MEASUREMENT

OF

LENGTH,MASS,TIME,LIGHT

Measurement of length:

Introduction

Length is probably the most measured physical parameter. This parameter is known under many alternative names - displacement, movement, motion.

Length is often the intermediate stage of systems used to measure other parameters. For example, a common method of measuring fluid pressure is to use the force of the pressure to elongate a metal element, a length sensor then being used to give an electrical output related to pressure.

Length can now be measured through over thirty decadic orders. Figure 4.1 is a chart of some common methods and their ranges of use. In most cases only two to three decades can be covered with a specific geometrical scaling of a sensor's configuration.

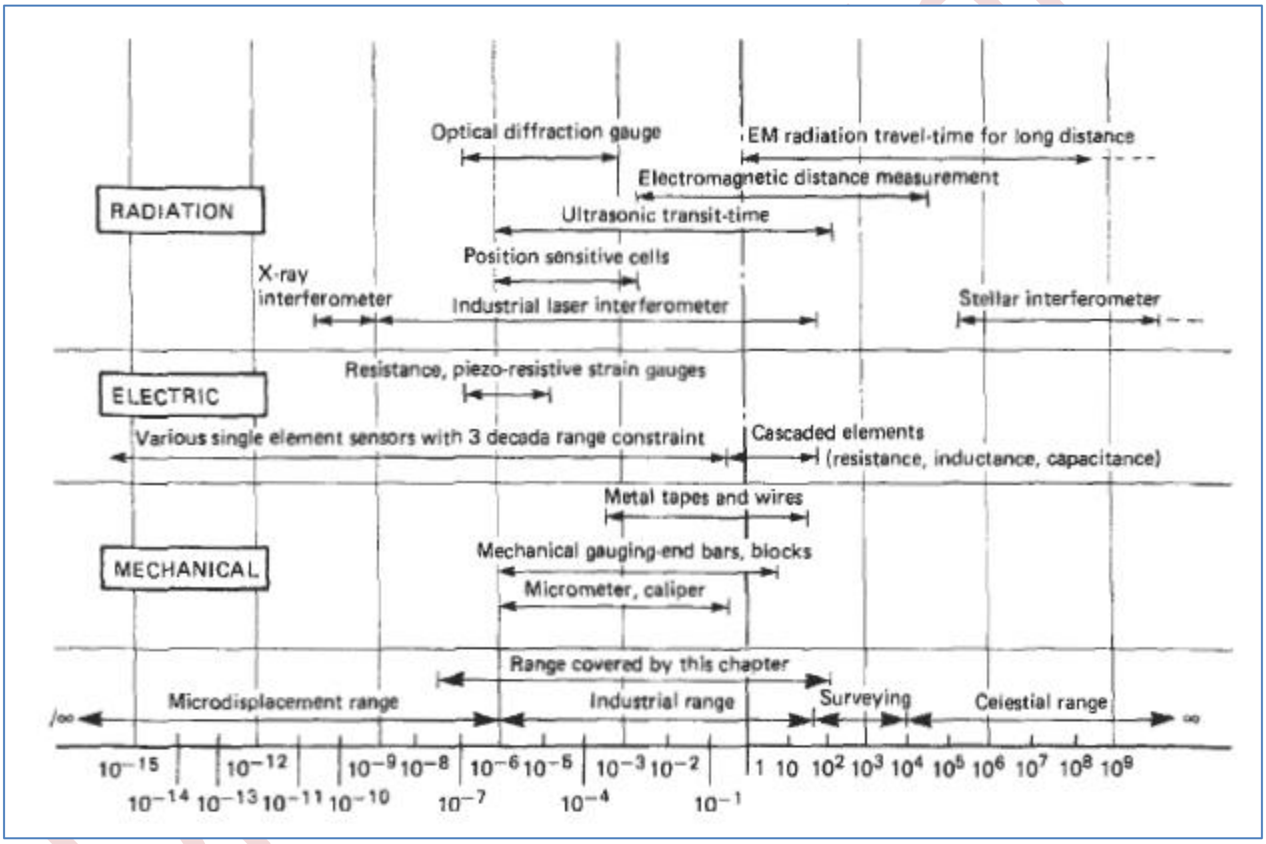


Figure 4.1 Ranges and methods of length measurement.

Definition:

The meter is the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second.

Derived from length measurement alone:

Length (m) comes into other measurement parameters, including relative length change (m/m), area (m^2) volume (m^3), velocity (m^{-1}), and acceleration (m^{-2}).

To **measure position**, several coordinate systems can be adopted.

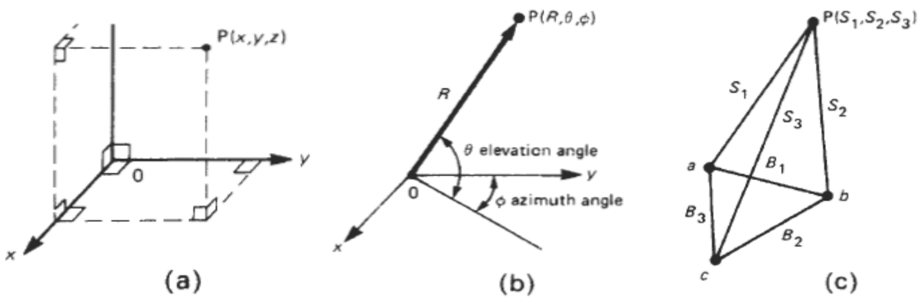
Figure 4.2 shows those commonly used. In each instance the general position of a point P will need three measurement numbers, each being measured by separate sensing channels.

The Cartesian (or rectangular) system shown in Figure 4.2(a) is that most adopted for ranges less than a few tens of meters. Beyond that absolute size it becomes very difficult to establish an adequately stable and calibratable framework. Errors can arise from lack of right angles between axes, from errors of length sensing along an axis, and from the imperfection of projection out from an axis to the point.

The polar system of Figure 4.2(b) avoids the need for an all-encompassing framework, replacing that problem with the practical need for a reference base from which two angles and a length are determined. Errors arise here in definition of the two angles and in the length measurement which, now, is not restricted to a slide-way. Practical angle measurement reaches practical and cost barriers at around one arc-second of discrimination. This method is well suited to such applications as radar tracking of aircraft or plotting of location under the sea.

The above two systems of coordinate framework are those mostly adopted. **A** third alternative which is less used, has, in principle, the least error sources. This is the triangular system shown as Figure 4.3(c). In this method three lengths are measured from a triangle formed of three fixed lengths. Errors arise only in the three length measurements with respect to the base triangle and in their definition in space. Where two or more points in space are to be monitored, then their relative position can be obtained accurately even if the base triangle moves in space. The major practical problem in adopting this method is that the three length measurements each require tracking arrangements to keep them following the point. The accuracy of pointing, however, is only subject to easily tolerated cosine forms of error which allow relatively poor following ability to give quite reasonable values. The three alternatives can also be combined to provide other arrangements but in each case there will always be the need to measure three variables (as combinations of at least one length with length and or angle) to define point position in a general manner.

Figure 4.2 Coordinate systems



Space can be described in terms of three length parameters. Three coordinate numbers describe the position of a point in space regardless of the kind of coordinate framework used to define that point's coordinates. The number of coordinates can be reduced if the measurement required is in two dimensions. Measuring position along a defined straight line only requires one length-sensing system channel; to plot position in a defined plane requires two sensors.

Length measurements fall into two kinds. those requiring determination of the absolute value in terms of the defined international standard and those that determine a change in length of a gauge length interval (relative length). For relative length there is no need to determine the gauge interval length to high accuracy. Measuring the length of a structure in absolute terms is a different kind of problem from measuring strains induced in the structure.

Descriptive terminology is needed to simplify general description of the measuring range of a length sensor. Classification into micro displacement, industrial, surveying, navigation, and celestial is included in Figure 3. I.

The actual range of a length sensor is not necessarily that of the size of the task. For example, to measure strain over a long test interval may make use of a long-range, fixed-length, standard structure which is compared with the object of interest using a short-range sensor to detect the small differences that occur. Absolute whole length measurement requires a sensor of longer range. It is often possible to measure a large length by adding together successive intervals, for example by using a single ruler to span a length greater than itself.

Standards and calibration of length:

With very little exception length measurements are now standardized according to SI measurement unit definitions, length being one of the seven base units. It is defined in terms of the unit called the meter.

Until early 1982 the meter was defined in terms of a given number of wavelengths of krypton-86 radiation.

Over the 1970 decade, however, it was becoming clear that there were improved methods available that would enable definition with reduced uncertainty.

Suitable equipment and experimental procedures have now been proven as workable. By choosing a convenient value for c that suited measurement needs (that given above) it was, in 1982, agreed by the signatories of the committee responsible for standardization of the meter that the new definition should be, "The meter is the length of the path travelled by light in vacuum during the fraction (11299, 792,458) of a second."

For lengths over a few meters, solid mechanical bars are less suitable as standard lengths due to handling reasons. Flexible tapes are used which are calibrated against the laser interferometer in standards facilities. Tapes are relatively cheap and easy to use in the field compared with the laser interferometer. They can be calibrated to the order of a part in 10^6.

For industrial use little difficulty will be experienced in obtaining calibration of a length-measuring device. Probably the most serious problem to be faced is that good calibration requires considerable time: the standard under calibration must be observed for a time in order to ensure that it does have the long-term stability needed to hold the calibration.

Practice of length measurement for industrial use

General remarks

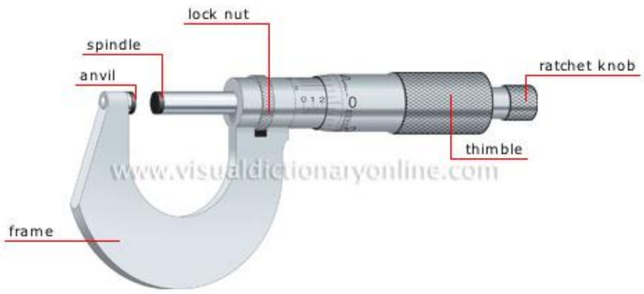
A large proportion of industrial range measurements can be performed quite adequately using simple mechanical gauging and measuring instruments. If, however, the requirement is for automatic measurement such as is needed in automatic inspection or in closed-loop control, then the manual methods must be replaced by transducer forms of length sensor.

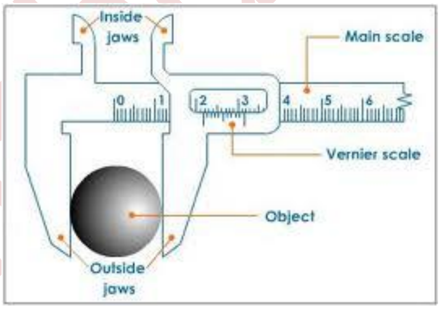
In many applications the speed of response needed is far greater than the traditional mechanical methods can yield. Numerically controlled mills, for instance, could not function without the use of electronic sensors that transduce the various axial dimensions into control signals.

Initially, that is, in the 1950s, the cost of electronic sensors greatly exceeded that of the traditional mechanical measuring tools and their servicing required a new breed of technician. Most of these earlier shortcomings are now removed and today the use of electronic sensing can be more productive than the use of manually read micrometers and scales because of the reduced cost of the electronic part of the sensing system and the need for more automatic data processing. There can be little doubt that solely mechanical instruments will gradually become less attractive in many uses.

Length measurement:

1. **thickness**

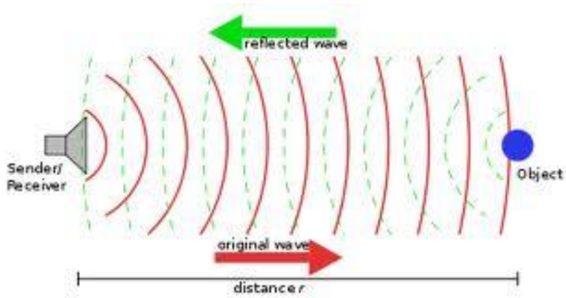




2. **length**

3. **distance**

4. Measurement of distance at sea:



ANGULAR MEASURING DEVICES:

INTRODUCTION

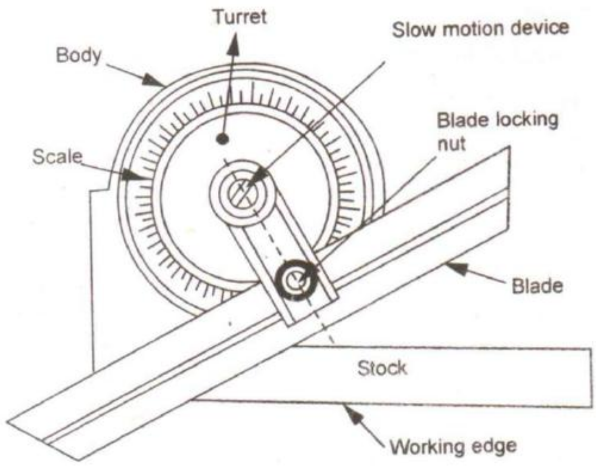
There are a wide variety of geometric features that are measured in angular units. These varieties include angular separation of bounding planes, angular spacing conditions related to circle, digression from a basic direction etc. Because of these diverse geometrical forms, different types of methods and equipment are available to measure angles in common angular units of degree, minute and second. Several factors come into picture in selection of suitable angular measuring instruments. These factors may be the size and general shape of the part, the location and angular accessibilities of the feature to be measured, expected range of angle variations, the required sensitivity and accuracy of measurement etc. Because of the different systems and techniques in angular measuring instruments, it is difficult to categorize them completely. As in linear measurement, they can be categorized in two groups. The first one is line standard instrument. It includes divided scales like protractors, bevel gauges. The second category of angular measuring instruments is called face standard instruments. Sine bars and angle gauges falls in this category. In this unit, we will discuss both types of angular measuring devices and the techniques used in determining the angle. In addition to that, we will have an overview of angle comparators (autocollimators).

LINE STANDARD ANGULAR MEASURING DEVICES

Line standard gives direct angular measurement from the engraved scales in the instruments. They are not very precise. Hence they are not used when high precision is required. However, they can be used in initial estimation of the angles in measurement. We will discuss some of the line standard angular measuring devices in the following sub-sections.

1- Protractor

It is the simplest instrument for measuring angles between two faces. It consists of two arms and an engraved circular scale. The two arms can be set along the faces between which the angle is to be measured. The body of the instrument is extended to form one of the arms, and this is known as the *stock*. It is the fixed part of the protractor and should be perfectly straight. The other arm is in the form of a *blade* that rotates in a *turret* mounted on the body. One of the bodies of the turret carries the divided scale and the other member carries a vernier or index. The ordinary protractor measures angles only in degrees and used for non-precision works. By using angular vernier scale along with it, precision up to 5° can be achieved. Figure shows the diagram of a protractor.



2- Universal Bevel Protractors

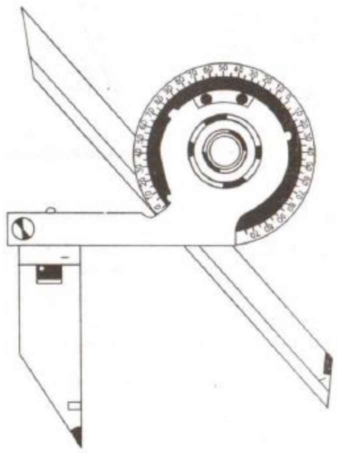
It is an angular measuring instrument capable of measuring angles to within 5 min. The name universal refers to the capacity of the instrument to be adaptable to a great variety of work configurations and angular interrelations. It consists of a *base* to which a vernier scale is attached. A *protractor dial* is mounted on the circular section of the base. The protractor *dial* is graduated in degrees with every tenth degree numbered. The *sliding blade* is fitted into this dial; it may be extended to either direction and set at any angle to the base. The blade and the dial are rotated as a unit. Fine adjustment are obtained with a small knurled headed pinion that, when turned, engages with a gear attached to the blade mount. The protractor dial may be locked in any position by means of the dial clamp nut.

Measurement in a universal bevel protractor is made either by embracing the two bounding elements of the angle or by extraneous referencing, for example, the part and the instrument resting on a surface plate.

The vernier protractor is used to measure an obtuse angle, or an angle greater than 90° but less than 180°. An *acute angle attachment* is fastened to the vernier protractor to measure angles of less than 90°. The main scale is divided into two arcs of 180°. Each arc is divided into two quadrants of 90° and has graduation from 0°to 90° to the left and right of the zero line, with every tenth degree numbered.

The vernier scale is divided into 12 spaces on each side of its zero (total 24). The spacing in the vernier scale is made in such a way that least count of it corresponds to 1/12th of a degree, which is equal to 5'.

If the zero on the vernier scale coincides with a line on the main scale, the number of vernier graduations beyond the zero should be multiplied by 5 and added to the number of full degrees indicated on the protractor dial. Figure shows a diagram of a bevel protractor.



MEASUREMENT OF INCLINES

Inclination of a surface generally represents its deviation from the horizontal or vertical planes. Gravitational principle can be used in construction of measurements of such inclinations. Spirit levels and clinometer are the instruments of this category. We will discuss these instruments in brief in the following sub-sections.

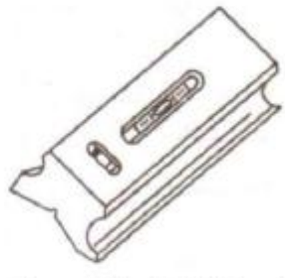
1- Spirit Level

Spirit level is one of the most commonly used instruments for inspecting the horizontal position of surfaces and for evaluating the direction and magnitude of minor deviation from that nominal condition. It essentially consists of a close glass tube of accurate form. It is called as the vial. It is filled almost entirely with a liquid, leaving a small space for the formation of an air or gas bubble. Generally, low viscosity fluids, such as ether, alcohol or benzol, are preferred for filling the vial. The liquid due to its greater specific weight tends to fill the lower portion of the closed space. Upper side of the vial is graduated in linear units. Inclination of a surface can be known from the deviation of the bubble from its position when the spirit level is kept in a horizontal plane. Temperature variations in the ambient condition cause both liquid and vial to expand or contract. Therefore, selection of proper liquid and material for the spirit level is very important for accurate result. To reduce the effect of heat transfer in handling spirit levels are made of a relatively stable casting and are equipped with thermally insulated handles. Figure 6.5 shows a schematic diagram of a spirit level.

Sensitivity of the vial used in spirit level is commonly expressed in the following two ways.

Each graduation line representing a specific slope is defined by a tangent relationship, e.g. 0.01 cm per meter.

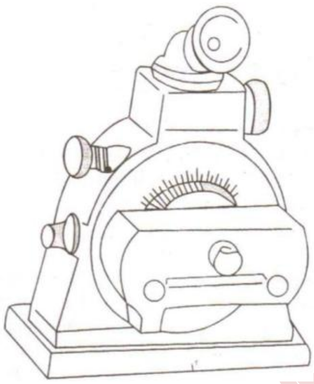
An angular value is assigned to the vial length covered by the distance of two adjacent graduation lines, i.e. the distance moved by the bubble from the zero will correspond the angle directly.



2- Clinometer

A clinometer is a special case of application of spirit level for measuring, in the vertical plane, the incline of a surface in relation to the basic horizontal plane, over an extended range. The main functional element of a clinometer is the sensitive vial mounted on a rotatable disc, which carries a graduated ring with its horizontal axis supported in the housing of the instrument. The bubble of the vial is in its center position, when the clinometer is placed on a horizontal surface and the scale of the rotatable disc is at zero position. If the clinometer is placed on an incline surface, the bubble deviates from the center. It can be brought to the center by rotating the disc. The rotation of the disc can be read on the scale. It represents the deviation of the surface over which the clinometer is placed from the horizontal plane. Figure 6.6 shows a diagram of a clinometer.

A number of commercially available clinometers with various designs are available. They differ in their sensitivity and measuring accuracy. Sensitivity and measuring accuracy of modern clinometers can be compared with any other high precision measuring instruments. For shop uses, clinometers with 10' graduations are available.



Applications

Two categories of measurement are possible with clinometer. Care must be taken to keep the axis of the rotatable disc parallel to the hinge line of the incline. The two categories of measurement are :

(i) Measurement of an incline place with respect to a horizontal plane. This is done by placing the instrument on the surface to be measured and rotating graduated disc to produce zero inclination on the bubble. The scale value of the disc position will be equal to the angle of incline.

(ii) Measurement of the relative position of two mutually inclined surfaces. This is done by placing the clinometer on each of the surface in turn, and taking the readings with respect to the horizontal. The difference of both the readings will indicate the angular value of the relative incline.

Mass and Mass Standards:

Definition of Mass

The following quotation of Condon and Odishaw1 is presented here as a succinct definition of mass:

"The property of a body by which it requires force to change its state of motion is called inertia, and *mass* is the numerical measure of this property."

The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram.

The Mass Unit

According to Maxwell,2 "every physical quantity [mass in the present case] can be expressed as the product of a pure number and a unit, where the unit is a selected reference quantity in terms of which all quantities of the same kind can be expressed." The fundamental unit of mass is the international *kilogram*. At present the kilogram is realized as an artifact, i.e., an object. Originally, the artifact was designed to have ***the mass of 1 cubic decimeter of pure water at the temperature of maximum density of water, 4°C***. Subsequent determination of the density of pure water with the air removed at 4°C under standard atmospheric pressure (101,325 Pa) yielded the present value of 1.000028 cubic decimeters for the volume of 1 kilogram of water.

Mass Artifacts, Mass Standards

The present embodiment of the kilogram is based on the French platinum kilogram of the Archives constructed in 1792. Several platinum-iridium (Pt-Ir) cylinders of height equal to diameter and nominal mass of 1 kg were manufactured in England. These cylinders were polished and adjusted and compared with the kilogram of the Archives. The cylinder with mass closest to that of the kilogram of the Archives was sent to the International Bureau of Weights and Measures (Bureau International des Poids et Mesures, BIPM) in Paris and chosen as the International Prototype Kilogram (IPK) in 1883. It was ratified as the IPK by the first General Conference of Weights and Measures (CPGM) in 1899. Other prototype kilograms were constructed and distributed as national prototypes. The United States received prototypes Nos. 4 and 20. All other mass standards in the United States are referred to these. As a matter of practice, the unit of mass as maintained by the developed nations is interchangeable among them.

FIGURE U.S. kilogram No. 20.

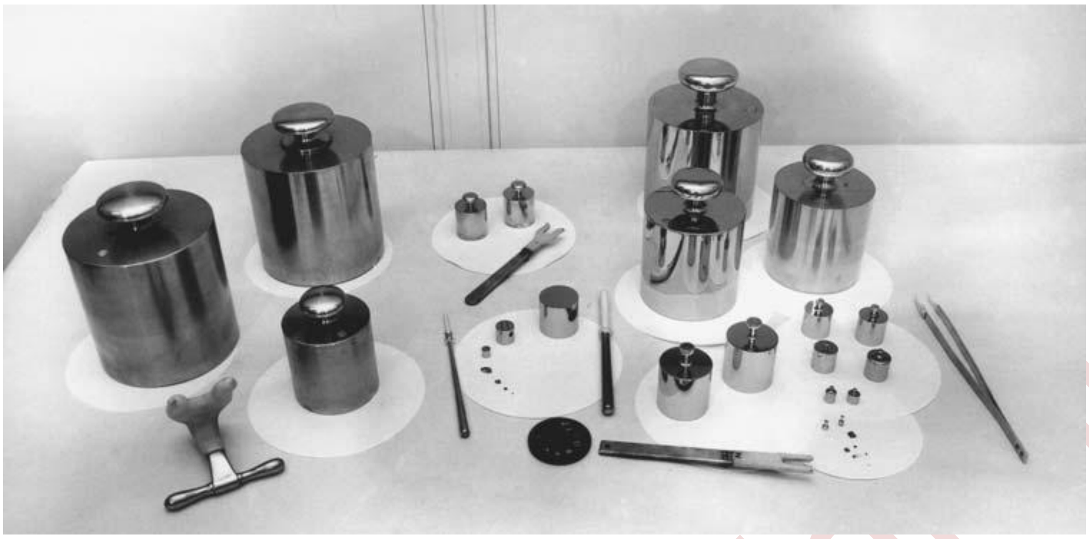


FIGURE Brass weight set.

FIGURE Stainless steel weight set.

Recalibration of the Kilogram

Introduction

In 1984, the U.S. National Prototype Kilogram, K20, and its check standard, K4, were recalibrated at the Bureau International des Poids et Mesures (BIPM). Two additional kilograms, designated CH-1 and D2, made of different alloys of stainless steel, were also included in the calibrations.

The mass of K20 was stated to be 1 kg – 0.039 mg in an 1889 BIPM certification; the mass of K4 was stated to be 1 kg – 0.075 mg in an 1889 BIPM certification. K20 was recalibrated at BIPM in 1948 and certified to have a mass of 1 kg – 0.019 mg. K4 had never before been recalibrated.

The nominal masses of the stainless steel kilograms were 1 kg + 13.49 mg for D2 and 1 kg – 0.36 mg for CH-1. The four 1-kg artifacts were hand-carried from the National Bureau of Standards, NBS (now National Institute of Standards and Technology, NIST), Gaithersburg, MD to BIPM on commercial airlines. The carrying case for K20 was an enclosure in which the kilogram was held firmly on the top and bottom and clamped gently at three places along the side. Clamped areas, conforming to the contour of the adjacent kilogram surfaces, were protected by low-abrasive tissue paper backed by chamois skin, which had previously been degreased through successive soakings in benzene and ethanol. The outer case of the container was metal, the seal of which was not airtight.

In the carrying case for K4, of simpler design, the artifact was wrapped in tissue, then wrapped in chamois skin, and finally placed in a snug-fitting brass container. The container seal was not airtight.

The stainless steel kilograms were wrapped in tissue paper and were then padded with successive layers of cotton batting and soft polyethylene foam. The outer container was a stiff cardboard tube. The kilogram was held fast within the tube by the padding.

1984 BIPM Measurements

The four NBS standards were compared to two platinum-iridium standards of BIPM, first in the state in which they arrived at BIPM. Then they were compared after cleaning with benzene. Platinum-iridium prototypes K4 and K20 were, in addition, washed under a steam jet of doubly distilled water.

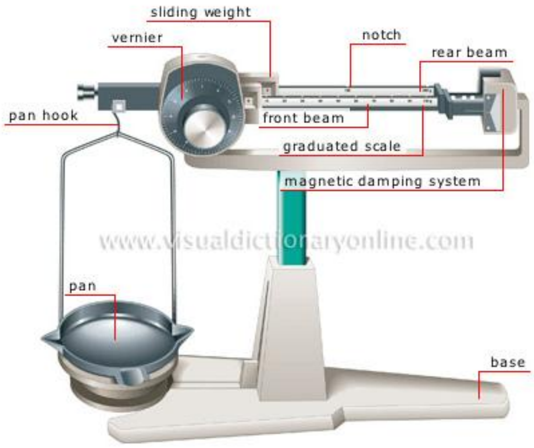
In the course of each weighing, the density of moist air was calculated using the “formula for the determination of the density of moist air (1981).”4 The parameters in the formula, temperature, pressure, relative humidity, and carbon dioxide concentration in the balance chamber were measured using a platinum resistance thermometer, an electro manometer, a hygrometer transducer, and an infrared absorption analyzer, respectively.

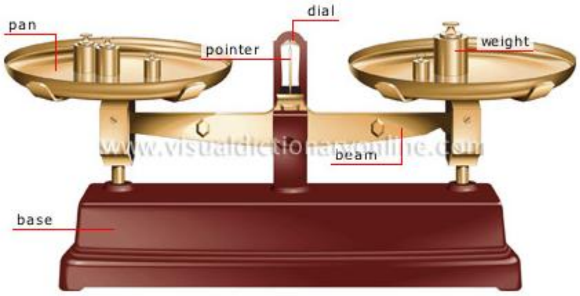
The mass values found at BIPM for the four artifacts are as follows:

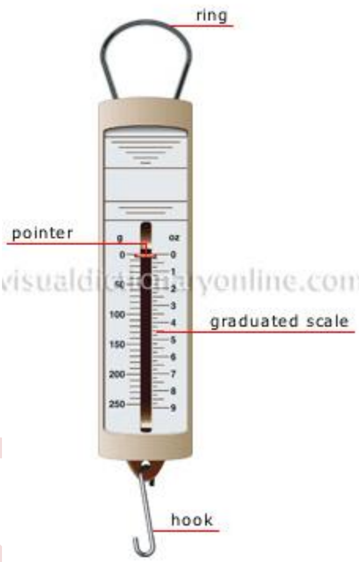
	Before Cleaning	After Cleaning
K20	1 kg – 0.001	1 kg – 0.022 mg
K4	1 kg – 0.075 mg	1 kg – 0.106 mg
CH-1	1 kg – 0.377 mg	1 kg – 0.384 mg
D2	1 kg + 13.453 mg	1 kg + 13.447 mg

The estimate of the standard deviation of each of the before cleaning results was 1.2 µg. The estimate of the standard deviation of each of the after cleaning results was 1.3 µg.

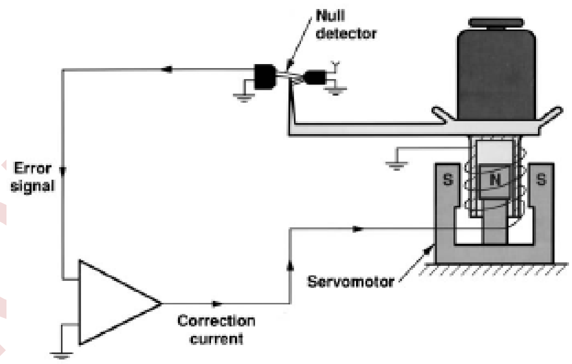
Mechanical Balancing:



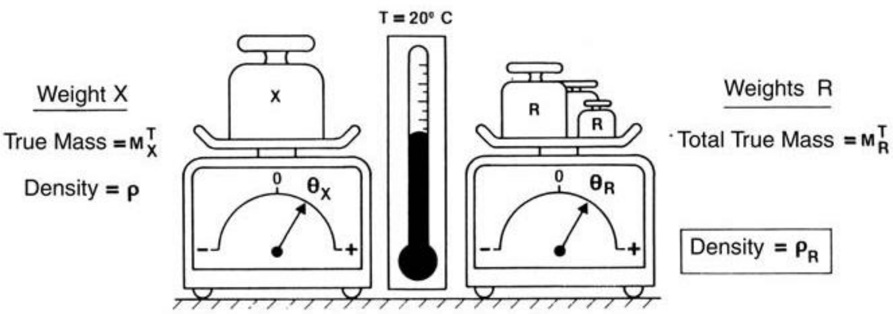




Electronic balancing:



Simplified electromagnetic balancing system.



Time:

the unit of time is indispensable for science and technology,(1967/68) definition of the second by the following:

The second is 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 caesium 133 atom.

It follows that the hyperfine splitting in the ground state of the caesium 133 atom is exactly 9 192 631 770 hertz, (hfs Cs) = 9 192 631 770 Hz.

At its 1997 meeting the CIPM affirmed that:

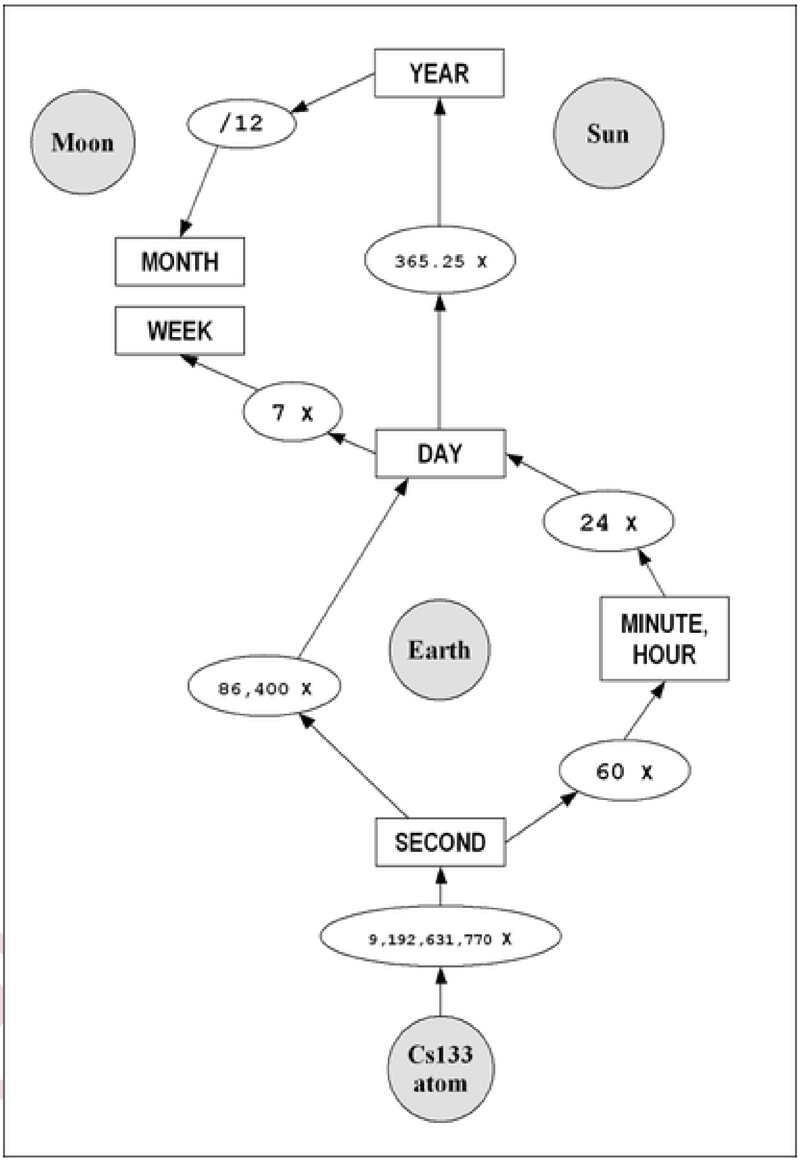
This definition refers to a caesium atom at rest at a temperature of 0 K. This note was intended to make it clear that the definition of the SI second is based on a caesium atom unperturbed by black body radiation, that is, in an environment whose thermodynamic temperature is 0 K. The frequencies of all primary frequency standards should therefore be corrected for the shift due to ambient radiation, as stated at the meeting of the Consultative Committee for Time and Frequency in 1999.

The unit of time, the second, was defined originally as the fraction 1/86 400 of the mean solar day. The exact definition of "mean solar day" was left to astronomical theories. However, measurement showed that irregularities in the rotation of the Earth could not be taken into account by the theory and have the effect that this definition does not allow the required accuracy to be achieved. In order to define the unit of time more precisely, the 11th CGPM (1960) adopted a definition given by the International Astronomical Union which was based on the tropical year. Experimental work had, however, already shown that an atomic standard of time-interval, based on a transition between two energy levels of an atom or a molecule, could be realized and reproduced much more precisely.

Considering that a very precise definition of the unit of time is indispensable for the International System, the 13th CGPM (**Credential for Green Property Management**) (1967) decided to replace the definition of the second by the following (affirmed by the CIPM (**Certificate in Investment Performance Measurement**) in 1997 that this definition refers to a cesium atom in its ground state at a temperature of 0 K):

The second is 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.

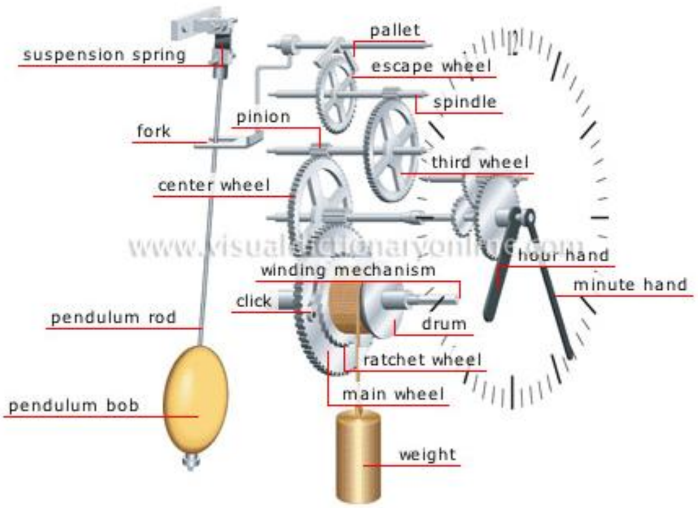
stop watch



sundialwatch

Mechanical watch:

Tree time



Unit of luminous intensity (candela)

Originally, each country had its own, and rather poorly reproducible, unit of luminous intensity; it was necessary to wait until 1909 to see a beginning of unification on the international level, when the national laboratories of the United States of America, France, and Great Britain decided to adopt the *international candle* represented by carbon filament lamps. Germany, at the same time, stayed with the *Hefner candle*, defined by a flame standard, and equal to about nine-tenths of an international candle. But a standard based on incandescent lamps, and consequently dependent upon their stability, would never have been fully satisfactory and could therefore be only provisional; on the other hand, the properties of a blackbody provided a theoretically perfect solution and, as early as 1933, the principle was adopted that new photometric units would be based on the luminous emission of a blackbody at the freezing temperature of platinum (2045 K).

The units of luminous intensity based on flame or incandescent filament standards in use in various countries before 1948 were replaced initially by the "new candle" based on the luminance of a Planckian radiator (a blackbody) at the temperature of freezing platinum. This modification had been prepared by the International Commission on Illumination (CIE) and by the CIPM before 1937, and was promulgated by the CIPM in 1946. It was then ratified in 1948 by the 9th CGPM which adopted a new international name for this unit, the *candela* (symbol cd); in 1967 the 13th CGPM gave an amended version of the 1946 definition.

In 1979, because of the experimental difficulties in realizing a Planck radiator at high temperatures and the new possibilities offered by radiometry, i.e., the measurement of optical radiation power, the 16th CGPM (1979) adopted a new definition of the candela:

The candela is the 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.