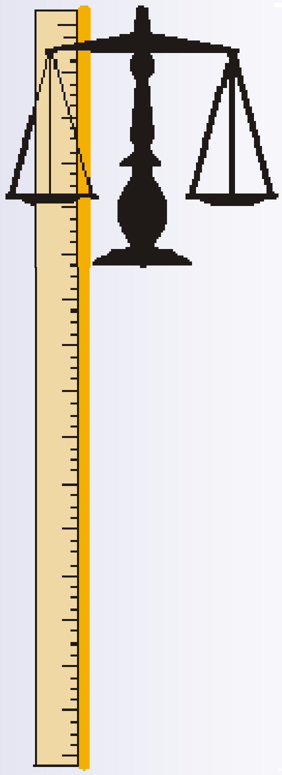
Division of Measurement Standards

Training Module



Five

Legal Metrology

Training for the
Weights and Measures Official

TRAINING FOR THE WEIGHTS AND MEASURES OFFICIAL

CURRICULUM

MODULE 5 - LEGAL METROLOGY

Module 1	-	**Introduction to Weights and Measures**
Module 2	-	**Laws and Regulations**
Module 3	-	**Enforcement Procedures**
Module 4	-	**Legal Action**
Module 6	-	**Field Standards and Test Equipment**
Module 7	-	**Basic Weighing and Measuring Principles**
Module 8	-	**Device Type Evaluation**
Module 9	-	**Weighing Devices**
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Module 11	-	**Weighmaster Enforcement**
Module 12	-	**Petroleum Products**
Module 13	-	**Quantity Control**
Module 14	-	**Service Agencies and Agents**

Acknowledgment

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Module Five
Legal Metrology

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Introduction

Welcome to "Legal Metrology". This is the fifth module in the series "Training for the Weights and Measures Official." "Metrology" is defined as the science of measurement. "Legal Metrology" is collectively the legislative, administrative and technical procedures established by, or by reference to, public authorities. Legal metrology is implemented on behalf of these authorities in order to specify and to ensure, in a regulatory or contractual manner, the appropriate quality and credibility of measurements related to official controls, trade, health, safety, and the environment. This module introduces the student to the key components of legal metrology including the Units and Systems of Measurement, National Institute of Standards and Technology (NIST) and its role in the development and maintenance of the physical artifacts and measurement technology associated with the Units and Systems of Measurement used in the United States, and a discussion of the standards and their care and traceability. The standards are used by private and public measurement organizations and are dependent on assigned values and uncertainties that are determined and maintained through a measurement system with documented traceability to the NIST artifacts or their equivalent.

At the end of each segment in this module you will find a series of self-evaluation questions to test your knowledge. Although you are not required to complete the self-evaluation, we encourage you to take a few minutes to read the questions before moving on to the next segment. Answers are provided at the end of the module. If you are unsure of a response, reread the training material and it will give you the information you need.

Module Objectives

When you have completed this module you will be able to understand:

- The origins of the units of measurement associated with the United States Customary and International systems of measurements.
- The role NIST plays in legal metrology from the International Standards Community through the Office of Weights and Measures and operation of the State Metrology Laboratory Program.
- The difference between mass and weight.
- The purpose of the NIST 105 series of handbooks and NIST Handbook 44.
- The concepts of accuracy, precision, and measurement uncertainty.
- Standards traceability.
- The proper care and handling of standards.

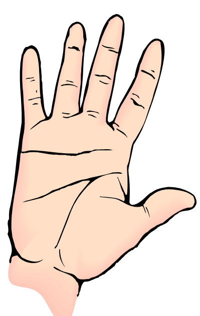
Units and Systems of Measurement

There are many systems of measurement used by different nations. This segment will provide some historic perspective and distinction between the Metric and English Systems of Measurement. It will discuss the units associated with the United States Customary Weights and Measures as well as the history, definitions, and values of the International System of Units (SI). The Relationship between "Mass" and "Weight" will also be discussed.

Early Units and Systems of Measurement

Historically, the dimensions of the human body were used for short distance units. The cubit of Noah's time, for instance, was the length of a man's forearm or the distance from the tip of the elbow to the end of his middle finger. This proved useful because it was readily available, it was convenient, and it could not be mislaid. The problem with this type of measurement, however, was that it was not a positive fixed dimension or a standard.

The cubit is no longer used as a unit of measurement, but there are many customary standards that originated in about the same way. Inch was originally the width of a thumb. In many languages the word for inch is also the word for thumb. Our foot started out as the length of a man's foot. In the early days of history, the foot varied in length, sometimes as much as three or four inches.



The ancients apparently noticed ratios that existed in body measurements. Twelve times the inch made a foot. Three times the length of the foot was the distance from the tip of a man's nose to the end of his outstretched arm. This closely approximates what we call the yard. The distance across a man's outstretched arms equaled a fathom or two yards (six feet). Half a yard was a cubit 18 inches and half a cubit was called a span, the distance across the hand from the tip of the thumb to the tip of the little finger when the fingers were spread out as far as possible.

The traditional method for measuring weights was comparing the weights of the two objects. The Babylonians made improvements in this technique by comparing the weight of each object with a set of stones that were kept for that purpose. Archaeologists have found some of these stones in the ruins of Babylonian cities that are believed to be the world's first weight standards.

Commercial figural weight of Babylonian origin: 16th-18th Century B.C.

Weight measures 15 mm long by 7 mm high and is carved from hematite in the shape of a frog.

The English traditionally used the same basis for weight measurements. The "stone" weight for horsemen was 14 pounds. The "stone" weight for wool was 16 pounds. The "stone" weight for meat, poultry and fish was 8 pounds. In the British Imperial System, the only legal stone weight was 14 pounds.

A wheat seed was used by the Egyptians and Greeks as the smallest unit of weight. This standard was very uniform and accurate for ancient times. As a standard weight, the grain is still in limited use today. A weight that is nearly the same as that of an average grain of wheat is arbitrarily assigned to the grain.

The Arabs assigned small weight standards for gold, silver and precious stones. This weight standard was a small bean called the karob. This is the origin of the word carat, which is used today by jewelers to express the weight of gems and precious metals.

Before the Norman conquest of 1066, Anglo-Saxon English short distance measurements were varied. An inch or ynch was defined as the length of three barleycorns. This is very close to its modern length. There were several foot units in use: 12 inches, 13 inches, and the natural foot which was about 9.8 inches. Also in use at this time was the fathom, but it did not have a definite relationship to the other units.

In trading between tribes and nations, many of the methods for measuring weights and distances gradually became intermixed. The Romans, particularly, spread this knowledge throughout the known world at that time, adding some standards of their own.

English System of Measurement

Distance

Henry 1

The Roman 12 inch foot was brought to England by the Normans. During the reign of Henry I (1100–1135) the 12 inch foot became official and the royal government took steps to make this foot length known. According to Russ Rowlett of the University of North Carolina at Chapel Hill, a 12-inch foot was inscribed on the base of a column of St. Paul's Church in London, and measurements in this unit were said to be "by the foot of St. Paul's" (de pedibus Sancti Pauli). Henry I also appears to have ordered construction of 3-foot standards, which were called "yards", thus establishing that unit for the first time in England. William of Malmesbury wrote that the yard was "the measure of his [the king's] own arm," thus launching the story that the yard was defined to be the distance from the nose to the fingertip of Henry I.

During his reign, King Edward I of England (1272–1307) ordered a permanent measuring stick made of iron to serve as a master standard yardstick for the entire kingdom. It was called the "iron ulna" after the bone of the forearm. This is very close to the length of our present-day yard. King Edward also decreed that the foot measure should be one-third the length of the yard and the inch should be one thirty-sixth.

The gyrd or rod remained the traditional measure for all land in England. This was an old Saxon unit that probably was equal to 20 "natural feet". Because the accuracy of deeds and other land records depended on the rod, the Norman kings made no change in that measure. The length of the rod was fixed at 5.5 yards (16.5 feet). This was not convenient, but 5.5 yards was the length of the rod as measured by the 12 inch foot.

The length of the traditional furrow (fuhr) by ox teams on Saxon farms became 40 rods or a furlong (fuhrlang). These ancient Saxon units, the rod and the furlong, are essentially unchanged today.

Miles were traditionally used in England to measure longer distances. The mile came from the Romans. As the Romans marched, they kept track of the distance they traveled by counting paces. A pace was the distance covered from the time one foot touched the ground until that same foot touched the ground again, or the length of a double step. The mile was originally used to define the length of 1 000 paces. This made the mile approximately 5 000 feet. In 1592, during the reign of Elizabeth I, Parliament standardized the mile by setting the length at 8 furlongs. This made the mile exactly 1 760 yards or 5 280 feet.

Area

Acre is the traditional unit of land measurement in all English-speaking countries. This is a very old Saxon unit. Reference to the word acre can be found as early as the year 732. Acre also meant field and originally it was a field that a farmer could plow in a single day. The oxen had to be rested in the afternoon so in practice an acre was a field that could be plowed in the morning. It is interesting to note that the French word for acre is “journal”, which comes from “jour” meaning “day”. The German word for acre is “morgen”, which means “morning” or “tagwerk” which means “day’s work”.

The long and narrow Anglo-Saxon farm field of one furlong (40 rods) long by 4 rods wide was the area defined as the “acre”. This equals 43 560 square feet or 4 840 square yards. Ten of these standard acres (4 rods by 40 rods) side by side would equal 10 acres in a square furlong. Since the mile is 8 furlongs, there are exactly 10 x 8 x 8 or 640 acres in a square mile.

Weight

The pound is the basic unit of weight in the English Customary System. Dating back to the Roman Empire, the pound was used as the basic unit of weight. It was divided into 12 ounces. Many merchants preferred to use a larger pound of 16 ounces because it could be conveniently divided into halves, quarters, or eighths. Both the 12 ounce pound and the 16 ounce pound were used in the middle ages.

The 12-ounce troy pound provided the basis on which coins were minted and gold and silver were weighed and is the oldest English weight system. It has been used since the time of the Saxon kings. The troy system was designed to model the Roman system since Roman coins were still in circulation in Saxon times. The troy pound weighs 5 760 grains, the ounce weighs 480 grains, and a pennyweight is 24 grains. Over time, the troy system was used specifically for precious metals, gems and pharmaceuticals. Today it is still used in financial markets for gold and silver, while pharmacies now use the metric system.

Medieval English merchants often used a larger “mercantile” pound that contained 15 troy ounces. Therefore, its weight was 7 200 grains. Merchants liked its size, but dividing it into 15 parts rather than 12 or 16 proved very inconvenient. The mercantile pound was replaced in English commerce around 1300 by the 16-ounce avoirdupois pound. The term was adapted from the French phrase “aveir de pois”, which roughly translated means “goods of weight”. The avoirdupois pound weighs exactly 7 000 grains and is divided into 16 ounces.

The avoirdupois system became the most widely used. The avoirdupois pound forms the basis of the U.S. Customary System of mass. All the other units of mass are defined in terms of it.

The U.S. Customary System and the British Imperial System are identical for the pound and smaller units. They differ when dealing with units larger than the pound. The hundredweight (cwt) has been a standard weight unit in Britain from about the middle of the 1300's. It is equal to 112 avoirdupois pounds which made it equivalent, for most purposes, with the units of the European market, especially the German zentner and the French quintal. Additionally, because 112 is a multiple of 16, the British hundredweight can easily be divided into 4 quarters of 28 pounds, 8 stone of 14 pounds, or 16 cloves of 7 pounds each. The ton was defined as equal to 20 hundredweight or 2 240 pounds. In the United States there just was not the need to align the hundredweight with the German zentner or the French quintal. The American definition came to equal exactly 100 pounds. Both systems use 20 cwt to the ton so to distinguish between the two, the British version is often called the long hundredweight and long ton and the American version is called the short hundredweight (or cental) and short ton. Therefore the British "long" ton remained at 2 240 pounds while the American "short" ton became exactly 2 000 pounds. It is interesting to note that today most international shipments are computed in metric tons (1 000 kg = 2 205 lb) which makes it rather close to the British long ton.

Volume

Until the 18th Century, it was hard to accurately measure the capacity of a container in volumetric units. It was common, therefore, to define the standard containers by specifying the weight of a particular substance which they could carry. The English gallon unit, for instance, was originally the volume of 8 pounds of wheat. As different commodities were carried in containers of slightly different sizes, the size of the gallon would vary with the commodity. Wine units were different from beer units which were different from ale units or from units for other liquids.

The colonial Americans tried to simplify things by selecting just two of the many possible gallons. They selected the two that had become the most common in British commerce around 1700. For dry commodities, Americans selected the "Winchester bushel" which was defined by Parliament in 1696 as the volume of a cylindrical container 18.5 inches in diameter and 8 inches deep (2 151.29 cubic inches). Americans selected the traditional British wine gallon for liquid measurement which in 1707, Parliament defined as exactly 231 cubic inches. The U.S. volume system, therefore, includes both "dry" and "liquid" units. The dry units are about 1/6 larger than the corresponding liquid units.

All the various traditional gallons were abolished by the British Parliament in 1824. The “Imperial” gallon of 277.42 cubic inches was defined as the volume of 10 pounds of pure water at 62°F. The Americans, content with their gallon measures, did not adopt this new, larger gallon. Consequently, the English “system” now includes three different volume measurement systems. They are the U.S. liquid, the U.S. dry, and the British Imperial.

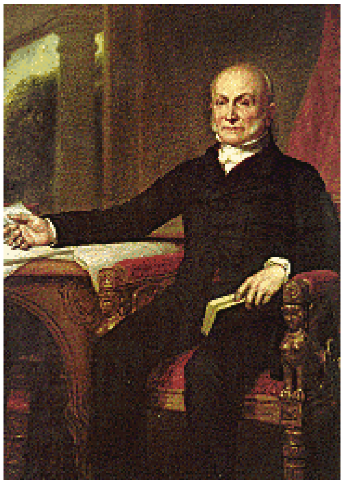
British Pint
20 fluid ounces

U.S. Pint
16 fluid ounces

Smaller volumes of liquid are traditionally measured in fluid ounces in the United States and in Britain. Fluid ounces are more or less equal to the volume of one ounce of water. Therefore, the smaller U.S. pint is divided into 16 fluid ounces and the larger British pint is divided into 20 fluid ounces.

The American colonists brought their measuring methods with them. Throughout our United States history, the system that was inherited from the British Imperial System has generally been used and is known as the U.S. Customary System.

U.S. Customary Weights and Measures



John Quincy Adams
U.S. President 1825-1829

Before the U.S Customary System of weights and measures was in wide use in the United States, John Quincy Adams, after noticing a conspicuous lack of an official system, performed an analysis of the metric system and provided a report and recommendations to the Congress. At the time, weights and measures were taken care of regionally without any coordination nationally or any standards of reference. The Adams report recommended "To fix the standards for the present, excluding all innovation" for the purpose of preserving what little uniformity there was, and "To consult with foreign nations, for the future and ultimate establishment of universal and permanent uniformity."

Congress took no action. Neither the metric system in France nor the system in common use in England was well established. Neither of these systems was in popular use in the United States, so Congress could take no action without introducing radical changes in the weights and measures already in use.

While Congress could not decide which standards to use the states needed to carry on commerce and so they adopted standards for themselves, typically English, since the states were recently English colonies. Nevertheless, even standards of the same denomination differed widely amongst themselves perpetuating confusion in the commerce amongst the states. While that was barely tolerable in commercial transactions, there was a desperate need for a standard in coinage.

The troy pound was adopted by Congress in 1828 as the standard for coinage and procured by Albert Gallatin, the United States Minister in London. The weight was brass and an "exact" copy of the Imperial troy pound of Great Britain (the troy pound is still used to trade precious metals in the United States).

While the act of Congress made this pound the standard for coinage, it virtually became the fundamental standard of the United States from which the avoirdupois pound, now in common use, was derived. The United States still had no official system of weights and measures.

In 1830 the Senate, recognizing the need for a uniform and accurate system, passed a resolution to make a comparison of the weights and measures in use at the principal customhouses of the U.S. to evaluate what was currently being used. Large discrepancies were found at the major ports. Without waiting for Congress, the Treasury Department took immediate steps to correct the situation by having constructed the weights and measures necessary for commerce.

In 1832, the Treasury Department adopted units for the customhouses. They were the yard of 36 inches, the avoirdupois pound of 7 000 grains, the gallon of 231 cubic inches, and the bushel of 2 150.42 cubic inches.

The 36 inch standard was supposed to be identical with the British Imperial yard at 62°F. The avoirdupois pound adopted by Ferdinand Hassler as the standard for the Treasury Department was derived from the troy pound of the Philadelphia mint (1 avoirdupois pound equals 7 000/5 760 pounds troy).

The units of capacity, the wine gallon of 231 cubic inches and the Winchester bushel of 2 150.42 cubic inches, were adopted because they represented more closely than any other English standards the average of the capacity measures in use in the United States at the time. Neither the gallon nor the bushel adopted by the United States Treasury Department was in accord with the legal capacity standards of England, they were smaller by about 17 percent and 3 percent, respectively, and these differences exist at the present time.

Such then were the fundamental standards adopted by the Treasury Department on Hasslers recommendation; and the weights and measures disseminated to the customs service were constructed to conform to these.

These seals were probably used by Hassler for stamping maps or envelopes. One has an image of a weight on it, which symbolized Hassler's role as the Superintendent of Weights and Measures. The larger seal frames a weight with a triangle, which made reference to Hassler's dual involvement with weights and measures and the Survey of the Coast.

English standards were used because they were already nominally in use at the time and the U.S. already possessed a weight and a length standard from which the new U.S. standards could be derived. The weight was the Troy pound being used at the mint in Philadelphia, and the length standard was the Troughton scale, brought by Ferdinand Hassler to the U.S. in 1815, and an "exact" copy of the British Imperial yard (although the two had never been compared).

While the U.S. and British customary systems have units that are at least nominally the same, their actual values as they are defined are different for two reasons. The first reason is that when adopting some of the units (the gallon and the bushel) the Treasury Department of the U.S. used values that were the average of whatever was currently in use in the U.S. The second reason is because the United States adopted "exact" copies (which could never be exact) of the English prototype standards which were later irreparably damaged leaving the U.S. nothing with which to calibrate their standards.

The title "U.S. Customary" originally was more of a description than a name. The system is called U.S. Customary because the system is just that, customary. It is not an official legal system of measurement for the United States. It has been adopted by the states individually after Ferdinand Hassler sent standards to them at the request of the Secretary of the Treasury. It could be argued that the Secretary of the Treasury had overstepped his bounds of authority, but the states adopted the standards legally using their own authority to do so. The Secretary only provided them with a set of standards so that they could participate more successfully in commerce.

The Yard is the U.S. Customary System and is defined as 0.914 4 meter.

The Avoirdupois pound is the U.S. Customary System and is defined as 0.453 592 37 kilogram.

Currently, the basis of the U.S. Customary System of weights and measures are the yard and the avoirdupois pound. The yard and the pound have been defined in terms of the SI meter and the international prototype kilogram since July 1, 1959. The yard is defined as 0.914 4 meter and the avoirdupois pound as 0.453 592 37 kilogram. All of the units of the U.S. Customary System are derived from these.

Units of the U.S. Customary System of Weights and Measures

Units of Linear Measure

1 yard = 0.9 144 meter

1 yard = 3 feet

1 international foot = 12 inches

1 inch = 0.083 33… foot (three dots denotes continuous string)

1 statute mile = 5 280 feet

6 076.115 feet = 1 International Nautical Mile

Units of Area Measure

1 township	=	36 sections
1 section	=	1 square mile
1 square mile	=	640 acres
1 acre	=	43 560 square feet
1 square yard	=	9 square feet
1 square foot	=	144 square inches

Units of Weight

Avoirdupois

1 pound	=	7 000 grains
1 pound	=	16 ounces
1 ounce	=	437.5 grains
1 short ton	=	2 000 pounds
1 long ton	=	2 240 pounds

Troy

(used for over-the-counter sales of precious metals)

1 pennyweight	=	24 grains (avoirdupois)
1 ounce troy	=	20 pennyweights
1 pound troy	=	12 ounces troy

Apothecaries

(used in measuring Pharmaceuticals)

1 pound apothecaries	=	12 ounces apothecaries
1 ounce apothecaries	=	8 drams apothecaries
1 dram apothecaries	=	3 scruples
1 scruple	=	20 grains (avoirdupois)

Units Of Volume

Liquid Measure

1 gallon = 231 cubic inches
1 gallon = 4 quarts
1 quart = 2 pints
1 pint = 4 gills
1 gill = 4 fluid ounces

Dry Measure

1 bushel = 2 150.42 cubic inches
1 bushel = 4 pecks
1 peck = 8 dry quarts
1 dry quart = 2 dry pints

1 U.S. survey foot = 0.304 800 61 meter
(U.S. survey foot is used in mapping and land measurement)

Note: Unless specified as a survey foot, all references to a "foot" or "feet" are the international foot.

Special Units

1 cord = 128 cubic feet
(the cord is used in the sale of firewood)

1 metric carat = 200 milligrams
(the metric carat is used in the sale of precious stones)

The Metric System

Designed during the French Revolution of the 1790's, the metric system brought order out of the conflicting and confusing traditional systems of weights and measures then being used in Europe. Prior to the introduction of the metric system, it was common for units of length, land area, and weight to vary, not just from one country to another but from one region to another within the same country. As the modern nations were gradually assembled from smaller kingdoms and principalities, confusion simply multiplied. Merchants, scientists, and educated people throughout Europe realized that a uniform system was needed, but it was only in the climate of a complete political upheaval that such a radical change could actually be considered.

The metric system replaces all the traditional units (except the units of time and of angle measure) with units satisfying three conditions

1. Only a single unit is defined for each quantity. These units are now defined precisely in the International System of Units.
2. Larger and smaller units are created by adding prefixes to the names of the defined units. These prefixes denote powers of ten, so that metric units are always divided into tens, hundreds, or thousands. The original prefixes included milli- for 1/1 000, centi- for 1/100, deci- for 1/10, deka- for 10, hecto- for 100, and kilo- for 1 000.
3. The units are defined rationally and are related to each other in a rational fashion.

The metric units were defined in an elegant way unlike any traditional units of measure. The Earth itself was selected as the measuring stick. The meter was defined to be one ten-millionth of the distance from the Equator to the North Pole. The liter was to be the volume of one cubic decimeter, and the kilogram was to be the weight of a liter of pure water. It did not turn out quite like this, because the scientific methods of the time were not quite up to the task of measuring these quantities precisely, but the actual metric units come very close to the design.

The metric system was first proposed in 1791. It was adopted by the French revolutionary assembly in 1795, and the first metric standards (a standard meter bar and kilogram bar) were adopted in 1799. There was considerable resistence to the system at first, and its use was not made compulsory in France until 1837. The first countries to actually require use of the metric system were Belgium, the Netherlands, and Luxembourg in 1820.

Around 1850 a strong movement began among scientists, engineers, and businessmen in favor of an international system of weights and measures. The scientific and technical revolution was well underway and a global economy was developing. The need for uniformity in measurement was becoming obvious. Furthermore, the metric system was the only real choice available. The only possible competitor, the British Imperial System, was so closely tied to the British Empire it was not even acceptable to the Americans, let alone to non-English speakers.

Between 1850 and 1900 the metric system made rapid progress. It was adopted throughout Europe (except in Britain), in Latin America, and in many countries elsewhere. It became firmly established as a key part of the language of science.

In the 1870's, the French made a key decision to turn control of the system over to an international body. In 1875, most of the leading industrialized countries (including the United States, but not Britain) signed the Treaty of the Meter. The treaty established the International Bureau of Weights and Measures*, which has presided ever since over what we now call the International System of Units. It also provided for distribution of copies of the metric standards throughout the world and for continuing consultation and periodic revision and improvement of the system through regular meetings of a General Conference of Weights and Measures. The 21st General Conference met in October 1999.

Member States of the Metre Convention and of the General Conference as of 3 September 2001

Member States:

Argentina	Hungary	Portugal
Australia	India	Romania
Austria	Indonesia	Russian Federation
Belgium	Iran (Islamic Rep. of)	Singapore
Brazil	Ireland	Slovakia
Bulgaria	Israel	South Africa
Cameroon	Italy	Spain
Canada	Japan	Sweden
Chile	Korea (Dem.	Switzerland
China	People's Rep. of)	Thailand
Czech Republic	Korea (Republic of)	Turkey
Denmark	Malaysia	United Kingdom
Dominican Republic	Mexico	United States
Egypt	Netherlands	Uruguay
Finland	New Zealand	Venezuela
France	Norway	Yugoslavia
Germany	Pakistan	
Greece	Poland	

* The acronym used is BIPM which derives from the French Bureau International des Poids et Measures.

Since 1875 the eventual triumph of the metric system in science and international commerce has been assured, despite continuing popular opposition in Britain and the United States. In fact, the metric system has met popular opposition in every country at the time of its adoption. People do not want to change their customary units, which are part of how they see and control the world. It is naturally disturbing to do so. This opposition has been overcome everywhere, except in the U.S., by economic necessity: the need to participate fully in the global economic system. Even in the U.S., economic needs assure the continued creeping adoption of the system in one area and then another.

Those Americans opposing adoption of metric units often argue that the metric system is abstract and intellectual or that its use would embroil us in calculations. This is not true. The metric system has been the customary measurement system in France for two centuries, in the rest of continental Europe for at least one century, and in the rest of the world for at least a generation or two. Most people in the world know exactly how long a kilometer is, how large a liter is, and how much a kilogram weighs, because they use these units every day of their lives in the same way Americans use miles, gallons, and pounds.

Britain is now a metric country. Only in the United States does anyone need to convert metric units into something else. In fact, the way to avoid conversion formulas is to adopt the metric system. As long as Americans continue to use traditional units, they will have to remember how these units relate to the metric units.

Distance

Meter or metre (m)

Metric and SI base unit of distance

Units of the Metric system of weights and measures

Units of Linear Measure

10 millimeters	=	1 centimeter
10 centimeters	=	1 decimeter
10 decimeters	=	1 meter
10 meters	=	1 dekameter
10 dekameters	=	1 hectometer
10 hectometers	=	1 kilometer

Units of the Metric system of weights and measures

Units of Area Measure

100 square millimeters	=	1 square centimeter
10 000 square centimeters	=	1 square meter
100 square meter	=	1 are
100 ares	=	1 hectare
100 hectares	=	1 square kilometer

Originally, the meter was designed to be one ten-millionth of a quadrant, the distance between the Equator and the North Pole. (The Earth is difficult to measure, and a small error was made in correcting for the flattening caused by the Earth's rotation. As a result, the meter is too short by about 0.013%. That is not bad for a measurement made in the 1790's.) For a long time, the meter was precisely defined as the length of an actual object, a bar kept at the International Bureau of Weights and Measures near Paris. In recent years, however, the SI base units (with one exception) have been redefined in abstract terms so they can be reproduced to any desired level of accuracy in a well-equipped laboratory. For the meter, the 17^{th} Conférence Générale des Poids et Mesures (CGPM) in 1983 defined the meter as that distance that makes the speed of light in a vacuum equal to exactly 299 792 458 meters per second. The speed of light in a vacuum, *c*, is one of the fundamental constants of nature. Since *c* defines the meter now, experiments made to measure the speed of light are now interpreted as measurements of the meter instead. The meter is equal to approximately 1.093 613 3 yards, 3.280 840 feet, or 39.370 079 inches. Its name comes from the Latin *metrum* and the Greek *metron*, both meaning "measure." The unit is generally spelled metre; there are many other spellings in various languages including *metr* (Czech, Polish, Russian, Ukrainian), *metri* (Finnish), and of course it is spelled *meter* in the United States.

Volume

Liter or litre (L or l)

The common metric unit of volume

Units of the Metric system of weights and measures

Units of Volume

10 milliliters	=	1 centiliter
10 centiliters	=	1 deciliter
10 deciliters	=	1 liter
10 liters	=	1 dekaliter
10 dekaliters	=	1 hectoliter
10 hectoliters	=	1 kiloliter

The liter was originally defined to be the volume occupied by a kilogram of water, and the gram as the mass of a cubic centimeter of water. This would make the liter equal to exactly one cubic decimeter, that is, to the volume of a cube 0.1 meter (or 10 centimeters) on a side. Unfortunately, the physical objects constructed to represent the meter and kilogram disagreed slightly. As measured by the standard meter and standard kilogram, the standard liter turned out to be about 1.000 028 cubic decimeters. This discrepancy plagued the metric system for a long time. In 1901, an international congress accepted the discrepancy and formally defined the liter to be exactly 1.000 028 dm^3. No one was particularly happy with such an awkward definition, so in 1964 the CGPM repealed the definition. In the SI, volumes are to be measured in cubic meters or power-of-ten multiples thereof, not in liters. However, the SI states that the liter "may be employed as a special name for the cubic decimeter." Throughout this text, the liter is used as a name for exactly 1 cubic decimeter, 1 000 cubic centimeters, or 0.001 cubic meter. In its new guise as the cubic decimeter, the liter is approximately 61.023 744 cubic inches. Compared to the customary volume units, the liter is a little more than a U. S. liquid quart (1.056 688 quart or 33.814 fluid ounces) but a little less than a U. S. dry quart (0.908 08 quart) or a British Imperial quart (0.879 89 quart or 35.195 fluid ounces). Its name comes from a French volume unit, the *litron*, which was in turn derived from the Latin *litra*. Both the lower case letter l and the upper case L are accepted as symbols for the liter, but the U.S. Department of Commerce specifies that L be used, at least by businesses, to avoid confusion with the numeral 1. The unit is spelled liter in the U.S. and litre in Britain; there are many other spellings in various languages.

Weight

Kilogram (kg)

Base unit of mass in the SI and meter, kilogram, second versions of the metric system

Units of the Metric system of weights and measures

Units of Weight

10 milligrams	=	1 centigram
10 centigrams	=	1 decigram
10 decigrams	=	1 gram
10 grams	=	1 dekagram
10 dekagrams	=	1 hectogram
10 hectograms	=	1 kilogram
1000 kilograms	=	1 metric ton

The kilogram is defined as the mass of the standard kilogram, a platinum-iridium bar in the custody of the International Bureau of Weights and Measures (BIPM) near Paris, France. Copies of this bar are kept by the standards agencies of all the major industrial nations, including the U.S. National Institute of Standards and Technology (NIST). NIST has two copies of the standard kilogram numbers -- 4 and 20 (4 = check standard and 20 = primary standard). One kilogram equals exactly 1 000 grams or about 2.204 622 6 pounds.

Standard Kilogram
International Bureau of Weights and Measures
Sevres, France

Time

Second (s or sec or ")

Fundamental unit of time in all measuring systems and the SI base unit of time

The name simply means that this unit is the second division of the hour, the minute being the first. The second was defined as 1/86 400 mean solar day until astronomers discovered that the mean solar day is actually not constant. The definition was then changed to 1/86 400 of the mean solar day January 1, 1900. Since we cannot go back and measure that day any more, this was not a real solution to the problem. In 1967, scientists agreed to define the second as that period of time which makes the frequency of a certain radiation emitted by atoms of cesium-133 equal to 9 192 631 770 hertz (cycles per second). In other words, if we really want to measure a second, we count 9 192 631 770 cycles of this radiation. This definition allows scientists to reconstruct the second anywhere in the world with equal precision.

International System of Units

In 1960 the 11th Conférence Générale des Poids et Mesures adopted the name Système International d'Unités (International System of Units, international abbreviation SI), for the recommended practical system of units of measurement. It was thought that an international system would benefit commerce, and be more conducive to collaborative efforts in engineering, science and technology. The 11th CGPM laid down rules for the prefixes, the derived units, and other matters.

The SI system of units is a system consisting of seven base units, and twenty-one derived units. Base units are, by convention, regarded as dimensionally independent (they are not composed of any other units - a kilogram is a kilogram, one single unit). Derived units are units composed of some combination of the base units (a Newton is a kilogram*meter/second^2, composed of three base units).

Historically, basic units have been defined by artifacts (for example: one foot would be the length of the human foot). The problem with this is that the definition is subjective so it is difficult to have a consistently accurate unit. Even if you define the foot as being as long as one specific person's foot; such as the King's foot, what is to be done when the artifact physically changes or is damaged or destroyed (bury him with his other foot sticking out)?

Ideally, the base units would all be derived from naturally occurring phenomena that are intrinsic to the universe as we know it. These phenomena would be constant, unchanging, well known, and well understood. Concisely defining the units in terms of these phenomena provides a means to accurately reproduce them whenever or wherever the necessary apparatus can be assembled. Accurately recreating the units is practical and necessary for consistency and ease of distribution to users of the units. The unit of mass is the only remaining base unit that is defined by an artifact. It is a weight made of a platinum iridium alloy and kept in Sèvres France (it is the definition of a kilogram of mass). Work is being done to redefine the kilogram in terms of quantum phenomena.
(BIPM web page: http://www.bipm.fr/enus/3_SI/si.html)

Currently the base units of the SI are as follows:

Meter	The meter is the unit of length. It is equal to the length of the path traveled by light in vacuum during a time interval of 1/299 792 458 of a second. The meter was originally defined as a unit equal to one ten-millionth part of a quadrant of the Earth's meridian as measured from the North Pole to the equator.
Kilogram	The kilogram is the unit of mass. It is equal to the mass of the international prototype of the kilogram. Originally the kilogram was defined as the mass of a volume of pure water equal to a cube of one tenth meter at the temperature of melting ice.
Second	The second is the unit of time. It is equal to the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom.
Ampere	The ampere is the unit of electric current. It is equal to that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross section, and placed 1 meter apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} Newton per meter of length.

Kelvin	The kelvin is the unit of thermodynamic temperature. It is equal to the fraction 1/273.16 of the thermodynamic temperature of the triple point of water (the point where water exists in gaseous, liquid and solid phases simultaneously).

Mole	The mole is the unit of the amount of substance of a system. 1. It is equal to the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon 12. 2. When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles. In the definition of the mole, it is understood that unbound atoms of carbon 12, at rest and in their ground state, are referred to. Note that this definition specifies at the same time the nature of the quantity whose unit is the mole.

Candela	The candela is the unit of luminous intensity. It is equal to luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540 x 10^{12} hertz and that has a radiant intensity in that direction of (1/683) watt per steradian.

(BIPM SI base units web page: http://www.bipm.fr/enus/3_ST/base_units.html)

The SI also uses prefixes in conjunction with the basic unit names to denote multiples and submultiples in the SI. The prefixes are as follows:

Multiples and Submultiples	Prefixes
10^24	Yotta
10^21	Zeta
10^18	Exa
10^15	Peta
10^12	Tera
10^9	Giga
10^6	Mega
10^3	Kilo
10^2	Hecto
10	Deka
10^-1	Deci
10^-2	Centi
10^-3	Milli
10^-6	Micro
10^-9	Nano
10^-12	Pico
10^-15	Femto
10^-18	Atto
10^-21	Zepto
10^-24	Yocto

(BIPM SI prefixes web page: http://www.bipm.fr/enus/3_SI/si-prefixes.html)

Relationship Between "Mass" and "Weight"

The relationship of "mass" and "weight" in its simplistic form may be visualized as follows:

"Mass" is "stuff" (a quantity of matter) regardless of what it is made of, any number of other conditions including shape, temperature, color … etc, where it is, and how it moves (disregarding relativistic effects).

"Weight" is "force" (specifically gravitational force) acting on the "stuff" in a special way. It is the force necessary to cause the "stuff" to accelerate (increase in speed) at a constant rate of an additional 32 feet per second for every additional second of elapsed time.

This happens to be the acceleration that falling "stuff" will experience as a result of "gravity" (the force of attraction between the earth and the falling "stuff", near the surface of the earth).

While the "stuff" is falling it is weightless (remember the amount of "stuff", its mass, never changes). Now if we gently bring a digital scale under this falling "stuff" and bring the digital scale to rest on Earth (lets say at sea level) with the "stuff" on top of the scale, the "stuff" will still want to accelerate through the scale since the gravity is still acting on it. The "stuff" unable to push through the scale simply transfers the force of gravity acting on the unchanged "mass" as a reading of its weight on the balance.

If the scale with the "stuff" on top were now transported from sea level to lets say one mile up, near Lake Tahoe; the amount of "stuff" (mass) would remain the same, but the scale would indicate a lower weight. This is because the force of gravity decreases with altitude. When the force of gravity on the "stuff" (mass) is lower, this force is displayed as "weight" on the balance which will also be lower.

Ok! Maybe the full scientific explanation is not so bad so here it is!

Scientific Explanation of
Relationship Between "Mass" and "Weight"

For the purpose of this discussion, we will introduce mass through the familiar.

Force = Mass x Acceleration (1)

That is, each object possesses a property called "mass" which appears in equation (1) as the constant of proportionality between a force applied to that object and the resulting acceleration of the object. Note that both force and acceleration are vector quantities: they have a direction associated with them. One should also note that mass is always a positive number (that is, for example, the acceleration is always in the same direction as the gravitational force, never opposite to it). These comments about mass are consistent with the qualitative idea of the mass of an object being a measure of the "amount of substance" in the object.

Unfortunately, our intuitive notions of "mass" are often confused with "weight." Such confusion is unacceptable for science and metrology. Therefore, we will now see how the notion of weight differs both logically and practically from that of mass.

We can take it as an experimental fact that over a small plane area of the earth's surface (such as the space occupied by a metrology laboratory) the acceleration of gravity is essentially constant. Since the acceleration of gravity is a vector quantity, this implies that, over a small area of the earth's surface, the direction of the acceleration of gravity is also practically constant. That is, the acceleration vectors are all parallel and define the direction "down." In this approximation, we can replace the acceleration of gravity by a numerical constant, $\bar{g}$.

The gravitational force on an object of mass M is then: $\mathbf{F_1} = \mathbf{M}\bar{g}$ (2)

The weight of an object of mass M is defined as F_1.[1] That is, weight is a force, not a mass.

Using $\boldsymbol{W} = \boldsymbol{F_1}$, *we have* $\boldsymbol{W} = \boldsymbol{M}\bar{g}$ *(3)*

From what was said about $\bar{g}$, it is clear that weight is not a constant property of matter, but depends on location. Consider, for example, a body of mass M taken out into deep space such that the gravitational forces are negligible (they are never zero). In this case, we can approximate (3) as: $\mathbf{W} = \mathbf{M}\bar{g} = \mathbf{0}$

which holds since $\bar{g} = \mathbf{0}$; $(\mathbf{M} \neq \mathbf{0})$

[1] This definition was adopted *for* international use by the General Conference for Weights and Measures.

SELF-EVALUATION QUESTIONS

1. What is the official system of weights and measures in the United States?

2. Which is larger: a millimeter or centimeter, and by how much?

3. Why is it important to define a practical system of measurement units?

4. Which base units of the International System of Units are associated with which measurement parameters?

Base SI Unit	Measurement Parameter
1) Second	A) Thermodynamic temperature
2) Ampere	B) Length
3) Kilogram	C) Luminous intensity
4) Kelvin	D) Time
5) Candela	E) Mass
6) Meter	F) Electric current
7) Mole	G) Amount of substance

5. What are some of the major differences between the English (customary) and Metric measurement systems?

6. How are the United States customary system and metric system currently related?

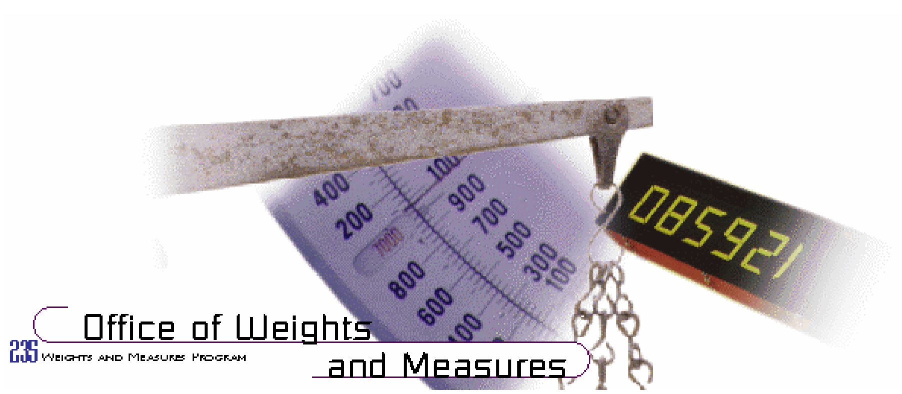
National Institute of Standards and Technology

NIST

National Institute of Standards and Technology Building
100 Bureau Drive
Gaithersburg, MD

National Institute of Standards and Technology (NIST) was developed in 1901 (initially named the “National Bureau of Standards”) to provide the measurements and standards needed to resolve and prevent disputes over trade and to encourage standardization. Today NIST develops technologies, measurement methods, and standards that help U.S. companies compete in the global marketplace. For legal metrology NIST is situated between the International Standards Community, from which it derives and inter-compares the standards that are part of the “SI” (International System of Units), and National Measurement Community including state and local weights and measures programs, other public and private measurement organizations. NIST also participates in associated International and National measurement organizations. The primary interactions with NIST are through the NIST Office of Weights and Measures, the NIST Office of Measurement Services, and the NIST programs associated with these offices.
(NIST web page: http://www.nist.gov)

NIST Office of Weights and Measures



The NIST Office of Weights and Measures (OWM) is a part of NIST Technical Services. The OWM promotes uniformity in U.S. weights and measures laws,

regulations, and standards to achieve equity between buyers and sellers in the marketplace. In doing this, the OWM attempts to enhance consumer confidence in the marketplace, enable U.S. businesses to compete fairly at home and abroad, and strengthen the U.S. economy. To help accomplish these goals the OWM established the National Conference on Weights and Measures (NCWM). OWM is organized into the following four program areas.
(NIST OWM web page: http://www.ts.nist.gov/ts/htdocs/230/235/ownhome.htm)

1. State Laboratory Program	Provides the basis for ensuring traceability of state weights and measures standards to NIST. It also conducts basic, intermediate, and advanced training for metrologists from the states, industry, and other countries. State legal metrology laboratories are custodians at the state level of measurement standards that serve as the basis for ensuring equity in the marketplace and as reference standards for calibration services for indigenous industry. As part of its program to encourage a high degree of technical and professional competence in such activities, NIST, OWM has developed performance standards and formalized procedures for voluntary recognition of State legal metrology laboratories. Certificates of Traceability are issued upon evaluation of the laboratory's ability to make reliable metrological measurements (principally mass, volume, length, and temperature). (NIST Laboratory Metrology web page with links relevant to the State Laboratory Program: http://www. ts.nist.gov/ts/tdocs/230/235/labmetrologypage.htm)
2. Device Technology Program	Develops procedures for testing weighing and measuring devices and conducts training on device testing for weights and measures officials. Program staff provide technical and administrative assistance to the NCWM Specifications and Tolerances Committee, National Type Evaluation Program Committee, and the various Sectors of the National Type Evaluation Technical Committee.

3.	**Laws and Regulations Program**	Provides guidance and training to the states, Federal regulatory agencies, and industry on the model weights and measures laws and regulations adopted by the NCWM. This group also gives technical and administrative support to the NCWM Laws and Regulations and Administration and Public Affairs Committees.
4.	**Administration and Publications Program**	Plans the technical agendas of meetings of the NCWM, coordinates the development and publication of key NIST and NCWM publications, and maintains OWM's information services. A member of this program and the Chief of OWM serve as advisors to the NCWM Board of Directors.

NIST Office of Measurement Services

The Office of Measurement Services supports industry and commerce with Standard Reference Data, Standard Reference Materials, and Calibration programs. Through these programs the measurement standards and services generated in the technical laboratories of NIST are provided to meet the needs of state and local governments, federal agencies, industry, and the scientific community for traceability, at necessary levels of accuracy, to national standards. Measurement Services provides expert guidance and services regarding legal metrology to state and local governments, business, and industry to ensure measurement uniformity, traceability, and equity in domestic and international commerce.
(NIST Office of Measurement Services web page:
http://www.ts.nist.gov/ts/htdocs/230.htm)

NIST Calibration Services

NIST Calibration Services provides leadership to the NIST Physical Calibration Services and Measurement Assurance Programs. Calibration Services also provides some 500 different services to industry, state and local governments, other federal agencies, and private sector organizations as well as providing assistance to NIST technical staff on physical measurement quality control and experimental design. Calibration Services develops policies and establishes priorities for fee-supported physical measurement services, and evaluates the effectiveness of dissemination mechanisms. It also assists other agencies, as required, in improving their physical measurement quality control systems, and provides a single point of contact with organizations outside NIST having requirements for measurement services.
(NIST Calibration Services web page:
http:// www.ts.nist.gov/ts/htdocs/230/233/calibration/home.html)

International Standards Community

The starting point of International Standards begins with the Bureau International des Poids et Measures (BIPM). The leading international legal metrology organization is the International Organization of Legal Metrology (OIML). While many countries have national laboratories and international regions have developed numerous regional metrology organizations BIPM and OIML are vanguards that are addressed in this module.

The BIPM has its headquarters in France. Its mandate is to provide the basis for a single coherent system of measurements throughout the world traceable to the International System of Units (SI). It directly disseminates units and coordinates international comparisons of national measurement standards as well as performing calibrations for member national metrology institutes.
(BIPM web page: http://www.bipm.fr/enus/welcome.html)

The OIML is an international treaty organization created to promote the global harmonization of BIPM procedures. The OIML provides its members with metrological guidelines for the elaboration of national and regional requirements concerning the manufacture and use of measuring instruments for legal metrology applications.

The OIML also develops model regulations which provide members with an internationally agreed-upon basis for the establishment of national legislation on various categories of measuring instruments. It also establishes cooperative agreements between the OIML and certain international standards and conformity assessment institutions, including the ISO (International Organization for Standardization) and IEC (International Electrotechnical Commission) with the objective of avoiding contradictory requirements.
(OIML web page: http://www.oiml.org)

National Measurement Community

The public and private National Measurement Community, for this discussion, will be considered in two parts: the first part dealing with Weights and Measures Sector Standards and the second part with all other Public and Private Sector Standards. There are occasions when these sectors and the standards organizations with their respective memberships interact. Both sectors exist in all 50 States, with California being considered herein.

Weights and Measures Sector Standards

These standards are used by the California Department of Food and Agriculture, Division of Measurement Standards, in partnership with California county weights and measures enforcement programs and service agencies during the installation and repair of commercial weighing and measuring devices. The Division of Measurement Standards, Metrology Branch or its recognized certification sources certify the standards used by enforcement and service organizations, traceable to the national units of measurement. The Division and the Metrology Branch are members of and participate in the activities of the National Conference on Weights and Measures (NCWM).

The NCWM is a professional organization of State and local weights and measures officials and representatives of business, industry, consumer groups, and Federal agencies. The Office of Weights and Measures partners with the NCWM to develop standards in the form of uniform laws, regulations, and methods of practice, which are then published by NIST. When State and local governments or Federal regulatory agencies adopt these standards, they become mandatory.
(NCWM web page: http://www.ncwm.net/main.html)

Public and Private Sector Standards

These standards are used by the many state governmental agencies and industries. The Division of Measurement Standards, Metrology Branch certifies these standards on a for-a-fee basis as do other private and public laboratories. The Division and the Metrology Branch are members of and participate in the activities of the National Conference of Standards Laboratories International (NCSLI), an organization closer to the non-weights and measures community.

NCSLI was formed in 1961 to promote cooperative efforts for solving the common problems faced by measurement laboratories. NCSLI is a nonprofit organization, whose membership is open to any organization with an interest in the science of measurement and its application in research, development, education, or commerce. The mission of NCSLI is to advance technical and managerial excellence in the field of Metrology, Measurement Standards, Conformity Assessment, Instrument Calibration, as well as Test and Measurement.
(NCSLI web page: http://www.ncsli.org)

California Department of Food and Agriculture
Division of Measurement Standards

Enforcement of California Weights and Measures laws and regulations is the responsibility of the Division of Measurement Standards.

The Division's activities are designed to:

Ensure the accuracy of commercial weighing and measuring devices.

Verify the quantity of both bulk and packaged commodities.

Enforce quality, advertising and labeling standards for most petroleum products.

The Division works closely with county sealers of weights and measures who, under the supervision and direction of the Secretary of the Department of Food and Agriculture, carry out the vast majority of weights and measures enforcement activities at the local level. The Division's Metrology Branch supports these activities by providing the traceability for the physical standards used by the State and county weights and measures enforcement programs.
(CDFA DMS web page: http://www.cdfa.ca.gov/dms)

Division of Measurement Standards
Metrology Branch

The Metrology Branch maintains, in concert with the National Institute of Standards and Technology, the State standards of measurement. These physical standards form the basis for all California transactions involving weight or measure. The Metrology Branch also coordinates measurement activities for a fee, among local agencies, industry and the general public.

The Metrology Branch is responsible for the certification of state, county and service agency standards; recognition standards certification sources; and providing scheduling and pricing information. The certification involves the “calibration” or “tolerance testing” of a physical standard relative to a similar standard of higher accuracy. Tolerance testing compares the standard being certified with a standard of sufficiently higher accuracy to assure that the certified standard is within its stated tolerance. Calibration performs the same testing and formally states the value of the certified standard and the uncertainty of that value at the time of testing.

State Metrology Laboratory
Services Available
(CDFA DMS Metrology web page: http://www.cdfa.ca.gov/dms/metrology.htm)

Parameter **Mass**	**Range**	**Uncertainty**
Accuracy Level 1 Weighing design [Calibration]	**ASTM Class 1, 1.1 and higher** 50 kg to 1 mg 100 lb. to 1 lb.	**Less than:** Tolerance/4 to Tolerance
Accuracy Level II 3-1 weighing design and substitution [Calibration and Tolerance test]	**ASTM Class 2 and 3** 50 kg to 1 mg 100 lb. to 1 lb.	**Less than:** Tolerance/4 to Tolerance/3 (for legal metrology)
Accuracy Level III Direct reading and substitution [Tolerance test]	**ASTM Class 4, 5 and 6** NIST Class F and lower 50 kg to 1 mg 1 000 lb. to 10 lb.	**Less than:** Tolerance/9 to Tolerance/3 (for legal metrology)

Volume	**Range**	**Uncertainty**
Gravimetric [Calibration]	**Metal provers, measures and glass volumetric standards** 20 L to 2 ml 5 gal. to 30 minim	**Less than:** Tolerance/4 to Tolerance/3 (for legal metrology)
Volume transfer [Calibration and Tolerance test]	**Metal provers, measures and glass volumetric standards** 5 000 L to 100 ml 1 500 gal. to 2 fl. oz.	**Less than:** Tolerance/4 to Tolerance/3 (for legal metrology)

State Metrology Laboratory
Services Available (continued)
(CDFA DMS Metrology web page: http://www.cdfa.ca.gov/dms/metrology.htm)

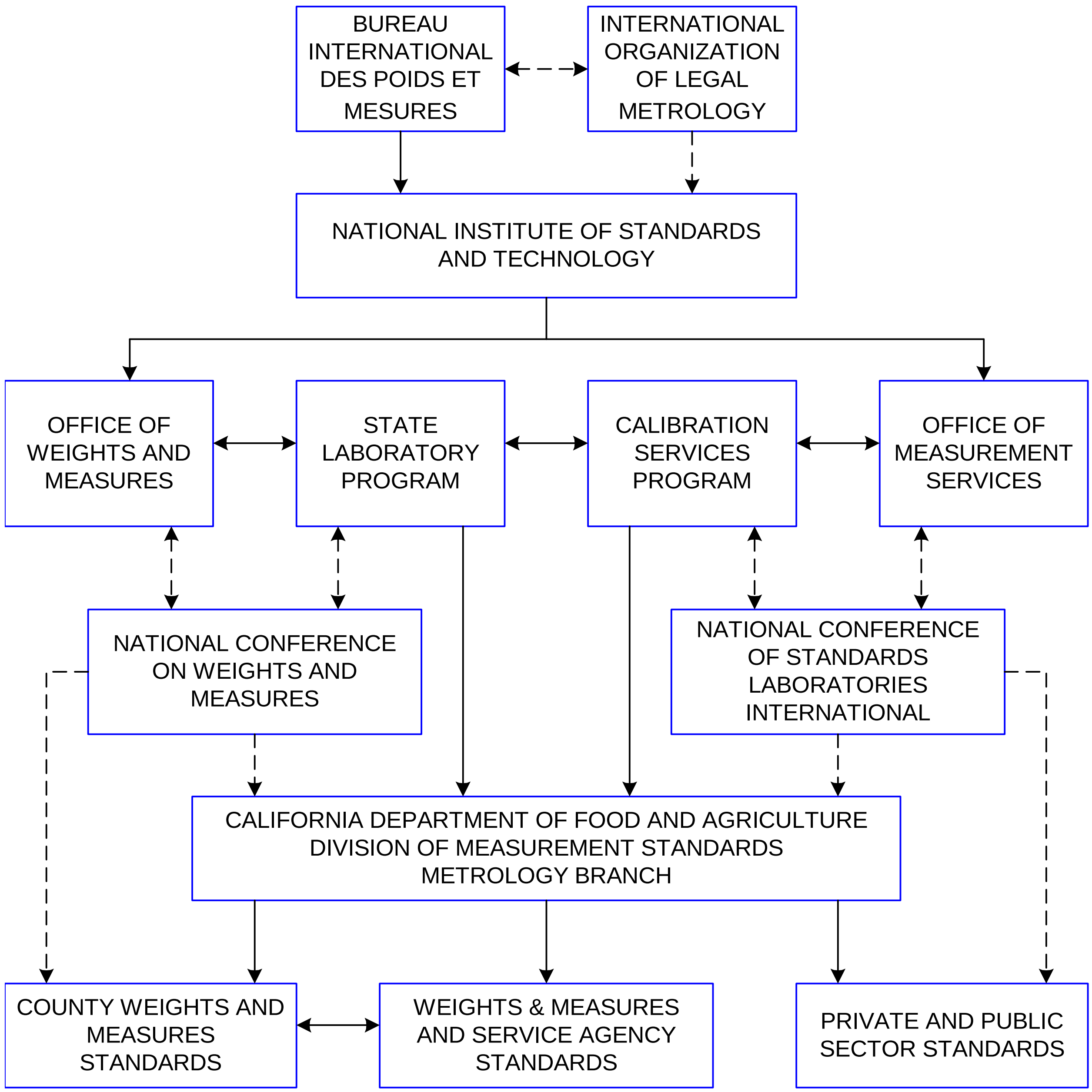
Length	Range	Uncertainty
Tape comparison to Tape or bench [Calibration and Tolerance test]	**Up to: 35 meters, 100 feet**	**Less than:** Tolerance/4 to Tolerance/3 (for legal metrology)
Rigid rule Direct comparison [Calibration and Tolerance test]	**Up to: 18 inches**	**Less than:** Tolerance/4 to Tolerance/3 (for legal metrology)

Temperature	Range	Uncertainty
Comparison with Platinum resistance thermometer [Calibration and Tolerance test]	**Thermometers:** Liquid in glass, electronic, digital and other temperature sensing devices 200 to –40 C 400 to –40 F	**Less than:** 0.05 C to Tolerance/3 (for legal metrology)

Time Interval	Range	Uncertainty
Comparison with NIST Time signals	**Stopwatches**	**Less than:** 2 seconds / 24 hours

Watthour	Range	Uncertainty
Comparison with watthour standard	**Watthour test sets and Standards power factor** [Unity and 0.5 lag] 120, 240 and 480 Volt 0.5 to 30 Amps	**Less than:** Tolerance/4 to Tolerance/3 (for legal metrology)

Legal Metrology Organization Chart



SELF-EVALUATION QUESTIONS

1. What is metrology and how does it relate to “Legal Metrology”?

2. What do the acronyms NIST, BIPM, OWM, and SI stand for?

3. What is the NIST relationship to Weights and Measures?

4. In what year was the National Conference of Standards Laboratories International formed?

5. What are the primary activities of the Division of Measurement Standards?

6. What organization is responsible for certification of State and County Standards?

7. What organization issues the State Metrology Laboratory a “Certificate of Traceability”?

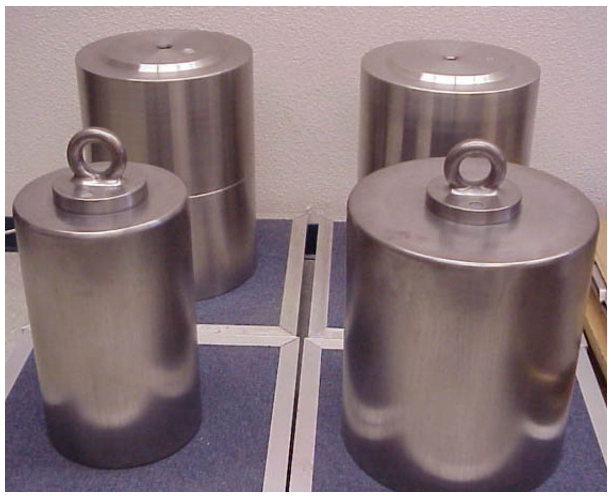
8. What was the original name of NIST and when was it developed?

Standards Their Care and Traceability

Standards

A measurement standard is an object, artifact, instrument, system or experiment that stores, embodies, or otherwise provides a physical quantity that serves as the basis for measurements of the quantity.

Primary State Standards



Cover removed to reveal detail

While measurement standards are the tools we use to evaluate, test or certify measurement devices, the way in which those standards are used, configured, calibrated, maintained and the specifications for their construction (features, materials, dimensions) are what makes them legitimate standards to reference. You cannot just use a rock as a standard reference weight because the weight of the rock will change due to the physical properties of the rock. You can use a weight that is designed and fabricated specifically to be used as a weight (constructed of specific materials to specific dimensions with specific features) because it is more stable than a rock and will stay within specified tolerances as a standard weight. The specifications for the parameters that are necessary for a standard to work as a standard are all written in two publications by NIST. The NIST Handbook 44 and the NIST 105 series of handbooks are documents that provide guidelines, specifications, tolerances, and conditions of use of measurement standards.

The 105 series of handbooks (see Bibliography and References) designates the specifications that standards must meet before they will be certified by the State for use. In other words, the standards must be manufactured to meet certain specifications and minimum tolerances if they are to be initially certified by the State. There are eight different handbooks in the 105 series.

Handbook 105 Series	
Handbook Number	**"Specifications and Tolerances for"**
1.	**Field Standard Weights (NIST F Class)**
2.	**Field Standard Measuring Flasks**
3.	**Graduated Neck Type Volumetric Field Standards**
4.	**Liquefied Petroleum Gas and Anhydrous Ammonia Liquid Volumetric Provers**
5.	**Field Standard Stopwatches**
6.	**Thermometers**
7.	**Dynamic Small Volume Provers**
8.	**Weight Carts (Draft 3)**

Handbook 44 covers the way the standards are to be used after they are certified. It indicates the methods of use, tolerances, and specifications of measurement standards that must be followed and maintained to use the standards in the field or laboratory. Its self-described purpose is to "eliminate from use, weights and measures and weighing and measuring devices that give readings that are false, that are of such construction that they are faulty (that are not reasonably permanent in their adjustment or will not repeat their indications correctly), or that facilitate the perpetration of fraud, without prejudice to apparatus that conforms as closely as practicable to the official standards". Handbook 44 serves as a template for the California Code of Regulations, Title 4, Division 9, and has been adopted by reference. Handbook 44 is developed primarily by the NCWM with assistance from the OWM at NIST and is published by NIST.

The following excerpt from Handbook 44, Appendix A, "Fundamental Considerations Associated with the Enforcement of Handbook 44 Codes" Section 3, "Testing Apparatus" addresses standards. (The term "standards" herein appears to be used interchangeably with the term "testing apparatus") as follows:

3. Testing Apparatus

3.1. Adequacy. – Tests can be made properly only if, among other things, adequate testing apparatus is available. Testing apparatus may be considered adequate only when it is properly designed for its intended use, when it is so constructed that it will retain its characteristics for a reasonable period under conditions of normal use, when it is available in denominations appropriate for a proper determination of the value or performance of the commercial equipment under test, and when it is accurately calibrated.

3.2. Tolerances for Standards. – The error in a standard used by a weights and measures official should be known and corrected for when the standard is used; or if the standard is to be used without correction, its error should be not greater than one-third of the smallest tolerance to be applied when the standard is used. The reason for this is to keep at a minimum the proportion of the tolerance on the item tested that will be used up by the error of the standard. Expressed differently, the reason is to give the item being tested as nearly as practicable the full benefit of its own tolerance.

Field testing operations are complicated to some degree when corrections to standards are applied. Except for work of relatively high precision, it is recommended that the accuracy of standards used in testing commercial weighing and measuring equipment be so established and maintained that the use of corrections is not necessary. Also, whenever it can readily be done, it will be desirable to reduce the error on a standard below the one-third point previously mentioned.

3.3. Accuracy of Standards. – Prior to the official use of testing apparatus, its accuracy should invariably be verified. Standards should be reverified as often as circumstances require. By their nature, metal volumetric standards are more susceptible to damage in handling than are standards of some other types. A standard should be recalibrated whenever damage is known or suspected to have occurred or significant repairs have been made. In addition, standards, particularly volumetric standards, should be recalibrated with sufficient frequency to affirm their continued accuracy, so that the official may always be in an unassailable position with respect to the accuracy of his testing apparatus. Secondary standards, such as special fabric testing tapes, should be verified much more frequently than such basic standards as steel tapes or volumetric provers to demonstrate their constancy of value or performance.

Accurate and dependable results cannot be obtained with faulty or inadequate standards. If either the service person or official is poorly equipped, their results cannot be expected to check consistently. Disagreements can be avoided and the servicing of commercial equipment can be expedited and improved if service persons and officials give equal attention to the adequacy and maintenance of their testing apparatus.

All standards require care in their preparation, calibration and/or use. They also have stated values and associated uncertainties. Standards are described by many words that provide information about the standards including its source, location, intended use, and accuracy. Respective examples of these descriptive words include:

- **Sources:**
  1. "Intrinsic" standard; derived locally from an accepted experimental protocol.
  2. "Ratio" standard; used to determine the ratio between two like units of measurement.

- **Locations:**
  1. "National" standard; maintained by a national laboratory.
  2. "Field" standard; used in locations outside the laboratory or production facility.

- **Intended uses:**
  1. "Working" standard; to be used for routine laboratory, production, or calibration work.
  2. "Transfer" standard; used to transfer the value of higher accuracy standards between laboratories.

- **Accuracy levels:**
  1. "Primary" standard; the highest accuracy level standard maintained by the laboratory.
  2. "Secondary" standard; similar to the primary but constructed, maintained and/or used in a way that limits its relative accuracy.

Traceability to the National Units of Measurement

"Traceability is the property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties." This quote from National Institute of Standards and Technology (NIST) Handbook 143, is one of many attempts to describe a concept that includes a series of components leading to the realization of a "TRACEABLE" measurement.

This chain of comparisons, calibrations, tests, and other terms that imply a measurement involves increasing levels of accuracy for each measurement in the hierarchy reaching or traceable to the highest accuracy level or measurement origin. This measurement origin is normally standards and procedures maintained at the NIST, the national laboratory for the United States of America. NIST conducts measurements and experiments on the standards it maintains traceable to the International System of Units. This subject is covered in Segment 2 of this module.

Traceable measurement results made anywhere and at any time, agree with each other within the stated uncertainty associated with each measurement result. This provides society with equity in commerce; assurance that fabricated things fit, and legal and medical decisions are based on accurate scientific data. Weights and measures, transportation, industry, manufacturing, the legal system, the physical and biological sciences, technology, and just about every aspect of our daily activities are dependent on traceable measurement.

Traceability is more than the act of conducting measurement comparisons leading from the local measurement to a national or international standard. There also must be documentation showing that each measurement was part of a unbroken chain of comparisons performed using standards that were calibrated within a specified interval, against standards of sufficiently greater accuracy. Documented procedures must be used by trained personnel to perform each comparison, collect and record the observed data, and calculate and report the results. Records on the standards must be kept and data analyzed to assure that the standards and procedures used remain stable over time. The higher the accuracy the more detail is required and more things need to be taken into account and documented including location, vibration, contamination and other environmental factors including barometric pressure, temperature, and humidity.

All this documentation is part of the metrology laboratory's quality system, which is self documented in the laboratory's Quality, Administrative, and Measurement Procedure Manuals. The laboratory also complies with the requirements of the NIST, Office of Weights and Measures, State Laboratory Program. These requirements are documented in NIST Handbook 143 and based on "ISO/IEC 17025", an international document addressing the "General Requirements for the Competence of Testing and Calibration Laboratories".

To get familiar with traceability, let us take a familiar 1 foot ruler, manufactured to be within plus-or-minus 1/32 inch at any mark along its length when used in accordance with an accepted length measuring procedure for the ruler. Let us use this ruler to measure and cut the length of a rod to be used in the construction of an art object. The rod requires a length of 10 inches plus-or-minus 1/8 inch to fit into the art object.

Let us say that the standard ruler comes with a "Report of Test" from a metrology laboratory that compared and calibrated the ruler with its 10-inch length standard. The "Report of Test" stated that the ruler's 10-inch mark was found to be 10 inches with an uncertainty of plus-or-minus 1/32 inch.

Of course the metrology laboratory's 10-inch length standard has been compared with and calibrated by an even more accurate length standard maintained at NIST. The NIST "Report of Test" stated that the working 10-inch length standard was found to be 10 inches with an uncertainty of plus-or-minus 1/100 inch. We could go even further, but you get the idea --- each standard is compared with and calibrated by a more accurate standard in this case "TRACEABLE" to and stopping at the national length standard maintained at the NIST.

Now let us, in Table I, for this case, consider some components that are involved to produce a "TRACEABLE" measurement during the cutting of the rod to a 10-inch length. Be aware that what is being discussed about the measurement of the rod also applies, at a higher level of accuracy, to the ruler and metrology laboratory length standard regarding their respective calibrations.

Table I

Traceability Component	Definition and Discussion
"Item Under Test"	The rod, that will be cut to a nominal length of 10 inches by comparison to the distance between the 0 and 10 inch marks on the ruler.
"Standard"	The ruler, that was calibrated and certified by a metrology laboratory by comparison with the laboratory's 10-inch length standard.
"Nominal Value"	Ten inch rod length after being cut.
"Tolerance"	The maximum measured distance of plus-or-minus 1/8th inch that the cut rod length may deviate from the10-inch nominal value.
"Measurement Procedure"	A published procedure or protocol that instructs how the measurement is to be conducted.
"Measurement"	The comparison of the rod with the ruler during the process to cut the rod length to 10 inches.
"Accuracy"	How close the measured rod length comes to the nominal value of 10 inches.
"Precision"	How close the repeated and independent rod length measurements with the ruler, under the same test conditions, are to each other.
"Error"	The actual difference between the length of the cut rod and the 10 inch mark on the ruler. Handbook 44, Appendix A, "Fundamental Considerations Associated with the Enforcement of Handbook 44 Codes", Section 3, "Testing Apparatus" states: "The error in a standard used by a weights and measures official should be known and corrected for when the standard is used; or if the standard is to be used without correction, its error should be not greater than one-third of the smallest tolerance to be applied when the standard is used."
"Uncertainty"	Uncertainty, based on the NIST Handbook 143 definition, is "a parameter associated with the result of a measurement that characterizes the dispersion of the values that could reasonably be attributed to the cut rod." Without getting into complex statistical detail, which is beyond the scope of this module; consider the following: The uncertainty, in this case, is about a plus-or-minus 1/24 inch range of values around the 10-inch nominal value for the rod. Based on the current method of calculating uncertainty, we would expect approximately 95 percent of repeated rod length measurements with the ruler, under the same test conditions to fall within this uncertainty.
"Report of Test"	A formal document providing the measurement results of the cut rod. While the rod would not need a "formal" report, the ruler has a report from the metrology laboratory and the metrology laboratory has a NIST report on its 10 inch length standard.

Care of the Standards

Proper care of working and field standards is important if they are expected to maintain their accuracy and usefulness as standards. There are a few things that can be done to care for and maintain standards that will work for almost all types of equipment.

Keep standards clean. Wipe off any oil or dirt that they may get on them. Any foreign material that gets into a case will eventually get into or onto equipment stored in the case.

Try to keep cases clean by keeping them closed while you are using the equipment. This will reduce the amount of dust that accumulates in the case and keep other foreign material from entering the case. Keep the cases closed while the equipment is being stored in them as well.

Weights especially should be kept clean. Weights too large to be stored in a case should be elevated off the ground to avoid abrading the bottoms, covered to avoid dust and dirt from settling on them, and stored indoors if possible to prevent condensation from forming on them. If they are stored outdoors they should be elevated to avoid abrading the bottom and so water and mud do not pool around them, and they should be covered so the accumulation of dust, dirt and condensation is kept to a minimum. Rust should be cleaned off and the weight lightly spray-painted with an aluminum paint. (Use only enough paint to prevent rusting. Rolling or brushing on paint may add too much weight.)

50 lb. Cast Block Weights Used in the field

Do not paint the bottom of the weight because normal wear and tear will remove the paint from the bottom, changing the weight between calibrations, maintenance and regular use. The idea is to keep the weight as stable as possible by keeping it clean and dry. Some clean weights will test badly (too much paint if heavy, too aggressive with cleaning if light). Lots of dirty weights will test badly. Keep them clean and they will repeat better.

Weight kit for use in the field

Keep cases in good repair so their contents do not fall out onto the ground, so they effectively stop dust, dirt and moisture from entering the case, and so their contents are protected from shock while in transport or storage.

Keep equipment dry. Moisture promotes corrosion and provides a vehicle for the deposition of foreign substances. Dry off your equipment, if it is possible, before storing it. Do not put equipment away in cases that have moisture in them and keep cases closed to discourage condensation from forming within the case. Sometimes it is not possible to completely dry a piece of equipment. Do what you can.

Standards stored at the Metrology Laboratory
Division of Measurement Standards
Sacramento, CA

SELF-EVALUATION QUESTIONS

1. What is the purpose of the National Institute of Standards and Technology 105 series handbooks?

2. How should the error of a standard be accounted for when used to test a device?

3. What is traceability?

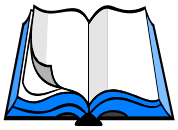
4. Why are traceable measurements important?

5. Why is it important to leave the bottom of weights unpainted?

6. How often should standards be reverified?

7. When is the known error, in a standard used by weights and measures officials, to be accounted for?

8. What condition must be met if a standard is to be used without an applied correction?



GLOSSARY

A LISTING OF TERMINOLOGY AND ACRONYMS MOST COMMONLY USED BY WEIGHTS AND MEASURES OFFICIALS.

APLMF	Asia Pacific Legal Metrology Forum
ASTM	American Society for Testing and Materials
B&P	Business and Professions Code
CACASA	California Agricultural Commissioners and Sealers Association
CDFA	California Department of Food and Agriculture
CTEP	California Type Evaluation Program
CWMA	Central Weights and Measures Association
DMS	Division of Measurement Standards
FDA	Food and Drug Administration
FTC	Federal Trade Commission
NCWM	National Conference on Weights and Measures
NEWMA	Northeastern Weights and Measures Association
NIST	National Institute of Standards and Technology
OIML	International Organization of Legal Metrology
OWM	Office of Weights and Measures
SWMA	Southern Weights and Measures Association
USDA	United States Department of Agriculture
WWMA	Western Weights and Measures Association

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SELF-EVALUATION ANSWERS

Segment 1

1. The title "U.S. Customary" originally was more of a description than a name. The system is called U.S. Customary because the system is just that, customary. It is an official legal system of measurement for the United States. It was adopted by the states individually after Ferdinand Hassler sent standards to them at the request of the Secretary of the Treasury. It could be argued that the Secretary of the Treasury had overstepped his bounds of authority, but the states adopted the standards legally using their own authority to do so. The Secretary only provided them with a set of standards so that they could participate more successfully in commerce.

2. The centimeter is ten times larger than the millimeter.

3. It was thought that an international system would benefit commerce, and be more conductive to collaborative efforts in engineering, science and technology.

4. [Example: 7 (Mole) = G (Amount of Substance]
   1=D, 2=F, 3=E, 4=A, 5=C, 6=B

5. The metric system replaced all the traditional units, except the units of time and of angle measure, with units satisfying three conditions:

   (1) Only a single unit is defined for each quantity. These units are now defined precisely in the International System of Units.
   (2) Larger and smaller units are created by adding prefixes to the names of the defined units. These prefixes denote powers of ten, so that metric units are always divided into tens, hundreds, or thousands. The original prefixes included milli- for 1/1,000; centi- for 1/100; deci- for 1/10; deka- for 10; hecto- for 100; and kilo- for 1,000.
   (3) The units are defined rationally and are related to each other in a rational fashion.

6. Currently, the basis of the U.S Customary system of weights and measures are the yard and the avoirdupois pound. The yard and the pound have been defined in terms of the SI meter and the international prototype kilogram since July 1, 1959. The yard is defined as 0.9144 4 meter and the avoirdupois pound as 0.453 592 37 kilogram. All of the units of the U.S. Customary system are derived from these.

SELF-EVALUATION ANSWERS

Segment 2

1. "Metrology" is defined as the science of measurement. "Legal Metrology" is collectively the legislative, administrative and technical procedures established by, or by reference to, public authorities. Legal metrology is implemented on behalf of these authorities in order to specify and to ensure, in a regulatory or contractual manner, the appropriate quality and credibility of measurements related to official controls, trade, health, safety and the environment

2. NIST -- National Institute of Standards and Technology
   BIPM -- Bureau International des Poids et Measures
   OWM -- Office of Weights and Measures
   SI -- International System of Units

3. The NIST Office of Weights and Measures is a part of NIST Technical Services. The Office of Weights and Measures promotes uniformity in U.S. weights and measures laws, regulations, and standards to achieve equity between buyers and sellers in the marketplace. In doing this the Office of Weights and Measures attempts to enhance consumer confidence in the marketplace, enable U.S. businesses to compete fairly at home and abroad, and strengthen the U.S. economy.

4. NCSLI (National Conference of Standards Laboratories International) was formed in 1961 to promote cooperative efforts for solving the common problems faced by measurement laboratories.

5. Enforcement of California Weights and Measures laws and regulations is the responsibility of the Division of Measurement Standards. The Division's activities are designed to:

   - Ensure the accuracy of commercial weighing and measuring devices;
   - Verify the quantity of both bulk and packaged commodities; and
   - Enforce quality, advertising and labeling standards for most petroleum products.

   The Division works closely with county sealers of weights and measures who carry out the vast majority of weights and measures enforcement activities at the local level.

SELF-EVALUATION ANSWERS

6. The Metrology Branch is responsible for the certification of state, county and service agency standards; recognition standards certification sources; and providing scheduling and pricing information.

7. The NIST, OWM has developed performance standards and formalized procedures for voluntary recognition of State legal metrology laboratories. Certificates of Traceability are issued upon evaluation of the laboratory's ability to make reliable metrological measurements.

8. NIST (National Institute of Standards and Technology) was developed in 1901 (initially named the "National Bureau of Standards").

Segment 3

1. The NIST 105 series of handbooks provides construction guidelines, specifications, and minimum tolerances that standards must meet to be certified and used for weights and measures enforcement.

2. The error in a standard used by a weights and measures official should be known and corrected for when the standard is used; or if the standard is to be used without correction, its error should not be greater than one-third of the smallest tolerance to be applied when the standard is used. The reason for this is to keep at a minimum the proportion of the tolerance on the item tested that will be used up by the error of the standard.

3. "Traceability is the property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties." This quote from NIST Handbook 143 is one of many attempts to describe a concept that include a series of components leading to the realization of a "TRACEABLE" measurement.

SELF-EVALUATION ANSWERS

4. Traceable measurement results made anywhere and at any time, agree with each other within the stated uncertainty associated with each measurement result. This provides society with equity in commerce; assurance that fabricated things fit, and legal and medical decisions are based on accurate scientific data. Weights and measures, transportation, industry, manufacturing, the legal system, the physical and biological sciences, technology, and just about every aspect of our daily activities are dependent on traceable measurement.

5. The bottom of the weights are left unpainted because normal wear and tear will remove the paint from the bottom, changing the weight between calibrations, maintenance and regular use.

6. Prior to the official use of testing apparatus, its accuracy should invariably be verified. Standards should be reverified as often as circumstances require. By their nature, metal volumetric standards are more susceptible to damage in handling than are standards of some other types. A standard should be recalibrated whenever damage is known or suspected to have occurred or significant repairs have been made. In addition, standards, particularly volumetric standards, should be recalibrated with sufficient frequency to affirm their continued accuracy, so that the official may always be in an unassailable position with respect to the accuracy of his testing apparatus. Secondary standards, such as special fabric testing tapes, should be verified much more frequently than such basic standards as steel tapes or volumetric provers to demonstrate their consistency of value or performance.

7. The error in a standard used by a weights and measures official should be known and corrected for when the standard is used.

8. If a standard is to be used without correction, its error should not be greater than one-third of the smallest tolerance to be applied when the standard is used.

We would appreciate your taking a few moments to complete our training evaluation feedback form. We welcome your comments and any suggestions you might have regarding Training Module 5. You may E-mail your response to us at DMS@cdfa.ca.gov or mail to Division of Measurement Standards at 6790 Florin Perkins Road, Suite 100, Sacramento CA 95828-1812.

1. Did this module fulfill your expectations?

2. What did you like/dislike about this module?

3. What areas would you like to see improved?

4. What specific changes, if any, would you recommend?

5. How could this module be better organized to make it easier to follow and learn from?

6. Was this module too basic or too advanced for someone with an entry level background in weights and measures?

7. Additional comments or suggestions.