, such as a cube or a cylinder. The latter form was adopted in making the standard of weight by the Committee of the Meter, and Lefèvre-Gineau, with the assistance of Fabbroni, standardized a hollow cylinder of brass, which was constructed for them by Lenoir. It was 243·5 millimeters in height and diameter, and thus had a volume

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[1] Benoît, *Rapports, Congrès International de Physique* (Paris, 1900), vol. i. p. 63.

[2] *Ibid.* p. 66.

slightly in excess of eleven cubic decimeters, and had a weight in water of about 200 grams.[1] The dimensions of the cylinder were obtained with a lever comparator from a scale equal to the $\frac{1}{16}$ part of the modulus (the double toise standard of Borda). As a result of these experiments, a theoretical value of 18827·15 grains (poids de marc) was assigned to the kilogram, and such a weight was constructed in pure platinum to be the prototype standard.[2] Unfortunately, no record has been left to us of the methods employed in constructing such a standard. It is known, however, that at the time when the platinum was prepared for the four standard meter bars, material was made ready for four cylinders destined for the standard kilogram. After adjustment, one of these was taken, and has since survived as the Kilogram of the Archives. It is unquestionable, however, that the same balance and weights employed in determining the weight of a cubic decimeter of water were used in these latter operations.[3]

During the first half of the 19th century, with the growth of experimental physics and with improvements of apparatus, new methods giving a high degree of precision were available for use with the balance. Consequently, in the construction of weights and in their reference to standards, much more precision was obtained than ever previously. This, however, did not cause any marked demand for new metric standards, although various physicists were of the opinion that the kilogram did not represent accurately the mass of a cubic decimeter of water. These determinations, however, varying as they did—being both greater and smaller than the Kilogram of the Archives—did not inspire any greater degree of confidence. Accordingly, when it was proposed to construct new standards for the meter and the kilogram, it was decided to use the Kilogram of the Archives as the basis, and then by subsequent experiments determine its relation to the mass of a cubic decimeter of water at its temperature of maximum density. Accordingly, the International Commission made arrangements for such an investigation.

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[1] Guillaume, *La Convention du Mètre*, p. 5.

[2] For full description of the determination of the standard of mass, see Delambre and Méchain, *Base du Système Métrique*, vol. iii. pp. 579-638; Bigourdan, *Le Système Métrique*, p. 107.

[3] Bigourdan, *Le Système Métrique*, p. 159.

To this body, in 1879, three cylinders of platinum-iridium alloy, designed for standard kilograms, were delivered, and were then compressed in a powerful coining-press of the Paris Mint. They were then given to an instrument maker for approximate adjustment, and samples of the material were submitted to chemical analysis by Stas and Sainte-Claire Deville, it having been found by experiments at the École Normale that the final density was 21·55. The first adjustment was made with the kilograms of the Paris Observatory, which were copied from that of the Archives, and for this purpose a balance of the École Normale Superieure was employed. After the three standards had received their final adjustment at the hands of M. A. Collet, they were then compared with the Kilogram of the Archives, with the standards of the Observatory and the Conservatoire, and with the standard kilogram of Belgium, and then final comparisons were made at the Paris Observatory, both the French section and the International Committee being duly represented.[1]

The volume of these three new standards was determined by hydrostatic weighings, and compared with that of the standard of the Archives, which, however, was determined by other methods, as it was not deemed advisable to place it in water.[2] The work was finished October 18, 1880, when the Committee submitted a report covering other duties.

After a careful examination of these three kilograms among themselves, and with the standard kilogram of the Archives, the committee deemed it wise to select one which was known as KIII as the standard kilogram, rather than to make a series of additional comparisons with the other kilograms, to be constructed as national standards, in the course of which the platinum-iridium cylinder would doubtless experience a certain amount of injury. Accordingly, this was adopted in a formal resolution, at a meeting held October 3, 1883, and that kilogram has since been designated by 𝔎, although it bears no mark.[3]

In the following year, after several attempts had been made to secure an alloy of the necessary purity, satisfactory material

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[1] Guillaume, *La Convention du Mètre* (Paris, 1902), p. 123.

[2] *Ibid.* p. 124.

[3] Bigourdan, *Le Système Métrique des Poids et Mesures* (Paris, 1901), p. 365.

suitable for the national prototypes was delivered in the form of forty cylinders. These were worked down to approximately the exact weight, and finished under the direction of the members of the commission and an elaborate series of comparisons was undertaken.[1]

The weighings were effected by means of the Rueprecht and Bunge balances already described, the latter being employed when comparisons were made with the international prototype, which, of course, was preserved most carefully from any deteriorating influences. The constants were calculated separately for each standard, and they were found to agree within a limit of one milligram, and were accepted by the International Committee, this decision being formally sanctioned at the International Conference in 1889. Originally it had been determined to insist on an accuracy of ·2 of a milligram for each kilogram, but in certain cases it was found that the polishing had been carried on too vigorously, and it was accordingly found necessary to fix the limit of accuracy at one milligram, within which limits the forty standards all fell. For example, those given to the United States, in the drawing by lot (Nos. 4 and 20) were found to have an error of − ·075 milligram and − ·039 milligram respectively.[2]

The permanence of the national standards of mass is no less important than that of the standards of length. After about ten years there was made at the Bureau International a comparison of eight standards from seven different nations with the working standards of the Bureau, and it was found that the deterioration experienced was barely appreciable, ranging as it did from ·027 milligram in the case of one of the Belgian standards, to ·001 of a milligram in the case of that from Roumania. It was possible that the deterioration in the case of some of the kilograms which had experienced considerable usage, was as much as ·04 of a milligram, but it was believed that the future would not show as great an amount of change.[3]

The idea of the founders of the Metric System to establish a unit of length which would be absolutely invariable, by means of its reference to the dimensions of the earth, and also by reference

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[1] Guillaume, *La Convention du Mètre*, p. 125.

[2] *Ibid.* p. 126.

[3] *Ibid.* p. 127. Also Report by M. Benoît in *Procès-Verbaux des Séances de 1900, Comités International des Poids et Mesures.* See also *Procès-Verbaux, 1905.*

to the seconds' pendulum, was not destined to survive. It soon was seen, in view of subsequent researches, that the trigonometrical operations on which the length of the meter was based were not carried on with an exactitude required by modern methods of geodetic work, and that, as a result, the standard was in error by about ·1 millimeter. This did not detract from the usefulness of the system, but it did require the abandonment of the idea of referring the meter to the ten-millionth of the earth's quadrant as a natural standard. A century after the Metric System was established, it was found possible to realize the condition of reference to a natural and invariable standard, which was at that time thought so fundamental, and the meter was defined in terms of wave-length of light, after a series of most elaborate experiments carried on at the International Bureau of Weights and Measures by Professor A. A. Michelson, later of the University of Chicago, who had previously distinguished himself by his accurate determination of the velocity of light.

The fundamental idea of using a wave-length of light was by no means new, as a unit of this nature had been proposed by J. Clerk Maxwell,[1] who suggested that a system of absolute units could be founded on the following basis:

As a unit of length, the wave-length of some determined kind of light in vacuo,

As a unit of time, the period of vibration of this light,

As a unit of mass, the mass of a single molecule of a specified substance.

By determining a unit of length in terms of wave-lengths of light, a standard would be obtained independent of any gradual contraction of the terrestrial globe, which naturally would produce a change in the length of the meridian, or other terrestrial disturbance. Likewise, it would be independent of molecular changes occurring in a metallic bar, and naturally affecting its dimensions. The length of a wave of light would under all conditions be most invariable, as it depends solely on the elasticity of the ether. Such a unit, then, gives us a means of establishing the permanent values of the meter, as by determining its length in these minute distances represented by the vibration of particles producing one kind of light, we have a much better

[1] Maxwell, *Electricity and Magnetism* (third edition, Oxford, 1891), vol. i. pp. 3, 4.

means of fixing its invariability than by comparing it with the length of a meridian or with the seconds' pendulum.

In order to define the standard of length in terms of the wave-length of light, a study of different sources of light was essential, and was carried on by Professor Michelson with great thoroughness. For this purpose, he used the luminous vapors of metals produced by the passage of an electric current from the induction coil through a vacuum tube. By a process of elimination, he found that the most suitable source of light was the spectrum furnished by the metal cadmium, which gave a series of lines valuable for his purpose. The visible spectrum of this metal consisted of four groups of lines,—one red, which was single and also fine; the second, a series of fine green lines; the third, a blue line; the fourth, a violet line. In his early experiments, Professor Michelson used the green rays, but in later work, especially by M. Hamy and M. Chappuis, the others were employed and greater precision was attained.[1]

Professor Michelson's method is based on the fact that interference is produced in a beam of light after two of its component parts are compelled by means of reflection to travel distances slightly unequal. The earliest application of this principle of interference in metrology was when Fizeau endeavored to determine accurately the coefficients of expansion of samples of various substances. By placing a plano-convex lens over and very close to the terminal surface of the body to be studied, and causing a beam of sodium (yellow) light to fall from above on the lens, he was able to obtain the optical phenomenon known as interference by observing the reflected beam. This was similar in nature to the well-known experiment called Newton's rings, where the difference in path of the rays of light reflected from the surface of a body and those reflected from the surface of the lens produces interference. The reason for this is found in the fact that waves of monochromatic light, when so impeded that a part of them lose a half-wave length or some odd number of half-wave lengths, will neutralize each other, and consequently produce darkness when they reach a certain point. This is due to the particles at this point being under the influence of waves in opposite phases. If, on the other hand, where they meet, the

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[1] Guillaume, *La Convention du Mètre*, p. 147.

number of half-wave lengths is even, there is increased effect, which is manifested by greater brightness. In the case of a lens, arranged as above, there would be a series of alternate light and dark concentric rings. If white light is used, these rings will show spectral colors, which become complex with an increase in distance from the center. With such an arrangement, Fizeau was able only to measure short distances, which did not exceed 12 or 15 mm. in length. His method was useful, however, in measuring accurately the screw of the micrometer of the comparators.[1]

Using the same idea, but developing it practically, Professor Michelson was able to measure the length of the meter in terms of waves of light. Part of the difficulty was solved by the American physicist when he found a suitable source of light, as has been described above, but it was largely due to his ingenious methods and apparatus, as well as to his manipulative skill, that he was able to carry his plan to so successful a conclusion.[2] His arrangement was, in substance, as follows: Light from the given source, *S*, was allowed to fall on a glass plate at *A*, ground so that the surfaces were perfectly plane and parallel. This plate was placed obliquely to the axis of the beam and on the side *A* was silvered, so that it formed a semi-transparent reflector. The beam falling on this silvered surface was divided into two parts, one of which passed through the silver film and glass, and after reflection at *E* in the mirror *R* to a mirror, *N*, from which it was reflected back through the glass plate to the interior surface of the film, where it underwent reflection again, back through the glass and to a telescope, *T*, so arranged as to enable the fringes produced in its field to be observed. The other part of the beam was reflected at the silvered surface and transmitted through a second glass plate, *Q*, whose thickness was equal to the first, to a mirror, *M*, where it was reflected back through the first plate in the same direction as the first beam. Both

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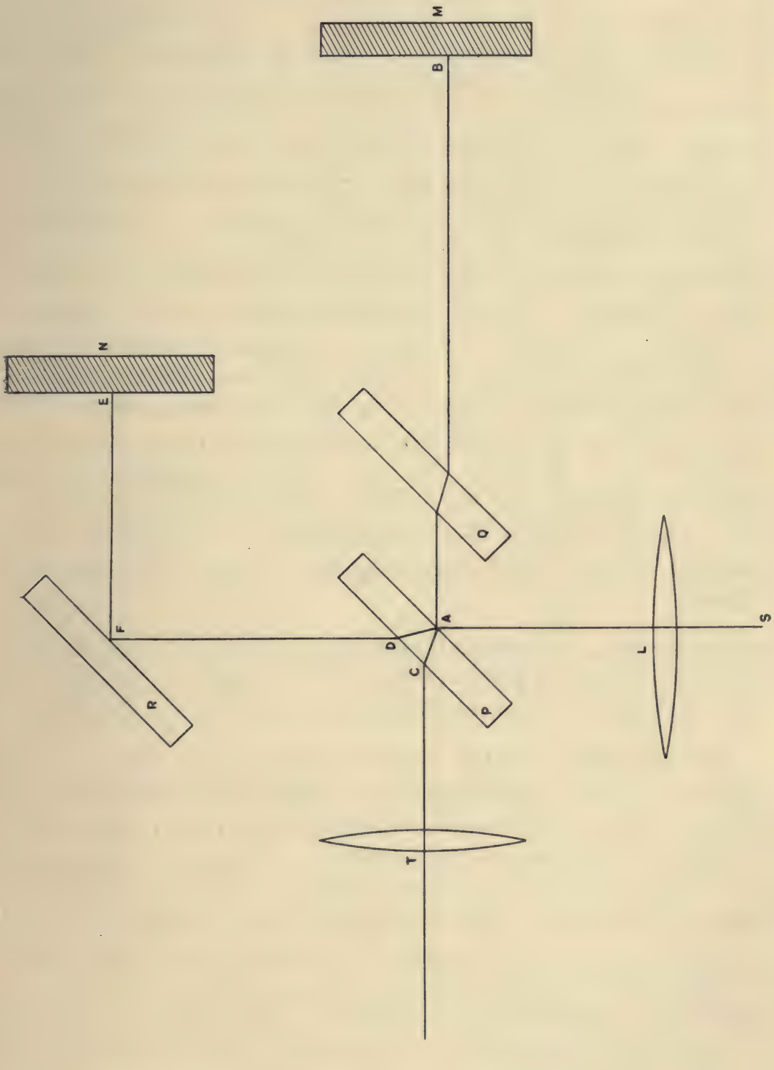
[1] J. René Benoît, "Etudes sur l'appareil de M. Fizeau pour la mesure des dilatations appartenant au Bureau International des Poids et Mesures," vol. ii. *Travaux et Mémoires, Bureau International des Poids et Mesures*, Paris.

[2] Guillaume, *La Convention du Mètre* (Paris, 1902), pp. 146-169. A. A. Michelson, "Détermination expérimentale de la valeur du mètre en longueurs d'ondes lumineuses," vol. xi. *Travaux et Mémoires, Bureau International des Poids et Mesures*, Paris.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beams meeting at the telescope, interference phenomena would appear if there were any difference in the length of their respective paths, *ADFEFDAC* and *ABAC*. By displacing one of the mirrors by a small amount through the agency of a screw, this difference of position could be measured in terms of wave-length. The first task of the investigator was to determine the length of a very short standard by displacing the fringes for a counted number of wave-lengths. Then with this as a standard, he would be able to construct a standard twice as long and derive its length in wave-lengths. In this way Professor Michelson prepared a number of standards of lengths, each double the length of another, so that he was able to step from one to the other and at the same time preserve the original accuracy, Finally he standardized a piece one decimeter in length, and with this he made a comparison with the international meter, displacing it ten times and measuring the displacement by interference methods so as to start from the first line of the meter and then reach the second, and so on; using three different kinds of light, viz. the red, green, and blue of the cadmium spectrum, he determined the wave-length of each or the number of times this wave-length was contained in the standard meter. The wave-lengths for each color were as follows:

Red radiations ...... 1 meter $= 1553163{\cdot}5\ \lambda_R$, of which $\lambda_R = {\cdot}64384722\ \mu$.
Green radiations ...... 1 meter $= 1966249{\cdot}7\ \lambda_V$, of which $\lambda_V = {\cdot}50858240\ \mu$.
Blue radiations ...... 1 meter $= 2083372{\cdot}1\ \lambda_B$, of which $\lambda_B = {\cdot}47999107\ \mu$.

The accuracy of this work is almost incredible, as the variation in the measurements was only about one part in ten million. In fact, where a precision of from one-fourth to one-fifth of a micron is possible in the case of determining the relative length of two standards, here is an absolute measurement which gives the length of a standard in terms of a natural unit, under conditions reproducible at any time. This, of course, gives a permanent check on the integrity of the meter, as in the event of the international prototype being damaged or destroyed, sufficient data is at hand to enable such physicists as may be found at any international laboratory or bureau of standards to redetermine this fundamental unit. The apparatus of Professor Michelson represented the highest skill of the instrument maker, as mirrors and optical planes were finished to a high degree of exactitude, reaching in some cases an accuracy as great as $\frac{1}{40000}$ of a millimeter, or the $\frac{1}{20}$ of the mean wave-length of light.

Just what this work of determining standards of length in terms of the wave-length of light means to science can be readily understood if a moment's consideration be given to the enormous mass of scientific and technical literature and knowledge, to the numberless instruments of measurement and tools and appliances of trade. At first thought it would seem that if some cataclysm should suddenly destroy all these evidences of advancement, then the poor individual who might have survived would be compelled to begin all over again, and his standards and units would have to be new, and he would have no means of connecting his system with the past. All the observations on matters astronomical or terrestrial, all that mass of information which it has taken centuries and centuries to accumulate, would be hopelessly lost because of the break in the standards of measurement. The meter would be gone, the quadrant of the earth no longer the same, and apparently our last tie broken. Not all the ties, for one, a little one, remains, like hope in the bottom of Pandora's box. A wave of light so small that a thousand would scarcely reach across the eye of a needle, this is the key to the restoration of our system of most complicated and complete units. So long as the earth has a material existence, so long as there is light and heat, so long is man in the position to rebuild his system of units and standards.

The work of Michelson in comparing the international meter with the wave-lengths of light has put our system upon a foundation that is as permanent as the universe. If man were transported to the uttermost confines of the universe, he would still have the little waves of light, and they would be just the same as here.

If some day we are able to communicate with the dwellers upon some other planet, it will be a simple thing to communicate to them our standard of length and time and mass, and with the little waves of light to convey our message we may ultimately impart our exact knowledge to them, and receive theirs in return. The laws of light motion, of gravitation, of electricity are undoubtedly identical for the whole universe, and given the first communication of another world we would be able to establish a truly universal system of units and standards. By this means inter-planetary communication would be placed upon a quantitative basis, and the omnipresent, everlasting, but ultra-microscopic wave of light would be the universal, unchanging standard.

APPENDIX.

TABLES OF CONVERSION FROM COMMON TO METRIC MEASURES, USEFUL CONSTANTS AND EQUIVALENTS.

NOTE.

UNLESS otherwise specified, the following tables are based on the U.S. Legal Equivalents. They are derived for the most part from the Tables of Equivalents published by the National Bureau of Standards of the U.S. Department of Commerce and Labor.

LEGAL EQUIVALENTS OF THE UNITED STATES.

Act of July 28, 1866. Revised Statutes 3570.

MEASURES OF LENGTH.

Metric Denominations and Values.		Equivalents in Denominations in Use.
Myriameter,	10,000 meters.	6·2137 miles.
Kilometer,	1,000 meters.	0·62137 miles or 3,280 feet and 10 inches.
Hectometer,	100 meters.	328 feet and 1 inch.
Dekameter,	10 meters.	393·7 inches.
Meter,	1 meter.	39·37 inches.
Decimeter,	$\frac{1}{10}$ of a meter.	3·937 inches.
Centimeter,	$\frac{1}{100}$ of a meter.	0·3937 inch.
Millimeter,	$\frac{1}{1000}$ of a meter.	0·0394 inch.

MEASURES OF CAPACITY.

Metric Denominations and Values.			Equivalents in Denominations in Use.	
Names.	Number of Liters.	Cubic Measure.	Dry Measure.	Liquor or Wine Measure.
Kiloliter or Stere	1000	1 cubic meter	1·308 cub. yards	264·17 gallons.
Hectoliter	100	$\frac{1}{10}$ of cubic meter	2 bushels and 3·35 pecks	26·417 gallons.
Dekaliter	10	10 cubic decimeters	9·08 quarts	2·6417 gallons.
Liter	1	1 cubic decimeter	0·908 quart	1·0567 quarts.
Deciliter	$\frac{1}{10}$	$\frac{1}{10}$ cubic decimeter	6·1022 cub. inches	0·845 gill.
Centiliter	$\frac{1}{100}$	10 cubic centimeters	0·6102 cub. inch	0·338 fluid ounce.
Milliliter	$\frac{1}{1000}$	1 cubic centimeter	0·061 cub. inch	0·27 fluid dram.

MEASURES OF SURFACE.

Metric Denominations and Values.		Equivalents in Denominations in Use.
Hectare,	10,000 square meters.	2·471 acres.
Are,	100 square meters.	119·6 square yards.
Centare,	1 square meter.	1,550 square inches.

WEIGHTS.

Metric Denominations and Values.			Equivalents in Denominations in Use.
Names.	Number of Grams.	Weight of what Quantity of Water at Maximum Density.	Avoirdupois Weight.
Millier or Tonneau	1,000,000	1 cubic meter	2204·6 pounds.
Quintal	100,000	1 hectoliter	220·46 pounds.
Myriagram	10,000	10 liters	22·046 pounds.
Kilogram or Kilo	1,000	1 liter	2·2046 pounds.
Hectogram	100	1 deciliter	3·5274 ounces.
Dekagram	10	10 cubic centimeters	·3527 ounce.
Gram	1	1 cubic centimeter	15·432 grains.
Decigram	$\frac{1}{10}$	$\frac{1}{10}$ cubic centimeter	1·5432 grains.
Centigram	$\frac{1}{100}$	10 cubic milliliters	0·1543 grain.
Milligram	$\frac{1}{1000}$	1 cubic milliliter	0·0154 grain.

BRITISH LEGAL (BOARD OF TRADE) EQUIVALENTS.

May, 1898.

LINEAR MEASURE.

Metric.

1 Millimeter (mm.) ($\frac{1}{1000}$ m.) = 0·03937 Ins.
1 Centimeter ($\frac{1}{100}$ m.) = 0·3937 Ins.
1 Decimeter ($\frac{1}{10}$ m.) = 3·937 Ins.
1 Meter (m.) = { 39·370113 Ins.
3·280843 Ft.
1·0936143 Yds.
1 Dekameter (10 m.) = 10·936 Yds.
1 Hectometer (100 m.) = 109·36 Yds.
1 Kilometer = ·62137 Mile.

Imperial.

1 Inch = 25·400 Millimeters.
1 Foot (12 ins.) = 0·30480 Meter.
1 Yard (3 ft.) = 0·914399 Meter.
1 Fathom (6 ft.) = 1·8288 Meters.
1 Pole (5½ yds.) = 5·0272 Meters.
1 Chain (22 yds.) = 20·1168 Meters.
1 Furlong = 201·168 Meters.
1 Mile (8 furlongs) = 1·6093 Kilometers.

SQUARE MEASURE.

METRIC.

1 Square Centimeter = 0·15500 Sq. In.
1 Sq. Decimeter (100 sq. centimeters) = 15·500 Sq. In.
1 Sq. Meter (100 sq. decimeters) = $\begin{cases} \text{10·7639 Sq. Ft.} \\ \text{1·1960 Sq. Yds.} \end{cases}$
1 Are (100 sq. meters) = 119·60 Sq. Yds.
1 Hectare (100 ares or 10,000 sq. meters) = 2·4711 Acres.

IMPERIAL.

1 Square Inch = 6·4516 Sq. Centimeters.
1 Sq. Ft. (144 sq. ins.) = 9·2903 Sq. Decimeters.
1 Sq. Yard (9 sq. ft.) = ·836126 Sq. Meter.
1 Perch (30¼ sq. yds.) = 25·293 Sq. Meters.
1 Rood (40 perches) = 10·117 Ares.
1 Acre (4840 sq. yds.) = 0·40468 Hectare.
1 Sq. Mile (640 acres) = 259 Hectares.

CUBIC MEASURE.

METRIC.

1 Cubic Centimeter = ·0610 Cubic In.
1 Cubic Decimeter (c.d.) (1000 cubic centimeters) = 61·624 Cubic Ins.
1 Cubic Meter (1000 cubic decimeters) = $\begin{cases} \text{35·3148 Cubic Ft.} \\ \text{1·307954 Cubic Yds.} \end{cases}$

IMPERIAL.

1 Cubic Inch = 16·387 Cubic Centimeter.
1 Cubic Foot (1728 cub. ins.) = 0·028317 Cubic Meter.
1 Cubic Yard (27 cub. ft.) = 0·764553 Cubic Meter.

CAPACITY.

METRIC.

1 Centiliter ($\frac{1}{100}$ liter) = ·670 Gill.
1 Deciliter ($\frac{1}{10}$ liter) = ·176 Pint.
1 Litre = 1·75980 Pints.
1 Dekaliter (10 liters) = 2·200 Gallons.
1 Hectoliter (100 liters) = 2·75 Bushels.

IMPERIAL.

1 Gill = 1·42 Deciliter.
1 Pint (4 gills) = ·568 Liters.
1 Quart (2 pints) = 1·136 Liters.
1 Gallon (4 quarts) = 4·5459631 Liters.
1 Peck (2 gallons) = 9·092 Liters.
1 Bushel (8 gallons) = 3·637 Dekaliters.
1 Quarter (8 bushels) = 2·909 Hectoliters.

WEIGHT.

METRIC.

Avoirdupois.

1 Milligram ($\frac{1}{1000}$ grm.) = 0·015 Grain.
1 Centigram ($\frac{1}{100}$ grm.) = 0·154 Grain.
1 Decigram ($\frac{1}{10}$ grm.) = 1·543 Grains.
1 Gramme (1 grm.) = 15·432 Grains.
1 Dekagram (10 grm.) = 5·664 Drams.
1 Hectogram (100 grm.) = 3·527 Oz.
1 Kilogram (1000 grm.) = { 2·2046223 Lb. oz. / 15432·3564 Grains.
1 Myriagram (10 kilog.) = 22·046 Lb.
1 Quintal (100 kilog.) = 1·968 Cwt.
1 Tonne (1000 kilog.) = 0·984 Ton.

Troy.

1 Gramme (1 grm.) = { 0·03215 Oz. Troy. / 15·432 Grains.

Apothecaries' Weight.

1 Gramme (1 grm.) = { 0·2572 Drachm. / 0·7716 Scruple. / 15·432 Grains.

IMPERIAL.

Avoirdupois.

1 Grain = 0·0648 Gramme.
1 Dram = 1·772 Grammes.
1 Oz. (16 drams) = 28·350 Grammes.
1 Pound (16 oz. or 7000 grains) = 0·45359243 Kilogram.
1 Stone (14 lb.) = 6·350 Kilograms.
1 Quarter (28 lb.) = 12·70 Kilograms.
1 Hundredweight (cwt.) (112 lb.) = { 50·80 Kilograms. / 0·5080 Quintal.
1 Ton (20 cwt.) = { 1·0160 Tonnes or / 1016 Kilograms.

Troy.

1 Grain = 0·0648 Gramme.
1 Pennyweight (24 grains) = 1·5552 Grammes.
1 Troy ounce (120 pennyweights) = 31·1035 Grammes.

Apothecaries' Weight.

1 Grain = 0·0648 Gramme.
1 Scruple (20 grains) = 1·296 Grammes.
1 Drachm (3 scruples) = 3·888 Grammes.
1 Oz. (8 drachms) = 31·1035 Grammes.

APOTHECARIES' MEASURE.

1 Minim = 0·059 Milliliter.
1 Fluid Scruple = 1·184 Milliliters.
1 Fluid Drachm (60 minims) = 3·552 Milliliters.
1 Fluid Ounce (8 drachms) = 2·84123 Centiliters.
1 Pint = 0·568 Liter.
1 Gallon (8 pints or 160 fluid oz.) = 4·5459631 Liters.

ENGLISH-METRIC AND METRIC-ENGLISH EQUIVALENTS OF UNITS OF LENGTH.

UNIT	IN.	FT.	YD.	ROD	FURL.	MILE	CM.	METER	KM.	UNIT
IN.	**1**	0·083 **$\bar{2}$·92082**	0·02$\dot{7}$ **$\bar{2}$·44370**	0·005051 **$\bar{3}$·70338**	—	—	2·54 **0·40483**	0·0254 **$\bar{2}$·40483**	—	IN.
FT.	12 **1·07918**	**1**	0·$\dot{3}$ **$\bar{1}$·52288**	0·$\dot{0}\dot{6}$ **$\bar{2}$·78252**	0·00$\dot{1}\dot{5}$ **$\bar{3}$·18046**	0·00018$\dot{9}\dot{3}$ **$\bar{4}$·27737**	30·48 **2·48402**	0·3048 **$\bar{1}$·48402**	—	FT.
YD.	36 **1·55630**	3 **0·47712**	**1**	0·$\dot{1}\dot{8}$ **$\bar{1}$·25964**	0·00$\dot{4}\dot{5}$ **$\bar{3}$·65758**	0·00056$\dot{8}\dot{1}$ **$\bar{4}$·75449**	91·4402 **1·96114**	0·914402 **$\bar{1}$·96114**	0·0009144 **$\bar{4}$·96114**	YD.
ROD	194 **2·28780**	16·5 **1·21748**	5·5 **0·74036**	**1**	0·025 **$\bar{2}$·39794**	0·003125 **$\bar{3}$·49485**	—	5·029 **0·70148**	0·005029 **$\bar{3}$·70148**	ROD
FURL.	7920 **3·89873**	660 **2·81954**	220 **2·34242**	40 **1·60206**	**1**	0·125 **$\bar{1}$·09691**	—	201·17 **2·30356**	0·20117 **$\bar{1}$·30356**	FURL.
MILE	63360 **4·80182**	5280 **3·72263**	1760 **3·24551**	320 **2·50515**	8 **0·903090**	**1**	—	1609·35 **3·20665**	1·60935 **0·20665**	MILE
CM.	0·3937 **$\bar{1}$·59517**	0·0328 **$\bar{2}$·51598**	0·01093 **$\bar{2}$·03862**	0·001988 **$\bar{3}$·29850**	—	—	**1**	0·01 **2·00000**	—	CM.
METER	39·37 **1·59517**	3·28083 **0·51598**	1·09361 **0·03886**	0·19884 **$\bar{1}$·29850**	0·00497 **$\bar{3}$·69644**	0·0006214 **$\bar{4}$·79335**	100 **2·00000**	**1**	0·001 **$\bar{3}$·00000**	METER
KM.	39370 **4·59517**	3280·83 **3·51598**	1093·61 **3·03886**	198·84 **2·29850**	4·97096 **0·69644**	0·62137 **$\bar{1}$·79335**	100000 **5·00000**	1000 **3·00000**	**1**	KM.

NOTE.—The heavy-faced type gives the logarithm of the conversion factor.

ENGLISH-METRIC AND METRIC-ENGLISH EQUIVALENT OF UNITS OF WEIGHTS.

Unit	Grain	Gram	Oz. Av.	Lb. Av.	Kilog.	Short Cwt.	Ton			Unit
							Short	Metric	Long	
Grain	1	0·0647989 **$\bar{2}$·81157**	0·0022855 **$\bar{3}$·35898**	0·00014286 **$\bar{4}$·15492**	0·000064799 **$\bar{5}$·81157**	—	—	—	—	Grain
Gram	15·43234 **1·18843**	1	0·035274 **$\bar{2}$·54744**	0·0022046 **$\bar{3}$·34329**	0·001 **$\bar{3}$·00000**	—	—	—	—	Gram
Oz. Av.	437·5 **2·64098**	28·3496 **1·45255**	1	0·0625 **$\bar{2}$·79588**	0·0283495 **$\bar{2}$·45241**	—	—	—	—	Oz. Av.
Lb. Av.	7000 **3·84510**	453·593 **2·65667**	16 **1·20412**	1	0·453593 **$\bar{1}$·65667**	0·01 **$\bar{2}$·00000**	0·0005 **$\bar{4}$·69897**	0·0004536 **$\bar{4}$·65667**	0·0004464 **$\bar{4}$·64972**	Lb. Av.
Kilog.	15432·34 **4·18843**	1000 **3·00000**	35·27392 **1·54744**	2·20462 **0·34333**	1	0·0220462 **$\bar{2}$·34333**	0·00110231 **$\bar{3}$·04230**	0·001 **$\bar{3}$·00000**	0·00098421 **$\bar{4}$·99308**	Kilog.
Short Cwt.	—	—	—	100 **2·00000**	45·3593 **1·65667**	1	0·05 **$\bar{2}$·69897**	0·045359 **$\bar{2}$·65667**	0·0446429 **$\bar{2}$·64975**	Short Cwt.
Short Ton	—	—	—	2000 **3·30103**	907·186 **2·95770**	20 **1·30103**	1	0·907186 **$\bar{1}$·95970**	0.8928571 **$\bar{1}$·95078**	Short Ton
Metric Ton	—	—	—	2204·62 **3·34333**	1000 **3·00000**	22·0462 **1·34333**	1·10231 **0·04230**	1	0·984206 **$\bar{1}$·99309**	Metric Ton
Long Ton	—	—	—	2240 **3·35025**	1016·05 **3·00691**	22·4 **1·35025**	1·12 **0·04922**	1·01605 **0·00691**	1	Long Ton

Note.—The heavy-faced type gives the logarithm of the conversion factor.

LENGTHS.

HUNDREDTHS OF AN INCH TO MILLIMETERS.

From 1 to 100 Hundredths.

Hundredths of an inch.	0	1	2	3	4	5	6	7	8	9
	0	·254	·508	·762	1·016	1·270	1·524	1·778	2·032	2·286
10	2·540	2·794	3·048	3·302	3·556	3·810	4·064	4·318	4·572	4·826
20	5·080	5·334	5·588	5·842	6·096	6·350	6·604	6·858	7·112	7·366
30	7·620	7·874	8·128	8·382	8·636	8·890	9·144	9·398	9·652	9·906
40	10·160	10·414	10·668	10·922	11·176	11·430	11·684	11·938	12·192	12·446
50	12·700	12·954	13·208	13·462	13·716	13·970	14·224	14·478	14·732	14·986
60	15·240	15·494	15·748	16·002	16·256	16·510	16·764	17·018	17·272	17·526
70	17·780	18·034	18·288	18·542	18·796	19·050	19·304	19·558	19·812	20·066
80	20·320	20·574	20·828	21·082	21·336	21·590	21·844	22·098	22·352	22·606
90	22·860	23·114	23·368	23·622	23·876	24·130	24·384	24·638	24·892	25·146

MILLIMETERS TO DECIMALS OF AN INCH.

From 1 to 100 Units.

Millimeters.	0	1	2	3	4	5	6	7	8	9
	0	·03937	·07874	·11811	·15748	·19685	·23622	·27559	·31496	·35433
10	·39370	·43307	·47244	·51181	·55118	·59055	·62992	·66929	·70866	·74803
20	·78740	·82677	·86614	·90551	·94488	·98425	1·02362	1·06299	1·10236	1·14173
30	1·18110	1·22047	1·25984	1·29921	1·33858	1·37795	1·41732	1·45669	1·49606	1·53543
40	1·57480	1·61417	1·65354	1·69291	1·73228	1·77165	1·81102	1·85039	1·88976	1·92913
50	1·96850	2·00787	2·04724	2·08661	2·12598	2·16535	2·20472	2·24409	2·28346	2·32283
60	2·36220	2·40157	2·44094	2·48031	2·51968	2·55905	2·59842	2·63779	2·67716	2·71653
70	2·75590	2·79527	2·83464	2·87401	2·91338	2·95275	2·99212	3·03149	3·07086	3·11023
80	3·14960	3·18897	3·22834	3·26771	3·30708	3·34645	3·38582	3·42519	3·46456	3·50393
90	3·54330	3·58267	3·62204	3·66131	3·70078	3·74015	3·77952	3·81889	3·85826	3·89763

LENGTHS.

INCHES AND MILLIMETERS.—EQUIVALENTS OF DECIMAL AND COMMON FRACTIONS OF AN INCH IN MILLIMETERS.

FROM $\frac{1}{64}$ TO 1 INCH.

$\frac{1}{2}$'s.	$\frac{1}{4}$'s.	8ths.	16ths.	32nds.	64ths.	Milli-meters.	Decimals of an inch.	Inch.	$\frac{1}{2}$'s.	$\frac{1}{4}$'s.	8ths.	16ths.	32nds.	64ths.	Milli-meters.	Decimals of an inch.
					1	= ·397	·015625							33	=13·097	·515625
				1	2	= ·794	·03125						17	34	=13·494	·53125
					3	= 1·191	·046875							35	=13·891	·546875
			1	2	4	= 1·588	·0625					9	18	36	=14·288	·5625
					5	= 1·984	·078125							37	=14·684	·578125
				3	6	= 2·381	·09375						19	38	=15·081	·59375
					7	= 2·778	·109375							39	=15·478	·609375
		1	2	4	8	= 3·175	·1250				5	10	20	40	=15·875	·625
					9	= 3·572	·140625							41	=16·272	·640625
				5	10	= 3·969	·15625						21	42	=16·669	·65625
					11	= 4·366	·171875							43	=17·066	·671875
			3	6	12	= 4·763	·1875					11	22	44	=17·463	·6875
					13	= 5·159	·203125							45	=17·859	·703125
				7	14	= 5·556	·21875						23	46	=18·256	·71875
					15	= 5·953	·234375							47	=18·653	·734375
	1	2	4	8	16	= 6·350	·2500			3	6	12	24	48	=19·050	·75
					17	= 6·747	·265625							49	=19·447	·765625
				9	18	= 7·144	·28125						25	50	=19·844	·78125
					19	= 7·541	·296875							51	=20·241	·796875
			5	10	20	= 7·938	·3125					13	26	52	=20·638	·8125
					21	= 8·334	·328125							53	=21·034	·828125
				11	22	= 8·731	·34375						27	54	=21·431	·84375
					23	= 9·128	·359375							55	=21·828	·859375
		3	6	12	24	= 9·525	·3750				7	14	28	56	=22·225	·875
					25	= 9·922	·390625							57	=22·622	·890625
				13	26	=10·319	·40625						29	58	=23·019	·90625
					27	=10·716	·421875							59	=23·416	·921875
			7	14	28	=11·113	·4375					15	30	60	=23·813	·9375
					29	=11·509	·453125							61	=24·209	·953125
				15	30	=11·906	·46875						31	62	=24·606	·96875
					31	=12·303	·484375							63	=25·003	·984375
1	2	4	8	16	32	=12·700	·5	1	2	4	8	16	32	64	=25·400	1·000

COMPARISON OF PRICES.

FRENCH AND GERMAN PRICES FOR METRIC UNITS, BRITISH PRICES FOR IMPERIAL UNITS, AND UNITED STATES PRICES FOR UNITED STATES STANDARD WEIGHTS AND MEASURES.

[Based upon the circular of the Secretary of the Treasury dated October 1, 1902, fixing the legal equivalent of the (German) mark at 23·8 cents, of the (French) franc at 19·3 cents, and the British pound sterling at $4·8665.]

Francs per kilogram.	Dollars per avoir. pound.	Francs per meter.	Dollars per yard.	Francs per liter.	Dollars per U.S. liquid gal.	Francs per hectoliter.	Dollars per bushel.	Shillings per British imp. gal.	Dollars per U.S. liquid gal.
1	= ·088	1	= ·176	1	= ·731	1	= ·068	1	= ·203
2	= ·175	2	= ·353	2	=1·461	2	= ·136	2	= ·405
3	= ·263	3	= ·529	3	=2·192	3	= ·204	3	= ·608
4	= ·350	4	= ·705	4	=2·922	4	= ·272	4	= ·810
5	= ·438	5	= ·882	5	=3·653	5	= ·340	5	=1·013
6	= ·525	6	=1·058	6	=4·384	6	= ·408	6	=1·216
7	= ·613	7	=1·234	7	=5·114	7	= ·476	7	=1·418
8	= ·700	8	=1·411	8	=5·844	8	= ·544	8	=1·621
9	= ·788	9	=1·587	9	=6·575	9	= ·612	9	=1·824
11·423	=1	5·667	=1	1·369	=1	14·703	=1	4·935	=1
22·846	=2	11·334	=2	2·738	=2	29·407	=2	9·871	=2
34·269	=3	17·000	=3	4·106	=3	44·110	=3	14·806	=3
45·691	=4	22·667	=4	5·475	=4	58·813	=4	19·742	=4
57·115	=5	28·334	=5	6·844	=5	73·517	=5	24·677	=5
68·537	=6	34·001	=6	8·213	=6	88·220	=6	29·612	=6
79·960	=7	39·668	=7	9·581	=7	102·923	=7	34·548	=7
91·383	=8	45·334	=8	10·950	=8	117·627	=8	39·483	=8
102·806	=9	51·001	=9	12·319	=9	132·330	=9	44·419	=9

Marks per kilogram.	Dollars per avoir pound.	Marks per meter.	Dollars per yard.	Marks per liter.	Dollars per U.S. liquid gal.	Marks per hectoliter.	Dollars per bushel.	Shillings per British bus.	Dollars per U.S. bus.
1	= ·108	1	= ·218	1	= ·901	1	= ·084	1	= ·236
2	= ·216	2	= ·435	2	=1·802	2	= ·168	2	= ·472
3	= ·324	3	= ·653	3	=2·730	3	= ·252	3	= ·707
4	= ·432	4	= ·871	4	=3·604	4	= ·335	4	= ·943
5	= ·540	5	=1·088	5	=4·505	5	= ·419	5	=1·179
6	= ·648	6	=1·306	6	=5·406	6	= ·503	6	=1·415
7	= ·756	7	=1·523	7	=6·307	7	= ·587	7	=1·650
8	= ·864	8	=1·741	8	=7·207	8	= ·671	8	=1·886
9	= ·972	9	=1·959	9	=8·108	9	= ·755	9	=2·122
9·263	=1	4·595	=1	1·110	=1	11·923	=1	4·241	=1
18·526	=2	9·190	=2	2·220	=2	23·847	=2	8·483	=2
27·789	=3	13·785	=3	3·330	=3	35·770	=3	12·724	=3
37·052	=4	18·380	=4	4·440	=4	47·693	=4	16·965	=4
46·316	=5	22·975	=5	5·550	=5	59·616	=5	21·207	=5
55·579	=6	27·570	=6	6·660	=6	71·540	=6	25·448	=6
64·842	=7	32·165	=7	7·770	=7	83·463	=7	29·689	=7
74·105	=8	36·760	=8	8·880	=8	95·386	=8	33·931	=8
83·368	=9	41·355	=9	9·990	=9	107·310	=9	38·172	=9

LENGTH.

INCHES AND CENTIMETERS.—EQUIVALENTS FROM 1 TO 100.

Inches to Centimeters.		Inches to Centimeters.		Centimeters to Inches.		Centimeters to Inches.	
0		50	127·000	0		50	19·6850
1	2·540	51	129·540	1	·3937	51	20·0787
2	5·080	52	132·080	2	·7874	52	20·4724
3	7·620	53	134·620	3	1·1811	53	20·8661
4	10·160	54	137·160	4	1·5748	54	21·2598
5	12·700	55	139·700	5	1·9685	55	21·6535
6	15·240	56	142·240	6	2·3622	56	22·0472
7	17·780	57	144·780	7	2·7559	57	22·4409
8	20·320	58	147·320	8	3·1496	58	22·8346
9	22·860	59	149·860	9	3·5433	59	23·2283
10	25·400	60	152·400	10	3·9370	60	23·6220
11	27·940	61	154·940	11	4·3307	61	24·0157
12	30·480	62	157·480	12	4·7244	62	24·4094
13	33·020	63	160·020	13	5·1181	63	24·8031
14	35·560	64	162·560	14	5·5118	64	25·1968
15	38·100	65	165·100	15	5·9055	65	25·5905
16	40·640	66	167·640	16	6·2992	66	25·9842
17	43·180	67	170·180	17	6·6929	67	26·3779
18	45·720	68	172·720	18	7·0866	68	26·7716
19	48·260	69	175·260	19	7·4803	69	27·1653
20	50·800	70	177·800	20	7·8740	70	27·5590
21	53·340	71	180·340	21	8·2677	71	27·9527
22	55·880	72	182·880	22	8·6614	72	28·3464
23	58·420	73	185·420	23	9·0551	73	28·7401
24	60·960	74	187·960	24	9·4488	74	29·1338
25	63·500	75	190·500	25	9·8425	75	29·5275
26	66·040	76	193·040	26	10·2362	76	29·9212
27	68·580	77	195·580	27	10·6299	77	30·3149
28	71·120	78	198·120	28	11·0236	78	30·7086
29	73·660	79	200·660	29	11·4173	79	31·1023
30	76·200	80	203·200	30	11·8110	80	31·4960
31	78·740	81	205·740	31	12·2047	81	31·8897
32	81·280	82	208·280	32	12·5984	82	32·2834
33	83·820	83	210·820	33	12·9921	83	32·6771
34	86·360	84	213·360	34	13·3858	84	33·0708
35	88·900	85	215·900	35	13·7795	85	33·4645
36	91·440	86	218·440	36	14·1732	86	33·8582
37	93·980	87	220·980	37	14·5669	87	34·2519
38	96·520	88	223·520	38	14·9606	88	34·6456
39	99·060	89	226·060	39	15·3543	89	35·0393
40	101·600	90	228·600	40	15·7480	90	35·4330
41	104·140	91	231·140	41	16·1417	91	35·8267
42	106·680	92	233·680	42	16·5354	92	36·2204
43	109·220	93	236·220	43	16·9291	93	36·6141
44	111·760	94	238·760	44	17·3228	94	37·0078
45	114·300	95	241·300	45	17·7165	95	37·4015
46	116·840	96	243·840	46	18·1102	96	37·7952
47	119·380	97	246·380	47	18·5039	97	38·1889
48	121·920	98	248·920	48	18·8976	98	38·5826
49	124·460	99	251·460	49	19·2913	99	38·9763

LENGTH.

FEET AND METERS.—EQUIVALENTS FROM 1 TO 100.

Feet.	Meters.	Feet.	Meters.	Meters.	Feet.	Meters.	Feet.
0		50	15·24003	0		50	164·04167
1	·30480	1	15·54483	1	3·28083	1	167·32250
2	·60960	2	15·84963	2	6·56167	2	170·60333
3	·91440	3	16·15443	3	9·84250	3	173·88417
4	1·21920	4	16·45923	4	13·12333	4	177·16500
5	1·52400	5	16·76403	5	16·40417	5	180·44583
6	1·82880	6	17·06883	6	19·68500	6	183·72667
7	2·13360	7	17·37363	7	22·96583	7	187·00750
8	2·43840	8	17·67844	8	26·24667	8	190·28833
9	2·74321	9	17·98324	9	29·52750	9	193·56917
10	3·04801	60	18·28804	10	32·80833	60	196·85000
1	3·35281	1	18·59284	1	36·08917	1	200·13083
2	3·65761	2	18·89764	2	39·37000	2	203·41167
3	3·96241	3	19·20244	3	42·65083	3	206·69250
4	4·26721	4	19·50724	4	45·93167	4	209·97333
5	4·57201	5	19·81204	5	49·21250	5	213·25417
6	4·87681	6	20·11684	6	52·49333	6	216·53500
7	5·18161	7	20·42164	7	55·77417	7	219·81583
8	5·48641	8	20·72644	8	59·05500	8	223·09667
9	5·79121	9	21·03124	9	62·33583	9	226·37750
20	6·09601	70	21·33604	20	65·61667	70	229·65833
1	6·40081	1	21·64084	1	68·89750	1	232·93917
2	6·70561	2	21·94564	2	72·17833	2	236·22000
3	7·01041	3	22·25044	3	75·45917	3	239·50083
4	7·31521	4	22·55525	4	78·74000	4	242·78167
5	7·62002	5	22·86005	5	82·02083	5	246·06250
6	7·92482	6	23·16485	6	85·30167	6	249·34333
7	8·22962	7	23·46965	7	88·58250	7	252·62417
8	8·53442	8	23·77445	8	91·86333	8	255·90500
9	8·83922	9	24·07925	9	95·14417	9	259·18583
30	9·14402	80	24·38405	30	98·42500	80	262·46667
1	9·44882	1	24·68885	1	101·70583	1	265·74750
2	9·75362	2	24·99365	2	104·98667	2	269·02833
3	10·05842	3	25·29845	3	108·26750	3	272·30917
4	10·36322	4	25·60325	4	111·54833	4	275·59000
5	10·66803	5	25·90805	5	114·82917	5	278·87083
6	10·97282	6	26·21285	6	118·11000	6	282·15167
7	11·27762	7	26·51765	7	121·39083	7	285·43250
8	11·58242	8	26·82245	8	124·67167	8	288·71333
9	11·88722	9	27·12725	9	127·95250	9	291·99417
40	12·19202	90	27·43205	40	131·23333	90	295·27500
1	12·49682	1	27·73686	1	134·51417	1	298·55583
2	12·80163	2	28·04166	2	137·79500	2	301·83667
3	13·10643	3	28·34646	3	141·07583	3	305·11750
4	13·41123	4	28·65126	4	144·35667	4	308·39833
5	13·71603	5	28·95606	5	147·63750	5	311·67917
6	14·02083	6	29·26086	6	150·91833	6	314·96000
7	14·32563	7	29·56566	7	154·19917	7	318·24083
8	14·63043	8	29·87046	8	157·48000	8	321·52167
9	14·93523	9	30·17526	9	160·76083	9	324·80250

LENGTH.

YARDS AND METERS.—EQUIVALENTS FROM 1 TO 100.

Yards.	Meters.	Yards.	Meters.	Meters.	Yards.	Meters.	Yards.
0		50	45·72009	0		50	54·68056
1	·91440	51	46·63449	1	1·09361	51	55·77417
2	1·82880	52	47·54889	2	2·18722	52	56·86778
3	2·74321	53	48·46330	3	3·28083	53	57·96139
4	3·65761	54	49·37770	4	4·37444	54	59·05500
5	4·57201	55	50·29210	5	5·46806	55	60·14861
6	5·48641	56	51·20650	6	6·56167	56	61·24222
7	6·40081	57	52·12090	7	7·65528	57	62·33583
8	7·31521	58	53·03530	8	8·74889	58	63·42944
9	8·22962	59	53·94971	9	9·84250	59	64·52306
10	9·14402	60	54·86411	10	10·93611	60	65·61667
11	10·05842	61	55·77851	11	12·02972	61	66·71028
12	10·97282	62	56·69291	12	13·12333	62	67·80389
13	11·88722	63	57·60731	13	14·21694	63	68·89750
14	12·80163	64	58·52172	14	15·31056	64	69·99111
15	13·71603	65	59·43612	15	16·40417	65	71·08472
16	14·63043	66	60·35052	16	17·49778	66	72·17833
17	15·54483	67	61·26492	17	18·92139	67	73·27194
18	16·45923	68	62·17932	18	19·68500	68	74·36556
19	17·37363	69	63·09372	19	20·77861	69	75·45917
20	18·28804	70	64·00813	20	21·87222	70	76·55278
21	19·20244	71	64·92253	21	22·96583	71	77·64639
22	20·11684	72	65·83693	22	24·05944	72	78·74000
23	21·03124	73	66·75133	23	25·15306	73	79·83361
24	21·94564	74	67·66573	24	26·24667	74	80·92722
25	22·86005	75	68·58014	25	27·34028	75	82·02083
26	23·77445	76	69·49454	26	28·43389	76	83·11444
27	24·68885	77	70·40894	27	29·52750	77	84·20806
28	25·60325	78	71·32334	28	30·62111	78	85·30167
29	26·51765	79	72·23774	29	31·71472	79	86·39528
30	27·43205	80	73·15214	30	32·80833	80	87·48889
31	28·34646	81	74·06655	31	33·90194	81	88·58250
32	29·26086	82	74·98095	32	34·99556	82	89·67611
33	30·17526	83	75·89535	33	36·08917	83	90·76972
34	31·08966	84	76·80975	34	37·18278	84	91·86333
35	32·00406	85	77·72415	35	38·27639	85	92·95694
36	32·91846	86	78·63855	36	39·37000	86	94·05056
37	33·83287	87	79·55296	37	40·46361	87	95·14417
38	34·74727	88	80·46736	38	41·55722	88	96·23778
39	35·66167	89	81·38176	39	42·65083	89	97·33139
40	36·57607	90	82·29616	40	43·74444	90	98·42500
41	37·49047	91	83·21056	41	44·83806	91	99·51861
42	38·40488	92	84·12497	42	45·93167	92	100·61222
43	39·31928	93	85·03937	43	47·02528	93	101·70583
44	40·23368	94	85·95377	44	48·11889	94	102·79944
45	41·14808	95	86·86817	45	49·21250	95	103·89306
46	42·06248	96	87·78257	46	50·30611	96	104·98667
47	42·97688	97	88·69697	47	51·39972	97	106·08028
48	43·89129	98	89·61138	48	52·49333	98	107·17389
49	44·80569	99	90·52578	49	53·58694	99	108·26750

LENGTH.

MILES AND KILOMETERS.—EQUIVALENTS FROM 1 TO 100.

Miles.	Kilometers.	Miles.	Kilometers.	Kilometers.	Miles.	Kilometers.	Miles.
0		50	80·4674	0		50	31·06850
1	1·6093	1	82·0767	1	·62137	1	31·68987
2	3·2187	2	83·6861	2	1·24274	2	32·31124
3	4·8280	3	85·2954	3	1·86411	3	32·93261
4	6·4374	4	86·9047	4	2·48548	4	33·55398
5	8·0467	5	88·5141	5	3·10685	5	34·17535
6	9·6561	6	90·1234	6	3·72822	6	34·79672
7	11·2654	7	91·7328	7	4·34959	7	35·41809
8	12·8748	8	93·3421	8	4·97096	8	36·03946
9	14·4841	9	94·9515	9	5·59233	9	36·66083
10	16·0935	60	96·5608	10	6·21370	60	37·28220
1	17·7028	1	98·1702	1	6·83507	1	37·90357
2	19·3122	2	99·7795	2	7·45644	2	38·52494
3	20·9215	3	101·3889	3	8·07781	3	39·14631
4	22·5309	4	102·9982	4	8·69918	4	39·76768
5	24·1402	5	104·6076	5	9·32055	5	40·38905
6	25·7496	6	106·2169	6	9·94192	6	41·01042
7	27·3589	7	107·8263	7	10·56329	7	41·63179
8	28·9682	8	109·4356	8	11·18466	8	42·25316
9	30·5776	9	111·0450	9	11·80603	9	42·87453
20	32·1869	70	112·6543	20	12·42740	70	43·49590
1	33·7963	1	114·2637	1	13·04877	1	44·11727
2	35·4056	2	115·8730	2	13·67014	2	44·73864
3	37·0150	3	117·4823	3	14·29151	3	45·36001
4	38·6243	4	119·0917	4	14·91288	4	45·98138
5	40·2337	5	120·7010	5	15·53425	5	46·60275
6	41·8430	6	122·3104	6	16·15562	6	47·22412
7	43·4524	7	123·9197	7	16·77699	7	47·84549
8	45·0617	8	125·5291	8	17·39836	8	48·46686
9	46·6711	9	127·1384	9	18·01973	9	49·08823
30	48·2804	80	128·7478	30	18·64110	80	49·70960
1	49·8898	1	130·3571	1	19·26247	1	50·33097
2	51·4991	2	131·9665	2	19·88384	2	50·95234
3	53·1085	3	133·5758	3	20·50521	3	51·57371
4	54·7178	4	135·1852	4	21·12658	4	52·19508
5	56·3272	5	136·7945	5	21·74795	5	52·81645
6	57·9365	6	138·4039	6	22·36932	6	53·43782
7	59·5458	7	140·0132	7	22·99069	7	54·05919
8	61·1552	8	141·6226	8	23·61206	8	54·68056
9	62·7645	9	143·2319	9	24·23343	9	55·30193
40	64·3739	90	144·8412	40	24·85480	90	55·92330
1	65·9832	1	146·4506	1	25·47617	1	56·54467
2	67·5926	2	148·0599	2	26·09754	2	57·16604
3	69·2019	3	149·6693	3	26·71891	3	57·78741
4	70·8113	4	151·2786	4	27·34028	4	58·40878
5	72·4206	5	152·8880	5	27·96165	5	59·03015
6	74·0300	6	154·4973	6	28·58302	6	59·65152
7	75·6393	7	156·1067	7	29·20439	7	60·27289
8	77·2487	8	157·7160	8	29·82576	8	60·89426
9	78·8580	9	159·3254	9	30·44713	9	61·51562

AREAS.

ACRES AND HECTARES.—EQUIVALENTS FROM 1 TO 100.

Acres.	Hectares.	Acres.	Hectares.	Hectares.	Acres.	Hectares.	Acres.
0		50	20·23436	0		50	123·55220
1	0·40469	1	20·63905	1	2·47104	1	126·02324
2	0·80937	2	21·04374	2	4·94209	2	128·49428
3	1·21406	3	21·44842	3	7·41313	3	130·96533
4	1·61875	4	21·85311	4	9·88418	4	133·43637
5	2·02344	5	22·25780	5	12·35522	5	135·90742
6	2·42812	6	22·66249	6	14·82626	6	138·37846
7	2·83281	7	23·06717	7	17·29731	7	140·84950
8	3·23750	8	23·47186	8	19·76835	8	143·32055
9	3·64219	9	23·87655	9	22·23940	9	145·79159
10	4·04687	60	24·28124	10	24·71044	60	148·26264
1	4·45156	1	24·68592	1	27·18148	1	150·73368
2	4·85625	2	25·09061	2	29·65253	2	153·20472
3	5·26093	3	25·49530	3	32·12357	3	155·67577
4	5·66562	4	25·89998	4	34·59462	4	158·14681
5	6·07031	5	26·30467	5	37·06566	5	160·61786
6	6·47500	6	26·70936	6	39·53670	6	163·08890
7	6·87968	7	27·11405	7	42·00775	7	165·55994
8	7·28437	8	27·51873	8	44·47879	8	168·03099
9	7·68906	9	27·92342	9	46·94983	9	170·50203
20	8·09375	70	28·32811	20	49·42088	70	172·97308
1	8·49843	1	28·73280	1	51·89192	1	175·44412
2	8·90312	2	29·13748	2	54·36297	2	177·91516
3	9·30781	3	29·54217	3	56·83401	3	180·38621
4	9·71249	4	29·94686	4	59·30505	4	182·85725
5	10·11718	5	30·35154	5	61·77610	5	185·32829
6	10·52187	6	30·75623	6	64·24714	6	187·79934
7	10·92656	7	31·16092	7	66·71819	7	190·27038
8	11·33124	8	31·56561	8	69·18923	8	192·74143
9	11·73593	9	31·97029	9	71·66027	9	195·21247
30	12·14062	80	32·37498	30	74·13132	80	197·68351
1	12·54531	1	32·77967	1	76·60236	1	200·15456
2	12·94999	2	33·18436	2	79·07341	2	202·62560
3	13·35468	3	33·58904	3	81·54445	3	205·09665
4	13·75937	4	33·99373	4	84·01549	4	207·56769
5	14·16405	5	34·39842	5	86·48654	5	210·03873
6	14·56874	6	34·80310	6	88·95758	6	212·50978
7	14·97343	7	35·20779	7	91·42863	7	214·98082
8	15·37812	8	35·61248	8	93·89967	8	217·45187
9	15·78280	9	36·01717	9	96·37071	9	219·92291
40	16·18749	90	36·42185	40	98·84176	90	222·39395
1	16·59218	1	36·82654	1	101·31280	1	224·86500
2	16·99686	2	37·23123	2	103·78385	2	227·33604
3	17·40155	3	37·63592	3	106·25489	3	229·80709
4	17·80624	4	38·04060	4	108·72593	4	232·27813
5	18·21093	5	38·44529	5	111·19698	5	234·74917
6	18·61561	6	38·84998	6	113·66802	6	237·22022
7	19·02030	7	39·25466	7	116·13906	7	239·69126
8	19·42499	8	39·65935	8	118·61011	8	242·16231
9	19·82968	9	40·06404	9	121·08115	9	244·63335

CAPACITY.

LIQUID QUARTS TO LITERS.—EQUIVALENTS FROM 1 TO 100.

Quarts.	Liters.	Quarts.	Liters.	Liters.	Quarts.	Liters.	Quarts.
0		50	47·31793	0		50	52·83409
1	·94636	1	48·26429	1	1·05668	1	53·89077
2	1·89272	2	49·21065	2	2·11336	2	54·94746
3	2·83908	3	50·15701	3	3·17005	3	56·00414
4	3·78543	4	51·10337	4	4·22673	4	57·06082
5	4·73179	5	52·04972	5	5·28341	5	58·11750
6	5·67815	6	52·99608	6	6·34009	6	59·17418
7	6·62451	7	53·94244	7	7·39677	7	60·23086
8	7·57087	8	54·88880	8	8·45345	8	61·28755
9	8·51723	9	55·83516	9	9·51014	9	62·34423
10	9·46359	60	56·78152	10	10·56682	60	63·40091
1	10·40994	1	57·72788	1	11·62350	1	64·45759
2	11·35630	2	58·67423	2	12·68018	2	65·51428
3	12·30266	3	59·62059	3	13·73686	3	66·57096
4	13·24902	4	60·56695	4	14·79355	4	67·62764
5	14·19538	5	61·51331	5	15·85023	5	68·68432
6	15·14174	6	62·45967	6	16·90691	6	69·74100
7	16·08810	7	63·40603	7	17·96359	7	70·79768
8	17·03446	8	64·35239	8	19·02027	8	71·85437
9	17·98081	9	65·29875	9	20·07696	9	72·91105
20	18·92717	70	66·24510	20	21·13364	70	73·96773
1	19·87353	1	67·19146	1	22·19032	1	75·02441
2	20·81989	2	68·13782	2	23·24700	2	76·08109
3	21·76625	3	69·08418	3	24·30368	3	77·13778
4	22·71261	4	70·03054	4	25·36036	4	78·19446
5	23·65897	5	70·97690	5	26·41705	5	79·25114
6	24·60532	6	71·92326	6	27·47373	6	80·30782
7	25·55168	7	72·86961	7	28·53041	7	81·36450
8	26·49804	8	73·81597	8	29·58709	8	82·42119
9	27·44440	9	74·76233	9	30·64377	9	83·47787
30	28·39076	80	75·70869	30	31·70046	80	84·53455
1	29·33712	1	76·65505	1	32·75714	1	85·59123
2	30·28348	2	77·60141	2	33·81382	2	86·64791
3	31·22983	3	78·54777	3	34·87050	3	87·70459
4	32·17619	4	79·49412	4	35·92718	4	88·76128
5	33·12255	5	80·44048	5	36·98387	5	89·81796
6	34·06891	6	81·38684	6	38·04055	6	90·87464
7	35·01527	7	82·33320	7	39·09723	7	91·93132
8	35·96163	8	83·27956	8	40·15391	8	92·98800
9	36·90799	9	84·22592	9	41·21059	9	94·04469
40	37·85436	90	85·17228	40	42·26727	90	95·10137
1	38·80070	1	86·11863	1	43·32396	1	96·15805
2	39·74706	2	87·06499	2	44·38064	2	97·21473
3	40·69342	3	88·01135	3	45·43732	3	98·27141
4	41·63978	4	88·95771	4	46·49400	4	99·32809
5	42·58614	5	89·90407	5	47·55068	5	100·38478
6	43·53250	6	90·85043	6	48·60737	6	101·44146
7	44·47886	7	91·79679	7	49·66405	7	102·49814
8	45·42521	8	92·74315	8	50·72073	8	103·55482
9	46·37157	9	93·68950	9	51·77741	9	104·61150

CAPACITY.

GALLONS AND LITERS.—EQUIVALENTS FROM 1 TO 100.

Gallons.	Liters.	Gallons.	Liters.	Liters.	Gallons.	Liters.	Gallons.
0		50	189·2717	0		50	13·20852
1	3·7854	1	193·0572	1	·26417	1	13·47269
2	7·5709	2	196·8426	2	·52834	2	13·73686
3	11·3563	3	200·6280	3	·79251	3	14·00103
4	15·1417	4	204·4135	4	1·05668	4	14·26521
5	18·9272	5	208·1989	5	1·32085	5	14·52938
6	22·7126	6	211·9843	6	1·58502	6	14·79355
7	26·4980	7	215·7698	7	1·84919	7	15·05772
8	30·2835	8	219·5552	8	2·11336	8	15·32189
9	34·0689	9	223·3406	9	2·37753	9	15·58606
10	37·8543	60	227·1261	10	2·64170	60	15·85023
1	41·6398	1	230·9115	1	2·90588	1	16·11440
2	45·4252	2	234·6969	2	3·17005	2	16·37857
3	49·2106	3	238·4824	3	3·43422	3	16·64274
4	52·9961	4	242·2678	4	3·69839	4	16·90691
5	56·7815	5	246·0532	5	3·96256	5	17·17108
6	60·5670	6	249·8387	6	4·22673	6	17·43525
7	64·3524	7	253·6241	7	4·49090	7	17·69942
8	68·1378	8	257·4095	8	4·75507	8	17·96359
9	71·9233	9	261·1950	9	5·01924	9	18·22776
20	75·7087	70	264·9804	20	5·28341	70	18·49193
1	79·4941	1	268·7658	1	5·54758	1	18·75610
2	83·2796	2	272·5513	2	5·81175	2	19·02027
3	87·0650	3	276·3367	3	6·07592	3	19·28444
4	90·8504	4	280·1222	4	6·34009	4	19·54861
5	94·6359	5	283·9076	5	6·60426	5	19·81279
6	98·4213	6	287·6930	6	6·86843	6	20·07696
7	102·2067	7	291·4785	7	7·13260	7	20·34113
8	105·9922	8	295·2639	8	7·39677	8	20·60530
9	109·7776	9	299·0493	9	7·66094	9	20·86947
30	113·5630	80	302·8348	30	7·92511	80	21·13364
1	117·3485	1	306·6202	1	8·18928	1	21·39781
2	121·1339	2	310·4056	2	8·45345	2	21·66198
3	124·9193	3	314·1911	3	8·71763	3	21·92615
4	128·7048	4	317·9765	4	8·98180	4	22·19032
5	132·4902	5	321·7619	5	9·24597	5	22·45449
6	136·2756	6	325·5474	6	9·51014	6	22·71866
7	140·0611	7	329·3328	7	9·77431	7	22·98283
8	143·8465	8	333·1182	8	10·03848	8	23·24700
9	147·6319	9	336·9037	9	10·30265	9	23·51117
40	151·4174	90	340·6891	40	10·56682	90	23·77534
1	155·2028	1	344·4745	1	10·83099	1	24·03951
2	158·9882	2	348·2600	2	11·09516	2	24·30368
3	162·7737	3	352·0454	3	11·35933	3	24·56785
4	166·5591	4	355·8308	4	11·62350	4	24·83202
5	170·3446	5	359·6163	5	11·88767	5	25·09619
6	174·1300	6	363·4017	6	12·15184	6	25·36036
7	177·9154	7	367·1871	7	12·41601	7	25·62454
8	181·7009	8	370·9726	8	12·68018	8	25·88871
9	185·4863	9	374·7580	9	12·94435	9	26·15288

MASSES.

AVOIRDUPOIS POUND & KILOGRAM.—EQUIVALENTS FROM 1 TO 100.

Pounds.	Kilos.	Pounds.	Kilos.	Kilos.	Pounds.	Kilos.	Pounds.
0		50	22·67962	0		50	110·2311
1	·45359	1	23·13321	1	2·2046	1	112·4357
2	·90718	2	23·58681	2	4·4092	2	114·6404
3	1·36078	3	24·04040	3	6·6139	3	116·8450
4	1·81437	4	24·49399	4	8·8185	4	119·0496
5	2·26796	5	24·94758	5	11·0231	5	121·2542
6	2·72155	6	25·40118	6	13·2277	6	123·4589
7	3·17515	7	25·85477	7	15·4324	7	125·6635
8	3·62874	8	26·30836	8	17·6370	8	127·8681
9	4·08233	9	26·76195	9	19·8416	9	130·0727
10	4·53592	60	27·21555	10	22·0462	60	132·2773
1	4·98952	1	27·66914	1	24·2508	1	134·4820
2	5·44311	2	28·12273	2	26·4555	2	136·6866
3	5·89670	3	28·57632	3	28·6601	3	138·8912
4	6·35029	4	29·02992	4	30·8647	4	141·0958
5	6·80389	5	29·48351	5	33·0693	5	143·3005
6	7·25748	6	29·93710	6	35·2740	6	145·5051
7	7·71107	7	30·39069	7	37·4786	7	147·7097
8	8·16466	8	30·84429	8	39·6832	8	149·9143
9	8·61826	9	31·29788	9	41·8878	9	152·1189
20	9·07185	70	31·75147	20	44·0924	70	154·3236
1	9·52544	1	32·20506	1	46·2971	1	156·5282
2	9·97903	2	32·65865	2	48·5017	2	158·7328
3	10·43263	3	33·11225	3	50·7063	3	160·9374
4	10·88622	4	33·56584	4	52·9109	4	163·1421
5	11·33981	5	34·01943	5	55·1156	5	165·3467
6	11·79340	6	34·47302	6	57·3202	6	167·5513
7	12·24700	7	34·92662	7	59·5248	7	169·7559
8	12·70059	8	35·38021	8	61·7294	8	171·9605
9	13·15418	9	35·83380	9	63·9340	9	174·1652
30	13·60777	80	36·28739	30	66·1387	80	176·3698
1	14·06137	1	36·74099	1	68·3433	1	178·5744
2	14·51496	2	37·19458	2	70·5479	2	180·7790
3	14·96855	3	37·64817	3	72·7525	3	182·9837
4	15·42214	4	38·10176	4	74·9572	4	185·1883
5	15·87573	5	38·55536	5	77·1618	5	187·3929
6	16·32933	6	39·00895	6	79·3664	6	189·5975
7	16·78292	7	39·46254	7	81·5710	7	191·8021
8	17·23651	8	39·91613	8	83·7756	8	194·0068
9	17·69010	9	40·36973	9	85·9803	9	196·2011
40	18·14370	90	40·82332	40	88·1849	90	198·4160
1	18·59729	1	41·27691	1	90·3895	1	200·6206
2	19·05088	2	41·73050	2	92·5941	2	202·8253
3	19·50447	3	42·18410	3	94·7988	3	205·0299
4	19·95807	4	42·63769	4	97·0034	4	207·2345
5	20·41166	5	43·09128	5	99·2080	5	209·4391
6	20·86525	6	43·54487	6	101·4126	6	211·6437
7	21·31884	7	43·99847	7	103·6172	7	213·8484
8	21·77244	8	44·45206	8	105·8219	8	216·0530
9	22·22603	9	44·90565	9	108·0265	9	218·2576

COMPARISON OF THE VARIOUS TONS AND POUNDS IN USE IN THE UNITED STATES.

FROM 1 TO 10 UNITS.

Long Tons.	Short Tons.	Metric Tons.	Kilograms.	Avoirdupois Pounds.	Troy Pounds.
·00036735	·00041143	·00037324	·37324	·822857	**1**
·00044643	·00050000	·00045359	·45359	**1**	1·21528
·00073469	·00082286	·00074648	·74648	1·64571	**2**
·00089286	·00100000	·00090718	·90718	**2**	2·43056
·00098421	·00110231	·00100000	**1**	2·20462	2·67923
·00110204	·00123429	·00111973	1·11973	2·46857	**3**
·00133929	·00150000	·00136078	1·36078	**3**	3·64583
·00146939	·00164571	·00149297	1·49297	3·29143	**4**
·00178571	·00200000	·00181437	1·81437	**4**	4·86111
·00183673	·00205714	·00186621	1·86621	4·11429	**5**
·00196841	·00220462	·00200000	**2**	4·40924	5·35846
·00220408	·00246857	·00223945	2·23945	4·93714	**6**
·00223214	·00250000	·00226796	2·26796	**5**	6·07639
·00257143	·00288000	·00261269	2·61269	5·76000	**7**
·00267857	·00300000	·00272155	2·72155	**6**	7·29167
·00293878	·00329143	·00298593	2·98593	6·58286	**8**
·00295262	·00330693	·00300000	**3**	6·61387	8·03769
·00312500	·00350000	·00317515	3·17515	**7**	8·50694
·00330612	·00370286	·00335918	3·35918	7·40571	**9**
·00357143	·00400000	·00362874	3·62874	**8**	9·72222
·00393683	·00440924	·00400000	**4**	8·81849	10·71691
·00401786	·00450000	·00408233	4·08233	**9**	10·93750
·00492103	·00551156	·00500000	**5**	11·0231	13·39614
·00590524	·00661387	·00600000	**6**	13·2277	16·07537
·00688944	·00771618	·00780000	**7**	15·4324	18·75460
·00787365	·00881849	·00800000	**8**	17·6370	21·43383
·00885786	·00992080	·0090000	**9**	19·8416	24·11306
·89287	**1**	·90718	907·18	2,000·00	2,430·56
·98421	1·10231	**1**	1,000·00	2,204·62	2,679·23
1	1·12000	1·01605	1,016·05	2,240·00	2,722·22
1·78571	**2**	1·81437	1,814·37	4,000·00	4,861·11
1·96841	2·20462	**2**	2,000·00	4,409·24	5,358·46
2	2·24000	2·03209	2,032·09	4,480·00	5,444·44
2·67857	**3**	2·72155	2,721·55	6,000·00	7,291·67
2·95262	3·30693	**3**	3,000·00	6,613·87	8,037·69
3	3·36000	3·04814	3,048·14	6,720·00	8,166·67
3·57143	**4**	3·62874	3,628·74	8,000·00	9,722·22
3·93683	4·40924	**4**	4,000·00	8,818·49	10,716·91
4	4·48000	4·06419	4,064·19	8,960·00	10,888·89
4·46429	**5**	4·53592	4,535·92	10,000·00	12,152·78
4·92103	5·51156	**5**	5,000·00	11,023·11	13,396·14
5	5·60000	5·08024	5,080·24	11,200·00	13,611·11
5·35714	**6**	5·44311	5,443·11	12,000·00	14,583·33
5·90524	6·61387	**6**	6,000·00	13,227·73	16,075·37
6	6·72000	6·09628	6,096·28	13,440·00	16,333·33
6·25000	**7**	6·35029	6,350·29	14,000·00	17,013·89
6·88944	7·71618	**7**	7,000·00	15,432·36	18,754·60
7	7·84000	7·11232	7,112·32	15,680·00	19,055·56
7·14286	**8**	7·25748	7,257·48	16,000·00	19,444·44
7·87365	8·81849	**8**	8,000·00	17,636·98	21,433·83
8	8·96000	8·12838	8,128·38	17,920·00	21,777·78
8·03571	**9**	8·16466	8,164·66	18,000·00	21,875·00
8·85786	9·92080	**9**	9,000·00	19,841·60	24,113·06
9	10·08000	9·14442	9,144·42	20,160·00	24,500·00

MEASURES OF CAPACITY.

EQUIVALENTS FROM 1 TO 10.

Milliliters. (c.c.)	U.S. Liquid Ounces.	Millilitres. (c.c.)	U.S. Apothecaries' Drams.	U.S. Apothecaries' Scruples.	Milliliters. (c.c.)	U.S. Liquid Quarts.	Liters.	U.S. Liquid Gallons.	Liters.
1	0·03381	**1**	0·2705	0·8115	**1**	**1**	0·94636	0·26417	**1**
2	0·06763	**2**	0·5410	**1**	1·2322	1·05668	**1**	0·52834	**2**
3	0·10144	**3**	0·8115	1·6231	**2**	**2**	1·89272	0·79251	**3**
4	0·13526	3·6967	**1**	**2**	2·4645	2·11336	**2**	**1**	3·78543
5	0·16907	**4**	1·0820	2·4346	**3**	**3**	2·83908	1·05668	**4**
6	0·20288	**5**	1·3525	**3**	3·6967	3·17005	**3**	1·32085	**5**
7	0·23670	**6**	1·6231	3·2461	**4**	**4**	3·78543	1·58502	**6**
8	0·27051	**7**	1·8936	**4**	4·9290	4·22673	**4**	1·84919	**7**
9	0·30432	7·3934	**2**	4·0577	**5**	**5**	4·73179	**2**	7·57087
29·574	**1**	**8**	2·1641	4·8692	**6**	5·28341	**5**	2·11336	**8**
59·147	**2**	**9**	2·4346	**5**	6·1612	**6**	5·67815	2·37753	**9**
88·721	**3**	11·0901	**3**	5·6807	**7**	6·34009	**6**	**3**	11·35630
118·295	**4**	14·7869	**4**	**6**	7·3934	**7**	6·62451	**4**	15·14174
147·869	**5**	18·4836	**5**	6·4923	**8**	7·39677	**7**	**5**	18·92717
177·442	**6**	22·1803	**6**	**7**	8·6257	**8**	7·57088	**6**	22·71261
207·016	**7**	25·8770	**7**	7·3038	**9**	8·45345	**8**	**7**	26·49804
236·590	**8**	29·5737	**8**	**8**	9·8579	**9**	8·51723	**8**	30·28348
266·163	**9**	33·2704	**9**	**9**	11·0901	9·51014	**9**	**9**	34·06891

U.S. Dry Quarts.	Liters.	U.S. Pecks.	Liters.	Deka-liters.	U.S. Pecks.	U.S. Bushels.	Hecto-liters.	U.S. Bushels per Acre.	Hectolitres per Hectare.
0·9081	**1**	0·11351	**1**	0·8810	**1**	**1**	0·35239	**1**	0·87078
1	1·1012	0·22702	**2**	**1**	1·1351	**2**	0·70479	1·14840	**1**
1·8162	**2**	0·34053	**3**	1·7620	**2**	2·83774	**1**	**2**	1·74156
2	2·2025	0·45404	**4**	**2**	2·2702	**3**	1·05718	2·29680	**2**
2·7242	**3**	0·56755	**5**	2·6429	**3**	**4**	1·40957	**3**	2·61233
3	3·3037	0·68106	**6**	**3**	3·4053	**5**	1·76196	3·44519	**3**
3·6323	**4**	0·79457	**7**	3·5239	**4**	5·67548	**2**	**4**	3·48311
4	4·4049	0·90808	**8**	**4**	4·5404	**6**	2·11436	4·59359	**4**
4·5404	**5**	**1**	8·80982	4·4049	**5**	**7**	2·46675	**5**	4·35389
5	5·5061	1·02157	**9**	**5**	5·6755	**8**	2·81914	5·74199	**5**
5·4485	**6**	**2**	17·61964	5·2859	**6**	8·51323	**3**	**6**	5·22467
6	6·6074	**3**	26·42946	**6**	6·8106	**9**	3·17154	6·89039	**6**
6·3565	**7**	**4**	35·23928	6·1669	**7**	11·35097	**4**	**7**	6·09545
7	7·7086	**5**	44·04910	**7**	7·9457	14·18871	**5**	**8**	6·96622
7·2646	**8**	**6**	52·85892	7·0479	**8**	17·02645	**6**	8·03879	**7**
8	8·8098	**7**	61·66874	7·9288	**9**	19·86420	**7**	**9**	7·83700
8·1727	**9**	**8**	70·47856	**8**	9·0808	22·70194	**8**	9·18719	**8**
9	9·9110	**9**	79·28838	**9**	10·2159	25·53968	**9**	10·33558	**9**

MEASURES OF MASS.

EQUIVALENTS FROM 1 TO 10.

Grains.	Grams.	Avoirdupois Ounces.	Grams.	Troy Ounces.	Grams.	Avoirdupois Pounds.	Kilograms.	Troy Pounds.	Kilograms.
1	=0·06480	0·03527=	**1**	0·03215=	**1**	**1**	=0·45359	**1**	=0·37324
2	=0·12960	0·07055=	**2**	0·06430=	**2**	**2**	=0·90718	**2**	=0·74648
3	=0·19440	0·10582=	**3**	0·09645=	**3**	2·20462=	**1**	2·67923=	**1**
4	=0·25920	0·14110=	**4**	0·12860=	**4**	**3**	=1·36078	**3**	=1·11973
5	=0·32399	0·17637=	**5**	0·16075=	**5**	**4**	=1·81437	**4**	=1·49297
6	=0·38879	0·21164=	**6**	0·19290=	**6**	4·40924=	**2**	**5**	=1·86621
7	=0·45359	0·24692=	**7**	0·22506=	**7**	**5**	=2·26796	5·35846=	**2**
8	=0·51839	0·28219=	**8**	0·25721=	**8**	**6**	=2·72155	**6**	=2·23945
9	=0·58319	0·31747=	**9**	0·28936=	**9**	6·61387=	**3**	**7**	=2·61269
15·4324=	**1**	**1**	= 28·3495	**1**	= 31·10348	**7**	=3·17515	**8**	=2·98593
30·8647=	**2**	**2**	= 56·6991	**2**	= 62·20696	**8**	=3·62874	8·03769=	**3**
46·2971=	**3**	**3**	= 85·0486	**3**	= 93·31044	8·81849=	**4**	**9**	=3·35918
61·7294=	**4**	**4**	=113·3981	**4**	=124·41392	**9**	=4·08233	10·71691=	**4**
77·1618=	**5**	**5**	=141·7476	**5**	=155·51740	11·02311=	**5**	13·39614=	**5**
92·5941=	**6**	**6**	=170·0972	**6**	=186·62088	13·22773=	**6**	16·07537=	**6**
108·0265=	**7**	**7**	=198·4467	**7**	=217·72437	15·43236=	**7**	18·75460=	**7**
123·4589=	**8**	**8**	=226·7962	**8**	=248·82785	17·63698=	**8**	21·43383=	**8**
138·8912=	**9**	**9**	=255·1457	**9**	=279·93133	19·84160=	**9**	24·11306=	**9**

APOTHECARIES' AND METRIC WEIGHT.

TABLE OF EQUIVALENTS.

Unit	Grain	Scruple	Drachm	Ounce	Milligram	Centigram	Decigram	Gram	Kilogram	Unit
Grain	1	·05 **$\bar{2}$·698970**	·0166 **$\bar{2}$·2201081**	·00208 **$\bar{3}$·318063**	64·7989 **1·8115678**	6·47989 **·8115678**	0·647989 **$\bar{1}$·8115678**	0·0647989 **$\bar{2}$·8115678**	0·0000648 **$\bar{5}$·8115688**	Grain
Scruple	20 **1·3010300**	1	·333 **$\bar{1}$·4771213**	·0416 **$\bar{2}$·6190933**	1295·978 **3·1125983**	129·5978 **2·1125983**	12·95978 **1·1125983**	1·295978 **·1125983**	·0012958 **$\bar{3}$·1125983**	Scruple
Drachm	60 **1·7781513**	3 **·4771213**	1	·125 **$\bar{1}$·0969100**	3887·934 **3·5897188**	388·793 **2·5897188**	38·8793 **1·5897188**	3·88793 **·5897188**	·00388793 **$\bar{3}$·5897188**	Drachm
Ounce	480 **2·6812412**	24 **1·3802112**	8 **·9030900**	1	31103·48 **4·4927953**	3110·348 **3·4927953**	311·0348 **2·4927953**	31·10348 **1·4927953**	·03110348 **$\bar{2}$·4927953**	Ounce
Milligram	·0154324 **$\bar{2}$·1884322**	·0007716 **$\bar{4}$·8874019**	·000257205 **$\bar{4}$·4102810**	·00003215 **$\bar{5}$·5071910**	1	·1 **$\bar{1}$·000**	·01 **$\bar{2}$·000**	·001 **$\bar{3}$·000**	·000,001 **$\bar{6}$·000**	Milligram
Centigram	·154324 **$\bar{1}$·1884322**	·00771617 **$\bar{3}$·8874019**	·00257205 **$\bar{3}$·4102810**	·0003215 **$\bar{4}$·5071910**	10 **1·000**	1	·1 **$\bar{1}$·000**	·01 **$\bar{2}$·000**	·000,01 **$\bar{5}$·000**	Centigram
Decigram	1·54324 **·1884322**	·0771617 **$\bar{2}$·8874019**	·02572058 **$\bar{2}$·4102810**	·0032150 **$\bar{3}$·5071910**	100 **2·000**	10 **1·000**	1	·1 **$\bar{4}$·000**	·0001 **$\bar{4}$·000**	Decigram
Gram	15·4324 **1·1884322**	·771617 **$\bar{1}$·8874019**	·2572058 **$\bar{1}$·4102810**	·0321507 **$\bar{2}$·5071910**	1000 **3·000**	100 **2·000**	10 **1·000**	1	·001 **$\bar{3}$·000**	Gram
Kilogram	15432·48 **4·1884322**	771·6174 **2·8874019**	257·2058 **2·4102810**	32·150727 **1·5071910**	1,000,000 **6·000**	100,000 **5·000**	10,000 **4·000**	1000 **3·000**	1	Kilogram

Note.—The heavy-faced type gives the logarithm of the conversion factor.

TABLE GIVING DENSITY (SPECIFIC GRAVITY), MELTING POINT AND BOILING POINT

MISCELLANEOUS ELEMENTS AND SOLIDS.

	Density.	Melting Point. Centigrade.	Boiling Point. Centigrade.
Aluminium	2·60—(2·70)	600—850	
Amber	1·078		
Antimony	6·71	425—450	1400—1700
Asbestos	2·0—2·8		
Asphaltum	1·07—1·2		
Bismuth	9·8	267—268	1400—1700
Bone	1·7—2·0		
Brass	8·1—8·6	900—920	
Bronze	8·7		
Butter	0·86	31—31·5	
Cadmium	8·6	315—320	760—770
Calcite	2·7		
Chalk	2·25—2·69		
Cobalt	8·6	1500—1800	
Constantan	8·8		
Copper	8·5—8·9	1000—1150	
Cork	0·2		
Feldspar	2·55		
German silver	8·5	1000	
Glass, common	2·50—2·70	800 to 1400	
,, plate, crown	2·45—2·72		
,, flint, light	3·15—3·4		
,, ,, heavy	3·6—3·9		
Gold	19·2—19·3	1065	
Granite	2·5—2·9		
Graphite	1·8—2·24		
Gutta percha	0·96—0·98		
Gypsum	2·32		
Ice	0·9167	0	100
Iron, cast	7·1—7·7	1200—1400	
,, wrought	7·8		
,, wire	7·7		
,, cast steel	7·8	1300—1400	
Ivory	1·9		
Lard	0·93	41—42	
Lead	11·3	325—327	1450—1600
Lime, burned	2·3—3·2		
Magnesium	1·7	630	About 1100
Manganese	7·4	1900?	
Manganin	8·4		
Marble	2·65—2·8		
Mica	2·65—2·93		
Nickel	8·8—8·9	1450—1600	
Paraffin	0·87	38—56	350—430
Platinum	21·4—21·5	1800	
Porcelain	2·2—2·5		
Potassium	0·87	62	687—731
Quartz	2·65	2000	
Rubber, unvulcanised	0·92—0·95		
,, hard	1·2		

MISCELLANEOUS ELEMENTS AND SOLIDS—*Continued.*

	Density.	Melting Point. Centigrade.	Boiling Point. Centigrade.
Sandstone	2·2—2·5		
Serpentine	2·4—2·7		
Silver	10·5	960	
Slate	2·6—2·7		
Sodium	0·98	95·6—97·6	740
Spermaceti	0·88—0·94	44	
Sulphur	2·07	114	448
Tallow, beef	0·97	43	
,, mutton	0·92	47—50	
Tin	7·3	227—232	1450—1600
Wax, Japanese	0·99	54	
,, white	0·96—0·97	63	
,, yellow	0·96—0·97	62	
Wood, beech	0·85		
,, box	1·33		
,, elm	0·80		
,, oak	0·7—0·8		
,, poplar	0·40		
,, yellow pine	0·66		
Zinc	7·15	412—420	930—950
LIQUIDS.			
Acid, hydrochloric	1·24		
,, nitric	1·42		
,, sulphuric	1·84		
Alcohol, ethyl	0·7911	–130	78·3
,, methyl, wood	0·80		66
Amyl acetate	0·90		140
Aniline, oil	1·02		185
Benzol,	0·881	5	80·3
Carbon disulphide	1·265	–113	46
Chloroform	1·53	–70	61·2
Ether, sulphuric	0·717	–118	34·9
Glycerine	1·24—1·26	–20	290
Mercury	13·596	–38·8	357
Oil, linseed	0·93		
,, olive	0·91		
Petroleum, crude	1·75—1·84		
,, refined	0·84		
,, rhigolene	0·65—0·66		40—70
,, gasolene	0·66—0·69		70—90
,, benzene	0·69 -0·70		90—110
Phenol, carbolic acid	1·08	40	180
Turpentine, oil	0·87		
GASES.			
Air	0·001293		–200
Carbonic acid	1865	–57?	–78 to –80
Hydrogen	0901	–250	–256
Nitrogen	1251	–203 to –214	–194
Oxygen	1429		–181 to –184
Water vapor	0804	0	100

THERMOMETER SCALES.

CENTIGRADE AND FAHRENHEIT EQUIVALENTS.

For Absolute Temperatures add 273° to Centigrade Scale.

Centigrade.	Fahrenheit.	Remarks.	Centigrade.	Fahrenheit.	Remarks.
-273	-549·4	"Absolute zero."	-6·1	21	
-250	-418	Hydrogen boils.	-6	21·2	
-200	-328	Temp. liquid air.	-5·6	22	
-190	-310	Nitrogen boils.	-5	23	
-180	-292	Oxygen boils.	-4·4	24	
-170	-274		-4	24·8	
-160	-256		-3·9	25	
-150	-238		-3·3	26	
-140	-220		-3	26·6	
-130	-202	Alcohol freezes.	-2·8	27	
-120	-184		-2·2	28	
-110	-166		-2	28·4	
-100	-148		-1·7	29	
-80	-112	Carbonic acid gas boils.	-1·1	30	
-60	-76		-1	30·2	
-40	-40	Mercury melts.	-0·6	31	
-30	-22	Ammonia boils.	0	32	Water freezes.
-25	-13		0·6	33	
-20	-4		1	33·8	
-19	-2·2		1·1	34	
-18	-0·4		1·7	35	
-17·8	0		2	35·6	
-17·2	1		2·2	36	
-17	1·4		2·8	37	
-16·7	2		3	37·4	
-16·1	3		3·3	38	
-16	3·2		3·9	39	
-15·6	4		4	39·2	Maximum density of water.
-15	5		4·4	40	
-14·4	6		5	41	
-14	6·8		5·6	42	
-13·9	7		6	42·8	
-13·3	8		6·1	43	
-13	8·6		6·7	44	
-12·8	9		7	44·6	
-12·2	10		7·2	45	
-12	10·4		7·8	46	
-11·7	11		8	46·4	
-11·1	12		8·4	47	
-11	12·2		8·9	48	
-10·6	13		9	48·2	
-10	14		9·5	49	
-9·4	15		10	50	
-9	15·8		10·6	51	
-8·9	16		11	51·8	
-8·3	17		11·2	52	
-8	17·6		11·7	53	
-7·8	18		12	53·6	
-7·2	19		12·3	54	
-7	19·4		12·8	55	
-6·7	20		13	55·4	

THERMOMETER SCALES.

CENTIGRADE AND FAHRENHEIT EQUIVALENTS.

For Absolute Temperatures add 273° to Centigrade Scale.

Centigrade.	Fahrenheit.	Remarks.	Centigrade.	Fahrenheit.	Remarks.
13·3	56		33	91·4	
13·9	57		33·3	92	
14	57·2		33·9	93	
14·4	58		34	93·2	
15	59		34·4	94	Ether boils.
15·6	60		35	95	
16	60·8		35·6	96	
16·1	61		36	96·8	
16·7	62		36·1	97	
17	62·6		36·7	98	
17·2	63		37	98·6	Human blood temperature.
17·8	64		37·2	99	
18	64·4		37·8	100	
18·3	65		38	100·6	
18·9	66		38·3	101	
19	66·2		38·9	102	
19·4	67		39	102·4	
20	68	Proper room temperature.	39·4	103	
20·6	69		40	104	
21	69·8		43·3	110	
21·1	70		45	113	
21·7	71		48·9	120	
22	71·6		50	122	
22·2	72		54·4	130	
22·8	73		55	131	
23	73·4		60	140	Chloroform boils, 62°.
23·3	74		65	149	Potassium melts, 62°.
23·9	75		65·6	150	Methyl alcohol bls., 66°.
24	75·2		70	158	Woods alloy melts, 65°.
24·4	76		71·1	160	
25	77		75	167	
25·6	78		76·7	170	
26	78·8		80	176	Ethyl alcohol boils, 79°.
26·1	79		82·2	180	
26·7	80		85	185	
27	80·6		87·8	190	
27·2	81		90	194	
27·8	82		93·3	200	
28	82·4		95	203	Sodium melts, 96°.
28·3	83		98·9	210	
28·9	84		99	210·2	
29	84·2		99·4	211	
29·4	85		100	212	Water boils, under 76 cm. pressure.
30	86		125	257	
30·6	87		150	302	
31	87·8	Critical temperature of carbonic acid.	175	347	
31·1	88		200	392	Solder melts, 183°.
31·7	89		250	482	Tin melts, 227°.
32	89·6		300	725	Lead melts, 335°.
32·2	90		350	662	Mercury boils, 357°·3.
32·8	91		400	752	

MISCELLANEOUS CONSTANTS AND EQUIVALENTS.

$\pi = 3{\cdot}1416$. $\pi^2 = 9{\cdot}8696$. $1/\pi = 0{\cdot}31831$. $4\pi = 12{\cdot}566$.
$1/4\pi = 0{\cdot}07958$. $\log \pi = {\cdot}49715$. $\log \pi^2 = {\cdot}99430$. $\log 1/\pi = \bar{1}{\cdot}50285$.
$\log 4\pi = 1{\cdot}09921$. $\log 1/4\pi = \bar{2}{\cdot}90079$.

Base of the natural system of logarithms, $e = 2{\cdot}7183$, $\log e = {\cdot}43429$ (Briggs).
Modulus ,, ,, ,, $M = 1/\log e = 2{\cdot}3026$, $\log M = {\cdot}36222$ (Briggs).
Radian = angle where the arc equals the radius $= 57^\circ{\cdot}2958 = 3437'{\cdot}75 = 206265''$.
log radian (in degrees) $= 1{\cdot}75812$, (in minutes) $= 3{\cdot}53628$,
(in seconds) $= 5{\cdot}31443$.
Steradian = the solid angle at the center of a sphere of unit radius which is subtended by the unit area. Total angle at a point equals 4π steradians.
Earth's radius in kilometers—
equatorial $= 6378{\cdot}2$, polar $= 6356{\cdot}5$, mean $= 6367{\cdot}4$,
log equatorial $= 3{\cdot}80469$, log polar $= 3{\cdot}80321$, log mean $= 3{\cdot}80396$.
Mean solar year $= 365{\cdot}2422$ days $= 8765{\cdot}813$ hours $= 525948{\cdot}8$ min. $= 31556928$ sec.
Stellar day is 3 min. 55·9 sec. shorter than the mean solar day, $= 0{\cdot}99727$ day.
Velocity of sound in dry air at 0° C. is 331 meters per second.
Coefficient of expansion of gases $= 1/273 = {\cdot}003665$.
Acceleration of gravity at poles $= 983{\cdot}2$; at equator $= 978{\cdot}0$; at $45^\circ = 980{\cdot}6$; at New York $= 980{\cdot}2$; at Greenwich $= 981{\cdot}2$; at ϕ° latitude $= 978(1 + 0{\cdot}0052 \sin^2\phi)$.
1 gram of water 1° C. = minor calorie $= 4{\cdot}2 \times 10^7$ ergs $= 4{\cdot}2$ joules.
Latent heat of water = 80; of steam = 539.
Specific heat of air at constant pressure $= 0{\cdot}237$. Ratio of specific heats $= 1{\cdot}40$.
Capillary constant of water $= 7{\cdot}7$, of alcohol $= 2{\cdot}3$, of mercury $= 50$ mg./mm.
Velocity of light in vacuo $= 3 \times 10^{10}$ cm./sec.
Wave length of sodium light $= 0{\cdot}0005893$ mm.
Length of the meter in wave lengths of red cadmium light $= 1553163{\cdot}5$.
1 ampere of current deposits 1·118 mgr. of silver per second $= 0{\cdot}1740$ c.c. (H. and O.).
A plate of quartz 1 mm. thick at 18° C. rotates the plane of polarization $21^\circ{\cdot}71$.
Ohm = resistance of a column of mercury 1 sq. mm. cross-section, 106·3 cm. long.
E.M.F. of Latimer Clark cell at 18° is 1·434, of cadmium (Weston) cell at 4° is 1·0190.
The solar constant = 3 gram-calories per sq. cm. per minute.
The mass of the hydrogen atom is $= 10^{-24}$ gram; of the electron is $= 10^{-27}$ gram.
Value of $e/m = 4{\cdot}5 \times 10^{17}$ electrostatic $= 1{\cdot}5 \times 10^7$ electromagnetic.
Velocity of the electrons—beta particles $= 2{\cdot}7 \times 10^{10}$, alpha particles $= 3 \times 10^9$.
Probable speed of a molecule of oxygen at 0° C. $= 376{\cdot}6$ m./sec., of hydrogen $= 1500{\cdot}9$.
Mean free path of a molecule of air at a pressure of 76 cm. and at 0° C. $= 9{\cdot}6 \times 10^{-6}$.
Number of molecules of air in a c.c. at 0° C. and 76 cm. $= 6 \times 10^{19}$.
One atmosphere pressure = 76 cm. of mercury $= 1{\cdot}0132$ megadynes per sq. cm.
A knot is a speed of one nautical mile per hour = 1·1515 statute miles or 1853·25 meters per hour.
A miner's inch of water is from 1·20 to 1·76 cu. ft. per min. = 0·708 liter per sec.
Ratio of the probable error to the mean error is 0·6745 (2/3).
Light year is the distance travelled by light in one year $= 9{\cdot}467 \times 10^{12}$ kilometers $= 5{\cdot}8825 \times 10^{12}$ miles.

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Hallock, William
Outlines of the evolution of weights and measures and the metric system