

CHAPTER 2: MECHANICAL MEASUREMENT CONCEPT

2.1 Introduction

In classical physics and engineering, **measurement** generally refers to the process of estimating or determining the ratio of a magnitude of a quantitative property or relation to a unit of the same type of quantitative property or relation. A process of measurement involves the comparison of physical quantities of objects or phenomena, or the comparison of relations between objects (e.g. angles). A *particular* measurement is the result of such a process, normally expressed as the multiple of a real number and a unit, where the real number is the ratio obtained from the measurement process. For example, the measurement of the length of an object might be 5 m, which is an estimate of the object's length, a magnitude, relative to a unit of length, the meter.

Measurement is not limited to physical quantities and relations but can in principle extend to the quantification of a magnitude of any type, through application of a measurement model such as the Rasch model, and subjecting empirical data derived from comparisons to appropriate testing in order to ascertain whether specific criteria for measurement have been satisfied.

In addition, the term measurement is often used in a somewhat looser fashion than defined above, to refer to any process in which numbers are assigned to entities such that the numbers are intended to represent increasing amount, in some sense, without a process that involves the estimation of ratios of magnitudes to a unit. Such examples of measurement range from degrees of uncertainty to consumer confidence to the rate of increase in the fall in the price of a good or service. It is generally proposed that there are four different levels of measurement, and that different levels are applicable to different contexts and types of measurement process.

In scientific research, measurement is essential. It includes the process of collecting data which can be used to make claims about learning. Measurement is also used to evaluate the effectiveness of a program or product (known as an evaluand).

A measurement is a comparison to a standard. -- William Shockley

By number we understand not so much a multitude of Unities, as the abstracted Ratio of any Quantity to another Quantity of the same kind, which we take for Unity -- Sir Isaac Newton (1728)

Units and systems of measurement

Because measurement involves the estimation of magnitudes of quantities relative to particular quantities, called units, the specification of units is of fundamental importance to measurement. The definition or specification of precise standards of measurement involves two key features, which are evident in the *Système International d'Unités* (SI). Specifically, in this system the definition of each of the *base units* makes reference to specific empirical conditions and, with the exception of the kilogram, also to other quantitative attributes. Each *derived SI unit* is defined purely in terms of a relationship involving itself and other

units; for example, the unit of velocity is 1 m/s. Due to the fact that derived units make reference to base units, the specification of empirical conditions is an implied component of the definition of all units.

The measurement of a specific entity or relation results in at least two numbers for the relationship between the entity or relation under study and the referenced unit of measurement, where at least one number estimates the statistical uncertainty in the measurement, also referred to as *measurement error*. Measuring instruments are used to estimate ratios of magnitudes to units. Prior comparisons underlie the calibration, in terms of standard units, of commonly used instruments constructed to measure physical quantities.

Metrology

Metrology is the study of measurement. In general, a metric is a scale of measurement defined in terms of a standard: i.e. in terms of well-defined unit. The quantification of phenomena through the process of measurement relies on the existence of an explicit or implicit metric, which is the standard to which measurements are referenced. If I say *I am 5*, I am indicating a measurement without supplying an applicable standard. I may mean *I am 5 years old* or *I am 5 feet high*, however the implicit metric is that I mean *I am 5 years old*.

History

Laws to regulate measurement were originally developed to prevent fraud. However, units of measurement are now generally defined on a scientific basis, and are established by international treaties. In the United States, commercial measurements are regulated by the National Institute of Standards and Technology NIST, a division of the United States Department of Commerce.

The history of measurements is a topic within the history of science and technology. The metre (us: meter) was standardized as the unit for length after the French revolution, and has since been adopted throughout most of the world. The United States and the UK are in the process of converting to the SI system. This process is known as metrication.

Difficulties in measurement

Measurement of many quantities is very difficult and prone to large error. Part of the difficulty is due to uncertainty, and part of it is due to the limited time available in which to make the measurement.

Examples of things that are very difficult to measure in some respects and for some purposes include social related items such as:

- a person's knowledge (as in testing, see also assessment)
- a person's feelings, emotions, or beliefs.
- a person's senses (qualia).

Even for physical quantities gaining accurate measurement can be difficult. It is not possible to be exact, instead, repeated measurements will vary due to various factors affecting the quantity such as temperature, time, electromagnetic fields, and especially measurement method. As an example in the measurement of the speed of light, the quantity is now known to a high degree of precision due to modern methods, but even with those methods there is some variability in the measurement. Statistical techniques are applied to the measurement samples to estimate the speed. In earlier sets of measurements, the variability was greater, and comparing the results shows that the variability and bias in the measurement methods was not properly taken into account. Proof of this is that when various group's measurements are plotted with the estimated speed and error bars showing the expected variability of the estimated speed from the actual number, the error bars from each of the experiments did not all overlap. This means a number of groups incorrectly accounted for the true sources of error and overestimated the accuracy of their methods.

2.2 Measurement concept

Measurement is Comparison Process:

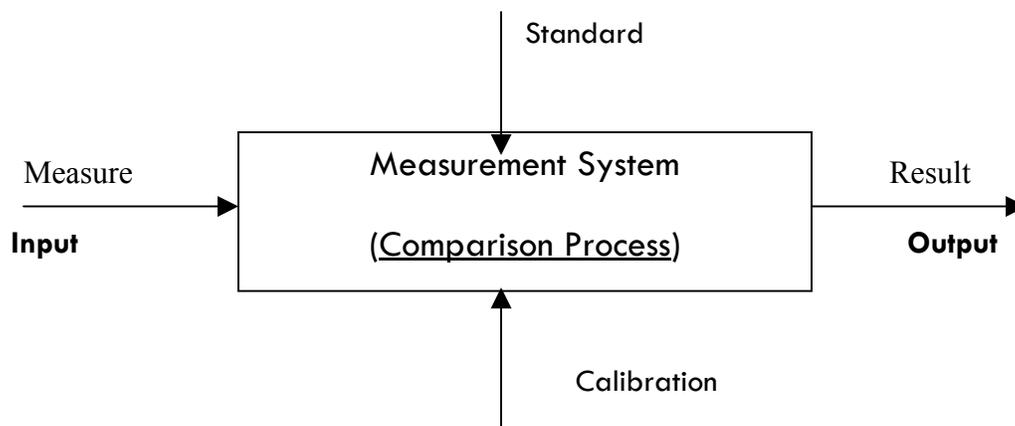


Figure 1: Measurement system

In designing measurement system, two types of information are needed (Doebelin (1995)):

- ✓ Method that been applied widely in explaining specification of system accuracy.
- ✓ Knowledge in dealing with the devices (transducer) for measurement purpose.

Measurement process:



Figure 2: Measurement process

Physical Parameter: Physical quantity that need to be measured, whether in electrical (current or voltage) or non-electrical. For physical parameter that non-electrical, transducer is needed as a converter from non-electrical parameter to electrical parameter.

Transducer: Transducer is an input devices that can receive one type of energy and convert it to another type of energy; may include a sensor and a circuit (usually signal conditioning) to convert the physical quantity that been received to an electrical signal and transmit it to an electrical control system where it is used as a process variable (PV) or feedback signal.

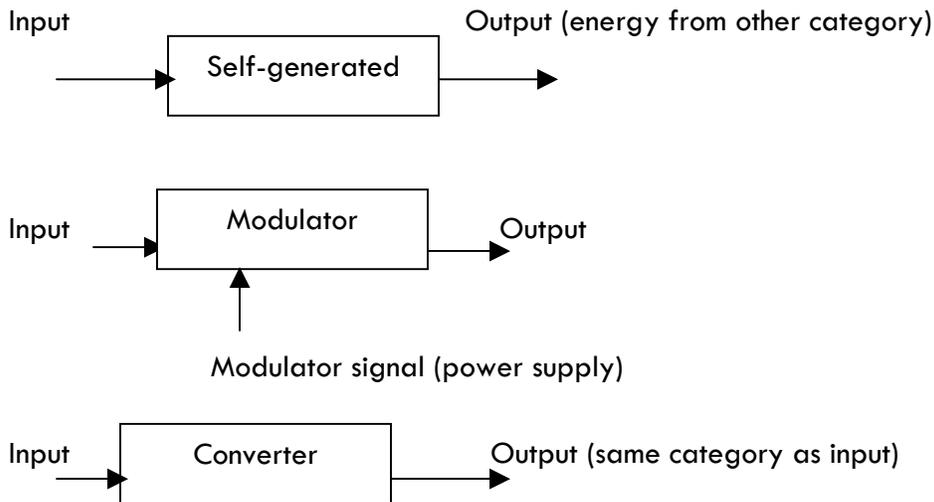


Figure 3: Classification of transducer

Signal Processing: Improving quality of transducer output; usually improvement is done in several ways including gaining a signal, signal reduction or signal shaping that can be received by output devices.

Display: Display measurement value that been done e.g. oscilloscope, screens etc.

2.3 Method of measurement

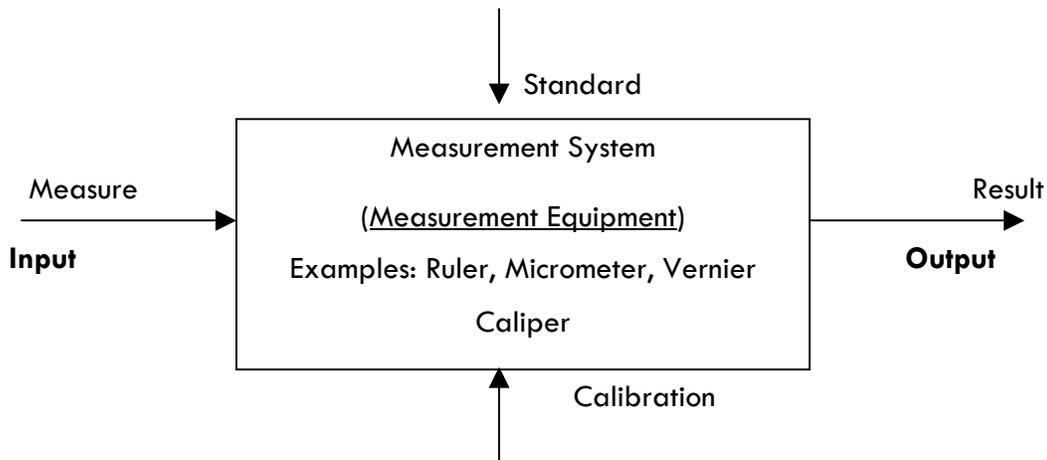
BASIC MEASUREMENT METHODS

- ✓ Direct Comparison Method
- ✓ Indirect Comparison Method

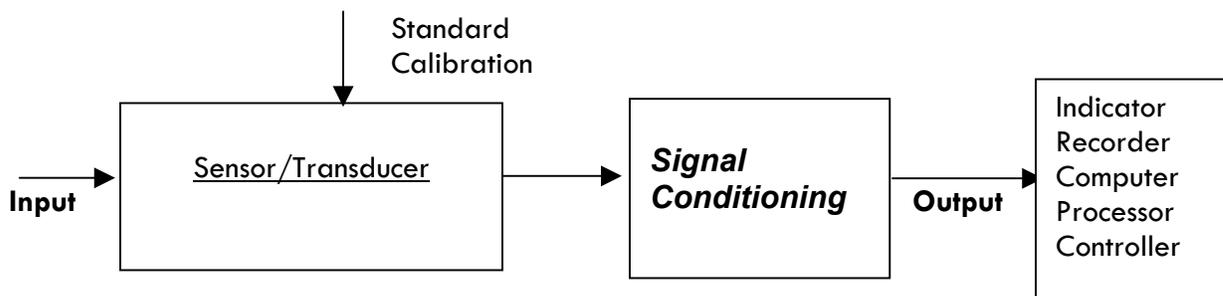
The measurement systems need to calibrate through methods below (Calibration Methods):

- ✓ Static
- ✓ Dynamic
- ✓ Sequential
- ✓ Random

(1) Direct Comparison Method



(2) Indirect Comparison Method



Example: Scanning laser measurement system

2.4 Type of measurement

2.4.1 Primary measurement

If the measurement is done by direct methods i.e. without converting the quantity (to be measured) into analogous form or you can say that by direct observation of quantity, then it is **called** primary measurements. For example, measuring the length of a bar, matching of **two colors** and light intensities are primary measurements.

2.4.2 Secondary measurement

When the quantity, which is to be measured, is not observable (like the temp. of liquid) then it is necessary to make indirect comparison. These types of measurements involve one conversion. The conversion is done with the help of a transducer. Transducer is a device that converts one form of energy to another.

For example, with the help of transducer temperature change can be converted into length changes. (*i.e.*, temperature variable can be converted to length variable).

2.4.3 Tertiary measurement

In this type of measurement two conversions of the quantity to be measured takes place. These measurements involve the conversion of the measured quantity into another quantity, which is then again converted into length and thus involves two conversion of the quantity that is to be measured.

For example, measurement of temperature by thermocouple. In this example, transducer generates the voltage signal that is directly proportional to the temperature difference. Thus here the first conversion takes place from temperature to voltage. This voltage signal is again converted to length that is second conversion by means of a device called transducer that is then transmitted to observer's eye.

2.5 Characteristic of instrument and measurement system

2.5.1 Static characteristic

When the instrument is used to measure a condition that is not lying with time, then static characteristic are considered.

2.5.2 Dynamic characteristic

When the measurements are related with rapidly varying quantities the n in such type of cases we must examine the dynamic relations that exists between the output and the input. Performance criteria based upon dynamic relations constitute the dynamic characteristic.

2.6 Some terminology

2.6.1 Data – information that been gathered from experiment; usually described as in number.

2.6.2 Population – collection of data, whether there are finite or infinite.

2.6.3 Sample – part of population, where can be described as one group of value that been gathered from experiment; has a finite value and can represents the population.

2.6.4 True value – true magnitude for quantities like pressure, velocity, temperature etc.; evaluation of these quantities may be estimated, but in whatever situation, it cannot be decided exactly.

2.6.5 Reading value – value that been pointed by measurement devices; source of raw data or data that been recorded directly.

2.6.6 Error – deviation from the true value; usually defined as a percentage:

$$\% \text{ error} = \frac{\text{error}}{\text{size of quantity}} \times 100$$

2.6.7 Range – A set of values that a number can have. A range is usually specified by its maximum and minimum value. Any number that is between these two values is said to be within the range.

- 2.6.8 Accuracy – deviation of the reading from a known input; usually expressed as a percentage of full-scale reading
- 2.6.9 Precision – for instruments, it indicates its ability to reproduce a certain reading with a given accuracy
- 2.6.10 Sensitivity – ratio of the linear movement of the pointer on the instrument to the change in the measured variable causing this motion
- 2.6.11 Hysteresis – difference in reading depending on whether the value of the measured quantity is approached from above or below; may result of mechanical friction, magnetic effects, elastic deformation or thermal effects.

2.7 Calibration

Calibration— refers to the process of setting the magnitude of the output (or response) of a measuring instrument to the magnitude of the input property or attribute within specified accuracy and precision. Through calibration, an accuracy of the device can be checked based on one standard and then reducing an error. Calibration process includes the comparison between output from devices or measurement system with:

- primary standard
- secondary standard
- input source where the value is remain unchanged

For physical constants, weights, and measures, there are known and agreed values in the International System of Units (SI). Such constants include the length of the metre, the mass of the kilogram, and the volume of a litre.

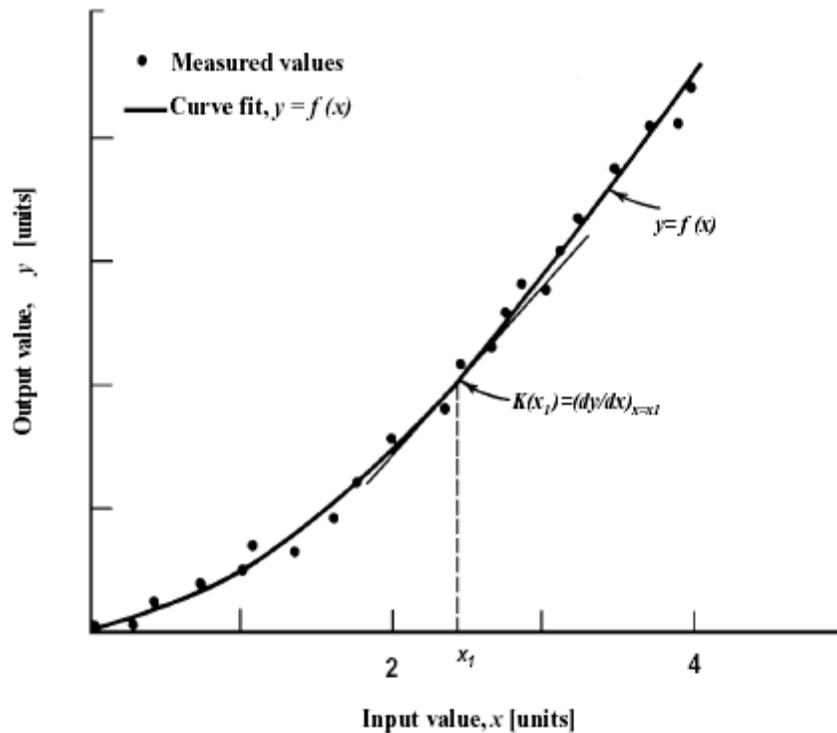
In the USA, the National Institute of Standards and Technology, a part of the federal government, maintains standards and is considered the arbiter and ultimate (in the U.S.) authority for values of SI units and industrial standards. NIST also defines traceability, by which an instrument's accuracy is established in an unbroken chain relating an instrument's measurements through one or more derivative standards to a standard maintained by NIST, as well as uncertainty.

In science, a calibrated test tube is one with measurements up the side.

2.7.1 Calibration concept

The relationship between the input and the output of a measuring system is established during the calibration of a measuring system. A **calibration** is the act of applying a known value to the input of the measuring system for the purpose of observing the system output. The known value applied to the input is known as the **standard**. By the application of a range of known values to the input and observation of the system output, a direct calibration curve can be developed for the measurement system. On such a curve the input x is plotted on the abscissa against the measurement output y on the ordinate as in Figure 1. In a calibration the input value should be a controlled input variable, while the measured output value becomes the dependent variable of the calibration.

Figure 1. A Static Calibration Curve



A calibration curve forms the logic by which a measurement system's indicated output can be interpreted during an actual measurement. For example, the calibration curve is the basis for fixing the output display scale on a measurement System, such as that of Figure 1. Alternatively, a calibration curve can be used as part of developing a functional relationship, an equation known as a **correlation**, between input and output. A correlation will have the form $y = f(x)$ and is determined by applying physical reasoning and curve fitting techniques to the calibration curve. The correlation can then be used in later measurements to ascertain the unknown input value based on the output value, the value indicated by the measurement system.

2.7.2 Static calibration

The most common type of calibration is known as a *static calibration*. In this procedure, a known value is input to the system under calibration and the system output is recorded. The term "static" refers to a calibration procedure in which the values of the variables involved remain constant during a measurement, that is, they do not change with time. In static calibrations, only the magnitudes of the known input and the measured output are important. A representative static calibration curve is shown in Figure 1. The measured data points describe the static input-output relationship for a measurement system. A polynomial curve fit to the data may be conveniently used to describe this relationship as $y = f(x)$.

2.7.3 Dynamic calibration

In a broad sense, dynamic variables are time dependent in both their magnitude and frequency content. The input-output magnitude relation between a dynamic input signal and a measurement system will depend on the time-dependent content of the input signal. When time-dependent variables are to be measured, a dynamic calibration is performed in addition to the static calibration. A **dynamic calibration** determines the relationship between an input of known dynamic behavior and the measurement system output. Usually, such calibrations involve either a sinusoidal signal or a step change as the known input signal.

2.7.4 Static Sensitivity

The slope of a static calibration curve yields the **static sensitivity** of the measurement system. As depicted graphically in the calibration curve of Figure 1, the static sensitivity, K , at any particular static input value, say x_1 , is evaluated by

$$K = K(x_1) = \left(\frac{dy}{dx} \right)_{x=x_1}$$

where K is a function of x . The static sensitivity is a measure relating the change in the indicated output associated with a given change in a static input. Since calibration curves can be linear or nonlinear depending on the measurement system and on the variable being measured, K may or may not be constant over a range of input values.

2.7.5 Range

The proper procedure for calibration is to apply known inputs ranging from the minimum and to the maximum values for which the measurement system is to be used. These limits define the operating *range* of the system. The input operating range is defined as extending from x_{\min} to x_{\max} . This range defines its **input span** expressed as the difference between the range limits $r_i = x_{\max} - x_{\min}$.

Similarly, the output operating range is specified from y_{\min} to y_{\max} . The output span or **full-scale operating range (FSO)** is expressed as $r_o = y_{\max} - y_{\min}$.

It is important to avoid extrapolation beyond the range of known calibration during measurement since the behavior of the measurement system is uncharted in these regions. As such, the range of calibration should be carefully selected.

2.7.6 Accuracy

The accuracy of a system can be estimated during calibration. If we assume that the input value is known exactly, then the known input value can be called the true value. The *accuracy* of a measurement system refers to its ability to indicate a true value exactly. Accuracy is related to absolute error. **Absolute error, e** , is defined as the difference

between the true values applied to a measurement system and the indicated value of the system:

$$\varepsilon = \text{true.value} - \text{indicated.value}$$

from which the percent relative accuracy is found by

$$A = \left(1 - \frac{|\varepsilon|}{\text{true.value}} \right) * 100$$

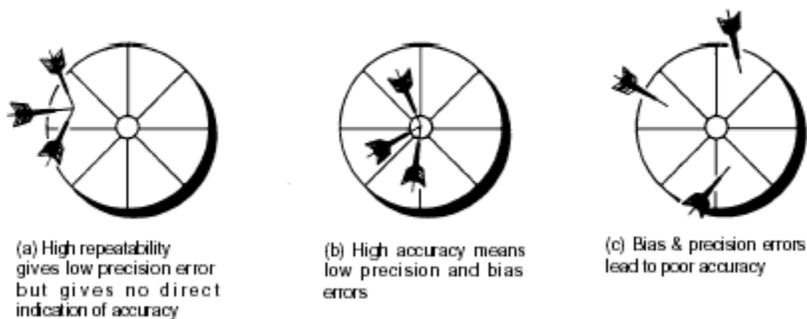
By definition, accuracy can be determined only when the "true value" is known, such as during a calibration.

An alternative form of calibration curve is the deviation plot. Such a curve plots the difference or deviation between a true or expected value, y' , and the indicated value, y , versus the indicated value. Deviation curves are extremely useful when the differences between the true and the indicated value are too small to suggest possible trends on direct calibration plots. They are often required in situations that require errors to be reduced to the minimums possible.

2.7.7 Precision and bias errors

The repeatability or precision of a measurement system refers to the ability of the system to indicate a particular value upon repeated but independent applications of a specific value of input. **Precision error** is a measure of the random variation to be expected during such repeatability trials. An estimate of a measurement system precision does not require a calibration, per se. But note that a system that repeatedly indicates the same wrong value upon repeated application of a particular input would be considered to be very precise regardless of its known accuracy.

Figure 2. Illustrating precision, bias errors & accuracy



The average error in a series of repeated calibration measurements defines the error measure known as *bias*. Bias error is the difference between the average and true values. Both precision and bias errors affect the measure of a system's accuracy.

The concepts of accuracy, and bias and precision errors in measurements can be illustrated by the throw of darts. Consider the dart board of Figure 2 where the goal will be to throw the darts into the bull's-eye. For this analogy, the bull's-eye can represent the true value and each throw can represent a measurement value. In Figure 2a, the thrower displays good precision (i.e., low precision error) in that each throw repeatedly hits the

same spot on the board, but the thrower is not accurate in that the dart misses the bull's-eye each time. This thrower is precise, but we see that low precision error alone is not a measure of accuracy. The error in each throw can be computed from the distance between the bull's-eye and each dart. The average value of the error yields the bias. This thrower has a bias to the left of the target. If the bias could be reduced, then this thrower's accuracy would improve. In Figure 2b, the thrower displays high accuracy and high repeatability, hitting the bull's-eye on each throw. Both throw scatter and bias error are near zero. High accuracy must imply both low precision and bias errors as shown. In Figure 2c, the thrower displays neither high precision nor accuracy with the errant throws scattered around the board. Each throw contains a different amount of error. While the bias error is the average of the errors in each throw, precision error is related to the varying amount of error in the throws. The accuracy of this thrower's technique appears to be biased and lacking precision. The precision and bias errors of the thrower can be computed using statistical methods. Both precision and bias errors quantify the error in any set of measurements and are used to estimate accuracy.

Suppose a measurement system was used to measure a variable whose value was kept constant and known exactly, as in a calibration. Ten independent measurements are made with the results, Figure 3. The variations in the measurements, the observed scatter in the data, would be related to the system precision error: associated with the measurement of the variable. That is, the scatter is mainly due to (1) the measurement system and (2) the method of its use, since the value of the variable is essentially constant. However, the offset between the apparent average of the readings and the true value would provide a measure of the bias error to be expected from this measurement system.

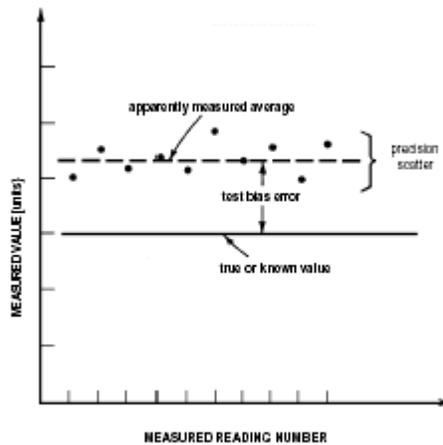


Figure 3. Effect of Precision & Bias errors on Calibration Readings

In any measurement other than a calibration the error cannot be known exactly since the true value is not known. But based on the results of a calibration, the operator might feel confident that the error is within certain bounds (a plus or minus range of the indicated reading). Since the magnitude of the error in any measurement can only be estimated, one refers to an estimate of the error in the measurement as the **uncertainty** present in the measured value. Uncertainty is brought about by errors that are present in the measurement system, its calibration, and measurement technique, and is manifested by measurement system bias and precision errors.

The precision and bias errors of a measurement system are the result of several interacting errors inherent to the measurement system, the calibration procedure, and the standard used to provide the known value. These errors can be delineated and quantified as elemental errors through the use of particular calibration procedures and data reduction techniques. An example is given for a typical pressure transducer in Table 1.

TABLE 1. Manufacturer's Specifications: Typical Pressure Transducer

Operation:	Input range	0 to 1000 cm (FSO)
	Excitation	+/- 15_V dc
	Output range	0 to 5 v dc
Performance:	Linearity error	+/- 0.5% full scale (FSO)
	Hysteresis error	< +/- 0.15% full scale (FSO)
	Sensitivity error	+/- 0.25% of reading
	Thermal sensitivity error	+/- 0.02% /degC of reading
	Thermal zero drift	0.02% /degC full scale (FSO)

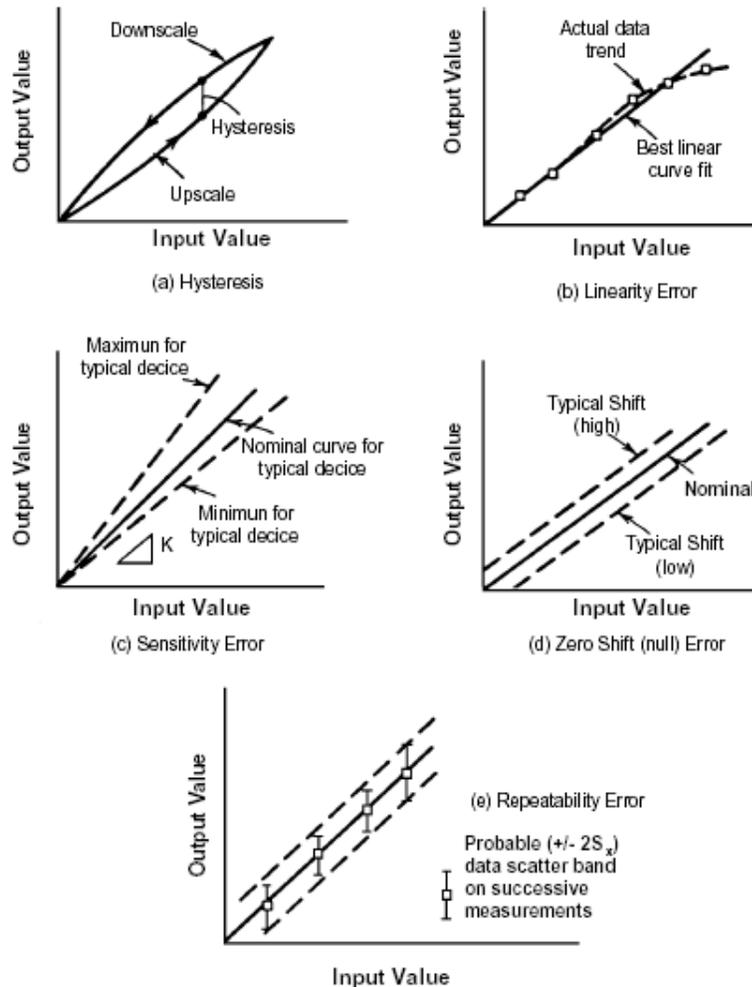


Figure 4. Examples of the Elements of Error

2.7.8 Sequential calibration

A *sequence calibration* applies a sequential variation in the input value over the desired input range. This may be accomplished by increasing the input value (up-scale direction) or by decreasing the input value (downscale direction) over the full input range.

2.7.8.1 Hysteresis error

The sequence calibration is an effective diagnostic technique for identifying and quantifying; hysteresis error in a measurement system. **Hysteresis error** refers to differences between an upscale sequence calibration and a downscale sequence calibration. The hysteresis error of the system is given by $e_h = (Y)_{upscale} - (Y)_{downscale}$. The effect of hysteresis in a sequence calibration curve is illustrated in Figure 4a. Hysteresis is usually specified for a measurement system in terms of the maximum hysteresis error as a percentage of full-scale output range (FSO):

$$\%(e_h) = \frac{[e_h(x)]_{\max}}{r_o} * 100$$

such as that indicated in Table 1. Hysteresis occurs when the output of a measurement system is dependent on the previous value indicated by the system. Such dependencies can be brought about through some realistic system limitations such as friction or viscous damping in moving parts or residual charge in electrical components. Some hysteresis is normal for any system and affects the precision of the system.

2.7.9 Random calibration

A *random calibration* applies a randomly selected sequence of values of a known input over the intended calibration range. The random application of input tends to minimize the impact of interference. It breaks up hysteresis effects and observation errors. It ensures that each application of input value is independent of the previous. This reduces calibration bias error. Generally, such a random variation in input value will more closely simulate the actual measurement situation. A random calibration provides an important diagnostic test for the delineation of several measurement system performance characteristics based on a set of random calibration test data. In particular, linearity error, sensitivity error, zero error, and instrument repeatability error, as illustrated in Figure 4e, can be quantified from a static random calibration.

2.7.9.1 Linearity error

Many instruments are designed to achieve a linear relation between an applied static input and indicated output values. Such a linear static calibration curve would have the general form:

$$y_L(x) = a_0 + a_1x$$

where the curve $y_L(x)$ provides a predicted output value based on a linear relation between x and y . However, in real systems, truly linear behavior is only approximately achieved. As a result, measurement device specifications usually provide a statement as to

the expected linearity of the static calibration curve for the device. The relation between $y_L(x)$ and measured value $y(x)$ is a measure of the nonlinear behavior of a system:

$$e_L(x) = y(x) - y_L(x)$$

where $e_L(x)$ is the **linearity error** that arises in describing the actual system behavior by eq.1. Such behavior is illustrated in Figure 4b in which a linear curve has been fitted through a calibration data set. For a measurement system that is essentially linear in behavior, the extent of possible non-linearity in a measurement device is often specified in terms of the maximum expected linearity error as a percentage of full-scale output range:

$$\%(e_L)_{\max} = \frac{[e_L(x)]_{\max}}{r_o} * 100$$

This value is listed as the linearity error expected from the pressure transducer in Table 1. Statistical methods of quantifying such data scatter about a line exist.

2.7.9.2 Sensitivity and zero errors

The scatter in the data measured during a calibration affects the precision in the slope of the calibration curve. As shown for the linear calibration curve in Figure 4c, if we fix the zero intercept at zero (a zero output from the system for zero input), then the scatter in the data leads to precision error in estimating the slope of the calibration curve. The **sensitivity error**, e_K , is a statistical measure of the precision error in the estimate of the slope of the calibration curve. The static sensitivity of a device is also temperature dependent and this is often specified. In Table 1., the sensitivity error reflects calibration results at a constant reference ambient temperature, whereas the thermal sensitivity error was found by calibration at different temperatures.

If the zero intercept is not fixed but the sensitivity is constant, then drifting of the zero intercept introduces a vertical shift of the calibration curve, as shown in Figure 4d. This shift of the zero intercept of the calibration curve is known as the **zero error**, e_z of the measurement system. Zero error can usually be reduced by periodically adjusting the output from the measurement system under a zero input condition. However, some random variation in the zero intercept is common, particularly with electronic and digital equipment subjected to temperature variations (e.g., thermal zero-drift in Table 1.).

2.7.9.3 Instrument repeatability

The ability of a measurement system to indicate the same value upon repeated but independent application of the same input is known as the **instrument repeatability**. Specific claims of repeatability are based on multiple calibration tests (replication) performed within a given lab on the particular unit. Repeatability, as shown in Figure 4e, is based on a statistical measure called the standard deviation, S_x , a measure of the variation in the output for a given input. The value claimed is usually in terms of the maximum expected error as a percentage of full-scale output range:

$$\%(e_r)_{\max} = \frac{2(S_x)}{r_o} * 100$$

The instrument repeatability reflects only the error found under controlled calibration conditions. It does not include the additional errors introduced during measurement due to variation in the measured variable or due to procedure.

2.7.9.4 Reproducibility

The term "**reproducibility**" when reported in instrument specifications refers to the results of separate repeatability tests. Manufacturer claims of instrument reproducibility must be based on multiple repeatability tests (replication) performed in different labs on a single unit.

2.7.9.5 Instrument precision

The term "**instrument precision**" when reported in instrument specifications, refers to the results of separate repeatability tests. Manufacturer claims of instrument precision must be based on multiple repeatability tests (replication) performed in different labs on different units of the same manufacture.

2.7.9.6 Overall instrument error

An estimate of the **overall instrument error** is made based on all known errors. This error is often misleadingly referred to as the **instrument accuracy** in some instrument specifications. An estimate is computed from the square root of the sum of the squares of all known errors. For **M** known errors, the instrument error, **e**, is estimated by

$$e_I = \left[e_1^2 + e_2^2 + \dots + e_M^2 \right]^{1/2}$$

For example, for an instrument having known hysteresis (**h**), linearity (**L**), sensitivity (**K**), and repeatability (**R**) errors, the instrument error is estimated by

$$e_I = \left[e_h^2 + e_L^2 + e_K^2 + e_R^2 \right]^{1/2}$$

2.8 Standard

The quality of the standard is evaluated based on its unchanged value. Suitable standard that been used in calibration depends on the using and accuracy that been needed from measurement system.

Dimension is used to define physical quantities that explain aspects of the physical system. Basic value that relates to such dimension is given by a unit; here, unit is used to define the measurement of the dimension. For example, mass, length and time are basic dimension that can be related to unit kilogram, meter and seconds. Primary standard has a role to define the value of all basic units, as well as preparing a guidelines to explain the unit with one unique number that can be understand in all places in the world. Hence, primary standard must define the unit in fixed definition and accurate.

The primary standard will be explained in details in following section:

Mass

The **kilogram** or **kilogramme**, (symbol: **kg**) is the SI base unit of mass. It is defined as being equal to the mass of the international prototype of the kilogram.

It is the only SI base unit that employs a prefix, and the only SI unit that is still defined in relation to an artifact rather than to a fundamental physical property.

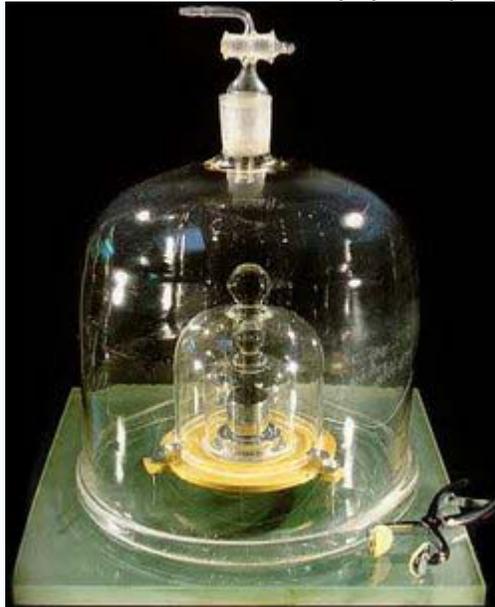


Figure: The international prototype, made of platinum-iridium, which is kept at the BIPM under conditions specified by the 1st CGPM in 1889.

History

The kilogram was *originally* defined as the mass of one litre of pure water at a temperature of 3.98 degrees Celsius and standard atmospheric pressure. This definition was hard to realize accurately, partially because the density of water depends ever-so-slightly on the pressure, and pressure units include mass as a factor, introducing a circular dependency in the definition of the kilogram.

To avoid these problems, the kilogram was redefined as *precisely* the mass of a particular standard mass created to approximate the original definition. Since 1889, the SI system defines the unit to be equal to the mass of the **international prototype of the kilogram**, which is made from an alloy of platinum and iridium of 39 mm height and diameter, and is kept at the Bureau International des Poids et Mesures (International Bureau of Weights and Measures). Official copies of the prototype kilogram are made available as national prototypes, which are compared to the Paris prototype ("Le Grand Kilo") roughly every 10 years. The international prototype kilogram was made in the 1880s.

By definition, the error in the repeatability of the current definition is exactly zero; however, in the usual sense of the word, it can be regarded as of the order of 2

micrograms. This is found by comparing the official standard with its official copies, which are made of roughly the same materials and kept under the same conditions. There is no reason to believe that the official standard is any more or less stable than its official copies, thus giving a way to estimate its stability. This procedure is performed roughly once every forty years.

The international prototype of the kilogram seems to have lost about 50 micrograms in the last 100 years, and the reason for the loss is still unknown (reported in *Der Spiegel*, 2003 #26). The observed variation in the prototype has intensified the search for a new definition of the kilogram. It is accurate to state that any object in the universe (other than the reference metal in France) that had a mass of 1 kilogram 100 years ago, and has not changed since then, now has a mass of 1.000 05 kg. This perspective is counterintuitive and defeats the purpose of a standard unit of mass, since the standard should not change arbitrarily over time.

The gram

The **gram** or **gramme** is the term to which SI prefixes are applied.

The gram was the base unit of the older cgs system of measurement, a system which is no longer widely used.

Atom-counting approaches

- The Avogadro approach attempts to define the kilogram as a fixed number of silicon atoms. As a practical realization, a sphere would be used and its size would be measured by interferometry.
- The ion accumulation approach involves accumulation of gold atoms and measuring the electrical current required to neutralise them.

Fundamental-constant approaches

- The Watt balance uses the current balance that was formerly used to define the ampere to relate the kilogram to a value for Planck's constant, based on the definitions of the volt and the ohm.
- The levitated superconductor approach relates the kilogram to electrical quantities by levitating a superconducting body in a magnetic field generated by a superconducting coil, and measuring the electrical current required in the coil.
- Since the values of the Josephson (CIPM (1988) Recommendation 1, PV 56; 19) and von Klitzing (CIPM (1988), Recommendation 2, PV 56; 20) constants have been given conventional values, it is possible to combine these values ($K_J \equiv 4.835\,979 \times 10^{14}$ Hz/V and $R_K \equiv 2.581\,280\,7 \times 10^4$ Ω) with the definition of the ampere to define the kilogram as follows:

The kilogram is the mass which would be accelerated at precisely 2×10^{-7} m/s² if subjected to the per metre force between two straight parallel conductors of infinite length, of negligible circular cross section, placed 1 metre apart in vacuum,

through which flow a constant current of exactly $6.241\ 509\ 629\ 152\ 65 \times 10^{18}$ elementary charges per second.

Link with weight

When the weight of an object is given in kilograms, the property intended is almost always mass. Occasionally the gravitational force on an object is given in "kilograms", but the unit used is not a true kilogram: it is the deprecated kilogram-force (kgf), also known as the kilopond (kp). An object of mass 1 kg at the surface of the Earth will be subjected to a gravitational force of approximately 9.80665 newtons (the SI unit of force). Note that the factor of 980.665 cm/s^2 (as the CGPM defined it, when cgs systems were the primary systems used) is only an agreed-upon conventional value (3rd CGPM (1901), CR 70) whose purpose is to define grams force. The local gravitational acceleration g varies with latitude and altitude and location on the Earth, so before this conventional value was agreed upon, the gram-force was only an ill-defined unit.

Examples

- **Attogram:** a research team at Cornell University made a detector using NEMS cantilevers with sub-attogram sensitivity.
- **Yoctogram:** can be used for masses of nucleons, atoms and molecules. It is a little large for light particles, but yocto- is the last official prefix in the sequence.
 - The coefficient is close to the reciprocal of Avogadro's number: 1 unified atomic mass unit = 1.660 54 yg
 - Although the unified atomic mass unit is often convenient as a unit, one may sometimes want to use yoctograms to relate easily to other SI values.
 - Mass of an electron: 0.000 91 yg
 - Mass of a proton : 1.672 6 yg
 - Mass of a neutron: 1.674 9 yg

SI multiples

Multiple	Name	Symbol	Multiple	Name	Symbol
10^0	gram	g			
10^1	decagram	dag	10^{-1}	decigram	dg
10^2	hectogram	hg	10^{-2}	centigram	cg

10^3	kilogram	kg	10^{-3}	milligram	mg
10^6	megagram	Mg	10^{-6}	microgram	μg
10^9	gigagram	Gg	10^{-9}	nanogram	ng
10^{12}	teragram	Tg	10^{-12}	picogram	pg
10^{15}	petagram	Pg	10^{-15}	femtogram	fg
10^{18}	exagram	Eg	10^{-18}	attogram	ag
10^{21}	zettagram	Zg	10^{-21}	zeptogram	zg
10^{24}	yottagram	Yg	10^{-24}	yoctogram	yg

Length

The **metre**, or **meter** (symbol: m) is the SI base unit of length. It is defined as the length of the path travelled by light in absolute vacuum during a time interval of $1/299,792,458$ of a second.

Adding SI prefixes to *metre* creates multiples and submultiples. For example *kilometre* and *nanometre*.

Conversions

1 metre is equivalent to:

- exactly $1/0.9144$ yards (approximately 1.0936 yards)
- exactly $1/0.3048$ feet (approximately 3.2808 feet)
- exactly $10000/254$ inches (approximately 39.370 inches)

History

The word itself is from the Greek *metron* (μετρον), "a measure" via the French *mètre*. Its first recorded usage in English is from 1797.

In the eighteenth century, there were two favoured approaches to the definition of the standard unit of length. One suggested defining the metre as the length of a pendulum with a half-period of one second. The other suggested defining the metre as one ten-millionth of the length of the earth's meridian along a quadrant (one-fourth the polar circumference of the earth). In 1791, the French Academy of Sciences selected the meridional definition over the pendular definition because of the slight variation of the force of gravity over the surface of the earth, which affects the period of a pendulum. In 1793, France adopted the metre, with this definition, as its official unit of length. Although it was later determined that the first prototype metre bar was short by a fifth of a millimetre due to miscalculation of the flattening of the earth, this length became the standard. So, the circumference of the Earth through the poles is approximately forty million metres.



International Prototype Metre standard bar made of platinum-iridium. This was the standard until 1960, when the new SI system used a krypton-spectrum measurement as the base. In 1983 the current metre was defined by a relationship to the speed of light in a vacuum.

In the 1870s and in light of modern precision, a series of international conferences were held to devise new metric standards. The Metre Convention (Convention du Mètre) of 1875 mandated the establishment of a permanent International Bureau of Weights and Measures (BIPM: Bureau International des Poids et Mesures) to be located in Sèvres, France. This new organisation would preserve the new prototype metre and kilogram when constructed, distribute national metric prototypes, and would maintain comparisons between them and non-metric measurement standards. This organisation created a new prototype bar in 1889 at the first General Conference on Weights and Measures (CGPM: Conférence Générale des Poids et Mesures), establishing the *International Prototype Metre* as the distance between two lines on a standard bar of an alloy of ninety percent platinum and ten percent iridium, measured at the melting point of ice.

In 1893, the standard metre was first measured with an interferometer by Albert A. Michelson, the inventor of the device and an advocate of using some particular wavelength of light as a standard of distance. By 1925, interferometry was in regular use at the BIPM. However, the International Prototype Metre remained the standard until

1960, when the eleventh CGPM defined the metre in the new SI system as equal to 1,650,763.73 wavelengths of the orange-red emission line in the electromagnetic spectrum of the krypton-86 atom in a vacuum. The original international prototype of the metre is still kept at the BIPM under the conditions specified in 1889.

To further reduce uncertainty, the seventeenth CGPM of 1983 replaced the definition of the metre with its current definition, thus fixing the length of the metre in terms of time and the speed of light:

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

Note that this definition exactly fixes the speed of light in a vacuum at 299,792,458 metres per second. Definitions based on the physical properties of light are more precise and reproducible because the properties of light are considered to be universally constant.

Timeline of definition

- 1790 May 8 — The French National Assembly decides that the length of the new metre would be equal to the length of a pendulum with a half-period of one second.
- 1791 March 30 — The French National Assembly accepts the proposal by the French Academy of Sciences that the new definition for the metre be equal to one ten-millionth of the length of the earth's meridian along a quadrant (one-fourth the polar circumference of the earth).
- 1795 — Provisional metre bar constructed of brass.
- 1799 December 10 — The French National Assembly specifies that the platinum metre bar, constructed on 23 June 1799 and deposited in the National Archives, as the final standards.
- 1889 September 28 — The first CGPM defines the length as the distance between two lines on a standard bar of an alloy of platinum with ten percent iridium, measured at the melting point of ice.
- 1927 October 6 — The seventh CGPM adjusts the definition of the length to be the distance, at 0°C, between the axes of the two central lines marked on the prototype bar of platinum-iridium, this bar being subject to one standard atmosphere of pressure and supported on two cylinders of at least one centimetre diameter, symmetrically placed in the same horizontal plane at a distance of 571 millimetres from each other.
- 1960 October 20 — The eleventh CGPM defines the length to be equal to 1,650,763.73 wavelengths in vacuum of the radiation corresponding to the transition between the $2p^{10}$ and $5d^5$ quantum levels of the krypton-86 atom.

- 1983 October 21 — The seventeenth CGPM defines the length to be distance travelled by light in vacuum during a time interval of $1/299\,792\,458$ of a second.

Time

The **second** (symbol: s) is the SI base unit of time.

Definition

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.

SI multiples

Multiple	Name	Symbol	Multiple	Name	Symbol
10^0	second	s			
10^1	decasecond	das	10^{-1}	decisecond	ds
10^2	hectosecond	hs	10^{-2}	centisecond	cs
10^3	kilosecond	ks	10^{-3}	millisecond	ms
10^6	megasecond	Ms	10^{-6}	microsecond	μ s
10^9	gigasecond	Gs	10^{-9}	nanosecond	ns
10^{12}	terasecond	Ts	10^{-12}	picosecond	ps
10^{15}	petasecond	Ps	10^{-15}	femtosecond	fs

10^{18}	exasecond	Es	10^{-18}	attosecond	as
10^{21}	zettasecond	Zs	10^{-21}	zeptosecond	zs
10^{24}	yottasecond	Ys	10^{-24}	yoctosecond	ys

Origin

Originally, the second was known as a "second minute", meaning the second minute (i.e. small) division of an hour. The first division was known as a "prime minute" and is equivalent to the minute we know today.

Conversions

- 60 seconds = 1 minute
- 3 600 seconds = 1 hour

Explanation

The factor of 60 may have been influenced by the Babylonians who used factors of 60 in their counting system. The hour had previously been defined by the Egyptians in terms of the rotation of the Earth as $1/24$ of a mean solar day. This made the second $1/86,400$ of a mean solar day.

In 1956 the second was defined in terms of the period of revolution of the Earth around the Sun for a particular epoch, because by then it had become recognized that the Earth's rotation on its own axis was not sufficiently uniform as a standard of time. The Earth's motion was described in Newcomb's Tables of the Sun, which provides a formula for the motion of the Sun at the epoch 1900 based on astronomical observations made during the eighteenth and nineteenth centuries. The second thus defined is

the fraction $1/31,556,925.9747$ of the tropical year for 1900 January 0 at 12 hours ephemeris time.

This definition was ratified by the Eleventh General Conference on Weights and Measures in 1960. Reference to the year 1900 does not mean that this is the epoch of a mean solar day of 86,400 seconds. Rather, it is the epoch of the tropical year of 31,556,925.9747 seconds of ephemeris time. Ephemeris Time (ET) was defined as the measure of time that brings the observed positions of the celestial bodies into accord with the Newtonian dynamical theory of motion.

With the development of the atomic clock, it was decided to use atomic clocks as the basis of the definition of the second, rather than the rotation of the earth.

Following several years of work, two astronomers at the United States Naval Observatory (USNO) and two astronomers at the National Physical Laboratory (Teddington, England) determined the relationship between the hyperfine transition frequency of the caesium atom and the ephemeris second. Using a common-view measurement method based on the received signals from radio station WWV, they determined the orbital motion of the Moon about the Earth, from which the apparent motion of the Sun could be inferred, in terms of time as measured by an atomic clock. As a result, in 1967 the Thirteenth General Conference on Weights and Measures defined the second of atomic time in the International System of Units (SI) as

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.

The ground state is defined at zero magnetic field. The second thus defined is equivalent to the ephemeris second.

The definition of the second was later refined at the 1997 meeting of the BIPM to include the statement

This definition refers to a caesium atom at rest at a temperature of 0 K.

In practice, this means that high-precision realizations of the second should compensate for the effects of ambient radiation to try to extrapolate to the value of the second as defined above.

Temperature

Kelvin temperature conversion formulas		
Conversion from	to	Formula
kelvins	degrees Celsius	$^{\circ}\text{C} = \text{K} - 273.15$
degrees Celsius	kelvins	$\text{K} = ^{\circ}\text{C} + 273.15$
kelvins	degrees Fahrenheit	$^{\circ}\text{F} = \text{K} \times 1.8 - 459.67$
degrees Fahrenheit	kelvins	$\text{K} = (^{\circ}\text{F} + 459.67) / 1.8$
Note that for temperature intervals rather than temperature readings, $1 \text{ K} = 1 ^{\circ}\text{C}$ and $1 \text{ K} = 1.8 ^{\circ}\text{F}$		

The **kelvin** (symbol: **K**) is the SI unit of temperature, and is one of the seven SI base units. It is defined as the fraction $1/273.16$ of the thermodynamic temperature of the triple point of water.

A temperature given in kelvins, without further qualification, is measured with respect to absolute zero, where molecular motion stops. It is also common to give a temperature relative to the reference temperature of 273.15 K, approximately the melting point of water under ordinary conditions; this convention is the Celsius temperature scale.

The kelvin is named after the British physicist and engineer William Thomson, 1st Baron Kelvin; his barony was in turn named after the River Kelvin, which runs through the grounds of the University of Glasgow.

Typographical conventions

The word *kelvin* as an SI unit is correctly written with a lowercase *k* (unless at the beginning of a sentence), and is never preceded by the words *degree* or *degrees*, or the symbol °, unlike *degrees Fahrenheit*, or *degrees Celsius*. This is because the latter are adjectives, whereas *kelvin* is a noun. It takes the normal plural form by adding an *s* in English: *kelvins*. When the kelvin was introduced in 1954 (10th General Conference on Weights and Measures (CGPM), Resolution 3, CR 79), it was the "degree Kelvin", and written °K; the "degree" was dropped in 1967 (13th CGPM, Resolution 3, CR 104).

Note that the symbol for the kelvin unit is always a capital K and never italicised. There is a space between the number and the K, as with all other SI units.

Unicode includes the "kelvin sign" at U+212A. However, the "kelvin sign" is canonically decomposed into U+004B, thereby seen as a (preexisting) encoding mistake, and it is better to use U+004B (K) directly.

Kelvins and Celsius

The Celsius temperature scale is now defined in terms of the kelvin, with 0 °C corresponding to 273.15 kelvins.

- *kelvins to degrees Celsius*

$$C = K - 273.15$$

Temperature and energy

In a thermodynamic system, the energy carried by the particles is proportional to the absolute temperature, where the constant of proportionality is the Boltzmann constant. As a result, it is possible to determine the temperature of particles with a certain energy; or to calculate the energy of particles at a certain temperature:

- *electron volts to kelvins*

$$K = eV \times 11,605$$

- *kelvins to electron volts*

$$eV = \frac{K}{11,605}$$

SI multiples

Multiple	Name	Symbol	Multiple	Name	Symbol
10 ⁰	kelvin	K			
10 ¹	decakelvin	daK	10 ⁻¹	decikelvin	dK
10 ²	hectokelvin	hK	10 ⁻²	centikelvin	cK
10 ³	kilokelvin	kK	10 ⁻³	millikelvin	mK
10 ⁶	megakelvin	MK	10 ⁻⁶	microkelvin	μK
10 ⁹	gigakelvin	GK	10 ⁻⁹	nanokelvin	nK
10 ¹²	terakelvin	TK	10 ⁻¹²	picokelvin	pK
10 ¹⁵	petakelvin	PK	10 ⁻¹⁵	femtokelvin	fK
10 ¹⁸	exakelvin	EK	10 ⁻¹⁸	attokelvin	aK
10 ²¹	zettakelvin	ZK	10 ⁻²¹	zeptokelvin	zK
10 ²⁴	yottakelvin	YK	10 ⁻²⁴	yoctokelvin	yK

Amount of substance

The **mole** (symbol: mol) is the SI base unit of the amount of particulate substance.

Definition

1. The mole is 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.

SI multiples

Multiple	Name	Symbol	Multiple	Name	Symbol
10^0	mole	mol			
10^1	decamole	damol	10^{-1}	decimole	dmol
10^2	hectomole	hmol	10^{-2}	centimole	cmol
10^3	kilomole	kmol	10^{-3}	millimole	mmol
10^6	megamole	Mmol	10^{-6}	micromole	μ mol
10^9	gigamole	Gmol	10^{-9}	nanomole	nmol
10^{12}	teramole	Tmol	10^{-12}	picomole	pmol
10^{15}	petamole	Pmol	10^{-15}	femtomole	fmol
10^{18}	examole	Emol	10^{-18}	attomole	amol

10^{21}	zettamole	Zmol	10^{-21}	zeptomole	zmol
10^{24}	yottamole	Ymol	10^{-24}	yoctomole	ymol

Origin

The name *mole* is attributed to Wilhelm Ostwald who introduced the concept around the year 1900.

Explanation

The number of atoms in 0.012 kilogram of carbon 12 is known as Avogadro's number. It is approximately 6.0221415×10^{23} (2002 CODATA value).

Because of the relationship of the atomic mass unit to Avogadro's number, a practical way of stating this for atoms or molecules is: *That amount of the substance containing exactly the same number of grams as the number of the atomic weight of the substance.* Since iron, for example, has an atomic weight of 55.845, there are 55.845 grams in a mole of iron.

Elementary entities

When the mole is used to specify the amount of a substance, it must be specified what kind of 'elementary entities' (particles) in the substance are being counted. The particles can be atoms, molecules, ions, electrons, other particles, or specified groups of such particles. For example, 18 grams of water contain about 1 mole of molecules, but 3 moles of atoms.

When the substance of interest is a gas, the particles are usually molecules. However, the noble gases (He, Ar, Ne, Kr, Xe, Rn) are all monoatomic, that is each particle of gas is a single atom. Almost all gases have the same molar volume of 22.4 litres per mole at standard temperature and pressure.

A mole of atoms or molecules is also called a 'gram atom' or 'gram molecule'.

Background

The name *mole* first appeared in 1902 when it was used to express the gram molecular weight of a substance. So, for example, 1 mole of hydrochloric acid (HCl) has a mass of 36.5 grams (atomic weights Cl: 35.5 u, H: 1.0 u).

The mole is useful in chemistry because it allows different chemical substances to be measured in a comparable way. If you are dealing with the same number of moles of two substances, both amounts have the same number of molecules or atoms. The mole makes it easier to interpret chemical equations in practical terms. Thus the equation:



can be understood as "two moles of hydrogen plus one mole of oxygen yields two moles of water."

History

Prior to 1959 both the IUPAP and IUPAC used oxygen to define the mole, the chemists defining the mole as the number of atoms of oxygen which had mass 16 g, the physicists using a similar definition but with the oxygen-16 isotope only. The two organisations agreed in 1959/1960 to define the mole as such:

"The mole is the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon 12; its symbol is "mol.""

This was adopted by the CIPM (International Committee for Weights and Measures) in 1967, and in 1971 it was adopted by the 14th CGPM (General Conference on Weights and Measures)

In 1980 the CIPM clarified the above definition, defining that the carbon-12 atoms are unbound and in their ground state.

Utility of "moles"

Moles are very useful in chemical calculations, because they enable the calculation of yields and other values when dealing with particles of different mass.

Number of particles is a more useful unit in chemistry than mass or weight, because reactions take place between atoms (for example, two hydrogen atoms and one oxygen atom make one molecule of water) that have very different weights (one oxygen atom weighs almost 16 times as much as a hydrogen atom). However, the raw numbers of atoms in a reaction are not convenient, because they are very large; for example, just one millilitre of water contains over 3×10^{22} (or 30,000,000,000,000,000,000) molecules.

Example calculation

In this example, moles are used to calculate the mass of CO₂ given off when 1 g of ethane is burnt. The equation for this chemical reaction is:



Here, 7 moles of oxygen react with 2 moles of ethane to give 4 moles of carbon dioxide and 6 moles of water. Notice that the number of moles does not need to balance on either side of the equation. This is because a mole does not count mass or the number of atoms involved, simply the number of individual particles. In our calculation it is first necessary to work out the number of moles of ethane that has been burnt. The mass in grams of one mole of a substance is by definition its atomic or molecular mass. The atomic mass of

hydrogen is 1, and the atomic mass of carbon is 12, so the molecular mass of C_2H_6 is $(2 \times 12) + (6 \times 1) = 30$. One mole of ethane is 30 g. The amount burnt was 1 g, or $1/30$ th of a mole. The molecular mass of CO_2 (the atomic mass of carbon is 12 and that of oxygen is 16) is $2 \times 16 + 12 = 44$, so one mole of carbon dioxide is 44 g. From the formula we know that

1 mole of ethane gives off 2 moles of carbon dioxide (because 2 give off 4).

We also know the masses of a mole of both ethane and carbon dioxide, so

30 g of ethane gives off 2×44 g of carbon dioxide.

It is necessary to multiply the mass of carbon dioxide by 2 because two moles are produced. However, we also know that just $1/30$ th of a mole of ethane was burnt. Again:

$1/30$ th of a mole of ethane gives off $2 \times 1/30$ th of a mole of carbon dioxide,

so finally:

$30 \times 1/30$ g ethane gives off $44 \times 2/30$ g of carbon dioxide = 2.93 g.

Luminous Intensity

The **candela** (symbol: cd) is the SI base unit of luminous intensity.

Definition

The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} hertz and that has a radiant intensity in that direction of $1/683$ watt per steradian.

SI multiples

Multiple	Name	Symbol	Multiple	Name	Symbol
10^0	candela	cd			
10^1	decacandela	dacd	10^{-1}	decicandela	dcd
10^2	hectocandela	hcd	10^{-2}	centicandela	ccd

10^3	kilocandela	kcd	10^{-3}	millicandela	mcd
10^6	megacandela	Mcd	10^{-6}	microcandela	μ cd
10^9	gigacandela	Gcd	10^{-9}	nanocandela	ncd
10^{12}	teracandela	Tcd	10^{-12}	picocandela	pcd
10^{15}	petacandela	Pcd	10^{-15}	femtocandela	fcd
10^{18}	exacandela	Ecd	10^{-18}	attocandela	acd
10^{21}	zettacandela	Zcd	10^{-21}	zeptocandela	zcd
10^{24}	yottacandela	Ycd	10^{-24}	yoctocandela	ycd

Origin

It may have been defined with reference to the luminous intensity of a single candle.

Explanation

The frequency chosen is in the visible spectrum near green. The human eye is most sensitive to this frequency. At other frequencies, more radiant intensity is required to achieve the same luminous intensity, according to the frequency response of the human eye (called the V-lambda curve in the reference below).

A common candle emits about 1 cd. A 100 W lightbulb about 120 cd.

Historically, the candela was a fundamental unit of the SI. It was defined in terms of the black-body radiation emitted by $1/60$ of 1 cm^2 of platinum at its melting point. The modern definition is no longer fundamental because it is based on another SI unit of power, the watt. Traces of its history remain, however. The arbitrary ($1/683$) term was chosen such that the new definition would exactly match the old definition.

SI photometric light units

SI light units			
Quantity	SI unit	Symbol	Notes
Luminous energy	lumen seconds	lm · s	lumen seconds are sometimes called Talbots
Luminous flux	lumen or (candela · steradian)	lm	also called Luminous power
Luminous intensity	candela or (lumen / steradian)	cd	
Luminance	candela / square metre	cd/m ²	also called Luminosity
Illuminance	lux or (lumen / square metre)	lx	
Luminous efficacy	lumens per watt	lm/W	maximum possible is 683

Current

An ampere is a unit of measure of the rate of electron flow or current in an electrical conductor. One ampere of current represents one coulomb of electrical charge (6.24×10^{18} charge carriers) moving past a specific point in one second. Physicists consider current to flow from relatively positive points to relatively negative points; this is called conventional current or Franklin current.

The ampere is named after Andre Marie Ampere, French physicist (1775-1836).

2.8.1 Standard hierarchy

In measurement science, the word 'standard' is used with two different meanings: first, as a widely adopted specification, technical recommendation or similar document; and, second, as a measurement standard. This note deals with measurement standards, which can be a physical measure, measuring instrument, reference material or measuring system intended to define, realize, conserve or reproduce a unit or one or more values of a quantity to serve as a reference. For example, the unit of the quantity 'mass' is given its physical form by a cylindrical piece of metal of one kilogram, which represents the international standard, and gauge blocks represent certain values of the quantity 'length'.

The hierarchy of measurement standards (see Figure) starts from the international standard at the apex, which is known with the highest precision and goes all the way down to working standards. International measurement standards are standards recognized by an international agreement to serve internationally as the basis for assigning values to other standards of the quantity concerned. The oldest standard in use today is the International Prototype of the Kilogram, kept at the Bureau International des Poids et Mesures (BIPM) in Sèvres. The role of the BIPM is to ensure the international consistency of the highest level measuring standards in each of the signatories of the international treaty known as the Metre Convention.

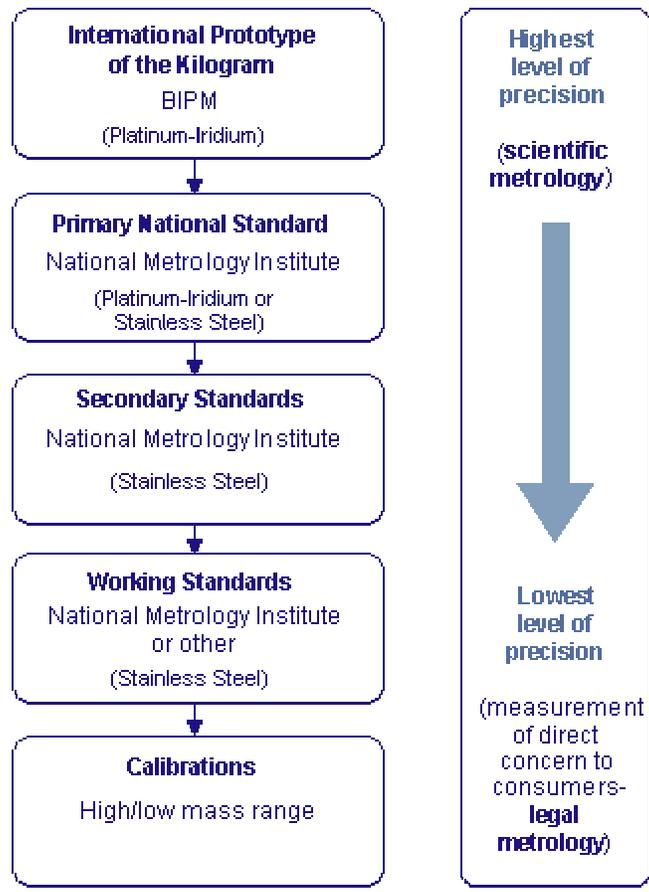


Figure. Schematic representation of the various types of standard that exist in a particular area of metrology, and how the level of precision will decrease along the chain of responsibility.

A national measurement standard is a standard, often a primary standard, recognized by national law to serve in a country as the basis for assigning values to other standards of the quantity concerned. The custodian of national measurement standards in, for example, the USA is the NIST and in the Netherlands it is the NMI.

A primary standard is a standard that is designated or widely acknowledged as having the highest metrological qualities and whose value is accepted without reference to other

standards of the same quantity. Primary standards are, for example, Josephson devices for the realization of the quantity 'volt', or stabilized lasers used in conjunction with interferometers for the realization of the quantity 'length'. The devices are used as national standards.

Secondary standards are standards whose value is assigned by comparison to a primary standard of the same quantity. Primary standards are usually used to calibrate secondary standards. A working standard is a standard that is used routinely to calibrate or check material measures, measuring instruments or reference materials. A working standard is usually calibrated with reference to a secondary standard, and may be used to ensure that routine measurements are being carried out correctly – a check standard.

A reference standard is a standard generally having the highest metrological quality available at a given location or in a given organization from which the measurements made at that location are derived. Calibration laboratories maintain reference standards for calibrating their working standards.

2.8.2 Laboratory accreditation

Previous section explained how standard hierarchy functioned and how national reference standard has been organized by the laboratories that been appointed in the world. In Malaysia, SIRIM is responsible to organize secondary standard (national level). Only big companies or company that related to produce measurement devices has their own standard.

In Malaysia, all firms that offer calibration consultation to industries must ensure that all their equipments must be calibrated by SIRIM through Malaysia Laboratory Accreditation Scheme (SAMM). Only laboratory that been accredited by this scheme can do testing and calibration work. Laboratory that been accredited in Malaysia must fulfill the requirement needed as in document SAMM-ISO/IEC G 25 for world recognition.