4. Tracing measurements made in practice to reference standards.

There are two types of metrological study:

1. Scientific metrology refers to the inquiry, organization, and development of a measurement standard, and its revision.
2. Applied metrology refers to the adequate functioning of measurement instruments used in operational and testing processes.

At the base of metrology is the definition, realisation and dissemination of units of measurement. Properties of existence (i.e., an existent [real world] concept) are quantised by assigning a property value (i.e., a geometric numerical signifier, real number) in some multiple of a 'measurement unit'.

3.1 Metrological outputs

Metrological standards are the primary data output of metrological studies. The basic classification of measurement standards are:

1. The definition of a 'unit' type: based on some physical constant or an agreed-upon arbitrary standard. For example, in the case of a physical constant, the measurement of [the concept] temperature may be based on any of the following: absolute zero, the freezing point of water, the freezing point of oxygen, etc.
2. The realisation of the unit: by experimental methods and the scaling into multiples and submultiples, by establishment of primary standards. In some cases, an approximation is used, when the realisation of the units is less precise than other methods of generating a scale of the quantity in question. This is presently the situation for the electrical units in the SI, where voltage and resistance are defined in terms of the ampere, but are used in practice from realisations based on the Josephson effect and the quantised Hall effect.
3. The transfer of unit traceability: from the primary standards to secondary and working standards. This is achieved by calibration.

Standards are objects and/or relationships designated as used by all (i.e., "authoritative") for an acceptable and accepted reason [derived through axiomatic metrological concepts]. Whatever value they possess is useful for comparison to unknowns for the purpose of establishing or confirming an assigned value based on the standard. The design of this comparison process for measurements is metrology. The execution of measurement comparisons for the purpose of establishing the relationship between a standard and some other measuring device is calibration.

The ideal standard is independently reproducible without uncertainty. This is what the creators of the "metre" length standard were attempting to do in the 19th century when they defined a metre as one ten-millionth of the distance from the equator to one of the Earth's poles. It was later learned that the Earth's surface is an unreliable basis for a standard, as the Earth is not spherical and it is constantly changing in shape. But the special alloy metre bars that were created and accepted in that time period standardized international length measurement until the 1950s. Careful calibrations allowed tolerances as small as 10 parts per million to be distributed and reproduced in metrology laboratories worldwide, regardless of whether the rest of the metric system was implemented and in spite of the shortfalls of the metres original basis.

3.2 Metrology standard sub-types

There are three principal metrological standard sub-types in the production hierarchy:

1. **Primary standards:**
   A. Used for calibrating secondary standards.
   B. At the highest level, a primary reference standard is assigned a value by direct comparison with the reference base.
   C. International Prototype meter, Imperial Standard yard.
2. **Secondary standards:**
   A. Comparison for error correction between primary and secondary standards is continuous (or, as continuous as resources allow).
   B. Exists as a secondary access control for reference of the primary references.
3. **Tertiary standards:**
   A. Exists as a tertiary access control for reference of the secondary references.

There are also:

1. **Working standards** – used by operators. Exist similar in design to primary, secondary, and tertiary standards. But, they are more numerous in access, and are made of easier to life-cycle (i.e., "lower grade") materials.
2. **Reference standards** – used for reference purposes.
3. **Calibration standards** – used for calibration of inspection and working standards.
4. **Inspection standards** – used by observing and analyzing (i.e., "inspecting") systems.

3.3 Modern standards for the dimensions of physical quantities

Currently, there are five independent units of measure (internationally recognized):

1. Temperature.
2. Interval.
3. Linear distance.
4. Electrical current.
5. Frequency.
6. Mass.

Any measurement can be based on one or more of these axiomatic units of measure (or, measurement units).

Pseudo-dimensional quantities involve angle (radian) measurement, of which there are two independent types:

1. Plane angle.
2. Solid angle.

> **Note that a 'pseudo-dimension' is a dimension in which all tags are pairwise equivalent.*

Interested parties believe that eventually, standards organizations will define each of the independent units of measure in terms of the other four independent units. Length (metre) and time (second) are already connected this way.

It is probable that, eventually, all dimensional units of measure will be defined in terms of the other four [in] dependent units. Length, a linear distance measured commonly by the metre, and time, a frequency measured commonly by the second, are already connected this way. Linear distance can be measured using the known constant (or close to constant) speed of light, and hence, eliminate the metre bar artifact. And, time is measured by setting a cosmic linear distance as a reference standard.

> **NOTE:** *Lesser known is the relationship between the luminance (candela) and current (ampere). The candela is defined in terms of the watt, which in turn derives from the ampere.*

3.4 The generation and application of metrological standards

In the market-State, the International Bureau of Weights and Measures (BIPM) develops measurement standards and enforces their application. In the United States, the National Institute of Standards and Technology (NIST) plays the dual role of maintaining and furthering metrology in the commercial and scientific fields. Presently, NIST does not enforce measurement accuracy directly. Instead, in the United States, the accuracy and traceability of commercial measurements is enforced per the laws of individual states. Therein, the government controls through regulation and enforcement of commercial measurement, as material sold by any unit of measure.

> **NOTE:** *Commercial metrology is also known as "weights and measures" and is essential to commerce of any kind above the pure barter level. Also note that the exact same term, "commercial metrology", is used to describe commercial calibration laboratories that are not owned by the companies they serve. In a commercial context, the term, "scientific metrology", addresses measurement phenomena not quantified in ordinary commerce. Calibration laboratories that serve scientific metrology are regulated as businesses only.*

In a hierarchy or market, a 'standard measure' (in this context, a measurement standard) is defined as something that is created, set up, and established as the norm by an authority as rule of the measure of quantity, weight, extent, value or quality. In other words, a body of people or systems in authority establish a set of rules for measuring things under their control and/or jurisdiction. However, 'standard measures' in community represent mutually integrated information that determines the resolution of a measurement-type inquiry or process. There is a difference between the market/state perception and the community perception, but the underlying concept that there shall exist a mutually used way to compare existence, remains the same.

In community, the metrology intersystem team resolves the determined "international" standards for measurement for the community, which is used by all community systems and sub-systems.

3.5 Axiomatic metrological conceptions

The axiomatic methodological conceptions in metrology (Read: concepts of or relating to the study of measurement methods) are:

1. **Accuracy** – Degree of exactness with which the final product corresponds to the measurement standard. How close is the observed measure to the actual (or, accepted) value. The measuring instrument/tool is a variable. Accuracy is calculated by the formula: % Error = (measured value – actual value) x 100 / actual value.
2. **Requirements for accuracy** – what is needed in order to acquire a set degree of accuracy.
3. **Precision** – Ability to produce a measurement consistently. How finely tuned a measurement is, or how close multiple measurements can be to each other? The measuring instrument/tool is a variable. Precision is determined by the number of relative significant digits.
4. **Reliability** - Consistency of accurate results over

consecutive measurements over time.

5. **Calibration** - The transfer of traceability from the primary standards to secondary and working standards is accomplished by calibration.
6. **Response time** – the time a system or functional unit takes to react to a given input.
7. **Traceability** - Ongoing validations that the measurement of the final product conforms to the original standard of measurement, and all calibrations therein are precise. Ongoing validations that the measurement of the final product conforms to the original standard of measurement.

NOTE: *Accuracy and precision may be demonstrated by shooting at a target. Accuracy is represented by hitting the center circle (the accepted/actual value). Precision is represented by the tight grouping of shots (they are finely tuned).*

3.6 Methods of measurement

The following are the most common methods of measurement in metrology:

1. **Precision or direct method** - measurements are directly obtained through . For example, micrometers, Vernier instruments, scales, and dial gauges.
2. **Indirect method** – calculation is used to visualize the measurement. For example, weight is length x width x height x density.
3. **Comparative method** – two measured values are compared.
4. **Coincidence method** – measurements coincide with certain lines and signals.
5. **Fundamental method** – measuring a quantity directly in related with the definition of that quantity.
6. **Contact method** – sensor/measuring tip touch the surface area.
7. **Complementary method** – the value of a quantity to be measured is combined with a known value of the same quantity. For example, volume determination by liquid displacement.
8. **Deflection method** – the value to be measured is directly indicated by a deflection of a pointer. For instance, pressure measurement.

3.7 Applied size categories

1. **Nominal size** – is the size of a part specified in the drawing. Note that nominal and basic size are often the same.
2. **Basic size** – is the size of a part to which all limits of variation are determined. Or it is the theoretical size from which limits of size are derived by the application of allowances and tolerances.
3. **Actual size** – is the actual measured dimension of a part.
4. **Tolerance** – the total amount that a specified dimension is permitted to vary. It is the difference between the maximum and minimum limits for the dimension. A tolerance is the total permissible variation from the specified basic size of the part.
   A. Upper deviation (maximum, max).
   B. Lower deviation (minimum, min).

3.8 Metrological standards of measurement

There are perceptions through which that which is being observed and analyzed (i.e., measured) may be understood. These perceptions represented a scale of how fully the operation of the universe is understood.

1. **Line standard** – a distance, a “meter”, is defined as the distance between scribed lines on a bar of metal under certain conditions of ‘temperature’ and ‘support’. The meter, for instance, is the distance between the center portions of two lines engraved on the polished surface of a bar of pure platinum-iridium alloy (90% platinum and 10% iridium).
   - **End standard** – is expressed as the distance between two surfaces; generally, with the usage of a precision measuring mechanism (a measuring instrument). Dimensional tolerance as small as 0.005mm can be obtained. These, are not subject to ocular parallax effect because the instrument resolves the distance.
2. **Wavelength standard** – a “meter” is defined as the study and design of interferometry:
   A. Interferometry is a family of techniques in which waves, usually electromagnetic, are superimposed in order to extract information. It is the study and design of system that can account for and control the vibration of a medium as a rate of induction.
   B. The emitted/inducted wavelength of the cadmium line (λ ≈ 644 nm), led to the definition of the angstrom as a secondary unit of length for spectroscopic measurements. The angstrom (ångström) is a unit of length equal to 10^{-10} m (one ten-billionth of a metre) or 0.1 nanometre.
   C. Krypton-86 (λ ≈ 606 nm) was selected (in 1960) as the new wavelength standard for the [1] meter distance. Hence, the metre is the length equal to 1 650 763.73 wavelengths in vacuum of the radiation corresponding to the transition between the levels 2p10 and 5d5 of the krypton

86 atom.

3.9 Computational metrology and geometry

Fitting is the computational metrological term for associating ideal geometric forms to a discrete set of points sampled on a computationally manufactured surface.

1. **Datum establishment** – for relative positioning of geometric objects.
2. **Deviation assessment** – how far has a part deviated from its intended idea form?
3. Form tolerances (syntax and semantics).

Fitting is an optimization problem:

- Given a set of points X, fit ideal geometric element(s) Y that minimize an objective function involving distances between X and Y, subject to certain constraints.

The two principal types of fitting are:

1. Continuous optimization (e.g., least squares fitting).
2. Combinatorial optimization (e.g., minimax fitting).

Two popular fits:

1. Least Squares Fit – when the objective function uses L2 norm.
2. Chebyshev Fit – when the objective function uses L_∞ or other norm.

Conversely, the main purpose of filtering is to extract scale dependent information, and no compression of data. Filtering refers to convolution:

1. Convolutions of functions (e.g., Gaussian filters).
2. Convolutions of sets (e.g., envelope filters using Minkowski sums).

4 The measurement [comparison] process

DEFINITION: *The process that measures a quantity is known as a 'measurement procedure'.*

In common parlance, the term 'measurement process' could be used to refer to: (1) the measurement system as a whole, including its inputs and outputs; (2) everything included in 1, and the total conversion process of converting the source of the measurand into something measurable; or, 3) it could be used to refer solely to the measurement systems operational process(es). In other words, the processes which might be present to convert some object into an intended measurable constituent are generally considered to be part of the measurement process itself. In some cases, there may be a particular sampling procedure included in the process. In all cases, measurement results are obtained by performing measurement actions.

As the operational element of a system, the measurement process involves a set of operations having the object[ive] of experimentally determining the value of a [unique input] quantity, for a given attribute/ property of an entity, through observation (and hence, attribution) of its relationship to an earlier quantity. Therein, measurement is the process of assigning to some specific instance (of a quality, categorical property or attribute of existence), a numerical value (quantification) and a referential standard (unit).

NOTE: *A 'characteristic' (unique inherent quality) of a system is called a 'property'.*

Measurement (i.e., the measurement process) involves a series of actions (steps, stages) that take place in a defined manner. Some measurements are a single step, and others have many stages. The purpose of the measurement process is to acquire new information (as comparative data) on empirical phenomena.

4.1 Conceptual phases of the measurement process

The generalized measurement process may be perceived to have the following conceptual phases:

1. Select an observable/sensible [empirical] event (or object).
    - Define the measurand by defining that which has an existent quality or quantity for which information can be acquired (or collected).
2. Develop a set of mapping rules (i.e., a scheme of principles for assigning numbers).
    - Define a standard comparison model.
3. Apply the mapping rule to each observation of that event.
    - Assign a number to a quality (property or

characteristic) of an object or event, which can be compared with other objects or events.

4.1.1 Comparison inputs

INSIGHT: *Measurement is an information acquisition by a process of comparison.*

Measurement is the act[ion] or the result of a quantitative comparison between a predefined standard (procedure and/or model), and an unknown magnitude.

In order to complete the mapping, process a determined comparison must occur between [at least] two comparatively aligning inputs:

1. The measurand (unknown magnitude) - Some “thing” defined to exist from which more information can be acquired (the ‘measurand’). The ‘measurand’ is the thing that is being measured, and for which a value will be determined. The measurand has a single value.
2. The comparative standard - A[n agreed upon] ‘standard’ method[ological scheme] of reference to determine the [standardized] value of the ‘measurand’. The measurement standard (or standard of reference) is the pre-existing referential process and/or configured objects used in the comparison.

The value of the ‘measurand’ (i.e., the quantity value assigned to the measurand) is determined by its relationship (position and/or alignment) to the ‘standard’. In usage, the standard [method or tool] of reference is used by an observer (or other decision processing, comparison resolution system) to assign a [quantity] value to the measurand by comparison with the standard in some pre-defined logical way (i.e., method or process).

4.1.2 Comparison methods

TERMINOLOGY: *A* **reference quantity** *value is a quantity value used as a basis for comparison with values of quantities of the same kind.*

There are two types of methodological comparison, direct comparison and indirect comparison:

1. **Direct comparison method** - Direct comparison with either a primary or a secondary standard. The direct comparison method involves a comparison of a measurand with either a primary or a secondary standard, which has the same physical nature as the measurand.
2. **Indirect comparison method** - Indirect comparison with a standard through the use of a calibrated system. Here, an empirical relation is established between the measurement actually made and the results that are desired. The indirect comparison method is the main method that is widely used in contemporary measurement and control systems. The indirect method of measurement consists of two stages. The first stage involves converting both the standard and measurand into the type of output parameters that are convenient for further processing. The most common output parameters are electrical signals. The second stage of measurement provides a comparison of the first stage output parameters related to the standard and measurand.

4.1.3 The counting and weighing processes

Mass and weight are understandable as different measurements of objects. The following reasons are provided to identify why weight ought to be measured in grams and refer to gravitational pressure, and mass in number of objects counted.

1. Weight (a.k.a., "relativistic mass") is measured by putting an object on a scale and weighing it against another object. The scale units for weight is grams (kilo-,mega-, etc.). How much pressure is an object causing on a scale. The dynamic question is: Did the object increase pressure against the scale? The weight of a given object is relative to its position in the physical universe relative to other objects; weight varies according to where in the universe the measurement takes place (e.g., a ball will weigh less on the moon than on earth). In this way, grams are a unit of [gravitational] pressure.
2. Mass is a quantity of matter, wherein the observer counts the presence of objects (which gives the units used their label). You don't measure mass, you count units of mass and the mass should be stated in units of object masses. When using mass, units are counted. Mass is not measured by putting an object on a scale. Instead, mass is measured by counting the amount of some scale unit of an object. The dynamic question is: Did the object accumulate more atoms? Units of mass are, for example, measured in what is being counted (note: units of mass are not measured in grams, because that is measure of weight, not mass):
   A. If counting atoms then state the answer in number of atoms.
   B. If counting apples, then use apples.

Note that the scientific community in the early 21st century measures mass in grams.

4.1.4 Standard [of reference]

A [standard of] reference can be a measurement unit, measurement procedure, a reference material, or a combination.

1. **Reference material** – a sufficiently homogeneous and stable material with reference to specified properties, which has been established to be fit for its intended use in measurement or in examination of nominal properties.
2. **Measurement procedure** – a description of a measurement according to one or more measurement principles and to a given measurement method, based on a measurement model and including any calculation to obtain a measurement result. A measurement procedure is usually documented in sufficient detail to enable an operator to perform a measurement.
3. **Measurement unit** – a real scalar quantity, defined and applied, with which any other quantity of the same kind can be compared to express the ratio of the two quantities as a unit.
4. **Combination** – a combination of the standards.

4.2 *Entities in a conceptually modeled measure*

NOTE: *Different disciplines have different measurement ontologies.*

An entity is a conceptual categorization of information defined by common attributes and constraints at the systems level. The term corresponds to the "Entity" construct as defined in ISO 10303-11.

There are at least two principal types (classifications/ categorizations) of entities in measurement [systems]: objects (i.e., events, values, methods) and properties (i.e., attributes and characteristics:

Objects (and events, respondents) - Objects are fundamental blocks of understanding (as in, unitizations of information). Objects are the entities ("building blocks") that compose a mental model of the world. Every "thing" is an object (as a significant, bounded information patterning set). Objects are, for example, phenomena, bodies, or substances, but also individuals, processes, and organizations. Objects and events are described through constraints

1. **Events** – An sensed or experienced interaction [between two or more differentiated objects].
2. **Methods** - A method is an action that an object can perform. An algorithm is a pre-set method. A method is a formal ordering of constraints.
3. **Numerical values (numbers, a syntactic category)** – A unit of information signifying an ordered rank meaning that expresses the magnitude (amount or quantity) of a fundamental iterating pattern. In measurement a number is not usually used by itself, but in tandem with some other term, its dimension[al property], which will normally correspond to some Aristotelian category of substance or quality. Numerical values are assigned to properties as the result of measurement. In application, a number is a relation between the concepts of 'magnitude' (amount) and 'unit' (reference).
4. **Properties (and attributes, characteristics)** – A 'property tag' names what is being measured. This is the measured property or attribute, which is organized into a relational system otherwise known as a measurement classification (or taxanomical, ontological) system. Herein, a property is either:
   A. A quality (characteristic or attribute) of an object (or event), or
   B. An aspect of its behavior.

Note that it is sometimes said that attributes are properties of entities. In this sense, there are two principal categories of attributes:

1. Internal attributes (direct measures) are measured directly from the entity.
2. External attributes (indirect measurement) are indirectly measured.

Properties are, for example:

- Length, loudness, and frequency.

The ISO VIM3 states that a 'property' is either a nominal property or a quantity, and a quantity is either an ordinal quantity or a Euclidean quantity for which a unit can be defined. Hence, a property is one of the following:

1. A **nominal property or qualitative property (no magnitude or scale)** - Nominal properties cannot form scales. Expressed by categories (names) in a set. A nominal property is a property of a phenomenon, body, or substance, where the property has no magnitude. A nominal property is a property that cannot be ordered according to magnitude. For example, the sex of a human being cannot be ordered according to magnitude – in normal physiological procreation, two sexes are required (i.e., there is no magnitude between each other, or the top-level category). In some disciplines, the term qualitative analysis is used to describe the examination of nominal properties. Qualitative analysis produces [measurement] data acquired without magnitude. In the previous sentence, the term measurement is crossed out; this is because, it is possible to measure a quantity, whereas obtaining information about a nominal property is not a measurement.
2. A **quantity [property] (measurable property)** -

> Quantities form scales, continuums. If it is not a nominal type property, then it is a quantity type property. A quantity is any property that has a size (magnitude) that can be evaluated (compared and integrated) through some measurement. 'Quantity' is a specific type of property. Only quantities [of phenomenological objects or events] are technically measurable. Each sub-type of this property has an accompanying application as something called a [quantity] 'scale'. A quantity scale (a.k.a., measurement scale) is an ordered set of values of quantities of a given kind used in [sequential] ranking, according to [the order of] their magnitude. Types of properties (e.g., nominal, ordinal, quantity, cardinal) become scales of quantities (e.g., nominal, ordinal, interval, ratio).
>
> A. An **ordinal quantity** [property] scale - expressed by ordering of categories in a set.
>
> B. A **cardinal quantity** [property] scales also known as a Euclidean quantity [property] which must have defined units. Expressed by a number and a measurement unit as part of a system of [existent] quantities. The physical quantities of the universe are cardinal/ Euclidean.

Geometric quantities are paradigmatic of measurable entities. Hence, quantity is an axiom of measurement – quantity grounds the theory of measurement. Because measurement requires quantity, and quantity is (axiomatically) logically numerical, the foundations of measurement can be notated in purely mathematical terms.

> **NOTE:** *The division of the concept of 'quantity' according to 'kind of quantity' is arbitrary to the extent that the unified principles of the universe are not yet known.*

The cardinality and ordinality:

1. Cardinal has to do with cardinality or the magnitude or quantity of things.
2. Ordinal has to do with ordinality or the ordering or ranking of things.
3. Thus, first is an ordinal number. Its cardinal equivalent is one.

4.3 Ordinal quantity (ordinal property)

An **ordinal quantity** is a quantity defined by a conventional measurement procedure, for which a total ordering relation can be established, according to magnitude, with other quantities of the same kind, but for which no algebraic operations among those quantities exist. Ordinal quantities are usually not considered to be part of a system of quantities, because they are related to other quantities through empirical relations only.

Examples of ordinal quantities (in applied scale form) are: Rockwell C hardness scale, Octane number for petroleum, and the strength of an earthquake on a Richter scale. The numbers on these scales are arbitrary and dimensionless.

Ordinal quantities have neither measurement units nor quantity dimensions. Ordinal quantities are arranged according to ordinal quantity scales.

4.3.1 Ordinal quantity scale (ordinal scale)

An ordinal quantity scale (ordinal scale) is a conventional reference scale or a quantity scale, defined by cooperation, on which only comparison of magnitude applies. An ordinal quantity scale may be established by measurements according to a given measurement procedure. Also of note, ordinal quantities are ordered on ordinal quantity scales.

4.4 Combining entities in measurement

Measurement combines the categories of quality and quantity in order to establish the quantity of a particular quality. Quantities are fusions of numbers and property dimensions (in metrology, the latter are called 'quantity dimensions', though there also exist qualified properties).

'Entity value' principle states that no entity can possibly at one and the same time take two specific values of the same property dimension (quantity variable). For example, no material object can simultaneously have two masses, two volumes, two electric charges, etc.

The concept of dimension is axiomatic to [material] existence, representing the class of information about which reality itself is composed. The spatial, material system is conceived to have the following initial dimension: length (x-axis), width (z x-axis), height (y x-axis), and time (technically, "space-time/memory"). Here, a 'dimension' is a "pure" measurement, as opposed to a scale, which is a ratio of measurements (e.g., kilometers per hour or amps per second, versus mass or temperature).

The principal [visualization] tool in measurement is 'scale'. A scale is a visualization tool that precisely enables deduction of a value of a given quantity (magnitude or amount) by knowing its position [on the scale] and the scale's ratio [between one position and the next]. A scale is the standard (reference) and scope (boundary) of measurement (e.g., nominal, ordinal, ratio scale, etc.).

A self-organizing system can encode the concepts of objects and properties (relationships) to form scales (visual expressions with position and ratio information), upon which logical processing (i.e., mathematical operations) may be performed.

Here, the concept of a [measurement] unit provides meaning to the 'scale' by differentiated identification of one categorical unit from other axiomatic or derived units).

For the supra-system, the level of measurement (i.e., scale of measurement, property scale, or variable scale) determines how the data will be interpreted (i.e., what mathematical operations can be performed). Therein, knowing the level of measurement resolves what statistical analysis is appropriate on the values that were assigned [to the variable at that level].

When there is a scale of possibilities, there becomes a need for defining quantifiable measures for the optimal functionality of a system. That optimally functional or desired value, of a measured system, is called a 'metric'.

A scale is required in measurement for a specific value, among a sequence of possible values, to have meaning.

4.5 Measurement scales

Measurement scales are the symbolic representation of possible measurement results. Measurement scales are used to categorize and/or quantify variables so that correct mathematical operations may be applied. Each additional mathematical operation generates a new "scale of" measurement. In general, there are four scales of measurement:

1. There are four scales of measurement commonly used in statistical analysis.
2. There are four types of data commonly used in information processing.
3. There are four types of variables commonly used in quantifying and qualifying.

Those four categories (i.e., scales of measurement) are, in order:

1. Nominal.
2. Ordinal.
3. Interval.
4. Ratio.

The scientifically accepted physical quantity-value scaled units are (Read: the fundamental/base quantity values are):

- ...
- The meter scale – property is length units.
- The kilogram scale – property is mass (weight) units.
- The second scale – property is time units.
- ...

4.6 Variables in measurement

> **NOTE:** *Measurement operationalization is the process of developing specific variables that will be used to measure a concept.*

A variable is any entity that can take on different values. In statistics, where variables are actually used, a variable is any characteristics, number, or quantity that can be measured or counted. A variable may also be called a data item.

Further, in statistics, the general property that is being measured through one or another of the three fundamental measurement processes (counting, ordering, sorting) is termed a 'variable'. Any particular measured instance of that property is spoken of as a 'variate'. 'Variate' is a single variable instance.

The term 'variable' implies that the results of the measurement process are capable of varying from one time to another or from one item to another. For instance, the categorical measurement of gender among a mixed group of human subjects will vary from one subject to another between the two possible outcomes, female and male.

A specific variable represents a specific concept with a logical indicator or value. It is a data point that can be counted, ordered, or sorted. **S**trictly speaking, measurement does not occur on things, or qualities, or properties, but "indicants" of properties.

The opposite of a variable is a constant. A constant does not vary from one time to another or from one item to another. It is an unchanging value that will applied mathematically to a data set.

In measurement, the word remains with a common meaning, but is often used in multiple different contexts. The following are the multiple ways in which the term 'variable' may be applied.

In measurement, a variable is:

1. A [measurable] property (attribute or characteristic) of an object or event (of existence) that can be assigned a number (numerical variable) or a category (categorical variables), and
2. Is expected to change over time (measurement variables).

In measurement, there are two types (categories) of variable [processes]:

1. **Qualitative variables (categorical variables)** - A qualitative variable is one which measurement occurs with categories possessing no meaningful numerical values.
2. **Quantitative variables (measurement variables)** - A quantitative variable is one which measurement occurs with meaningful numerical values.

There are different ways variables can be described according to the ways they can be studied, measured, and presented. In common application, entities become types of variables [in numerical-mathematical scales of operation], whereupon variables are typically classified as either of two types:

1. **Categorical variables (a.k.a., qualitative variables)** - Categorical variables are variables whose levels are distinguished by name only.

Properties become categorical variables. Categorical variables have values that describe a 'quality' or 'characteristic' of a data unit, like 'what type' or 'which category'. Categorical variables fall into mutually exclusive (in one category or in another) and exhaustive (include all possible options) categories. Therefore, categorical variables are qualitative variables and tend to be represented by a non-numeric value.

A. Categorical variables may be measured on one "scale": nominal.

2. **Numeric variables (a.k.a., quantitative variables or measurement variables)** - Numerical values become numerical variables. Numerical variables have values designated by numbers that have some meaning relative to one another. Numeric variables have values that describe a measurable quantity as a number, like 'how many' or 'how much'. Therefore numeric variables are quantitative variables.
    A. Numerical variables may be measured on three scales: ordinal; interval; and ratio.

Numeric, quantitative measurable variables may be further described as either continuous or discrete:

1. **Continuous variables** – variables that have an infinite (or significantly large) number of possible values. A continuous variable is a numeric variable. Observations can take any value between a certain set of real numbers. The value given to an observation for a continuous variable can include values as small as the instrument of measurement allows. Examples of continuous variables include: height, time, age, and temperature.
2. **Discrete (meristic) variables** – variables that only have whole number values. A discrete variable is a numeric variable. Observations can take a value based on a count from a set of distinct whole values. A discrete variable cannot take the value of a fraction between one value and the next closest value. Examples of discrete variables include the number of registered cars, number of business locations, and number of children in a family, all of which measured as whole units (i.e. 1, 2, 3 objects).

The data collected for a numeric variable are quantitative data.

Categorical, qualitative variables may be further described as:

1. **Nominal variable** - a categorical variable. Observations can take a value that is not able to be organized in a logical sequence. Examples of nominal categorical variables include sex, business type, eye color, religion and brand.
    - **Qualitative-nominal** – qualitative variables where the categories have no natural ordering.
2. **Ordinal variable** - a categorical variable. Observations can take a value that can be logically ordered or ranked. The categories associated with ordinal variables can be ranked higher or lower than another, but do not necessarily establish a numeric difference between each category. Examples of ordinal categorical variables include academic grades (i.e. A, B, C), clothing size (i.e. small, medium, large, extra large) and attitudes (i.e. strongly agree, agree, disagree, strongly disagree).
    A. **Qualitative-ordinal** – qualitative variables where the categories have a natural ordering.
3. **Qualitative-dichotomous** – qualitative variables with two categories.

The data collected for a categorical variable are qualitative data.

> **CLARIFICATION:** *The words "measurement variable" are used here in reference to two related things. First, the term 'measurement variables' refers to all possible variables in measurement (as a concept, quantity and quality variables), and secondly, the term 'measurement variable' refers to only quantitative variables.*

In experimentation and measurement data acquisition, there are two axiomatic (principal or ontological) categories, each with two principal types of variables:

1. **Categorical variables** – a variable that can be placed into categories, but these categories may not have any logical ordering. A categorical variable is a property of an object which can be broken down into different classes or categories.
    A. *[Scale level 1]* **Nominal variables** – classification is made into unordered categories. Nominal variables are expressed as names (such as "female"). Nominal variables classify observations into discrete[ly named] categories.
    B. *[Scale level 2]* **Ordinal variables (ranked variables)** – classification is rank ordered on some characteristic. However, there is no indication of how much greater one instance is than another. These are expressed as positions (such as "third"). Ranked variables, also called ordinal variables, are those for which the individual observations can be put in order from smallest to largest, even though the exact values are unknown.
2. **Measurement variables** (a.k.a., numeric variables

or quantitative variables) – a measurement variable is one where numerical values can be assigned and objects or events can be ordered according to those values. Measurement variables are expressed as numbers and a reference (such as 3.7 mm).

A. *[Scale level 3]* **Interval variables** – values for interval variables have equal intervals between them; however, they lack an absolute zero point.
B. *[Scale level 4]* **Ratio variables** – values for ratio variables have equal intervals between values, and there is an absolute zero point.

The principal [measurement] variable from which all other variables (except nominal) are derived is 'quantity'. Quantity is the source conception of a 'measurement variable' -- if there is a potential differentiation for that which may be known to exist, then what is the separation?

> **NOTE:** *The mathematical theories underlying statistical tests involving measurement variables assume that the variables are continuous. However, [continuous] statistical tests also work on discrete measurement variables. The only exception is when there is a small number of possible values of a discrete variable, in which the variable may be treated as nominal (instead of, a measurement variable).*

In the application of statistics to measurement variables, there is the possibility of calculating for more than one numeric value for a variable:

1. A measurement variable with only two values should be treated as a nominal variable;
2. A measurement variable with six or more values should be treated as a measurement variable;
3. A measurement variable with three, four, or five values requires complex simulation.

4.6.1 Numeric variable scales

1. **The cardinal number scale and cardinal measurement** - In the cardinal measurement there are two subcategories, ratio scale and interval scale, and all cardinal variables are either continuous or discrete.
   A. **Discrete cardinal variables** – count variables. For example, number of people in a town, family size, number of books, number of heads in 10 tosses of a coin, and so on. Discrete variables can have negative values; for example, if the net change in demand is measured by the difference of arrival of customers the result can be negative or positive. Discrete numerical variables are variables that can take on only whole number values. Discrete numerical variables are typically the result of the counting operation/process (e.g., counting things, events, activities, types).
   B. **Discrete scale of measurement** - Discrete cardinal variables - Discrete/Integer scale of indivisible units: 1,2,3,4,5,6,...
   C. **Continuous cardinal variables** - All these cardinal variables (time, height, weight, distance) are examples of Continuous variables - they are measured in real numbers and they have unit of measurement. Continuous numerical variables are variables that can take on any value whatsoever. They can be whole numbers, or they can be numbers to any number of radix points (e.g., decimal points - fractions of a whole number).
   D. **Continuous scale of measurement** - Continuous/ratio[nal]/fraction scale of [in principle] infinitely divisible units: 1.23,2.9120,4.323442,...
2. **Equal interval scale** – equal intervals exist between their successive units of measurement. If a measurement scale possesses this property, then it is possible and meaningful to take two or more measures from that scale and perform the simple arithmetic operations of addition and subtraction.
   A. **Ratio scale** – a point is designated as zero, which represents an absolute zero of the quantity that is being measured (e.g., zero length represents the absolute absence of length). Scales of measurement that have both equal intervals and absolute zero points are known as ratio scales.
   B. **Non-ratio scale (interval scale)** – a point [on the scale] is either:
   C. Not designated as absolute zero of the quantity that is being measured (e.g., kelvin temperature scale).
   D. Or, the designation of zero is only an arbitrary point that happens to be called "zero" (e.g., celsius temperature scale).

4.7 Conceptual mapping of the empiric, real world through qualification and quantification

Conceptual mapping of the empiric, real world is carried out through [at least] two processes, qualification and quantification.

Note here that the terms 'qualification' and 'quantification' both end with the suffix "-fication". The suffix-noun "-fication" means - making, producing, or representing. For example, reification means to making something real or physical (such as, making a clay pot). However, the concept 'reification' can also be applied philosophically. For example, an actual 'shadow' is the absence of light, where light is an actual thing. The shadow is not the presence of a thing, but its absence. A shadow cannot be reified; it cannot be experienced and conceived of as a separate object/thing. To make the experience of an absence [of a thing] into a thing itself is bound to cause instability in a societal trajectory toward fulfillment and ecological well-being. It could be said that qualification and quantification depend to a large degree on accurately experiencing, and hence conceiving, of the real world. When absences are turned into qualified things and then quantitatively measured, that data may still have usefulness, but the context in which it was

Human cognition can recognize patterns of quality and quantity in our environment. These patterns are mapped to concepts. In concern to measurement, the supra-mapping conceptions are 'quality' and 'quantity'. Whereas quality represents categories and their ordering, quantity represents the presence of a meaningful number.

The properties, characterizations, and attributes of existence can be categorically described in two ways: qualitatively (through words and linguistics) and quantitatively (through numbers and mathematics).

There are two principal descriptive forms (notations or expressions) of 'measurement', in the most general use of the term:

1. A **qualitative description** is the use of words and linguistics.
2. A **quantitative descriptio**n is the use of numbers and mathematics.

Hence, there are two principal types of measurement:

1. **Qualitative measurement** uses words, representing linguistic, semantic conceptions, to describe [that which is/was existent] in relation to a model (scheme) conceived to pre-exist. Qualitative measurement requires the assigning of a word (concept) capable of functioning under linguistical logic (i.e., in a linguistic system).
2. **Quantitative measurement** uses numbers, representing mathematical conceptions, to describe [that which is/was existent]. Quantitative measurement requires the assigning of a number (value or count) capable of functioning under mathematical logic (i.e., in a mathematical system).

Measurement involves processes that determine the value of a [new] quantity or quality of [some category of] information.

1. **Qualitative information** - involves processes that determine the value of [new] qualitative [information].
2. **Quantitative information** - involves processes that determine the value of a [new] quantity [of information].

In this sense, there are two general types of measurement data (and research):

1. **Qualitative data (qualitative research)** is information about qualities; information that cannot be expressed or processed through numerical conception. Qualitative data involves linguistic characteristics and descriptors that can't be measured, but can be observed subjectively.
2. **Quantitative data (quantitative research)** is information about quantities; that is, information that can be measured and written down with numbers. Quantitative data involves numbers and systems that can be measured objectively. When something [existent] is "measured", then the result is quantitative data. All [numerical] measurement is quantitative data.

And, in measurement experimentation there are two types of variables (Read: a concept, factor, trait, condition, behavior, etc) of an object or system (in the real world) that can exist with differentiation (i.e., in differing amounts or types):

1. **Qualitative variables** - take on values that are names or labels.
2. **Quantitative variables** – take on values that are numeric.

4.8 Mapping process categories

There are two mapping process categories for mapping existence to workable information sets. The two process categories are:

1. **Qualify[ing]** means to characterize by naming an attribute; it means to state any property or characteristic of something. Qualify refers to meeting the terms of eligibility or criteria.
   A. There is categorization by descriptive values (categorical values).
2. **Quantify[ing]** means to find, determine, or otherwise calculate the quantity or amount of (something). In application, quantify is describing [some thing] numerically.
   A. There is categorization by numbers (numerical values).

Measurement is the process of assigning to some specific instance (of a category of existence), a numerical value (quantification) and/or qualifying condition (qualification). All quantities (quantity values) are actually qualified by [their] units, which represent either a qualifying procedure and/or a qualified definition.

> **NOTE:** *"Qualify" is also defined in common parlance as: to have the necessary skill, knowledge, or other requirements to do a particular process, activity, or to have the qualifications to do something.*

4.9 Quantity defined by standards

ISO 80000-1:2009, 3.1: The International Standards Body defines a 'quantity' as a property of a phenomenon, body, or substance, where the property has a magnitude that can be expressed by means of a number and a reference.

A reference can be:

1. A measurement unit.
2. A measurement procedure.
3. A standardized reference material/tool
4. Or, a combination of these.

Simply, a quantity is a property of a phenomenon, body or substance, to which a number can be assigned with respect to a reference (of which there are four possible reference types).

Quantity is a specific type of property. And, only quantities [of phenomenological objects or events] are technically measurable.

International Vocabulary of Metrology 3rd edition (VIM3): starts with a definition of 'quantity' (def. 1.1) followed (1.2) by one for 'kind-of-quantity'. Two other VIM3 definitions relevant are those of 'quantity dimension' (1.7) and 'quantity value' (1.19).

- 1.1 quantity = property of a phenomenon, body, or substance, where the property has a magnitude that can be expressed as a number and a reference.
- 1.2 kind-of-quantity = aspect common to mutually comparable quantities.

> **Insight:** *The first axiom of measurement is quantity, and the second, uncertainty.*

VIM3 then defines quantity value as an expression that is related to a spatio-temporally localized (individual) quantity (i.e., a quantity value is a representation of a (individual) quantity). The definition says:

- 1.19 quantity value = number and reference together expressing magnitude of a (individual) quantity [1, p.12, the parenthesis added].
- 1.7 quantity dimension = expression of the dependence of a quantity on the base quantities of a system of quantities.

Continuous quantities possess a particular structure that can be explicitly characterized as a set of axioms that define such features as identities and relations between magnitudes (sequences of patterns). In science, **quantitative structure** is the subject of empirical investigation and cannot be assumed to exist a priori for any given property.

Every quantity structure has the following fundamental characteristics:

1. Relationships of equality or inequality can in principle be stated in comparisons between particular magnitudes, unlike quality, which is marked by likeness, similarity and difference, differentiation.
2. Additivity may involve concatenation, such as adding two lengths A and B to obtain a third A + B. Additivity is not, however, restricted to extensive quantities but may also entail relations between magnitudes that can be established through experiments that permit tests of hypothesized observable manifestations of the additive relations of magnitudes.
3. Continuity, as a type of quantitative attribute, where continuity means is that if any arbitrary length (dimension), a, is selected as a unit, then for every positive real number, r, there is a length b such that b = ra.

4.9.1 Qualifiers

Quantifiers are words and phrases used to indicate quantity. These include, but are not limited to:

1. A number.
2. Few.
3. Many.
4. Each / every.
5. Several.
6. An amount.
7. Little.
8. Less.
9. More.
10. Much.
11. All.
12. Some.

4.10 Quantity commonly defined

Take note that synonyms for quantity include:

1. Sequence.
2. Magnitude.
3. Amount.
4. Size.
5. Degree.

6. Weight (not the tool, 'scale').

A quantity is some measured or measurable amount (i.e., quantity or sensation) of some "thing" (of a pre-existing pattern). Therein, a 'unit' of measurement is assigned to selectively identify and categorize (tag, name) the concept[ual thing or dimension] being measured. A quantity is a quantifiable numerical assignment of some property, which is conceptualized as a particular phenomenon (natural process), body (object), or substance (material).

> **CLARIFICATION:** *Magnitude (size) means the numerical value which tells the amount of that physical quantity.*

In measurement, the terms quantity, quantity value, and value, can mean the same thing:

1. A 'quantity' is an amount of something that must have a value.
2. A "quantity value" is a number and reference together expressing the referential magnitude of a quantity.
3. A "value" is a number with a reference.

Terminological clarification:

1. **Quantity kind or type (quantity dimension)** – any observable property of any object that can be measured and quantified numerically. A quantity is any property which has size (magnitude) that can be evaluated (compared and integrated into an information model) through some measurement process.
   A. For example: length, mass, time, force, energy, electric charge.
2. **Quantity** – observable property of a particular object that can be measured and quantified numerically.
   A. For example: length, mass, speed, temperature of a particular object.
3. **Quantity value** – Magnitude of a quantity expressed as a product of a number and a unit.
   A. For example: a velocity of m/s.
   B. The term 'indication' (result) is used to express the quantity value provided by a measuring instrument.

> **INSIGHT:** *A quantity is anything that can be measured.*

In practice, the terms 'dimension' and 'quantity' tend to become synonymous. Each base quantity is regarded as having its own dimension, and the dimension of a derived quantity is contains the same information about its relation to the base quantities as that provided by the SI unit of the derived quantity as a product of powers of the SI base units. A quantity is also sometimes called a 'quantified dimension'.

Table 5. Measurement > Quantity Comparison*: Table shows two examples (length and power) of the physical dimensions of quantity, physical dimension, and unit.*

Quantity	Dimension	Unit
Length	L	Metre
Power	ML^2T^{-3}	Js^{-1} or watt

Relations between different quantity types/dimensions are defined by units. A unit is a particular physical quantity, defined and adopted by convention, with which other particular quantities of the same kind are compared to express their value. All physical quantities can be expressed in terms of seven base units.

4.11 A system of quantities

All quantities together with their defined relations form a 'quantity set', otherwise known as a 'system of quantities'. A system of [physical] quantities is a set of quantities together with a set of non-contradictory equations relating those quantities:

1. Quantity objects (quantities) - Base/fundamental and derived quantities.
2. Relational objects (equations) - a set of non-contradictory equations relating those quantities.

In order to establish a system of units, such as the International System of Units (SI), it is necessary first to establish a system of quantities, including a set of equations defining the relations between those quantities.

That which indicates the thing being measured is the reference part, and that which indicates the numerical result of the measurement is the number part:

1. The number part is called a numerical value. Take note here that the number part is also sometimes referred to by just the word "value".
2. The reference part is an entity called a measurement unit, which is defined (VIM, Section 1.9) as a "real scalar quantity, defined and adopted by convention, with which any other quantity of the same kind can be compared to express the ratio of the two quantities as a number".

> **NOTE:** *Quantity values are viewed as data by a supra-system.*

4.12 Expressing quantity (in natural language)

A quantity is the combination of a [sequenced] number and a [referential] unit, where the unit may be "pure" (base/fundamental), or a ratio of two relatable units (that describe some function present in the real physical world).

Quantity is expressed by three principal elements (of naming):

1. Identifiers (definite and indefinite) – identify a class of object ("thing") or an example of a class.
    A. **Indefinite identifiers** – indefinite articles (a or an) and the zero article.
    B. **Definite identifiers** – definite article (the), some pronouns (the demonstratives, possessives, anaphoric pronouns), and ordinal numbers. Note, the definite article "the" identifies the particular class.
2. **Quantifiers (definite and indefinite)** – express (or otherwise specifically identify) a quantity.
    A. **Indefinite quantifiers** – express uncertain quantities, such as: a few or a little; many or much; a great number or a great amount of; several; all; plenty of; a lot of; enough; some; any; every; no. The most common logical quantifiers are:
    B. "All" refers to the whole number, to all the elements or units.
    C. "Some" refers to a portion of the whole number, elements, or units.
    D. "Every" refers to all taken separately.
    E. "Each" refers to one example of a class of all.
    F. "Any" refers to all classes.
    G. "None" refers to no one of all.
    H. Definite quantifiers – are cardinal numbers.
3. Nouns of the following three types:
    A. Count unit nouns or countables.
    B. Mass nouns, uncountables, referring to the indefinite, unidentified amounts;
    C. Nouns of multitude (collective nouns).

The word 'number' is a noun of multitude, and stands for either:

1. A single entity, or
2. the individuals making the whole.

4.13 Classifying property-quantities: system quantity dependency

NOTE: *The type of quantity to be measured also impacts measurement requirements.*

Some quantifiable properties (i.e., quantities) are dependent on the quantity, size and extent of the system of which they are a part; and, others are not dependent on the system's quantity.

A quantity, as a sub-part of a system, can depend, or not depend, on the size of the system itself or the quantity (amount) of matter (mass) present in it. A quantity that does not depend on (i.e., is independent) the size of the system expresses an in-tensive type of property/quantity, and a quantity that does depend on the size or extent of the system expresses an ex-tensive property.

NOTE: *The term, tensive, means causing or expressing tension.*

In physics, a fundamental distinction is made in measurement between intensive and extensive quantities (here, a quantity is a property):

1. **Intensive property** - The magnitude of an intensive quantity is independent of the mass of its system (e.g., temperature, density, or pressure). Here, the word quantity may be replaced with property. As in, an intensive property is a physical property of a system that does not depend on the system size or the amount of material in the system. They are independent of the quantity of the system; it is independent of mass. They are independent of the size or extent of the system.
2. **Extensive property** - The magnitude of an extensive quantity is additive (like mass, volume, or energy). Here, the word quantity may be replaced with property. An extensive property is additive for subsystems. This means the system could be divided into any number of subsystems, and the extensive property measured for each subsystem; the value of the property for the system would be the sum of the property for each subsystem. They depend on the quantity of the system; it is dependent on mass (as a variable). They depend on the size and extent of the system.

    A. Mass (conserved quantity of matter measured by smallest unit Hydrogen 1).
    B. Extensive quantity: weight (e.g., the tension or pull of gravity).
    C. Un-/available energy, potential/used energy/ power (quantity in medium with technical release method). Stored energy/power density. Pressure is stored or active energy/power, mechanical by atom or electro-gravitic (EG-effect) by electro-mechanical (EM-object) rope.
    D. Available energy (heat interaction as entropy, and work interaction). Heat is molecular motion; the motion of molecules.

NOTE: *In some disciplines, there is no recognized type-distinction between intensive and extensive quantities.*

The fundamental 'unit of mass' is the hydrogen atom. The unit of mass is always the hydrogen atom, because from every hydrogen atom there is a single rope connected to every [other hydrogen] atom in the universe. A uranium atom for example, is 92 hydrogen atoms. Hence, there are 92 ropes, one for each atom, connected (via tension) to every other atom in the universe. Every hydrogen atom is a 'unit of mass'. Every hydrogen atom has a single rope connected to every other hydrogen atom in the universe. The more the atoms come closer together, the more the ropes fan out and pull is increased (i.e., the pull of "gravity", because of the fanning out of tense ropes). As two objects approach each other the atoms that are in each object is a fixed amount, and as they approach, the ropes interconnect each atom fan out. All atoms are already connected by electromagnetic ropes; these ropes can fan out and also be conduits for torsion waves (i.e., for light). Turning on an electromagnetic emission-light stimulates the ropes that are already connected between all atoms to torque at a higher frequency. Simply, all objects are only composed of groups of hydrogen (unit) atoms. Light is torsion along a physical entity, a two stranded rope, which is a physical object that binds any two hydrogen atoms. Light is a torsion of the rope, a torquing of the rope. Gravity is tension and the fanning out of the ropes between objects as they come into closer distance (proximity) with one another.

4.13.1 Quantity and quantity value in mathematics

> **NOTE:** *Mathematically, a quantity is a scalar. However, a vector or a tensor, the components of which are quantities, is also considered to be a quantity.*

From a mathematical perspective, a ‘quantity value’ is an algebraic term. In algebra, the concept ‘term’ represents a mathematical expression composed of two different parts: the number part (a.k.a., numerical coefficient) and the variable part (often notated as “x” or “y”). Similarly, the result of a measurement is, mathematically speaking, a ‘term’, for there is a number part and a unit (variable) part, which may be expressed [in notation] with constants and other variables, and equality symbols may be included to form equations from which [statistical] mathematical operations may be performed [to acquire more/new information].

The language of algebra has no meaning in and of itself. The theoretical mathematician deals entirely within the realm of the formal language and is concerned with the structure and relationships within the language. The applied mathematician or statistician, on the other hand, is concerned not only with the language, but the relationship of the symbols in the language to real world objects and events. The concern about the meaning of mathematical symbols (numbers) is a concern about measurement.

Magnitude (how much?) and multitude (how many?) are the two principal types of quantities, which may be further divided as mathematical and physical. The essential part of mathematical quantities consists of having a collection of variables, each assuming a set of values. These can be a set of a single quantity, referred to as a scalar when represented by real numbers, or have multiple quantities as do vectors and tensors, two kinds of geometric objects.

Quantities can be used as arguments of a function, variables in an expression (independent or dependent), or probabilistic as in random and stochastic quantities.

Number theory covers the topics of the discrete quantities as numbers: number systems with their kinds and relations. Geometry studies the issues of spatial magnitudes: straight lines, curved lines, surfaces and solids, all with their respective measurements and relationships.

Algebra operations are used for performing computations with quantities. Here, algebra operations allow for computations with uncertain values. These operations enable model-level simulations that consider data uncertainty and units (encoded through referential databases). In application, [physical] information processing requires a computational kernel for computing quantities.

> **NOTE:** *Quantities may be integrated with modeling language, as in the case of UML.*

4.14 Physical and non-physical quantities

> **INSIGHT:** *All physical measurements are geometric measurements.*

There are two categories of quantities as viewed from the physical, material perspective:

1. A **physical quantity** is a quantity that can be used in the mathematical equations of science and technology. Systems exist along a spatial-temporal continuum. Physical quantities are used in science and engineering because they are objective, and hence, may be used for logical inquiry and construction.
   A. The material properties of the surrounding world include: The existence, operation, placement, and composition of material (spatial-temporal) objects.
   B. Sud-divided into base and derived quantities.
2. A **non-physical quantity** is a quantity that cannot be measured by any mean or media. These quantities do not have magnitude of themselves. A non-physical quantity is a qualitative measure (and, non-physical quantities can have order). Some common example of non-physical quantities are: feelings, angriness, rudeness, etc. For these measurements (as in, the measurement of non-physical quantities), it is not possible to ensure traceability because of their exclusive nature as substantiated solely by the author. It is relevant

to note here that it is scientifically understood (in neurophysiological flow literature) that biology responds before psychology (or with psychology, in the case of highly intelligent consciousness). And, all aspects of biology and electromagnetism area measured as physical quantities (and not, non-physical quantities). Biology can be quantifiably measured.

A. The immaterial properties of the inner world include: anything experiential which can be described as feeling or e-motion. Non-physical quantities exist only in the mind of people either as reflections of properties of the real world, or in the form of people's own understandings (...to which the body responds faster than the mind, and can be accurately, traceably quantified).
B. Immaterial properties do not only exist in people's minds without any material dimension, in fact, the human body express in more or less optimal, or disturbed, functioning.
C. Sud-classified (sub-divided) into simple (a.k.a., base) and compound (a.k.a., derived) quantities. The simple physical quantities are constituent parts of the compound quantities, the latter being composed of a set of simple or compound quantities of a lower level.

INSIGHT: *The human organism cognates the material world by means of sense organs, through organoleptic measurements of its quantitative characteristics, while the immaterial world is perceived through measurements of its qualitative characteristics.*

When measuring physical quantities, standard reference objects and/or machines may be used, such as: length gauges (rulers) to measure length, and mass gauges (weights) to measure mass.

It is not accurate to say that non-physical quantities (qualities) only measure human opinion; they can also measure felt (experiential) fulfillment. Organisms express bio-electrical responses to particular environments. Therein, there is an ordering between suffering and well-being.

There are cases where the non-physical (immaterial) quantity being measured is a human opinion. Human opinion is subjective estimation. And, human opinion is largely dependent on an individual's specific life circumstances (social, decision, lifestyle, and material, without reference to an exist world). Opinion is largely dependent on exposure to information, personal preference, social influence, personal well-being, environmental factors, tastes, health, etc.

Here, the measurement of an immaterial property (opinion) comes down to a comparison of manifestations of this property, and, as a result, the question about when the property has manifested itself in a greater degree can be answered.

From the acquisition of opinions expressed about the manifestation of an immaterial property comes a comparative, quantitative estimate (i.e., a single measurement is taken on an ordinal scale). Here, one opinion is one measurement unit (along an ordinal [quantity] scale). And, the number of opinions is a quantitative characteristic of a non-physical quantity (a quality).

Note that besides felt human fulfillment and ecological well-being, human opinion has no fixed dimension, and hence, without the concepts of fulfillment and well-being, it is separated from a unified model of understanding and constructing.

4.15 *Classifying physical quantities*

Physical quantities can be classified in a number of ways:

1. **Electrical quantities:** resistance, capacitance, permeability, permittivity (voltage, current, inductance, electrical power, electrical energy).
2. **Non-electrical quantities:** fluid pressure, displacement, torque, temperature, area, volume.

The concept of a physical quantity can be classified according to whether it is electrical or non-electrical:

1. **Length-type quantities:** The quantities diameter, circumference, and wavelength are generally considered to be quantities of the same kind, namely of the kind of quantity called length.
2. **Energy-type quantities:** The quantities heat, kinetic energy, and potential energy are generally considered to be quantities of the same kind, namely of the kind of quantity called energy.

Note: *Many traditional economists hold the view that utility is measured quantitatively, like length, height, weight, temperature, etc. This concept is known as cardinal utility concept. On the other hand, ordinal utility concept expresses the utility of a commodity in terms of 'less than' or 'more than'.*

4.15.1 The dimensional property attribute of [classified] physical quantities.

A quantity as an information data point may be either a scalar quantity or a vector quantity. In physics, there are two principle types of physical quantities [that can be measured]: scalar quantities and vector quantities. These two categories are typified by what information they require. Scalars require one piece of information (a number), and vectors require two pieces of information (a number and [coordinated] direction). A scalar measurement is the measure[d result] of a scalar quantity, and a vector measurement is the measure[d result] of a vector quantity.

4.15.2 Scalar – magnitude only (a scalar represents the magnitude or size of a quantity)

A scalar variable is a variable that holds an individual value (single number). A scalar number is a number used to measure some quantity to any desired degree of accuracy.

1. **Scalar quantities** - Scalars are used to describe one dimensional quantities, that is, quantities which require only one number to completely describe them. A scalar quantity represents a physical quantity specified by magnitude. Scalar [quantities] are physical [quantities] represented by a single number [magnitude] and no direction. Scalars can be represented by a |x| matrix. In visualization, scalars are numbers.
   A. Examples include, but are not limited to: temperature, time, height, speed, mass, volume, location along a line (1D). Position and distance are scalars, because there is no direction.
   B. one scalar • another scalar = a scalar
   C. one scalar • a vector = a vector
2. **Scalar measurement** – a numerical descriptive signifier of a quantity, magnitude, or size of a bounded sensation. A scalar measurement can be represented with a number alone (with relevant units). It describes a quantity, magnitude or size of a measurement alone. For example, mass and temperature are scalar measurements.

4.15.3 Vector – magnitude and direction (a vector represents the magnitude, size and direction of a quantity)

A vector variable is a variable that holds more than one individual value.

1. **Vector quantities** - Vectors are used to describe multi-dimensional quantities. Multi-dimensional quantities are those which require more than one number to completely describe them. Vectors, unlike scalars, have two characteristics, magnitude and [a systematically coordinated] direction. The magnitude of a vector is its "length" (or other quantity in some units). Vector quantities are [not necessarily physical quantities and] are represented by a number (magnitude) and a direction. The direction is usually given in terms of some angle. Vectors can be represented by a lxA ([4 2], row vector) or an nxl ([4 / 2], column vector) matrix. Vectors are one dimensional. In visualization, vectors are arrows.
   - Examples include, but are not limited to: location in a plane (2D), location in space (3D), velocity, acceleration, force, displacement, momentum.
   - one vector • another vector = a vector.
2. **Vector measurements** – a numerically descriptive signifier of the relationship between the two fundamental dimensions of magnitude (size or quantity; inertia and acceleration) and direction (force and motion). Vectors are a form of measurement that conveys both magnitude (size or quantity) and direction (with relevant units). Velocity is a good example of a vector measurement (the object moves at 3m/s to the East). It is not to be confused with speed, which is scalar (e.g., the object moves at 3m/s). When visualizing vector measurements, an arrow is a common symbol for the vector.

Vectors (vector numbers) can be added together in ways that scalars (scalar numbers) cannot.

> **NOTE:** *A vector space is defined as a set of vectors, a set of scalars, and a scalar multiplication operation that takes a scalar k and a vector v to another vector kv.*

The term "scalar" comes from linear algebra, where it is used to differentiate a single number from a vector or matrix.

4.15.4 Standard scalar measurement

In standard scalar measurement, points exist along a principal standard measurement scale, the scale of cardinal numbers. The following are ways of taking a standard scalar measurement; if, for example, "you" measure the width of "your" desk, "you" take a tape measure and align it with a point on the desk, and then, "you" count off the number of centimeters or inches. Or, if "you" measure the outdoor temperature at the present moment, "you" take a thermometer outdoors and count off the number of degrees Celsius or degrees Kelvin. If "you" are sitting in a room measure the number of humans in the room, "you" count them. This type of measurement is known as standard scalar measurement, since each individual instance of it results in a numerical value that refers to a point on some particular standard measurement [conceptual unit] scale, such as: inches, centimeters, degrees Kelvin, degrees Celsius, pints, liters, bushels, grams, ounces, light years, volts, ohms, etc. A standard scalar measurement is a point on a standard measurement scale.

1. **Absolute scale**: When measurement involves simply counting out the number of a set of items or events according to the series of cardinal numbers (i.e., one, two, three, four, etc.), then the scale of measurement is otherwise known as

an absolute scale. An absolute scale is a system of measurement that begins at a minimum, or zero point, and progresses in only one direction. An absolute scale begins at a natural minimum, leaving only one direction in which to progress. When counting with cardinal numbers (0,1,2,3,4,5,...), the cardinal number set represents the scale. An absolute scale can only be applied to measurements in which a true minimum is known to exist.

A. Absolute scales are typically used in science and anywhere precise values are needed in comparison to a natural, unchanging zero point.
B. Measurements of length, area and volume are inherently absolute, although measurements of distance are often based on an arbitrary starting point.

2. **Relative (or arbitrary) scale**: All other commonly recognized measurement scales are relative, in the sense that they are designed to measure, not the absolute number of items or events, but rather the 'magnitude' of some particular attribute (e.g., length, width, weight, temperature, velocity, electrical potential, etc.) relative to the units [of some particular scale that has been designed, or has evolved, for taking the measure of that attribute].

In concern to several important measurable physical quantities:

1. Weight can be absolute, such as atomic weight, but more often they are measurements of the relationship between two masses, while measurements of speed are relative to an arbitrary reference frame.
2. Temperature has a known minimum, absolute zero (where all vibrational motion of atoms ceases), and therefore, can be measured either in absolute terms (kelvins or degrees Rankine), or relative to a reference temperature such as the freezing point of water at a specified pressure (Celsius and Reaumur) or the lowest temperature attainable in 1724 (Fahrenheit).
3. Pressure is a force that can be measured absolutely, because the natural minimum of pressure is total vacuum. Pressure is frequently measured with reference to atmospheric pressure rather than on any absolute scale, relative to complete and perfect vacuum. And, with measurements of things like blood pressure or tire pressure, a measurement relative to air pressure is a better indication of "burst pressure" (damage threshold) than an absolute scale.

4.16 Conceptual composition of 'quantity' by attribute

The concept of a [measurable] 'quantity' is sub-composed of the following attributes (every quantity may be categorized according to these four sub-conceptions):

1. **Measure[able quantity]** (it has a physical referent): The physical variable. For example, molecular density. If something has a quantity, then it is measurable.
2. **Dimension** (it has a dimension or is dimensionless): A dimension is a measure of a physical variable (without numerical value[s]). It could be said that a dimension refers to the extent of all possible units of a given type. For example, length is a dimension. The terms measurable quantity and dimension are often synonymous.
3. **Unit** (it has a unit name-quantity): a unit is a logical process ("way") to assign a number (or, "measurement") to that dimension. A unit is a name (and description) of the value being measured for. For example, the meter is a unit of length.
4. **Value** (it has a numerical value): the number, logically sequenced to represent the 'magnitude' or 'amount' of an instance of the physical variable (a pattern). For example, when there are three interval patterns of the category meter, then the value is 3.

NOTE: *There are 7 quantities on which all international[ly standardized, ISO] quantities are based. Yet, a system of three base units, consisting of units of mass, length, and time, is sufficient to express the units of all other mechanical quantities.*

4.17 Measureable quantities

NOTE: *The concept 'measure' conveys the idea that measurement involves a chain of coherently connected relationships, which start the sequencing of their relationships at a source, and with which ("against") all new information of a like kind is compared (for patterns). The source of the chain of conceptual relationships is called its: base, fundamental, or axiomatic conception.*

There are two (or at least one, which becomes two) axiomatic/base conceptions of a quantity in science and measurement:

1. **Base/fundamental quantities** are those quantities that are common to any object or event. For example: length, mass, charge, time. A base quantity is a conventionally chosen quantity. No base quantity can be expressed as a product of powers of the other base quantities. Hence, it is

said that base quantities are mutually independent (axiomatic).

   A. **System of base quantities** – where no member of the subset can be expressed in terms of the others. In terms of expression, every other quantity can be conveniently expressed in terms of base quantities. Normally, the symbol of a quantity is written in italics, and that of its dimension in capital letters.

2. **Derived quantities** are quantities formed by combining two or more base quantities (using multiplication or division, algebra). For example, area (length x width), volume (length x width x height, a3), speed (distance/time). A quantity in a system of quantities, which is defined in terms of its base quantities.

Or, the conception of physical quantity could be viewed as follows:

1. Base axiom quantities.
2. Derived mathematical operational quantities.

A complete system of quantities includes both base and derived quantities.

4.17.1 The dimensional attribute of quantity

Dimension refers to the name of the quantity being measured. The “dimensions” of a quantity refer to the basic/fundamental composition (“nature”) of the quantity (i.e. how the quantity is related to the base/fundamental quantities of existence: length, mass, time, charge, etc). Every measurement consists of an empirical comparison of dimensions.

In concern to dimensionality, the measurement of a physical quantity may be classified as one of the following:

1. **Dimensionless with units** – has units, but no dimensions.
   A. Quantities having units, but no dimensions include, but are not limited to: plane angle, angular displacement, solid angle. These physical quantities possess units, but they do not possess dimensional formulas.
2. **Dimensionless without units** – has no units, and no dimensions.
   A. Physical quantities having no units, cannot possess dimensions: trigonometric ratios, logarithmic functions, exponential functions, coefficient of friction, strain, Poisson’s ratio, specific gravity, refractive index, relative permittivity, relative permeability. All these quantities neither possess units nor dimensional formulas.
3. **Dimensioned with units** – has units and dimensions.
   A. Quantities having both units and dimensions include, but are not limited to: area, volume, density, speed, velocity, acceleration, force, energy, etc.

A dimensionless quantity is a quantity to which no physical dimension is applicable. It is also known as a “bare” number, “pure” number, or a quantity of dimension one. A “pure” number is a number with no unit attached. For example, 2 is a dimensionless quantity, 2 apples, is not (as in, the dimension is “fruit’). Other dimensionless quantities include, for example: 1, i, π, e, and φ, 1/φ, and 1/φ-3 or φ3.

All “pure” numbers are dimensionless and unitless quantities, for example 1, i, π, e, and φ. A “pure” number is a kind of a number that has a dimensionless quantity, and does not have a physical unit. Note here that the use of the word “pure” as a qualification of number, is not useful, because the numeric portion of a dimensioned number is also “pure” in the sense that it is a value.

Presently, given what is known, there are between five and seven primary dimensions (or dimensional [physical] quantities) to material reality. Primary (a.k.a., basic or fundamental) dimensions are defined as independent or fundamental dimensions, from which other dimensions can be obtained. In other words, these dimension are axiomatic to our conception of the dimension of something real.

Hence, remember that when working in mass the base standard to which every other standard and mass (weight) measurement is being compared, is the *kilo*+gram (kilogram), and not the *null*+gram (gram). The base unit is a [prefix] multiple of the one unit, kilo-.

4.17.2 Unit attribute

Whereas a quantity is a measurable property for a phenomenon, body or substance, a measurement unit is chosen by convention as the reference to which measurements of that property refer.

The presence of the ‘unit’ signifies the type of relationship that exists between the number part of a measure (the ‘value’) and the dimension part of a measure. “Units” refer to specific ways of reporting (or denoting) a quantity.

A unit is the label of a scalar quantity, defined and adopted by cooperation/convention, with which any other quantity of the same dimensional kind can be compared to express the ratio for the two quantities as a number.

> **NOTE:** *The ratio of two quantities of the same dimensional kind is a pure[ly dimensionless] number.*

The measurement unit allows for the [numerical] value [of the quantity] indicated for an object or event, to be compared with the value indicated for the measurements’ reference dimension (e.g., mass, length, etc.). The reference dimension is the reference used to calibrate the measurement system (i.e., the relative source of all standard comparisons).

The measuring unit is the relational signifier assigned to the numerical measure, to identify it out of all potential possible [unitized] representations.

Corresponding to a system of quantities, where there are base and derived quantities, there is also a system of corresponding units, where there are base and derived units. A system of [measurement] units is a set of measurement units corresponding to every quantity in the system of quantities. The set of system units consists of:

1. **Base units** (a.k.a. system of base units)
2. **Derived units** (a.k.a., system of derived units)
3. **Dimensionless quantities** (or, quantities of dimension 1)

For every base 'quantity' (as a concept), there exists a base 'unit'. Base units can be used to build and/or express newly "derived" units (Read: derived units). The principal set of units (also sometimes viewed as a subset of units) from which all other units are expressed, is called a [system of] base units.

> **NOTE:** *The magnitude of any given quantity can be expressed by (i.e., associated with) a number equal to the ratio of the quantity to its unit.*

The following are important principled clarification on the conception of base units:

1. There is only 1 base [standardized] unit for a quantity. In every system of units there is only one base unit for each base quantity. For example, in the SI, *the metre is the base unit of [the dimensional quantity] 'length'*. The centimeter and the kilometer are also units of length, but they are not base units in the SI.
   A. **A [unit] conversion factor** – is a ratio of two measurement units of quantities of the same kind. For example, km/m=1,000 and thus, 1km=1,000m; here, 1/1000 is the conversion factor (ratio).
   B. In the SI, there are seven base [quantity] dimensions. Mass is the only base/fundamental dimensional quantity whose base [standardized] unit is a conversion factor, the kilogram (Read: kilo as a 1000 conversion factor combined (+) with 'gram' as unit mass). The other base dimensions are standardized to a non-conversion factor base. In other words, notice how length is meter, time is second, amount of substance is mole, but mass is kilogram. Mass is not standardized to a zero-conversion factor.
2. A base unit may serve for a derived quantity of the same dimension. For example, when rainfall is defined as volume per unit area, and the meter is used as a coherent derived unit (in the SI).
3. For any number of entities, the number one, symbol "1", can be regarded as a base unit in any system of units.

> **NOTE:** *A system of three base units (mass, length, and time) is sufficient to express the units of all other mechanical quantities. However, a system of four base quantities is required to express each and every other quantity.*

A particular quantity "can" be reported in many different kinds of units, but it will always have the same dimensions. It is best to have a unified measurement model where a particular quantity can only be reported with one particular kind of unit (that may be orderly scaled itself), forming a 1 to 1 matching (pairing) between units and dimensions. For example, in early 21st century society, force (which can be expressed F=ma) has dimensions of mass x length/time2. Here, force can be expressed in different units, which leads to confusion and is a sign of a lack of social cooperation and conceptual integration: Newtons, ergs, pounds-cm per square hour, pressure, force, and torque.

4.17.3 Quantities of the same kind

Quantities of the same kind will have the same unit, but two quantity values having the same unit do not have to be of the same kind. For example, the unit of 'mass density' and of 'mass concentration' is kgm-3, but these are not quantities of the same kind. Similarly, the measurement unit of both frequency and activity of radio nuclides is s-1, but they are not quantities of the same kind. The unit in each [conceptually modeled] case is given a unique unit label, namely frequency is hertz (Hz) and the activity of radio nuclides is Becquerel (Bq).

4.17.4 Unit prefixes (unit multiple prefixes)

Prefixes denote smaller or larger multiples of the unit. Because the continuum of each physical unit is so large, notation via multiple(s) becomes necessary for human cognition. A multiple of a unit is indicated by a prefix. The prefixes designating the multiples and submultiples of physical units (e.g., length, frequency, power) are: deca-, hector-, kilo-, mega-, ...

4.17.5 Value attribute (number)

Here, the 'value' is the quantity's numerical association, and the 'quantity value' is the value (number) and unit (reference) together. The quantity's value is the measure's number, and the reference is the measurement unit. To be more specific, a 'quantity value' may be expressed as either:

1. A number and a measurement unit (the unit one is

generally not indicated for a quantity of dimension one).
2. A number and a reference to a measurement procedure.
3. A number and a reference material.

A 'quantity' value maintains the following characteristics:

1. The number can be real or complex.
2. A quantity value can be represented in more than one way.

The size (magnitude) of a quantity is expressed as a number accompanied by a measurement unit, and if appropriate, by additional reference to a measurement procedure or a reference material. Here, the term 'quantity value' refers to a number "multiplied by" its tagged unit (or reference), forming a mathematical 'term' upon which calculation operations are possible.

Clarification: The term "true" value is sometimes used in common parlance. The concept of a 'true value' has been redefined in metrology. It used to mean: The true value (of a quantity) is the value which characterizes a quantity "perfectly" defined, in the conditions which exist when that quantity is considered. The concept of a 'true quantity value' now means: a quantity value consistent with the definition of a quantity.

4.18 Conceptual systems model of measurement

Measurement may be represented as a logical [conceptual] information system with inputs, operational processes, and outputs.

1. Inputs [static]: logic, definitions, algorithms, reference standards, units. Answers the question, What is required for measurement?
2. Inputs [dynamic]: quality (property, attribute, characteristic), quantity, measurand. Answers the question, What is being measured?
3. Processes: calibration, measurement. Answers the question, How does measurement occur?
4. Outputs: quantity value (a.k.a., quantity or value), indication, result, term. Answers the question, What is the output of measurement?

4.19 Input (static): Measurement standards

Any measurement requires a measurement standard ("etalon"), which is the embodiment of the definition of a given quantity, with state quantity value and associated measurement uncertainty, used as reference.

There is a hierarchical mapping to the concept of a standard [of comparative] reference. The primary (base) standard (in the hierarchy) is checked (i.e., calibrated) to be the same value as new standard at one level lower in the mapping chain. This new, second (and not primary) standard can be used for direct comparison, or a new lower level (third) standard could be checked (i.e., calibrated), and the process continues. All standards are pre-aligned or pre-calibrated, except for the primary, which acts as the standard for all calibrations.

Working/operational level standards are lower in the hierarchy, and that which is closest to a pure conception of the object/event being measured is higher in the hierarchy. Herein, working-level standards are, in turn, calibrated against higher-level standards, which reference (trace, map, or have been demonstrated to align) back to a primary [procedural unit] system.

> **NOTE:** *A proper chain of traceability must include a statement of uncertainty at every step.*

The following are characteristics of measurement standards:

1. The primary standard is the physical representation of the units defined in the system of units.
2. In measurement, standards define the units and scales, which allow for comparison of measurements made in different times and places.
3. Measurement standards are "devices" (tools, processes, and objects) that represent the standard system's unit (e.g., SI) in a measurement.
4. A [measurement] standard is a fundamental reference for determining the value of new information moving into a measurement system.

The four common definitions of a measurement standard are:

1. Measurement standards are those devices, artifacts, procedures, instruments, systems, protocols, or processes that are used to define (or to realize) measurement units, and on which all lower echelon (less accurate) measurements depend.
2. A measurement standard may also be said to store, embody, or otherwise provide a physical quantity that serves as the basis for the measurement of a new quantity of some thing [that the measurement standard accounts for].
3. A standard is the physical embodiment of a measurement unit, by which its assigned value is defined, and to which it can be compared for calibration purposes.
4. A standard is a unit of known quantity or dimension to which other measurement units can be compared.

Multiple measurements of a similar category or thing require a 'standard' to which the measuring instrument and/or observer will refer when determining the measure.

> **NOTE:** *Any quantity used as a standard of reference is a unit of measure.*

There are two primary measurement standard categories:

1. **The base/fundamental physical [standard of] reference** – a fundamental physical constant is used as the reference. The real physical world is the metric.
2. **The derived [standard of] reference** – something has been designated by a conscious observer or decisioning system to act as a reference standard. Some object (or digital process) is used as the reference standard. The fundamental physical referent is the reference.

When the word 'magnitude' is used, then there are two measurement system magnitudes:

1. **Fundamental magnitudes (fundamental measurement procedures)** – magnitudes determined from measurement procedures that satisfy the conditions of additivity and do not involve the measurement of any other magnitude. Here, ordering and concatenation operations are active.
2. **Derived magnitudes (derived measurement procedures)** – magnitudes that can only be determined through their relations to other, fundamentally measurable magnitudes. Note here that additivity is not necessary for a measurement.

When the word 'quantity' is used, then there are two measurement system quantities:

1. **Fundamental quantity (a.k.a., base quantity, basic quantity, or metric quantity)** – defined by specifying a[n operational] measurement process.
    A. Fundamental base[-ic] system of dimensional units [of measure-ment]
2. **Derived quantity** - Defined by algebraic[ally expressed] combination of base units.
    A. Derived/defined units of relational dimensions [of measure-ment]

4.20 Input (dynamic): The measurand (the measured variable)

The measurand is a[n object] name and a description of a (particular) quantity intended to be measured) as the first step in the process of measurement. This step or phase is known as the "problem of definition". The measurand is a description of the specific quantity intended to be measured. The specification of the measurand should be sufficiently detailed to avoid any ambiguity. The measurand is not just another name for analyte. Analyte is the component represented in the name of a measurable quantity, whereas measurand refers to a specific quantity to which quantity values are expected to be attributed by means of a measurement.

The measurand is also sometimes called the 'state name variable'. Technically, that which is being measured is the state of a system, which have been given a [logical] name, and represents a variable (static or dynamic) in the operation of the system. Wherein, more information is being gathered about the system by inquiring into a bounded sub-set of the system.

Hence, a measurand is a particular quantity subject to measurement. Measurand is the [label given in the context of measurement to the] quantity intended to be measured. The measurand is the measured variable.

The problem of clearly defining the measurand ("that which is measured") is called the problem of definition, and it has two parts, one simple and one rather subtle and complex.

The first and simplest part of the phase of definition, relates to the identification (pattern recognition, categorization) of the quantity measured. In principle, all that is required is to provide sufficient information to allow the measurement to be repeated, or otherwise predicted similarly. Herein, influences may also have to be specified.

The second and most difficult part of the problem of definition relates to the technical definition of the attribute that is being measured. In the case of 'temperature', what is the meaning of 'temperature'? The temperature of a system is strictly defined only in conditions of thermal equilibrium, that is no net flow of heat between any of the components of the system.

Measurements with definition problems (i.e., incoherencies) are often the source of great argument. The telltale sign of a definition problem is a measurement where the result seems to vary with the measurement technique.

The standard definition of the term 'measurand' was once different. In fact, the former definition of measurand was, "The quantity subject to measurement." It could be said that a quantity is experimentally 'subject' to the interaction with a measuring instrument (in part, because the measurement instrument is designed and applied with an intent).

4.21 Measurement processes

In addressing measurement problems, it is necessary to have a conceptual model of the measurement process.

4.21.1 Calibration

Calibration is comparison of a measurement device against a standard and adjustment if necessary. Calibration is the process of checked some quantity against a known standard, and adjusting the quantity [to match the known standard] if necessary. Calibration is a comparison of an item to a standard that is closer to the primary (or the primary) standard (e.g., SI), also known as a higher-level standard. Adjustment of the lower-level standardized device is part of the operation required (as in, if the lower-level device does not align correct). Such comparison requires traceability of the calibration. Traceability is defined as an unbroken chain of comparisons to National or international standards (e.g. standards maintained by NIST), AND stated uncertainties at each step. The traceability of course needs to ultimately go to SI.

Calibration is a set of operations that establish, under specified conditions, the relationship between values of quantities indicated by a measuring instrument or measuring system, or values represented by a material measure, or a reference material, and the corresponding values realized by the standard.

Calibration can be further defined:

1. **Calibration** - operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication.
2. **Calibration** is the procedure of establishing a relation (adjusting or checking) a scale so that the readings of the (lower-level standard) instrument conforms to an accepted standard (higher-level standard).
3. **Calibration hierarchy** - sequence of calibrations from a reference to the final measuring system, where the outcome of each calibration depends on the outcome of the previous calibration.

The results of a calibration include:

1. The result of a calibration permits either the assignment of values or measurands to the indications or the determination of corrections with respect to indications.
2. A calibration may also determine other metrological properties such as the effect of influence quantities.
3. The result of a calibration may be recorded in a document sometimes called a calibration certificate or a calibration report. (International Vocabulary of Basic and General Terms in Metrology)

In a calibration experiment, the analyst typically prepares a set of calibration solutions (also known as, calibrators, standard solutions, or working standards; i.e., a set of measurement standards). When measured, each of them gives rise to an indication (signal, response). The relation $y = f(x)$ between the indication and the corresponding quantity value is called a calibration curve. The uncertainty of the calibration will include contributions from the uncertainty of the measurement standards, variation in indications, and limitations in the mathematical model when establishing the relation $y = f(x)$.

Calibration and verification are carried out on measurement equipment to determine (and adjust if necessary) their accuracy.

In application, calibration is the process of mechanically or electronically setting the parameters for a measuring instrument.

In concern to calibration, there are two types of measurement instruments (devices, equipment, tools, etc.):

1. **Adjustable** – The instrument's operation may be changed (adjusted) to result in different measurement readings (indications) for the same quantity under the same conditions. Adjustable instruments are calibratable after their creation. Calibration may occur on adjustable measuring instruments after their creation (e.g., micrometers, scales, verniers, etc.). Because the accuracy of adjustable instruments will drift naturally over time, these instruments must be periodically calibrated against a higher-standard.
2. **Non-adjustable** – The Instrument's operation cannot be changed (i.e., it is non-adjustable). Non-adjustable instruments are calibrated once during their creation, which cannot be changed without re-creating the instrument.

Calibration process ("pipeline") involves:

1. Identification.
   A. Purity of substance.
2. Verification.
   A. Secondary reference materials (RMs) and controls.
3. Recognition.

A measurement standard is the prerequisite of any calibration, which is the operation that establishes a relation between the quantity value provided by a measurement standard and corresponding device outputs (Read: indications), with associated uncertainties. A calibration may be expressed by a calibration diagram, calibration curve, or calibration table. It can be an additive or multiplicative correction.

> **Note:** *Calibration should not be confounded with the adjustment of a measuring system, sometimes called autocalibration, which is the set of operations (zero, offset, and span or*

gain adjustment) performed on a measuring system so that it provides prescribed outputs (indications) corresponding to given values of a quantity to be measured. Therefore, in practice, the best performance will be obtained by a first calibration to determine the approximate magnitude of the adjustment needed, then the adjustment, then a final recalibration.

Calibration is an operation. Under specific conditions, it has a first step that establishes relations between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties. And, in a second step, use this information to establish a relation for obtaining a measurement result from an indication.

A calibration measurement is traceable to NIST when the parameter being measured is clearly defined:

1. **An unbroken chain:** Comparisons from the measurement result reported by a laboratory all the way back to a nationally recognized primary standard (NIST).
2. **Documentation** – Every link in the chain must be performed according to documented procedures, and the results of these procedures must be documented. This documents the measurement system.
3. **Competence** – Laboratories performing steps in the chain must have demonstrated competence as demonstrated by accreditation to ISO 17025.
4. **Measurement assurance** – The laboratory must systematically establish the status of reference materials and working standards at all times pertinent to a given result.
5. **Measurement uncertainty** – The measurement uncertainty must be determined for each link in the traceability chain, and the measurement uncertainty must be reported for the final measured result. Uncertainty reporting is mandated for ISO accredited calibrations.

4.21.2 Measurement equipment calibration

When uncertainty is relevant (in a decision), the uncertainty reported by a measurement device system (or calibration certificate) is necessary to calculate the uncertainty of measurement.

The calibration system metadata (calibration certificate) must contain specific information to fulfill the purpose of supporting traceable measurement:

1. Identity of device.
2. Location of device storage.
3. Location of device usage.
4. Identity of device user.
5. Measurement data.

The following may affect performance of measurement equipment and create uncertainty with their reliability:

1. Drift.
2. Environmental factors.
3. Component age.
4. Shock.
5. Misuse.

For Community Habitat Service System operations, the equipment must be properly:

1. Monitored.
2. Maintained.
3. Used.
4. Stored.
5. Transported.

4.21.3 Conditions for calibration

Calibration requires traceability. Traceability requires:

1. An unbroken chain of comparison to National or international standards; and
2. Stated uncertainties at each step.

NOTE: *The only way to "prove" that measurements are right (i.e., there is a "right measurement"), is to prove that their uncertainty is low enough to allow the desired conclusions to be drawn from the results, such as whether or not a workpiece meets its specification.*

4.22 Measurement output

Two types of measurement outputs include:

1. **Instrument indications (or "readings")** - these are properties of the measuring instrument in its final state after the measurement process is complete.
2. **Measurement outcomes (or "results")** - these are knowledge claims about the values of one or more quantities attributed to the object being measured, and are typically accompanied by a specification of the measurement unit and scale and an estimate of measurement uncertainty.

4.22.1 Uncertainty

Uncertainty is a parameter associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand.

4.22.2 Properties of the output (result) of measurement

Accurate measurement requires the following principle enablers (and accompanying tools):

1. **Traceability** – enables comparison over time and place.
2. **Uncertainty** – enables meaningful comparison of results.
3. **Confidence** – enables meaningful interpretation of results.
   A. Results are only useful when the same pattern ("thing") is compared.
   B. Where uncertainty is assessed qualitatively, it is characterized by providing a relative sense of the amount and quality of evidence (that is, information from theory, observations or models indicating whether a statement or proposition is true or valid) and the degree of the understanding.

4.22.3 Traceability

Measurement includes an experimental (primary method) and representational component (additional standards), the latter implying the requirement for metrological traceability.

Metrological traceability is the property of a measurement result, whereby the result can be related to a reference [unit] through a documented unbroken chain of calibrations (comparisons), all having stated uncertainties. Measurability requires [metrological] traceability. Only measurement results are traceable.

There are five sub-conceptions to the definition of [metrological] traceability:

1. An unbroken chain (or relationships)
2. An uncertainty of measurement
3. Documentation
4. Reference to the formal standard (SI units)
5. Calibration intervals

4.22.4 Claiming traceability

The provider of the result of a measurement is responsible for supporting its claim of the traceability of that result or value.

To support a claim, the provider of a measurement result must document the measurement process or system used to establish the claim and provide a description of the chain of calibrations that were used to establish a connection to a particular specified reference. There are several common elements to all valid statements or claims of traceability:

1. A clearly defined particular quantity that has been measured.
2. A complete description of the measurement system or working standard used to perform the measurement.
3. A stated measurement result, which includes a documented uncertainty.
4. A complete specification of the reference at the time the measurement system or working standard was compared to it.
5. An 'internal measurement assurance' program for establishing the status of the measurement system or working standard at all times pertinent to the claim of traceability.
6. An 'internal measurement assurance' program for establishing the status of the specified reference at the time that the measurement system or working standard was compared to it.

The user of the result of a measurement is responsible for assessing the validity of a claim of traceability.

4.22.5 Measurement as a feedback calculation sub-systems

In the context of decisioning, there are [at least] two feedback calculation sub-systems:

1. Measurement systems are used to assess existing entities by numerically characterizing one or more of its attributes.
2. Prediction systems are used to predict some attribute of a future entity, involving a mathematical model with associated prediction procedures:
3. Deterministic prediction system – the same output will be generated for a given input. The output of deterministic models is fully determined by the parameter values and the initial conditions.
4. Stochastic prediction system – the output for a given input will vary probabilistically. Stochastic models involve some inherent probability ("randomness"), wherein the same set of parameter values and initial conditions will lead to more than one output.

Measures and predictions may (sometimes, must) be validated. Validation routines determine if:

1. A measure is valid if it accurately characterizes the attribute it claims to measure.
2. A prediction system is valid if it makes accurate predictions.
3. Validation is defined in ISO 9000 section 3.8.5 as "confirmation, through the provision of objective evidence, that the requirements for a specific intended use or application have been fulfilled".
4. The process of ensuring that the measure is a proper numerical characterization of the claimed attribute by showing that the representation condition is satisfied.
5. The accuracy of prediction systems are validated through the process of establishing empirical

means (i.e., by comparing model performance with known data in the given environment.

4.23 Measurement operations for the supra-information system

If supra-system information processing occurs, then the value and its accompanying variable become data (polynomial terms) in mathematical operations.

The result of statistical operations performed on numerical measurement values is the production of additional numerical values.

4.23.1 Utilization and/or calculation

The output of a measurement may be useful in itself, or it may have statistical calculations carried out on it to increase the amount of information available.

The two most important and common statistical calculations are:

1. **Averaging** to determine the arithmetic mean.
2. **The standard deviation** for a set of numbers. The standard deviation of a set of measurements is an indication of how much the measurements vary from their average value. The standard deviation is the 'root mean square' of the deviations.

The following procedure will provide the standard deviation (root mean square) of a set of numbers:

1. Square all the deviations from the mean.
2. Add them together.
3. Divide by the number of measurements.
4. Determine the square root.

4.23.2 Validation and Verification

Validation is defined in ISO 9000 section 3.8.5 as:

- Confirmation, through the provision of objective evidence, that the requirements for a specific intended use or application have been fulfilled.

Validation ensures measuring processes are aligned. Validation is the process of determining whether functional and/or performance requirements are met.

Validation has a secondary meaning; it also means ensuring that whatever is verified or calibrated is fit for the intended use. Hence, systems can be validated, measurements can be validated, and tools can be validated for intended uses.

Here, measurement validation leads to either a verified or refuted initial measurement(s):

1. Verification of the previous measurement.
2. Contradiction of the previous measurement -- discover that there is a different measurement available.

Verification means verifying something, such as repeating a measurement process or using another method to check that the results are aligned with what was previously measured.

Note here that there is no need to encode the concept of defense, and hence, there is either verification or contradiction, and not, verification or refutation. Refutation comes from the encoding of defense, and contradiction is simply logical incompatibility.

4.24 The method of measurement

Measurement involves processes, which are also known in some applications as methods. As a method, measurement involves the acquisition of [quantity value] information about the properties of objects (or events); and hence, about a larger and more simplex reality.

There are many measurement methods, because existence can be categorized and inquired into in many ways. For different scientific disciplines, there are different methods. For example, the thermoelectric effect is a measurement method of two meanings: temperature, and the infrared spectroscopy of molecular concentration.

> **TERMINOLOGY:** *A '***reference measurement procedure***' is a process accepted as providing measurement results that fit for their intended use.*

4.25 Measurement as "an approach"

Measurement is a set of operations having the object of determining a value of a measurement result, for a given attribute of an entity, using a measurement approach. A measurement approach is a sequence of operations aimed at determining the value of a measurement result. A measurement approach is either:

1. A measurement method,
2. A measurement function, or
3. An analysis model.

4.26 Methodical measurement categorization

Measurement is/involves a system that processes information to answer a question or otherwise determine a relational value. Herein, there are various ways/modes of categorizing the process by which information about an unknown is acquired.

4.26.1 Measurement categorized by the number of [standard] conversions

There are three modes (methods) of measurement, categorically separated based upon the number of conversions present. A "conversion" refers to a 'signal conversion', whereupon a signal from one source is converted by a system into another signal readable by another system (in a network of signal conversion systems). Here, the signal represents information (that may be useful in our fulfillment) about a surrounding real world.

1. **Primary measurement (direct method, no conversions)** – direct observation and comparison. Does not involve a conversion. For example, compare a length of something along a measuring meter stick, and record the observation.
2. **Secondary measurement (1 conversion indirect method)** – involvement of one conversion. For example, the measurement of a thermometer by someone -- a thermometer changes in relationship to its environment (1st conversion), and then, the observer reads the thermometer. Here, the physical system sends a signal to the thermometer (1st conversion), and the thermometer sends a secondary signal to the conscious observer.
3. **Tertiary measurement (2 conversion indirect method)** – involvement of two conversions. For example, the measurement of a rotating shaft by someone using an electronic display -- a rotating shaft changes in relationship to its environment (signal output), whereupon an electromagnetic system perceives the rotations (1st conversion). The electromagnetic system then outputs the reading as a (2nd) signal to a digital display (2nd conversion). From there, a conscious observer perceives the digital measurement of the rotating shaft.

4.26.2 Measurement categorized by type of comparison

There are two principal methods of measurement; one which involves humans, and one which does not involve humans (or, at least, human involvement is superfluous to the observation and value determination). When a human's sensory system is involved in the comparison (measurement), then the method is known as direct. When human's sensory system is not involved, it is known as indirect.

1. **Direct (human sensation)** – A unknown quantity is visually compared, directly with another of the same pattern. Human senses are necessary for measurement. Here, results are obtained from direct comparison. Because a human is involved, the results are not always accurate.
2. **Indirect (no direct human involvement)** – An unknown magnitude is measured by an instrument with a referentially standardized procedure. The indirect method consists of a chain of [a] synchronously connected devices, which form a measuring instrumentation system. This system generally consists of a detector element to detect, a transducer to transduce, and a memory database unit to indicate or record the processed signal. This system is as accurate as its design and application, and may or may not involve human effort

4.26.3 Measurement categorized by proximity

There are two types of measurement method categorized by contact proximity between the measurement instrument and the thing being measured.

1. With physical contact – instrument is placed in direct physical (less than 1mm) contact with the object. The sensing element is known as the sensory. Here, contact is generally molecular.
2. Without physical contact – instrument is not placed in direct physical contact (less than 1mm) with the object. The sensing element is known as the sensory. Here, "contact" is generally electromagnetic.

4.26.4 Measurement categorized by method sub-type

There are many possible measurement method sub-types, including but not limited to the following:

1. **Absolute/fundamental** –the measurements of base quantities enter into the definition of the quantity being measured.
2. **Comparative** – comparison of the value of a quantity to be measured with a known value of the same quantity.
3. **Null measurement** – the difference between the measurand value and the known value of the same quantity with which it is compared is brought to zero.
4. **Substitution method** – the quantity to be measured is replaced by a known value of the same quantity, so selected that the effects produced in the indicating device by these two values are the same (a type of direct comparison).
5. **Complementary method** – the value of a quantity to be measured is combined with a known value of the same quantity.
6. **Transposition** – the value of the quantity to be measured is first balanced by an initial known value, and then, balanced by another new known value.
7. **Coincidence** – measurements coincide with certain

lines and signals.

8. **Deflection** – the value of the quantity to be measured is directly indicated by the deflection of a pointer on a calibrated scale.

4.27 A measurement system

> **INSIGHT:** *A measurement systems indicates the condition of the environment; whereby informed decisions are taken.*

Measurement systems display and/or record an output quantified according (corresponding) to the variable input quantity. The input to the measurement system is the true value of the variable; the system output is the measured value of the variable. Therein, the measurement process may be viewed as a sub-system that generates and outputs information. A measurement system becomes a collection of procedures, gages and operators that are used to obtain measurements. The function of a measurement system is to provide accurate information about the relative quantity value of a measurand.

> **CLARIFICATION:** *A "variable" is an abstract category of information that can assume different values. An "algebraic" variable usually takes on any value but it can be constrained by equations and other kinds of relationships. A "statistical" variable, in the realm of statistics and data analysis, typically represents an observable quantity or characteristic that can vary or change across different individuals, cases, or observations within a dataset.*

The output/result of the interaction between a measuring system and its measured quantity (measurand) is generally termed an 'indication' (expressed with a value, the number part, and a unit, the unifying categorical reference part, forming a mathematical term upon which further statistical calculation can be performed).

In an ideal measurement system, the measured value would be equal to the true value. Here, the accuracy of a measurement system can be defined as the closeness of the measured value to the true value. A perfectly accurate system is a theoretical ideal and the accuracy of a real system is quantified using measurement system error E, where

1. E = measured value − true value.
2. E = system output − system input.

4.28 System of measurement

A 'system of measurement' includes a collection of 'units of measurement' and rules (logic) relating them to each other. A system of measurement is a set of related measures that are used to give a numeric value to something. It is a system of related measures that facilitates the quantification of some particular characteristic of an object or objects. A "system of measurement" is also known as a "metric" (which is confusing because the system of measurement used as an international standard is called, "the metric system"). There are many systems of measurement, and the metric system is one of those many. The metric system is a base ten measurement system using the digits from the decimal system and ten fingers and ten toes as the cycle. Whereas the decimal system has ten digits, the metric system uses [scientific] prefixes to reduce the number of digits (and make the figures/values more manageable).

Systems of measurement can be applied to describe physical and conceptual systems. Some systems of measurement describe physical systems. Other systems of measurement describe conceptual systems.

A 'system of measurement' involves:

1. A group of 'units of measurement'.
2. The rules relating them to each other.

Systems of measurement are important for the coherent sensing, communication, and construction of systems in the real world.

4.28.1 The metric system of measurement

The International Metric System is an absolute system. Its basic units are the meter, kilogram, and second. It is called an MKS system.

4.29 Elemental composition of a measurement systems

In some cases, the measurement system is made up of only a single component, which gives an output (signal) according to the magnitude of the variable applied to it. However, in most cases, a measurement system is made up of several ordered elements (sub-systems or blocks) between which a signal passes.

It is possible to identify the following types of element (in order), although in a given system one type of element may be missing or may occur more than once:

1. **Transducer (sensing element)** – The element and/or sub-system in contact with the [phenomenological] process, whose output depends in some way on the variable to be measured. Functionally, a transducer is a device that converts a difficult to measure property into a more easily measured property. The transducer often comes into contact with the measured input. A transducer is sometimes referred to as the sensing element. A sensing element is also known as a transducer (sensor). If there is more than one sensing element in a system, the element

in contact with the process is termed the primary sensing element, the others are secondary sensing elements. When digital technology is present, generally, the sensing element transduces the input physical effect (input signal) into another physical output, an electrical output signal(s).

A. The primary sensing element:
   1. Quantity under measurement makes [first] contact with a primary sensing element.
   2. The condition, state or value of the process variable is sensed, by extracting a small part of energy from the measurand.
   3. This element produces an output which maps to (or otherwise, reflects) the condition, state or value of the measurand.

2. **Signal conditioning element** – The element and/or sub-system that takes the output of the sensing element and converts it into a form[at] more suitable for further processing. In most cases, the output of the sensor or the element quantity to be measured is so "small" in signal magnitude that it is not suitable for the output presentation element. The signal conditioning element converts the signal into a form matching the characteristics of the output device (or more suitable for further processing). Common electrical operations performed on the signal here include, but are not limited to: bridging; amplification; oscillation change; and filtration.
3. **Signal processing/conversion element** – The element and/or sub-system that takes the output of the conditioning element and converts it into a form more suitable for presentation. Here, typical calculations are: computational; integrational; and correctional. This is a digital, not analog, process.
   A. Variable conversion (transducer) element:
      1. Map ("convert") one physical form into another form [of signal] without changing the information content (meaning) of the signal.
      2. There may be multiple conversions.
   B. Variable modification element:
      1. Modifies the signal by amplification, filtration, or other means so that a desired output is produced according to some mathematical rule.
   C. Data processing element:
      1. Modifies the data before it is displayed or finally recorded.
      2. Performs mathematical operations: To calculate average, statistical, and logarithmic values. To convert data into desired form. To separate undesired signal from noise. To provide correction on the output signal.
4. **Signal utilization element** – The element and/or sub-system that displays the signal to an observer, records the signal, and/or uses the signal as input into a functional control system.
5. **Data presentation element** – The element and/or sub-system that presents the measured value in a form which can be easily recognized by an observer. Common examples of these are: simple pointer-scale indicator (indicator gauge); chart recorder; alphanumeric display; visual display unit; and virtual simulation.
   A. Provides a record or indication of the output.
   B. Transmitting information (measured quantity) - to another location or device.
   C. Signaling – to give a signal that the pre-defined value has been reached.
   D. Recording – to produce a continuous record of measured quantity.
   E. Indicating – to indicate the specific value on a calibrated scale.
6. **Data transmission element** – The system, sub-system, or element, that transmits the signal from one location to another without changing its information contents.

4.30 Instrumentation

Tooling is the automation of the process of measurement capture and computation, and it is desirable if efficiency and optimization is valued. An instrument is a device that transforms a physical variable of interest (the measurand) into a form that is suitable for recording (the measurement).

When using an instrument to take observations of a variable, it is essential to apply/encode the following:

- Validity, unbiasedness, and reliability

Measurement instruments have three primary functional elements:

1. **The detector/sensor** – detects and responds to measurement.
2. **The transducer** – converts measurand to an easier to measure property.
3. **The signal conditioner** – modifies signal.
4. **The readout** – displays result.

4.30.1 Instrumentation reading quality

The following terms are used to describe the quality of an instruments reading:

1. **Range** – The region between the limits within which a quantity is measured, received or transmitted expressed by starting the lower and upper range values.

2. **Span** – The algebraic difference between the upper and lower range values.
3. **Measured variable (a.k.a., measurand)** – a quantity, property or condition that is measured.
4. **Accuracy** – indicates the deviation of the reading from a known value. Accuracy is typically expressed as:
   A. Percentage of full scale reading (upper range value).
   B. Percentage of span.
   C. Percentage of actual reading.
5. **Uncertainty** – Uncertainty of measurement is the doubt that exists about the result of any measurement. Uncertainty is important to make good quality measurements and to understand the results. It is also important in calibration.

4.30.2 Instrumentation systems

An instrument is a device for determining the value or magnitude of a quantity or variable. An instrumentation system is an assembly of various instruments and/ or components interconnected to measure, analyze and control various physical quantities (variables). The purpose of an instrumentation (measurement) system is to present an observer with a numerical value corresponding to the variable being measured.

Applications of measurement systems include, but are not limited to:

1. **Monitoring of processes and operations** – measurement systems display and/or record data.
2. **Control of processes and operations** – control systems use measurement data to adjust functioning.
3. **Experimental analysis for science** – science involves the usage of measurement data to evolve/ advance.

When action is taken based on measurement, then the measurement serves a [system] control function. Note that a control system that automatically controls its own functioning based upon its own measurements, is known as, an automatic control system.

Here, there are two principal categories of operation (or processing):

1. **Closed-loop systems (a.k.a., a feedback control system)** – A control system that uses the concept of an open loop system as its forward path, but has one or more feedback loops (hence its name) or paths between its output and its input. The control system measures the value of the parameter being controlled at the output of the system, and compares it to a desired signal, then adjusts its functioning if required. This is also known as an automatic feedback control system, or cybernetic/ cybernated system.
2. **Open-loop systems** - To control the variable, it is first necessary to measure it. Here, an environmental signal enters a controller. The controller is required to:
   - Compare the output variable with the desired value of the controlled variable, and
   - React by sending a message to the control element to take corrective action.

To solve engineering problems two general methods are available: theoretical and experimental. Many problems require the application of both methods. Types of experimental-analysis problems include, but are not limited to:

1. Study of phenomena with intention of developing a theory.
2. Testing the validity of theoretical predictions.
3. Formulation of generalized empirical relationships.
4. Determination of material, component, and system composition.
5. Determination of material, component, and system parameters, variables, and performance indices/ metrics.
6. Solutions to mathematical equations by means of analogies.

In concern to scale, there are two primary types of instrumentation (signal measurement) scaling system:

1. **Absolute systems** – generate and/or measure an absolute signal (e.g., the position).
2. **Incremental system** – counts the number of steps between positions.
3. **Pure** – the number of steps between the start of the system and now is provided.
4. **Referential** – there is a reference, where a reference position is aligned with upon increment of the scale.

The clock is an absolute measurement system, it allows consciousness to determine a point in time. A stop watch is an incremental system, it allows consciousness to determine how many seconds (increments of 'time') have occurred ("gone by") since the start of the measurement.

4.30.3 Sensor / Measuring instrument

A measuring system may consist of only one measuring instrument. A measuring system is one or more (a set of) sensors distributed in space, and an integrated means for data processing information from the sensor with a set of pre-existing, and pre-structured information.

A measuring system must include the following:

1. **Sensor** - A sensor is an element of a measuring system that is directly affected by a phenomenon, body, or substance carrying a quantity to be measured. A sensor is the sensitive element in a measuring system. In practice this term is also applied for designating the device that:
   A. Includes a group of sensitive elements (e.g. an array);
   B. Consists of a number of separate transducers, connected in series (e.g. a primary transducer and amplifier);
   C. Contains a) and b) + additional signal processing units (analogue-to-digital converter, interface, microcontroller, and indicator in any combination).
2. **Intelligent sensor (a.k.a., smart sensor)** - sensors which are able to:
   A. Realize automatic switching of a sub-range of measurements,
   B. Introduce corrections depending on a change of influence quantity,
   C. Carry out automatic self-check of metrological serviceability (a self-validating, adaptive, self-checking, self-diagnosing, self-calibrating, fault-tolerant sensor).

It is possible to describe the measuring system consisting of one sensor (item c) of the list). The sensor may contain a number of sensors according to item b) of the list, each of them containing a group of sensors according to item a) and each sensor of the last group containing a group of sensors according to the VIM-3 definition.

Sensor types include, bit are not limited to:

1. **Multisensor** - A group of sensors perceiving the same physical quantity (an analog: the tip of the tongue.
2. **Polysensor** - A group of sensors perceiving various physical quantities (an analog: a surface of the tongue as a whole).

Sensors are often transducers in that they are devices that convert input energy of one form into output energy of another form.

Sensors can be categorized into two broad classes depending on how they interact with the environment they are measuring.

1. **Passive sensors** do not add energy as part of the measurement process but may remove energy in their operation.
2. **Active sensors** add energy to the measurement environment as part of the measurement process.

Sensory fusion is a process where two or more sensors are used to observe the environment and their output signals are combined in some manner (typically in a processor) provide a single enhanced measurement. This process frequently allows measurement of phenomena that would otherwise be unobservable.

> **NOTE:** *Biological sensor systems enable determining a value of a "measurand", and moreover, evaluating the distribution of the "measurand" in a multiparameter field and forming a "multiparameter image".*

4.30.4 Measurement system sensor types

Measurement systems sensors may be divided into three categories of guidance.

1. **Direct [guidance]** – wire guidance, magnetic guidance. These are the most reliable. These systems suffer from the considerable problem of path planning. If the path has to be changed, a certain number of hours are required to install the cable inside the floor and the guidance system must be stopped during installation.
2. **Relative [guidance]** - The relative or dead-reckoning methods, such as encoders, gyroscopes, ultrasound, etc., have the considerable advantage of being totally self-contained inside the system, relatively simple to use and able to guarantee a high data rate. However, since these systems integrate relative increments, errors grow considerably over time.
3. **Absolute [guidance]** - use of external references to achieve an absolute measurement with respect to the environment in which the system exists. These systems are more complicated than the relative ones, work at a slower rate, and lead to the problem of the visibility of the targets needed during the systems' path through an environment. Generally, since these measure the system's position and attitude with respect to absolute references (targets), the error is always bounded and absolute repeatability guaranteed.
4. **Combination** – a combination of the three types.

From the above considerations it is clear why many systems currently make use of both a relative and an absolute system.

4.31 Measuring devices, instruments, and tools

Sensors observe, sense, and otherwise, interact with the environment. Sensors observe stimulus, producing an "observation" of a property(s), such as time, location, and distance. And, this observation allows for interactive change with the environment generating or otherwise relating to a stimulus.

A measuring instrument is a device used for making measurements alone or in conjunction with one or more supplementary devices (as part of measuring system). A measuring instrument (gauge) is frequently a form of transducer. A transducer is a device that provides an output quantity (most often an electric current) having a specific relation with an input quantity (most often a physio-logic signal). The physiologic signal is collected by a sensor defined as an element of a measuring system that is directly affected by a phenomenon, body, or substance carrying a quantity to be measured, or less frequently, by a detector defined as a device or substance that indicates the presence of a phenomenon, body, or substance when a threshold value of an associated quantity is exceeded.

4.32 Properties of measuring devices

Measuring instruments provide a quantity value for the measurand. Therein, the measuring 'interval' or measuring 'range' is the set of values of quantities of the same kind that can be measured by a given instrument with specified instrumental uncertainty under defined conditions. A measuring instrument/system is characterized by [at least] the following properties or quality criteria:

1. **Sensitivity** - the minimum change in input signal to which an instrument can respond. Sensitivity is the ratio of o/p response to a specific range in i/p.
2. **Selectivity** – is a property used with a specified measurement procedure, whereby it provides measured quantity values for one or more measurands, such that the values of each measurand are independent of other measurands, or other quantities in the phenomenon, body, or substance being investigated.
3. **Resolution** - is the smallest change in a quantity being measured that causes a perceptible change in the corresponding output of the measuring instrument.
4. **Stability** - is the property of a measuring instrument, whereby its metrological properties remain constant in time. An instrumental drift is the continuous or incremental change over time of the indication because of change in metrological properties.
5. **Step response time** - is the duration between the instant when an input quantity value of a measuring instrument is subjected to an abrupt change between 2 specified constant quantity values and the instant when a corresponding device output settles within specified limits around its final steady value.
6. **Maximum permissible measurement error or limits of error** - the boundary value of measurement error, with respect to a known reference quantity value, permitted by specifications for a given measurement, measuring instrument, or measuring system. The term 'tolerance', which is the magnitude of permissible variation of a quantity, should not be used to designate the maximum permissible error. Tolerance includes the true value ± the maximum permissible error.

Strictly speaking, accuracy, trueness, and precision are qualifying measurements, whereas sensitivity, selectivity, resolution, stability, and step response time are qualifying dynamic outputs of devices.

NOTE: *The dynamic output of a measuring instrument is sometimes known as an 'indication'.*

4.33 Measurement performance characteristics (i.e., measurement output parameters)

Measurement generally occurs through instrumentation. That instrument has a set of output/performance characteristics.

4.33.4.1 Static performance characteristics

Static performance characteristics include principally, that desired input to the instrument not change in relation to time. Therein, the following sub-conceptualizations are required:

- Error, accuracy, calibration, hysteresis, dead zone, drift, sensitivity, threshold, resolution, precision, repeatability, reproducibility, linearity, etc.

4.33.4.2 Dynamic performance characteristics

Dynamic performance characteristics include, but are not limited to: speed of response, measuring lag, fidelity, frequency response, dynamic error, overshoot, dead time and dead zone.

Therein,

1. **Readability** indicates the closeness with which the scale of the instrument may be read.
2. **Least count** is the smallest difference between two indications that can be detected on the instrument scale.
3. **Range** represents the highest possible value that can be measured by an instrument, or limits within which the instrument is designed to operate
4. **Linearity** is a measurement system category;

wherein, a measurement system is linear if the output is linear proportional to the input.

5. **Repeatability** is the ability of a measuring system to repeat output readings when the same input is applied to it consecutively, under the same conditions and in the same direction. Repeatability is expressed as the maximum difference between output readings.
6. **Reproducibility** is the degree of closeness with which the same value of a variable may be measured at different times.
7. **System response** is the ability of the system to transmit and present all the relevant information contained in the input signal.
8. **Threshold** is the minimum value of a ratio (e.g., i/p or a/b) required to cause a detectable change [from 0(zero)], o/p.
9. **Hysteresis** is the maximum differences in two output (indicated values) at same input (measurand) value within the specified range when input is continuously increased from zero and when input is continuously decreased for maximum value.

4.34 Measurement uncertainty and error

Error is the difference between the measured value and the 'true value' of the thing being measured. Uncertainty is a quantification of the doubt about the measurement result. Here, the accuracy of an instrument is defined as the difference between the true value of the measurand and the measured value indicated by the instrument. Typically, the true value is defined in reference to some absolute or agreed upon standard.

A measure (attribute) is "well-defined" if scale and unit are clearly specified; specification of the unit and scale ensures the measure is unambiguous.

4.34.4.1 Measurement accuracy

Measurement accuracy is the closeness of agreement between a measured quantity value and a true quantity value of the measurand. The concept of accuracy is a quality and is not given a numerical value. A measurement is said to be more accurate when it offers a smaller measurement error. Therefore, a measurement error is qualifying a single measurement.

4.34.4.2 Measurement trueness

Measurement trueness is the closeness of agreement between the average of an infinite number of replicate measured quantity values and the true or a reference quantity value. The concept trueness is a quality and is not given a numerical value. Measurement trueness is inversely related to systematic measurement error but not to random measurement error. Since the mean random error is zero, the bias (average of measured value – reference value) is an estimate of the systematic measurement error. The traditional averaging of (measured value – reference value) is equivalent to the former formula only when there is a unique true (or reference) value. When there are different quantities of the measurand, the bias can be fixed, proportional, or distributed following specific functions. Since a systematic error cannot be normally/randomly distributed, averaging (measured value – reference value) is therefore an approximate representation of the averaged bias (systematic error).

4.34.4.3 Measurement precision

Measurement precision is the closeness of agreement between measured quantity values obtained by replicate measurements on the same or similar objects under specified conditions. Measurement precision is related to random measurement error and usually expressed numerically by measures of imprecision, such as standard deviation (σ), variance (σ2), or coefficient of variation (σ/mean) and assuming a mean = zero.

4.34.4.4 Measurement error

Measurement error. We have seen in "Measurement Accuracy" that it is the difference between a unique measured quantity value and a reference quantity value. The measurement error can be systematic (bias) qualifying the untrueness (i.e., "measurement trueness") or random qualifying the imprecision (i.e., "measurement precision"). When the term "measurement error" is used without further information, it combines systematic and random errors and qualifies the inaccuracy.

- % error = |experimental-accepted| x 100 / accepted value

For any particular measurement there will be some error due to systematic (bias) and random (noise) error sources. The combination of systematic and random error can be visualized by considering the analogy of the target.

There are three classifications of measurement error:

1. **Gross errors or mistakes**
   A. **Accidents and mistakes** – can avoid only by staying focused (and in flow).
2. **Systematic error sources (bias)** – these have definite magnitude and direction.
   A. **Instrument error** – the instrument's design, maintenance, selection, calibration, and/or operation-usage cause an error.
   B. **Environment error** – due to conditions external to the measuring instrumentation sub-system. Use the instrument under the conditions (parameters) it was designed and calibrated for. Calibrate for local conditions.
   C. **Observation error** – error due to poor

capabilities and/or motivations of operator.

D. **Operational error** – misuse of the instrument or poor operational technique.

E. **System interaction error** – an interaction error may occur between a system (to be measured) and the direct point of contact with the instrument's body. The contact could change the condition of the measuring instrumentation system. For example, a ruler pressed against a body (system) resulting in the deformation of the body and a reading with a large error.

3. **Random error sources (noise)**
   A. If systematic errors can be removed from a measurement, some error will remain due to the random error sources that define the precision of the measurement. Random error is sometimes referred to as noise, which is defined as a signal that carries no useful information.
   B. Presently uncategorizable errors.

4.34.4.5 Stability and consistency

All measurements have to exhibit two basic characteristics: stability and consistency. To the degree that they do, they are called, "reliable measures".

1. **Stability** - A stable measure will yield identical measurement results whenever it encounters an identical amount of the theoretical concept.
2. **Reliability** – An operational definition describing a measurement procedure which behaves in a consistent fashion.
3. **Validity** - The amount of measurement validity cannot be determined by any numerical method. It relies on a self-evident overlap between "verbal world" theoretical definitions and "measurement world" operational definitions. Furthermore, the self-evident overlap must be generally agreed upon by independent observers. It is not enough that an operational definition shows measurement validity to the researcher who constructs it; it must also exhibit the same measurement validity to other researchers and critics.
   A. Concurrent validity
   B. Discriminant validity
   C. Construct validity

4.34.4.6 Measurement uncertainty

Measurement uncertainty is a parameter characterizing the dispersion of the quantity values being attributed to a measurand based on the information used. This concept is broader than precision including uncertainty due to time drift, definitional uncertainty, and other uncertainties. There are 2 types of evaluation of the uncertainty of measurements: type A based on statistical analysis of measured values and type B based on other means such as certified references, authoritative published values, or personal experience.

4.34.4.7 Error triangulation

This process of combining information from multiple sources to arrive at a true or at least more accurate value is called triangulation, a loose analogy to the process in geometry of determining the location of a point in terms of its relationship to two other known points. The key idea behind triangulation is that, although a single measurement of a concept might contain too much error (of either known or unknown types) to be either reliable or valid by itself, by combining information from several types of measurements, at least some of whose characteristics are already known, we can arrive at an acceptable measurement of the unknown quantity. We expect that each measurement contains error, but we hope it does not include the same type of error, so that through multiple types of measurement, we can get a reasonable estimate of the quantity or quality of interest.

4.35 Categorization and classification

Categorization and classification mean essentially the same thing (the process is also sometimes called "division") – the delineation of discreteness of variables. Discreteness of variables is a key part of evaluation and the naming of variables for quantitative research/measurement. This delineation results in an organized structuring of information based upon inter-relationships.

> **NOTE:** *Classification can only occur on similar items (i.e., items expressing a similar pattern).*

In general parlance, however, the words categorization and classification have slightly different definitions:

1. In general parlance, **categorization** is a systematic method of modeling using related conceptual nodes. Every node in the model/map represents a concept, and sub-/supra-nodes represents a more specific/more general concept.
2. In general parlance, **classification** is the representation of knowledge (or awareness) by discrete organization.

Regardless, terms mean the use of concepts (and sub-/supra-concepts) to formalize a difference or similarity (a delineation or division).

> **INSIGHT:** *How someone categorizes and the results of that categorization will affect someone's thinking, and consequently, their motivations and behaviors.*

Therein, a category or class is a collection of similar objects or entities, which are dissimilar from other objects or entities [of a different category or class]. From the perspective of unification, those other categories/

classes may exist:

1. At the same level in a leveled/tiered arrangement of categories/classes.
2. At different levels in a leveled/tiered arrangement of categories/classes.

Suffix: -ization and -ication mean “the act of”.

1. **Classification** – act[ion] of classifying – identifying similar and different classes.
2. **Categorization** – act[ion] of categorizing – identifying similar and different categories.

The nodes (concepts) in the organized structure are called by different names, including but not limited to: class, type, set, or taxon, and to a lesser degree of usage, unit, topic, and subject.

In other words,

1. Each node in a classification structure is called a class.
2. Each node in a categorization structure is called a category.

The supra- and sub-nodes (supra-/sub-concepts) in a categorization or classification structure (scheme) may be said to exist on different levels or ranks. Rank is the relative level of a group of classified objects/events. A given rank subsumes under it less general categories, that is, more specific descriptions. Above it, each rank is classified within more general categories. Therein,

1. Each level “down” in the structure zooms in on a smaller and smaller physical/conceptual area.
2. Each level “up” in the structure zooms in on the larger physical/conceptual area.

> **NOTE:** *All measurement data is categorical data. Categorical data is data that can be organized into mutually exclusive categories. Given the presence of categorical information, quantitative and qualitative data may also be considered categorical data.*

4.36 Classification operations

In order to classify/categorize, the following classificatory operations (classification operations) must be performed:

1. Conceptualization operation (defining, identifying terminological and definitional classes/types/categories) – ensuring that concepts (classes or types) have clear, logical, and delineated/bounded definitions. Concepts must be clarified and denominated by a “suitable” (linguistically precise) term or expression. If there is a hierarchy, then concepts “higher up” the hierarchy represent greater unification. Concepts corresponding to individual classes are either formed or clarified by the definition of their boundaries with contiguous concepts.
2. Conceptual analysis operation (divisioning, conceptual elaboration) - the extension of a concept [at a given level of generality] is subdivided into several (two or more) narrower extensions corresponding to as many concepts at lower level of generality; this subdivision is obtained by stating that an aspect of each of the latter concepts is a different partial articulation of the corresponding aspect of the higher concept. Notice that in principle all other aspects of the higher concept are carried into each of the lower concepts. This is a process of conceptual elaboration.
3. Pattern recognition operation (grouping) - the objects or events of a given set are grouped into two or more subsets according to the perceived similarities of their states on one or (more frequently) several properties; subsets may be successively grouped into subsets of wider extension and higher hierarchical level.
4. Assignment operation (assigning, classing, assigning to a class/type) - whereby objects or events are assigned to classes or types which have been previously defined. This is the assignment of objects/events to classes, types or taxa which have been previously defined.

These classification operations produce a classification (categorization) structure that organizes related information by named relationships. That organized information may be viewed as a model/map and used for creating in the world. The input of additional related information becomes organized according to the classification model (which may be known as an ontology, taxonomy, or typology), and its integration may change may change the model (if defining, divisioning, and grouping continue during the assigning process).

4.36.1 Combinatorics

In order to combine parts (or elements) into a whole, a series of processes (process functions) must occur. The three primary functional process to combing parts are:

1. Labeling
2. Selecting
3. Grouping [given all information is known].

4.37 Classification/categorization output: Ontology, taxonomy, or typology, or typology

The result of categorization/classification is an organizational structure known as an ontology, taxonomy, or typology. In common usage, the words typology, taxonomy, and ontology mean essentially the same thing - the categorization/classification of something (or things) and its (their) resulting structurally organized output as an information system (model/map). They are different words used by different disciplines that mean essentially the same thing. In some disciplines, the term ontology is used to imply a broader scope of categorized information about reality and the nature of existence. In other disciples and contexts, the word taxonomy or typology is used.

When ontology and taxonomy are used in the same context, but to mean different things, then the term ontology is likely being used to encompass a number of taxonomies, with each taxonomy organizing a concept/subject/topic in a particular way.

In their disciplined application, the terms have different originations and a slight variance of definition, but still mean the same thing – a structural organization of those objects/entities which have undergone categorization/classification:

1. The word “**ontology**” comes from philosophy, and is a series of categorized characterizations of the nature of being, or reality. Philosophically speaking, it is intended to be a systematic account of existence. Ontologies are concept specifications and relations about reality. The term ontology means the science or study of being and the nature of existence. Etymologically, the word “ontology” comes from modern latin, ontologia (c. 1600), from onto- + -logy. Onto- means “a being, individual; being, existence.
2. The word “**taxonomy**” means the science of classification. The word was neologized (“coined”) by someone studying botany. Etymologically, the word “taxonomy” comes from French taxonomie (1813), coined irregularly from Greek taxis “arrangement” + -nomia “method,” from -nomos “managing,” from nemein “to manage”. The word has come to mean the science of defining groups on the basis of shared characteristics, and giving names to those groups. It is the classification of existence according to characteristics; it is the science of organizing existence into a system of different groups according to the features that they share, and of giving them names. In other words, a taxonomy is a method of partitioning (with purposeful and identified parameters) and giving names.
    A. A taxonomy is a semantic hierarchy in which information entities are related by either the subclassification of relation or the subclass of relation. Note: subclassification is semantically weaker than subclass of relation. A taxonomy is a form of classification scheme. Designed to group related things together. It is a hierarchical thesaurus with terms applied at the final node. It is a tangible hierarchy forming a structure of information related to a root or axiomatic conception. It expresses similar relationships between things. It is an information model. A taxonomy is a knowledge organization system. It is a hierarchy of relationships. It is a hierarchy of related types.
    B. The dimensions of a taxonomy represent empirically observable and measurable characteristics. It is a classification structure based on the empirical/operational.
    C. Each node in a taxonomy may be called a taxon (plural, taxa).
    D. A taxonomy is:
    E. Organized into a hierarchy.
    F. Each tag is unique.
    G. The tags relate to one another logically, and preferentially relate to the existent, which they are classifying.
    H. A structure for organizing incoming information.
3. The word “typology” means the study of types (e.g., types of systems, for example, biological, chemical, linguistical, architectural, etc.) It refers to the science of classifying existence. The study or system of dividing a large group into smaller groups according to similar features, qualities, and characteristics. Typology involves the process of partitioning (based on identified parameters) for the purpose of study. Working with typologies contributes decisively to forming concepts, exploring dimensionality, establishing measurement categories, and grouping cases.
    A. The dimensions of a typology represent concepts rather than empirical classes. It is a classification structure based on the abstract (i.e., the conceptual).
    B. Each node in a typology is called a type.
    C. Typification – act[ion] of typifying – identifying similar and different types.

In computer science, what “exists” is what is represented. Hence, programmatically speaking, ontologies/taxonomies/typologies represent explicit domain conceptual specifications -- an ontology/taxonomy/typology is a domain of interest’s formal, explicit specification of a shared conceptualization. Thus, ontologies/taxonomies ensure a shared conceptualizations formal specification.

> **NOTE:** *Tabulation is the logical operation of [numerically] counting the number of cases that fall into each category.*

4.38 Real world category continuity

Real world categories differ in their range and level of continuity. For example, members of the category "atomic element" are highly similar (having atoms, electrons, and protons), and thus, have a relatively small category range and are fairly cohesive (i.e., highly continuous). On the other hand, the category "weapon" is highly variable and contains items such as knives, bombs, guns, etc., which are highly discontinuous.

4.39 Qualitative data type classification

Qualitative data can be nominal and ordinal, but not interval or ratio. Qualitative data cannot be continuous. Discrete, quantitative counts must be ratio. Therein, there are five different possibilities, which forms the following taxanomical concept map:

1. **Categories**: Qualitative, discrete, nominal data (such as colors, names, or labels).
2. **Ranks**: Qualitative, discrete, ordinal data (such as sizes, preferences, or grades).
3. **Counts**: Quantitative, discrete, ratio data that count something.
4. **Relative (or Relative Scale) Measures**: Quantitative, continuous, interval data (such as temperatures).
5. **Absolute (or Absolute Scale) Measures**: Quantitative, continuous, ratio data (such as heights and weights).

4.40 The conceptual components of a measurement system

The measurement of a property [of a bounded existence] may be categorized according to the following sub-concepts (i.e., "criteria"). For a measurement to represent an unambiguous comparison, all four conceptual criteria must have accurate information. The measurement of an attribute (property) of a real world system requires the following conceptual information:

1. Typological/taxonomical positioning (level/scale of measurement): The type or level of measurement is a taxonomy (classification) for the methodological character of a comparison. In other words, the data collected on a variable, and accompanying data, fit into one of several taxonomical scale (or scaling) categories, which determine the methods (and operations) that may be used in its [mathematical-statistical] processing.
2. Numerical quantity (magnitude determination): The magnitude or [numerical] quantity is the numerical value of the characterization, usually obtained with a suitably chosen measuring instrument (a referencing process or tool). A numerical value is a real number that represents a quantity.
3. Unit (referential unit system): A unit assigns a mathematical weighting factor to the magnitude that is derived as a ratio to the property of an artefact used as a standard or a natural physical quantity. Measurement always includes units - without units, a quantity and its corresponding measurement carry no understanding.
4. Uncertainty (determination): An uncertainty represents the "random" and systemic errors of the measurement procedure; it indicates a confidence level in the measurement. All measurements have some degree of uncertainty associated with them, which is usually expressed as a 'standard error of measurement'. Errors are evaluated by methodically repeating measurements and considering the accuracy and precision of the measuring instrument:
   A. Measurement accuracy - How close a measurement comes to the true value (a.k.a., correct value).
   B. Measurement precision - How close a series of measurements are to one another.
   C. Precision refers to how small an uncertainty the measuring instrument and conditions will provide.

4.40.1 Typological/taxonomical positioning(i.e., levels/scales of measurement)

All measurement data and variables fit into one of several possible levels (or scales) of measure[ment]. Together, the levels/scales form a taxonomy/typology known as a 'level of measurement' or 'scale of measure', which classifies the nature of information assigned to a variable.

In specific, the terms, 'level/scale of measure[ment]', refer to the degree of relationship among the values that are assigned to the attributes for a variable upon which measurement data is being collected and will be processed. Associated with each "level" of measurement is a set of permissible [mathematical] transformations [of the data]. (see illustrator for "level of measurement")

In its expression, a 'level/scale of measure[ment]' is a typology (categorically mapped arrangement of concepts) for defining data processed by measurement operations as part of a variable. Data represented as numbers can be grouped/categorized into 4 types (or levels) known as the levels of measurement (or scales of measure). The levels/scales have an order. Each ascending level possesses the characteristics of the preceding level, plus an additional quality.

In common parlance, the terms 'levels of measurement' and 'scales of measure' convey the same (or highly similar) meaning. However, in practice, the terms 'level of measurement' and 'scale of measurement' may have slightly different meanings:

1. **Level of measurement** refers to the particular way/order [in the taxonomy] that a variable is measured, and
2. **Scale of measurement** refers to the particular tool/process for sorting the data that applies based on the level.

Note that sometimes these levels/scales of measurement are referred to as "levels of measurement scales". Regardless of labeling, the concept refers to the classification/categorization of the type of data it is possible to collect from a variable due to the presence of underlying relationships.

'Level of measurement' or 'scale of measure[ment]' is a classification that describes the nature of information within the numbers assigned to variables. It could also be said that [measurement] scales are distinguished by their level of measurement. There are four levels of measurement.

The most commonly used 'level of measurement' typology has three scales of measurement, and one level of basic categorization:

1. Level 1 (not a scale): Basic categorization/sorting – **nominal categorizing**
   - The initiation of categorization; initiating categorization.
2. Level 2 (1st scale): A one dimensional ordering – **ordinal scaling**
   - Associating an ordering dimension to the categorization.
3. Level 3 (2nd scale): Subdivisioning/delineating the order – **interval scaling**
   - Divisioning the categorical dimension.
4. Level 4 (3rd scale): Affixing/absoluting the order [to a zero point] – **ratio scale**
   - Absoluting the categorization.

Note: *The "list" of available levels/scales [of measurement] is itself an ordinal typology categorization of data complexity.*

There is a [categorical] hierarchy (order) implied in the concept, 'level of measurement'. At lower 'levels' of measurement assumptions tend to be less restrictive and data analyses tend to be less sensitive. At each level up the hierarchy, the current level includes all of the qualities of the one below it and adds something new. In general, it is desirable to have a higher level/scale of measurement (e.g., interval or ratio) rather than a lower one (nominal or ordinal).

Hence, it could be said that measurement data is distinguished by the relationship complexity of the information it carries. All measurements must take one of four (sometime five) forms, also known as "levels of measurement". The four levels of measurement are:

1. **Nominal scale/level (non-metric or categorical)** - lowest level of information. There are only categories (strictly qualitative information). Herein, there is only the assignment of numbers. This is commonly referred to as the "nominal [measurement-level] scale". Note that this scale/ level does not represent true measurement.
2. **Ordinal scale/level (non-metric or categorical)** - a higher level of information, ranking scale; it consists of a set of categories that are sequentially ranked-ordered with care to size or magnitude of difference between different variates (quantitative order exists among them). Ranking/ordering of the available numbers by conceptual criteria, but no information is available to derive an understand of how far apart they are separated conceptually and/ or numerically. This is commonly referred to as the "ordinal [measurement-level] scale".
3. **Interval (cardinal) scale/level (metric)** - an even higher level of information; interval scale consists of ordered categories with precisely equal intervals between each category. Differences will reflect relative changes in magnitude, but ratios are not meaningful due to the absence of an absolute zero reference point. A scale which represents quantity, and has equal units, but for which zero represents an additional point of measurement is an interval scale. This is commonly referred to as the "interval [measurement-level] scale".
4. **Ratio scale/level (metric)** - the highest level of information. The ratio scale is a specific interval scale that includes an absolute-zero point such that ratios of data do reflect changes in magnitude, precisely. A[n interval] scale that has an absolute zero (no numbers exist below the zero). This is commonly referred to as the "ratio [measurement-level] scale".

Objective measurement scales are otherwise known as numeric measurement scales. The [objective/numeric] scales of measurement are nominal, ordinal, interval, and ratio. These scales represent an order in themselves -- the scales themselves are a scale of increasingly bound understanding. The ratio (or absolute) scale is the most restrictive of all, and the nominal scale is the least bound (and may not even be considered a scale, because it does not scale along any dimensions). The four scale types are ordered in that all later scales have all the properties of earlier scales— plus additional properties.

Each level of measurement and its corresponding scale is able to measure one or more of the four properties of measurement:

1. Identity (nominal)
2. Magnitude (ordinal)
3. Equal intervals (interval)
4. Minimum value of zero (ratio or absolute)

> **HISTORICAL NOTE:** *These levels and scales of measurement were invented by Stanley Smith Stevens, who wrote about them in a 1946 article in Science, titled "On the Theory of Scales of Measurement."*

All levels of measurement give the ability to determine the presence or absence of some thing. A second level of measurement adds the idea of quantity (e.g., "more of ..." or "higher than ..."), or an underlying dimension, to the measure's ability to detect. If the measurement contains only detection and comparative ordering information, then it is called ordinal. At the next higher level, measurement adds the idea of units, such that absolute statements (rather than comparative) can be given about the similarity or difference between measurements. That is, it is possible to state the number of units by which observations are measured to be different. This level of measurement is called interval. Finally, if the measure is interval, but also contains an absolute zero category or scale point, then it is possible to give statements of proportion ("only one half of") or ratios ("twice as much...") about the magnitude of the measurement. This highest level of measurement is called the ratio-level.

The importance of the measurement level is threefold:

1. It determines the selection of test statistics.
2. It affects the amount of information collected about variables.
3. It affects how questions (inquiries) are formed.

Knowing the level/scale of measurement facilitates decisioning on the interpretation of data from that variable. If a variable is known to be nominal, then it is known that the numerical values are simply short codes for the longer names. Second, knowing the level of measurement facilitates decisioning in concern to what statistical analysis is appropriate on the values that were assigned. The type of scale used in taking measurements directly impinges on the statistical techniques which can legitimately be used in the analysis.

In statistics, different types of data utilize different scales. In other words, not every attribute or variable can be translated to numerical values in the same way.

The nominal scale offers the least statistical information content, and the ratio scale the highest. Nominal and ordinal are non-metric (or categorical) scales; that is, their response values are not directly usable as a numerical value. Interval and ration scales are metric scales that allow for various arithmetic operations.

The level of measurement expresses, how quantifiable a data value actually is (i.e., to what extent mathematical operations can be applied).

Scales [of measurement] with greater complexity, and hence, more categorical data, allow for greater mathematical (logical) processing (analysis and synthesis). In other words, the accurate processing of greater complexity will facilitate greater understanding. A greater number of meaningful operations (data processing) can be done on complex data. This delineation of scales [of measurement] by data complexity is otherwise, and unnecessarily, referred to as levels [of measurement].

The type of measurement scale determines:

- How measurement data is processes.
- Whether statements involving measurement data are meaningful.

> **TERMINOLOGY:** *A continuous scale has units of measurement that are in principle infinitely divisible, so that any particular outcome (continuous variable) could be drawn out to as many points (e.g., decimal places) as practical.*

4.40.2 Scaling

A scale is a conceptual technique to measure some thing. It is an abstract measurement tool for comparing (relating) common attributes of entities. Therein, scaling is the process of ordering a series of items along some type of continuum. A concept, object, or event may be assigned a [measured] number along a scale representing a dimension (or concept). In other words, the data of an observation/sensation is encoded via a rule/principle along a pre-existing comparison continuum known as a [dimensional] scale. A scale is defined as the collection of attributes used to measure a specific [conceptual] variable (e.g., time, temperature, gender, etc.). A scale is a structure for mapping. A particular way of assigning numbers or symbols to measure something is called a scale of measurement (sometimes also called a system of measurement).

> **Clarification:** *In drafting, architecture and engineering, the term scale has two meanings. A scale is a dimension that represents the structure shown in a plan. A scale is also a ruler used in drawing and measuring architectural and engineering plans. Hence, the term scale is sometimes used to refer to a measuring instrument, and sometimes even the standard of measurement.*

Simply, a scale is a rule (principle) used for the assignment of numerals to properties of objects or events. The concept depicting the rule upon which a scale is based is sometimes called the 'dimension' [of the scale]. This equates a scale to a specific method of measurement. Measurement always occurs in a specific way, which means that every measurement process must have a rule of measurement. Every process of measurement must have a scale of measurement.

> **Note:** *A 'measurement scale' is a set of predefined symbols or values in order to represent certain common measures.*

Visually, a scale is a set of points on a line (or, ordered attributes of a concept) used for measuring (associating objects/events with words and/or numbers in a logical manner so that the data can be processed by a mathematical system.

A 'scale' represents the way a variable is measured or quantified. For example, the variable "gender" is commonly measured on a scale defined by the specific attributes "male" and "female". A scale could be considered a "technique" to measure something and integrate it within a numeric, semantic, or graphical system. These are simply ways to categorize different types of variables.

Scaling is the procedure for the assignment of numbers (or symbols) to a property of events/objects in order to impart some of the characteristics of numbers to the properties in question. It describes the procedure of assigning numbers to concepts – a scale is a continuum, consisting of the highest point and the lowest point. Simply, scaling is the assignment of objects to numbers according to a rule. The objects can be linguistic concepts, or numerical concepts.

Scales are generally divided into two broad categories: unidimensional and multidimensional. A scale can have any number of dimensions in it. What's a dimension? Think of a dimension as a number line. If we want to measure a construct, we have to decide whether the concept can be measured well with one number line or whether it may need more.

> **NOTE:** *Concept mapping is a technique for visualizing scales.*

The scale determines what operations among the numbers assigned in a measurement will yield results significant for what is being measured. In other words, it carries the information for an initial interpretation of the numbers arrived at in a measurement. What mathematical transformations measurement can be subjected to depends on the scale in terms of which they were arrived at. Of course, this depends entirely on the available mathematics. There is no advantage in using a scale that allows operations that are no known how to perform.

Scales are important because they define the nature of information about variables.

A rating scale is an assessment instrument (technique) involving a set of categories designed to elicit information about a quantitative or qualitative attribute (based on pre-determined criteria). Through the use of the rating scale technique, the observer or rater categorizes the objects, events or persons on a continuum represented by a series of continuous concepts or numerals. There are four types of rating scale: nominal; ordinal; interval; and ratio.

Rating scales may be presented in six ways:

1. The graphic rating scale – various points are positioned along a line to form a continuum and the measurement is associated with its compared position along the line.
2. Numerical scale - A numerical scale is a rating scale that is used to measure or identify quantitative data.
3. Graphic scales.
4. Percentage rating.
5. Standard scales.
6. Scales of cumulated points.
7. Forced choice scales.

4.40.3 Scale traceability

For metric scales the traceability problem is relatively simple -- all measurements have to be related to a single standard. For the qualitative scale types, the traceability problem can be more complicated because more standards are required.

Nominal scales typically have the greatest number of standards associated with them, usually one for each possible category on the scale. The standards may be descriptive or based on artefacts, such as standard reference materials.

Ordinal scales require a minimum of two standards, and in many cases require an approved or specified interpolating instrument.

Many interval scales can be expressed in terms of metric quantities, so the traceability problem is not too difficult. The log-ratio scale, for example, requires a definition of the multiplying constant, which can be defined without error, and a reference value, which in most cases takes the place of the unit on metric scales. All of the time scales (time of day, year, etc.) rely on measurements of time interval (a metric quantity) and an arbitrarily defined zero. Angle scales, such as latitude and longitude, also rely on angle interval and an arbitrary zero.

4.40.4 Evaluation through comparative and non-comparative scaling

In comparative scaling, evaluation involves comparing one thing of a certain type with another thing of the same type against a categorized set of criteria (e.g., one product with a specific function against another product with the same function). With noncomparative scaling, only one product is evaluated against a categorized set of criteria.

4.40.5 Degrees

The points along a scale may be referred to as degrees. A set of degrees (points) creates the scale. Therein, a 'property' of a scale is a 'degree'. A single degree within a scale represents:

1. A sub-delineation (subdivision) of a concept.
2. An iteration of a conceptual pattern.

A degree is a measurement of a whole concept (plane angle), defined so that the whole concept (full rotation) is expressed in the categorically (typologically) sub-divided manner of scales/levels of measurement (e.g., ordinal or interval; 360 degrees). Together, the categorical sub-divisions represent the whole set of possible divisions. For instance, there are 360 of the unit "degree" in the full rotation around a plane angle. A degree is a subdivided point along a conceptual line.

Here, the term 'range' refers to the bounds/endpoints of the concept or system. It represents the range of that which is possible, the range of possible numeric or conceptual values. For instance, the range of common subdivisions chosen for a plane angle (because history, or logic) is 360 (as, the count of 1,2,3,4,...). Hence, the range would be 0 at one boundary and 360 at the other (in a 2-axis/attribute system). Presently, the concept gender, and its relationship to genetic expression has a 2 attribute/characteristic [system]: female and male. In terms of gender, the scale [of measurement] has 2 attributes/degrees, which represent the entire range of possible attributes/degrees.

The range is the mapping of an attribute in the real world to a mathematical system. The mapping itself can be seen as a function behaving according to set of rules

> **NOTE:** *Only information with a value (or number) assignment can be processed statistically.*

4.40.6 Statistics

Statistics is a type of mathematics. It is a mathematical data analysis system where uncertainty is fundamental, and the results are always expressed in terms of probabilities. Therein, models serve as both inputs and outputs of statistical analyses. Statistical analyses begin and end with models.

Statisticians often refer to the "levels of measurement" of a variable, a measure, or a scale to distinguish between measured variables that have different properties. In statistics, the term measurement is used more broadly and is more appropriately termed 'scales of measurement'. The term 'scales of measurement' refers to ways in which variables/numbers are defined and categorized. Each scale of measurement has certain properties which in turn determines the appropriateness for use of certain statistical analyses.

> **NOTE:** *Drafting scale rulers read architectural and engineering drawings.*

4.41 Level of measurement: Qualitative (categorical)

Qualitative information is determined by the nominal and ordinal level of measurements, which represent techniques (or scales).

4.41.1 Nominal [-level of measurement, scale] - categorized data, name, not numerical

Nominal levels of measurement are used to distinguish between features only on the basis of qualitative information. Nominal data does not imply quantitative differences. The only understanding conveyed is that two things (objects/events) of the same category have a difference (i.e., that in the category containing A and B, that A is different to B. It is meaningless to add, subtract, multiply, or divide nominal data. Attributes are only named; weakest. The assignment of a number. Classification of objects where the fact that the objects are different is preserved. Categorical data and numbers that are simply used as identifiers or names represent a nominal scale of measurement. This is not a 'scale' because it does not scale objects along any dimensions; it simply labels objects. Gender, for example, is a nominal scale: female = 1 & male = 2. The nominal type differentiates between items or subjects based only on their names or (meta-) categories and other qualitative classifications they belong to; thus dichotomous data involves the construction of classifications as well as the classification of items. Discovery of an exception to a classification can be viewed as progress. Numbers may be used to represent the variables but the numbers do not have numerical value or relationship: for example, a Globally unique identifier. Nominal scales were often called qualitative scales, and measurements made on qualitative scales were called qualitative data. However, the rise of qualitative research has made this usage confusing. The numbers in nominal measurement are assigned as labels and have no specific numerical value or meaning. No form of mathematical computation (+,-x etc.) may be performed on nominal measures. The nominal level is the lowest measurement level used from a statistical point of view.

Nominal is without order. Nominal could be considered a qualitative scale technique for grouping into unique categories (e.g., eye color).

Nominal is hardly measurement. It refers to quality more than quantity. A nominal level of measurement is simply a matter of distinguishing by name, e.g., 1 = male, 2 = female. Even though we are using the numbers 1 and 2, they do not denote quantity. The binary category of 0 and 1 used for computers is a nominal level of measurement. They are categories or classifications.

Nominal data refers to data which can be organised into categories e.g. gender: men and women, type of pet: cat, dog, fish, etc. Nominal data does not refer to numbers or quantities. You can't divide a dog by 2 (or at least you shouldn't).

1. A variable that has a nominal-level measurement scale is commonly referred to as a nominal-level variable, or simply, a nominal variable.
2. Define classes or categories, and then place each entity in a particular class or category, based on the value of the attribute.
3. The empirical relation system consists only of different classes; there is no notion of ordering among the classes.
4. Any distinct numbering or symbolic representation of the classes is an acceptable measure, but there is no notion of magnitude associated with the numbers or symbols.

TERMINOLOGY: *Dichotomous – nominal, but two categories only (e.g., male/female).*

4.41.2 Ordinal [-level of measurement, scale] - ordered categorized data, semantic data, name with order, positional, categories with numerical order only

NOTE: *This scale is qualitative, but seemingly quantitative.*

Ordinal scales involve differentiation by class, but they also differentiate within a class of features on the basis of rank according to some qualitative measure. Only rank is involved in ordinal scales. We are able to say that object A has a higher rank than object B, but we cannot say by how much.

Ordinal is nominal with order. Ordinal could be considered is a qualitative scale technique for grouping categories with order (e.g., mild, moderate, or severe; or, 1,2,3). In application, this can sometimes be difficult to separate from nominal.

APHORISM: *Question: What is ordinal? Response: What number are you in line?*

Values assigned to the levels of a variable simply indicate that the levels are in order of magnitude.

Scale for ordering observations from low to high with any ties attributed to lack of measurement sensitivity (e.g., score from a questionnaire).

Ordinal refers to order in measurement. An ordinal scale indicates direction, in addition to providing nominal information. Low/Medium/High; or Faster/Slower are examples of ordinal levels of measurement. Ranking an experience as a "nine" on a scale of 1 to 10 tells us that it was higher than an experience ranked as a "six." Many psychological scales or inventories are at the ordinal level of measurement.

The scale is constructed so that there is an order to all divisions.

NOTE: *Subjective measurement scales may otherwise be known as semantic measurement scales.*

Calculation is possible with ordinal information, through the use of numbers which may be applied to these qualitative scales, which when algebraically calculated, will give a mathematical result (a.k.a., "score").

Ordinal data refers to data which can be put into an order or ranked. Individual items can be organised by importance, general size or some arbitrary preference. Ordinal data ignores the exact degree of difference between individual ranked items. Attributes can be ordered/ranked.

Rank order of that which is being measured. Ordered categories of data. Objects are ranked/ordered based upon a criteria, but no information about the distance between the values is given. An ordinal scale of measurement represents an ordered series of relationships or rank order. The ordinal type allows for rank order (1st, 2nd, 3rd, etc.) by which data can be sorted, but still does not allow for relative degree of difference between them. Examples include, on one hand, dichotomous data with dichotomous (or dichotomized) values such as 'sick' vs. 'healthy' when measuring health, 'guilty' vs. 'not-guilty' when making judgments in courts, 'wrong/false' vs. 'right/true' when measuring truth value, and, on the other hand, non-dichotomous data consisting of a spectrum of values, such as 'completely agree', 'mostly agree', 'mostly disagree', 'completely disagree' when measuring opinion.

1. A variable that has an ordinal-level measurement scale is commonly referred to as an ordinal-level variable, or simply, an ordinal variable.
2. The empirical relation system consists of classes that are ordered with respect to the attribute.
3. Any mapping that preserves the ordering (that is, any monotonic function) is acceptable.
4. The numbers represent ranking only, so addition, subtraction, and other arithmetic operations have no meaning.

Common qualitative, ordinal measurement scales include the following scaling techniques:

1. Likert-type scale (qualitative)
   A. Evaluation-type: little, unsatisfactory, satisfactory, excellent.
   B. Frequency-type: never, rarely, occasionally, most of the tie.
   C. Agreement-type: strongly agree, agree, disagree, strongly disagree.
2. Semantic differential scale – scale includes semantic opposition.
   A. Slow <> Fast; Timely <> Untimely.

3. Summative scale

In this context a scale would give a score (qualitative), a dimension would be an actual measurement (quantitative). For example:

1. Dimension – Length of an object (quantitative).
2. Dimension - Percentage of organisms who die from the same mass dosage of a poison (quantitative; "lethal dose 100/50/30/10).

4.42 Level of measurement: Quantitative (cardinal, metric scale, numerical)

There are three quantitative levels of measurement note here:

1. Interval.
2. Ratio.
3. Absolute.

4.42.1 Interval [-level of measurement, scale] – identified intervals, space between categories is identified

Note: Some statistics software packages may refer to cardinal and ratio data as 'scale'.

Values assigned to the levels of a variable simply indicate that the levels are in order of magnitude in equal intervals. "Interval" itself means "space in between," which is the important thing to remember–interval scales not only tell us about order, but also about the value between each item. Interval scales provide information about order, and also possess equal intervals.

A degree represents the same underlying amount of that which is being measured (e.g., heat if temperature is measured), regardless of where it occurs on the scale.

Interval scales don't have a "true zero." For example, there is no such thing as "no temperature."

Interval scales are those that are known to be linear in some fundamental sense, and are the simplest scale type to allow meaningful comparison of differences. Interval scales typically have an arbitrary zero. Familiar examples include the latitude and longitude scales, which are used to determine position on the surface of the earth. The longitude scale requires two standards to define it: the position of the zero, which is arbitrarily chosen to be Greenwich, and the number of degrees in a full revolution of the earth, which is arbitrarily chosen to be 360. It is possible to compare changes in longitude meaningfully, or to add and subtract intervals of longitude, but it is still not meaningful to talk about ratios. Statements such as 'a country at 40 degrees of longitude is twice the country at 20 degrees of longitude' are nonsense.

Other examples of interval scales include all of the time scales that we use to tell the time of day, date and year, and the 4 mA to 20 mA current loop representation used by many industrial instruments (a symbol need not be a squiggle on paper). One of the earliest thermodynamic temperature scales, the centigrade scale, was an interval scale based on the definition of the melting and boiling points of water at 0 °C and 100 °C respectively. Because interval scales are the first that enable us to talk meaningfully about intervals, these are the first scales that allow us to do normal statistics, that is to calculate means and standard deviations.

Without a true zero, it is impossible to compute ratios.

Interval scales add information about the distance between ranks. To employ an interval scale we must use some kind of standard unit. For example, we differentiate between temperatures by using the standard unit of degrees celsius. We distinguish among elevations by using the arbitrary datum of mean sea level. We cannot multiply or divide interval scale data. For example, it would be incorrect to say 40 °C = 2 * 20 °C. Interval scales have no true or absolute zero. A temperature of 0 °C does not imply an absence of heat, it is just the point at which water freezes.

Cardinal data (also known as interval data) refers to data comprised of consistent units/intervals. Higher numbers mean more of something whereas lower numbers always mean less of something e.g. height, weight, time, temperature, etc. Cardinal data doesn't always have what's known as a 'true zero'.

Distance [between attributes] is meaningful. Differences between values are meaningful. Equal degree/rating (in a 'range') on a scale between two numbers (numerical values). A scale which represents quantity, and has equal units, but for which zero represents an additional point of measurement is an interval scale. The interval type allows for the degree of difference between items, but not the ratio between them. Examples include temperature with the Celsius scale, which has two defined points (the freezing and boiling point of water at specific conditions) and then separated into 100 intervals, date when measured from an arbitrary epoch (such as AD), percentage such as a percentage return on a stock, location in Cartesian coordinates, and direction measured in degrees from true or magnetic north. Ratios are not meaningful since 20 °C cannot be said to be "twice as hot" as 10 °C, nor can multiplication/division be carried out between any two dates directly. However, ratios of differences can be expressed; for example, one difference can be twice another. Interval type variables are sometimes also called "scaled variables", but the formal mathematical term is an affine space (in this case an affine line).

1. A variable that has an interval-level measurement scale is commonly referred to as an interval-level variable, or simply, an interval variable.
2. Interval scale carries information about the size of the intervals that separate the classes.
3. An interval scale preserves order, as with an ordinal

scale.

4. An interval scale preserves differences, but not ratios. In other words, the difference between any two of the ordered classes in the range of the mapping is known, but computing the ratio of two classes in the range does not make sense.
5. Addition and subtraction are acceptable on the interval scale, but not multiplication and division.

> **NOTE:** *Occasionally, in common parlance, the ratio scale is considered a second [categorical] class of cardinal measurement, with the first being the interval scale. In other words, there are two sub-categories of cardinal measurement: the interval scale and the ratio scale.*

4.42.2 Ratio [-level of measurement, scale] – measured intervals zero, relation to an absolute datum

Ratio data is the highest measurement scale. All forms of arithmetic operations can be meaningfully applied to ratio scale data. There is a meaningful "zero" value (a fixed origin), and ratios between values are meaningful. Equal degrees on a scale, and the non-existence of a degree is meaningful. The ratio scale of measurement is similar to the interval scale in that it also represents quantity and has equality of units. However, this scale also has an absolute zero (no numbers exist below the zero). Very often, physical measures will represent ratio data (for example, height and weight). If one is measuring the length of a piece of wood in centimeters, there is quantity, equal units, and that measure cannot go below zero centimeters. A negative length is not possible. The ratio type takes its name from the fact that measurement is the estimation of the ratio between a magnitude of a continuous quantity and a unit magnitude of the same kind (Michell, 1997, 1999). A ratio scale possesses a meaningful (unique and non-arbitrary) zero value. Most measurement in the physical sciences and engineering is done on ratio scales. Examples include mass, length, duration, plane angle, energy and electric charge. In contrast to interval scales, ratios are now meaningful because having a non-arbitrary zero point makes it meaningful to say, for example, that one object has "twice the length" of another (= is "twice as long").

In a ratio scale, the following is known:

1. The order
2. The exact value between units
3. An absolute zero
   A. A variable that has a ratio-level measurement scale is commonly referred to as a ratio-level variable, or simply, a ratio variable.
   B. The most common scale in the physical sciences.
   C. It is a measurement mapping that preserves ordering, preserves size of intervals between entities, and preserves ratios between entities.
   D. There is a zero element, representing a total lack of the attribute.
   E. The measurement mapping must start at zero and increase at equal intervals, known as units.
   F. All arithmetic can be meaningfully applied to the classes in the range of the mapping.

A scale in which the values assigned to the levels of a variable indicate both the order of magnitude and equal intervals, but in addition, assume a real zero. The real zero represents the complete absence of the trait that is being measured.

In addition to possessing the qualities of nominal, ordinal, and interval scales, a ratio scale has an absolute zero (a point where none of the quality being measured exists). Using a ratio scale permits comparisons such as being twice as high, or one-half as much. Reaction time (how long it takes to respond to a signal of some sort) uses a ratio scale of measurement -- time. Although an individual's reaction time is always greater than zero, we conceptualize a zero point in time, and can state that a response of 24 milliseconds is twice as fast as a response time of 48 milliseconds.

This type of scale is also known as the metric scale. Metric scales include all of the familiar SI scales of length, mass, thermodynamic temperature, etc. The mass scale is defined in terms of the prototype kilogram stored in a safe in a basement of the Bureau International des Poids et Mesures (BIPM) in Paris. All other measurements reported on the mass scale are expressed as ratios with respect to the kilogram. The standard used to define the scale is known as the metric or the unit of the scale. Metric scales are also known as ratio scales, and the literal translation of the word metrology, from the Greek metrología, is the study of ratios.

> **NOTE:** *The measurement scales for counting oranges and apples are different, because they have different metrics, one orange and one apple respectively, and one cannot take one apple from two oranges and obtain a meaningful result*

The log-ratio scales form a special class of interval scales that are actually based on metric quantities. Because of the very large range of values encountered, it is often convenient to transform metric measurements to a logarithmic scale. These scales are typically constructed as value on log scale = constant × log (value/reference value).

There are two definitions required to define a log-ratio scale: the multiplying constant and the reference value. Examples of such scales include the various decibel scales, the visual magnitude of stars, and the Richter scale for the energy dissipated in earthquakes. On these scales equal intervals correspond to constant multiplying factors of the underlying metric quantity. An interval of 10 dB corresponds to a 10 times increase in power, five steps of visual magnitude correspond to 100 times decrease in the brightness of stars, and two steps on the Richter scale correspond to a 1000 times increase in the energy dissipated in an earthquake.

The progression of scales given above (from lower to higher mathematical operations) suggests that as the nature of quantities and measurements becomes well understood, the associated scales evolve towards metric scales (i.e., a scale with a natural zero).

Some scales can never be metric: colour will always be a three-dimensional scale based on two interval quantities and one metric quantity, and the Rockwell hardness scales will always be ordinal scales.

The counting/natural scale is a metric scale.

With metric scales, an additional possibility is available, namely geometric or harmonic analysis, which is based on distributions measured in terms of ratio rather than interval. An analysis of quantities measured on log-ratio scales using interval statistics is effectively a ratio analysis of the underlying metric quantity.

4.42.3 Absolute [-level of measurement, scale] – measured intervals with true zero, relation to an absolute datum

The ratio scale with an absolute zero (a.k.a., true zero) is sometimes called absolute. No transformation (other than identity) is meaningful. The non-existence of a degree means the non-existence of something in the real world.

An absolute scale is a system of measurement that begins at a minimum, or zero point, and progresses in only one direction. An absolute scale can only be applied to measurements in which a true minimum is known to exist.

Absolute scales are used when precise values are needed in comparison to a natural, unchanging zero point. Measurements of length, area and volume are inherently absolute, although measurements of distance are often based on an arbitrary starting point. Measurements of weight can be absolute, such as atomic weight, but more often they are measurements of the relationship between two masses, while measurements of speed are relative to an arbitrary reference frame.

Defined over a closed set (e.g., objective probability).

1. A variable that has a absolute-level measurement scale is commonly referred to as a absolute-level variable, or simply, a absolute variable.
2. The absolute scale measurement process involves counting the number of elements in an entity set (a conceptualization or pattern). In other words, the absolute scale measurement process involves quantizing the quantity of separations/patterns in a conceptualization or pattern (in a, concept pattern).
3. The measurement for an absolute scale is made by counting the number of elements in the entity set.
4. The attribute (measure) always takes the form:
    A. Number of occurrences of conceptual entity.
    B. Quantity, Unit.
5. There is only one possible measurement mapping.
6. All arithmetic analysis of the resulting count is meaningful.

5 The unit

A measurement necessarily involves a reference frame, and therefore, units. In decades past, there were numerous units, which had little in common with each other. The first coherent system of units only appeared with the French revolution, and it has been given the familiar name, the Metric System.

A unit of measurement (a.k.a., measurement unit, or just, unit) is a real scalar quantity, defined and adopted by convention, with which any other quantity of the same kind can be compared to express the ratio of the second quantity to the first one as a number. In physics, a given unit carries the semantic information of a [physical] property [of the universe] and an associated quantity. Hence, a unit is a standard measurement of the same quantity, for the purpose of comparison.

SEDRIS provides useful definitions of terminology herein:

1. *Environmental Data Coding Specification (EDCS): 3 Terms, definitions, symbols and abbreviated terms*. SEDRIS Standards. Accessed: January 7, 2020. [standards.sedris.org]
2. *Environmental Data Coding Specification (EDCS): 2 Normative references*. SEDRIS Standards. Accessed: January 7, 2020. [standards.sedris.org]

> **NOTE:** *More general, a unit signifies the presence of a quantity or quality.*

The value of a quantity is generally expressed as the product of a [measurement] number and a [measurement] unit. Instances of the same unit category may have a quantitative difference represented by the number. It could be said that a measurement unit is a standardized quantity of a physical property, used as a factor to express occurring quantities of that property. A 'unit of measurement' is a definite magnitude of a quantity (number), defined and applied, that is used as a standard for measurement of the same quantity. Any other value of that quantity can be expressed as a simple multiple of the unit of measurement (e.g., metric is multiples of ten, and time is multiples of 60). In other words, a measurement unit is a standard that is used to measure some physical quantity. A report of a quantitative measurement is not meaningful without its units.

A 'measurement unit' is also known as a:

1. Unit of measurement or units of measure.
2. A measurement unit.
3. A measurable unit.
4. A unit.

The measurement of a different sub-category of existence is signified by different units. Therein, units [of measure] are names (not numbers) that signify (characterize) the type of property (concept or system) under measurement, and they associate a standard of comparison to which each is related.

> **NOTE:** *The condition of a system described by its properties (temperature, pressure, etc ...) is defined as its 'state'. At a given 'state', all properties of a system have fixed values. These values may, or may not, fluctuate in time – they may have different values at different states (i.e., dynamic; they may have different values).*

In the language of measurement, quantities are quantifiable aspects of the world, such as time, distance, velocity, mass, temperature, energy, and weight, and units are used to describe their magnitude (or quantity).

A unit must be related to the aspect of the object (system or event) to be measured. For example, a unit of area is required to measure area; area cannot be measured without a linear tool. A linear tool measures length. "We" give a name to a set amount length (i.e., a meter is a meters length). "We" give the name 'meter' to the set quantity length of a 'meter'. Meter and length are both units. The unit name is 'meter', and the dimensional unit [quantity] is 'length'. Once a reference point is established (i.e., a meter is a meter in length), then a scale of units may be created using prefixes, such as kilo (1000, 10-3) and milli (-1000, 10-3). Hence, kilometer is 1000 (or 103) meters, and nanometer is -1000 (or 10-3) meters.

A unit of measurement is relatively arbitrary but consistent. Why is a meter [distance] the quantitative length it is? Why is a second of time the quantitative time it is? These dimensional quantitative amounts have been selected by humans for their ease of perceptual comprehension as quantitative unit reference points from which to base (i.e., compare) existence within a similar conceptual category (Read: dimension).

A measured or counted quantity has a numerical value (e.g., 2.48) representing the quantity, and a unit signifier (whatever there are 2.48 of) representing the constant (fundamental or derived). Hence, when communicating measurements, it is essential to write both the value (#) and the unit (linguistic signifier) of each quantity/constant.

Note that it should not necessarily be presumed that within a single human and/or computational organization where most measurements tend to be reported consistently in the same units, that users will correctly infer the units when they are omitted. The omission of units may lead to unnecessary errors (or, "mistakes"). Further, automatic conversion and computer-assisted calculations become easier with the proper use of unit. It is optimal to always indicate the units.

The first step to check the validity of an equation or an expression in physics is to look at the unit. The units involved in the construction of equations will influence (determine) the form of the equation.

Dimensions and units

In application, the term 'unit' means essentially the same thing as the term 'dimension'. The terms unit and dimension are often used synonymously. However, there are slight differences in definition and rule application in the two alike terms when dimensions are defined as the conceptual quantities of a system, and units represent the name(s) given to a set quantity (quantitative amount) of the dimension. Units and dimensions have the following definitional differences:

1. An equation in which the units balance on both sides of the equal sign is called **coherent**.
2. An equation in which the dimensions balance on both sides of the equal sign is called **homogeneous**.
3. A unit system constructed so that all physical laws are represented by coherent equations is called a **coherent unit system**. Physics, chemistry, and most of engineering are built upon coherent systems.

Units and dimensions have the following rule differences:

1. Dimensions combine by the ordinary rules of algebra. Units do also.
2. Terms which are added or subtracted must have the same dimensions and the same units.
3. Quantities on either side of the equal sign must have the same dimensions and the same units.
4. Powers are dimensionless and unitless (though factors within them may have dimensions and units).
5. Percentages are dimensionless quantities, since they are ratios of two quantities with the same dimensions, and hence, have the same units.
6. dy/dx and ∂y/∂x have the dimensions and the units of y/x (look at the formula for the definition of the derivative).
7. ∫ y dx has the dimensions and the units of yx.
8. Arguments of sin, cos, tan, log, etc., must be dimensionless, but may have units.
9. Sin, cos, tan, log, etc., are dimensionless and unitless.
10. The mathematical constants pi (π) and e are dimensionless and unitless. Specific gravity, being a ratio of two densities, is dimensionless. It has no unit name. Index of refraction, a ratio of two speeds (of light), also has no unit name. Pi (π), the ratio of a circle's circumference to its diameter is therefore dimensionless and has no unit name.
11. Sometimes measurables of physically different quantities have the same dimensions. The commonest example is work and torque: both result from multiplying force by distance. In these cases the unit names are often assigned in a distinctive manner. Names of work units, erg, Newton, etc., are never used for torques.
12. It is also possible for different quantities with different unit names to have the same dimensions. The quantity, 'luminous flux', has the unit 'lumen'. A light's source strength is expressed in the unit 'candela'. A one candela source is said to emit 4π lumens. It may be written, 4πC, where C is the source strength and F is the flux. 4π is dimensionless, so C and F have the same dimensions, even though representing distinctly different quantities with different unit names.

5.1 Units and countability

A.k.a., Measurable units, countable units, and uncountable units.

In measurement, there are three categories of unit:

CLARIFICATION: *The term "units of measure" refers to the names of the units themselves, and not to the first category, "measurable units".*

1. **Measurable units** (as opposed to countable units) are specific values of dimensions [of a system] that have been defined for communication and construction concerning physical quantities. Example units of measure include:
   A. Grams for weight ("mass").
   B. Seconds for time.
   C. Centimeters or feet for length.
   D. Etc.
2. **Countable noun units (a.k.a., countable objects, noun units, unit nouns, object units)** are separate objects that are inherently countable (because they are separate). Countable noun units can be used with "a" or "an." Countable object/ noun units are objects (nouns) that have both singular and plural forms. Example countable noun units include:
   A. Chair (singular), chairs (plural).
   B. System (singular), systems (plural).
   C. Habitat (singular), habitats (plural).
   D. Etc.
3. **Uncountable noun units (a.k.a., uncountable objects, mass nouns, flow-mass objects)** - are flow-mass nouns only have one form, and hence, are fixed as a singular or plural. Mass nouns represent substances, concepts, or ideas considered as a whole. Uncountable noun units represent objects that are not directly countable. For instance, it is not possible to say: 1 furniture, 2 furnitures, 3 furnitures, etc. However, it is possible to use "a part of / an system of" for singular and "some" for plural. For instance, it is possible to say, "a piece of furniture" or "some furniture", and "an

item of cloth" or "some cloth". Uncountable noun units usually do not use "a" or "an" directly but can become countable by adding units of measure.

A. Example uncountable noun units include:
   1. Water (uncountable).
   2. Air (uncountable).
   3. Information (uncountable).
   4. Furniture (uncountable).
   5. Powder
   6. Etc.
B. Countable forms (of uncountable noun units) using countable noun units of measure include:
   1. A glass of water.
   2. A liter of air.
   3. An item of information.
   4. Etc.

There are 4 types of mass nouns:

1. Singular nouns that are always mass nouns (no plural form).
2. Plural nouns that are always mass nouns (no singular form).
3. Nouns that can be unit nouns or mass nouns and have the same meaning.
4. Nouns that can be unit nouns or mass nouns but have different meanings.

In many languages, 'information' is a unit noun, and has both singular and plural forms (information and informations respectively). However, in English and the community in general, 'information' is a singular mass noun; there is only information, and no informations.

5.2 Unit taxonomy

The concept of a 'unit' is taxonomically classified according to the three components of classification, identification, and nomenclature (naming):

5.2.1 Classification

Unit classification includes:

1. **Concept naming** - the logical, orderly naming of units based on derivation location.
   A. **Basic or fundamental units (a.k.a., base units, fundamental units, and dimensional units, fundamental dimensions)** - The smallest set of quantities that are accepted by definition. The basic measurables (a.k.a., fundamental measurable units and dimensions) are the basic/fundamental measurable units or dimensional units of a system. A base unit (also referred to as a fundamental unit) is a unit adopted for measurement of a base quantity (an axiomatic physical, natural property of existence or reality, fundamental dimension). A base quantity is one of a conventionally chosen subset of physical quantities, where no subset quantity can be expressed in terms of the others. The basic measurables of a system are called the "dimensions of the system". Practically, they are the dimensions (parts/coordinates separated axiomatically) of the system. Here, the use of the word, "dimension", is analogous to its use in analytic geometry. In space, any point can be specified by its coordinates measured along axes of a three-dimensional coordinate system (generally signified in a standard manner as: x, y, and z). The dimensions of a quantity do not have an inherent unit association. The dimensions, and hence, units, arise from the logical interrelations between quantities, reflecting the structure of physical laws and definitions.
   B. **Dimensional units** – concepts identifying the base/fundamental dimensions of a system.
   C. **Base/fundamental units (a.k.a, metric units)** – the dimensional quantity associated name. For example, the metre unit as length dimension, kilogram unit as mass dimension, second unit as time dimension, kelvin unit as temperature dimension, etc.
   D. **Multiple units** - express (by name) multiples or fractions of base units, such as minutes, hours, and milliseconds (for time), all of which are defined in terms of the base unit of time, a second. Multiple units are defined for convenience rather than necessity: it is simply more convenient to refer to 3 years than to 94608000 seconds.
   E. **Derived units (sub-units)** - recognized by the dimensions and can be defined as the complete algebraic formula for the derived unit. In a system of measurable units, any derived measurable will be expressed as an algebraic combination of the basic/fundamental measurables (dimensions or basic units) of the system. Derived units are based on base/fundamental units, and can always be represented by these units. In other words, derived units are composed of several other units combined together.
2. **Concept Modifying** - modifying the name of a unit to indicate scale.
   A. **Unit [multiple] prefixes**
   B. A quantity of a unit can be re-written using a different logical name via a prefix multiplication scale. A prefix precedes the associated unit symbol to form a multiple or sub-multiple.

This scale re-framing may make reading and calculation of the data more efficient (if human) or less efficient (if computer). For a human, it is easy to multiply by 10, for instance. Metric [unit] prefixes include: deca-, hector-, kilo-, deci-, centi-, milli-, etc. In total, there are twenty prefixes that have been officially adopted to be used with the Metric Unit System.

5.2.2 Identification

Procedures and methods for determination of an unknown unit.

5.2.3 Nomenclature

The logical naming of all the units in the taxonomy. Note here that there is little logical linguistic naming between the multiple units for the base unit of time, the second and a multiple unit of time, the minute and the hour. What is the relationship between the letters that compose the dimension 'time', the base unit 'second', and the unit multiples minute and hour? The words minute and hour do not appear logically related to 'second' or 'time'.

Summarily, classification refers to the sub-organization of unit-type concepts. Identification ensures that it is possible to procedurally (methodically) determine the unit for a known quantity. And, nomenclature ensures that names are logical, and hence, easy to recall and use.

> **NOTE:** *A 'dimensional analysis' is a scientific analyses conducted to determine the basic/ fundamental measurable (measurable units) of a system.*

5.3 Fundamental and derived units [of measurement]

The basis of the physical sciences is a set of names, definitions, and equations, which allow for awareness, experimentation, and adaptation to a physical environment (i.e., our physical reality).

Not all quantities require a unit of their own. Using physical laws, units of quantities can be expressed as combinations of units of other quantities. Only a small set of units is required from which a more complex functional set can be built. The small set of required units of physical quantity are called base units (a.k.a., fundamental units), and all others units are derived [units]. Derived units are a matter of convenience, as they can always be expressed in terms of basic units.

> **CLARIFICATION:** *A [physical] quantity is a quantifiable [physical] aspect/attribute of the world (the universe, nature, reality), such as time, distance, velocity, mass, temperature, energy, and weight. A 'physical quantity' is a characteristic (property or quality) that can be measured, and which follows the laws of physics (which, describe and/or predict behavior and relationships). Here, physical quantity units are used to describe the magnitude or quantity of a physical aspect/attribute of the world.*

A base quantity is characterized by the following two principles:

1. Base quantities are those quantities which are distinct in nature and cannot be expressed in the form of other quantities.
2. Base quantities are those quantities on the basis of which other quantities can be expressed.

Similarly, a 'fundamental measurement' is characterized by the following two principles:

1. Measurement that is not derived from other measurements.
2. Measurement that is produced by an additive (or equivalent) measurement operation.

Hence, the two types of measurable physical quantities (i.e., physical units of measure) are:

1. **Axiomatic (base/fundamental quantity)**: A quantity that cannot be expressed in terms of other quantities. A quantity that is axiomatic (i.e., fundamental or base), and hence, cannot be defined in terms of the others. Those few which cannot be defined in terms of others, the "basic/fundamental measurable or dimensions", are defined through operational definitions (by specifying a measurement process).
2. **Derived (quantity)**: A quantity that can be expressed in terms of other quantities (/units). This type is not axiomatic, and is defined ("derived") algebraically in terms of other quantities.

In other words, the two physical units of measurement are:

1. **Fundamental units (a.k.a., basic units, fundamental measurable, basic measurable, and dimensions [of a system]** - Those defined by specifying a measurement process (i.e., by operational definitions). A base unit (also referred to as a fundamental unit) is a unit adopted for measurement of a base (fundamental axiomatic) quantity/constant. These are so directly connected with measurement that they are defined by the measurement process. Fundamental units describe axiomatic existent quantities (given what is known) from which all other units can be derived.
    A. Base quantities are those quantities that are common to any object.
2. **Derived units (a.k.a., defined measurable)** - Those defined by algebraic mathematical equations

in terms of other previously defined and/or fundamental measurables (measurable units).
   A. Derived quantities are quantities formed by combining two or more base quantities (using multiplication or division).

Fundamental units may be perceived of from several different problem-oriented contexts:

1. In **mechanical problems**, a fundamental set of units is mass (M), length (L), time (T). With this fundamental system, velocity V = LT −1 and force F = MLT −2 are derived units. Alternatively, if instead, force (F), length (L), and time (T) are the fundamental system of units, then mass M = F L−1T 2 is a derived unit.
2. In **thermodynamic problems** (i.e., problems involving heat flow), the concept of temperature (measured, for example, in Kelvin) is a fundamental unit.
3. In **problems involving electromagnetism**, current is introduced as a fundamental unit (measured, for example, in Amperes in the SI system) or charge (measured, for example, in electrostatic units in the cgs system).
4. In **problems involving relativistic mechanics**, if mass (M), length (L), and time (T) are fundamental units, then the speed of light c is a dimensional constant (c = 3 × 108 ms−1 in SI-units). Therein, ‘c’ may be set to equal 1 (c = 1), and mass (M) and time (T) are the fundamental units. This means that length is measured in terms of the travel-time of light (one nanosecond being a convenient choice for everyday lengths).

NOTE: *The ‘Rasch Analysis’ operationalizes ‘fundamental measurement’ based on ordered qualitative observations. Therein, ‘voltage’ as charge pressure, no matter the scale, is the most fundamental measurement for energy.*

5.4 The fundamental, base physical dimensional units [of measurement]

Today, there are seven scientifically recognized basic (base, fundamental) units of measurement, as that which is perceived as a fundamentally constant unit/quantity in the universe. Every other perceived [unitized] measure[able] is derived from those seven.

In other words, in physics, there are seven fundamentally perceivable:

1. Base quantities (detailed in the International System of Quantities, ISQ).
2. Fundamental dimensions of an axiomatic physical existence.
3. Units of [physical] measurement.

In physics, there are seven defined and measurable (dimensional) units. However, all seven fundamental units can be derived with three-four of the fundamental units.

1. **Mechanics requires four** fundamental measurable unit dimensions:
   A. Kinematical (3 units)
      1. Mass (kilograms).
      2. Length or distance (meters).
      3. 3 length dimension (x,y,z).
      4. Time (seconds).
   B. Electrical (1 unit):
      1. Ampere.
2. It could be said that our **human experience of the world encompasses five** dimensions:
   A. Three linear spatial dimensions (x,y,z).
   B. One mass dimension.
   C. One temporal dimension (time).
3. **Electricity requires two** fundamental measurable units:
   A. Voltage (eV or Volts, depending on scale).
   B. Time (seconds).

However, it could be said that time is the only true unit of measure; because without time, no change can occur, and thus, no measurement. Measurement involves the perception of a change from a baseline, and change cannot occur without time. Time gives everything its existence, but it is not the true unit of measure. The nature of time is to flow (iterate), and the nature of consciousness is to experience the rate. Time (iteration) is essential in measurement in principle, for instance:

1. A mole is an exact number of “atoms”. Measuring a mole requires time.
2. A candela is a measure of “luminocity”. Luminocity is dictated by wavelength and frequency. A wave length has no length without time to travel said length, and frequency cannot be determined without measuring this length travelled over a time.
3. A meter is a measure of “length”. The very action of measuring length requires time. Can you measure this without time? Grab a ‘tape measure’ and try. You have already failed as taking the measurement takes time.

That which involves a system in time, involves:

1. **Duration** (of time of system).
2. **Volume** (3x length dimensions of system in time).
3. **Concentration** (mass of system in time).
4. **Intensity** (electric current of system in time).

Take note here that the common properties of physical systems include, but are not limited to:

1. Pressure (P).
2. Temperature (T).
3. Volume (V).
4. Density (D).
5. Mass (M).
6. Energy (E).

It is common in the realm of the elementary particle physics to redefine units so that speed of light and Plank's constant become equal to one, c=1 and h =1. This imposes two constraints on the three kinematical units, and therefore, provides a choice one of the three kinematical units. The units of electrical charge, also, can be, and are redefined (see below). Such system of units is often referred to as Natural Units (natural for the elementary particle physics, that is). The kinematical unit of the choice is energy, E, and it is usually measured in eV (keV, MeV, GeV, TeV). Once c and h are fixed (c=1 and h =1), all other kinematical units can now be expressed in terms of units of energy.

> **INSIGHT:** *If every point in the universe (i.e., every proton has the information of all other protons in the universe) has all the information about the universe (a holographic system), then the universe has the ability to self-organize. Then, every point knows exactly how to self-organize, because all the information is present in every point. We are feeding the universe information, and the universe is feeding us information through all the protons we are made of.*

5.4.1 Geometrized units [of measurement]

A geometrized unit system or geometric unit system is a system of natural units in which the base physical units are chosen so that the speed of light in vacuum, c, and the gravitational constant, G, are set equal to unity.

- c = 1
- G = 1

The geometrized unit system is not a completely defined or unique system: latitude is left to also set other constants to unity. We may, for example, also set Coulomb's constant, ke, and the electric charge, e, to unity.

- ke = 1
- e = 1

The reduced Planck constant, ħ, is not equal to 1 in this system (Stoney units), in contrast to Planck units.

5.5 Physical constant, natural units [of measurement]

In physics, **natural units** are physical units of measurement based only on universal physical constants (a.k.a., the fundamental constants of physics; invariant quantities), and not on human constructs. There are many physical constants in science.

For example,

1. The elementary charge 'e' is given as the natural unit of electric charge, and
2. The speed of light 'c' is given as the natural unit of speed.

A physical constant (a.k.a., fundamental physical constant) is a physical quantity (a.k.a., fundamental physical quantity) that is understood to be both universal in nature and having constant value in time. It is contrasted with a mathematical constant, which has a fixed numerical value, but does not directly involve any physical measurement. Natural units are "natural" because the origin of their definition comes only from properties of nature and not from any human construct (i.e., they can be experimentally demonstrated).

> **NOTE:** *Using dimensional analysis, it is possible to combine dimensional universal physical constants to define a system of units of measurement that has no reference to any human construct.*

Properties of the universe that are likely to have quantity may be represented as natural units. Natural units are intended to simplify particular algebraic expressions appearing in the laws of physics, or to normalize some chosen physical quantities that are properties of universal elementary particles, and are reasonably understood to be constant.

The value of any one of these seven constants is written as the product of a numerical coefficient and a unit, Q = {Q} [Q], where Q denotes the value of the constant and {Q} its numerical value when expressed in the unit [Q]. By fixing the exact numerical value — that is, not assigning any uncertainty to it — the unit becomes defined, as the product of the numerical value and the unit must equal the value of the constant, which is invariant.

There are many natural units (as defined constants), including but not limited to:

1. The speed of light in vacuum - c
2. The Planck constant - h
3. The elementary [electric] charge - e
4. The Boltzmann constant - kB
5. The Avogadro constant - NA
6. The luminous efficacy - Kcd

7. The gravitational constant – G
8. The electron rest mass – me
9. The Josephson constant – KJ
10. The frequency of the ground-state hyperfine splitting of the caesium-133 atom - Δν(133Cs)hfs

A purely natural system of units has all of its units defined by physical constants. Usually, the numerical values of the selected physical constants defined in terms of these units are exactly dimensionless (1).

These constants should not be omitted from mathematical expressions of physical laws; though omission has the apparent advantage of simplicity, it may entail a loss of clarity due to the loss of information, which is otherwise is required for dimensional analysis. Omission of the constant precludes the easy cognitive interpretation of an expression in terms of fundamental physical constants, such e and c.

Throughout all of the formulations of the basic theories of physics, and their application to the real world, there appear certain fundamental invariant quantities. These categorical delineations in our understanding of the reality system of our experiences are called, [fundamental] physical quantities/constants (i.e., fundamental physical quantities and fundamental physical constants). These constants/quantities have specific and universally used symbols.

It is important to understand that most measurements are relative by nature, so only measurements (and units) as the basis for other measurements need to be solitary by nature. Those measurements (or units) that are presently understood to foundation all others are: time, current-voltage, mass, and length. All other measurements (i.e., all other measurables) are based on those units. For instance, velocity is distance per unit of time, Hertz is the number of voltage cycles per unit of time, and calories is the chemical energy (measurable as eV) released per unit mass, etc.

5.6 A unit system (system of units)

A system of measurement is a collection of measurement units, for various concepts of "measure" (i.e., dimensions and units; e.g. length, mass, time), where various units are mutually consistent, and interrelate in a standardized way. Practically, a system of units (a.k.a., unit system) forms a group of pre-determined reference amounts with logical naming. Simply, a standard[ized] set of units is called a 'unit system'. In order to take (i.e., "make") a quantitative measurement, a system of units is required; that is, a set of magnitudes with which to compare those things (properties/attributes) for which comparison (i.e., measurement) is desired.

A system of units is a necessary input for cooperatively measuring ourselves and our environment (Read: the cosmos, the universe, nature, reality).

A set of fundamental/basic units is otherwise known as a 'system of units'. Different fundamental/basic systems of units are based on different choices of base units. A [basic, fundamental] system of units is a set of independent (axiomatic) units from which all other units in the system can be derived. The choice of fundamental units in a particular class of problems is not unique, but, given a fundamental system of units, any other derived unit may be constructed uniquely as a product of powers of the fundamental units.

5.7 Coherent versus incoherent unit systems

A unit system may be either coherent or incoherent. In order to establish a coherent system of units (e.g., the SI) it is necessary to first establish a system of quantities, including a set of equations defining the relations between those quantities. Units therein are consistently constructed and consistently named. Incoherent unit systems have units with no direct relation to each other, and when there are relations, they lack consistency (e.g., the Imperial and US systems). The units within incoherent unit systems are therefore difficult to remember and less efficient to work with.

A coherent unit system is built by choosing appropriately sized basic/fundamental dimensional units for the users' cognition and/or computational parameters. For instance, a meter is given the quantity it has been given, in part, because it is easy for human cognition. The units of other measurable dimensions will then be determined by their defining equations, as combinations of the units of the base/fundamental measurable dimensions, in the same manner as dimensions are determined.

A coherent unit system is a set of coherent axiomatic (base, fundamental) dimensional units that can be used to accurately understand and construct that which is conceptualized. The most widely used system of units is the International System of Units, or SI. There are seven SI base units; all other SI units (non-base) can be derived from these base units.

> **NOTE:** *A logically standardized system of units allows for efficiency in measurement, and hence, efficiency in design, development, and operation [of service systems].*

Take note that in physics, coherent unit systems can presently be built upon a set of basic units that includes only one of the following:

1. When mass is included within the set of basic units, the system is called '**absolute**'.
2. When force is included within the set of basic units, the system is called '**gravitational**'. The fps system is characterized by a gravitational unit of force, called the pound-force (lbf). The unit is so defined that a standard gravitational field exerts a force of one pound on a mass of one avoirdupois pound.

5.8 Common unit systems in use on the planet today

The four most common unit systems in use today are:

1. **The International Metric System (MKS, the [Decimal] Metric System)** is an absolute system. Its basic units are the meter, kilogram, and second. There are several variants of the metric system, including:
   A. **The International System of Units (SI, for System, International**) is the modern/revised form of the metric system, and is the most widely used system of measurement. It has seven basic units, including the meter, kilogram, and second.
   B. **The CGS (centimeter-gram-second) system** was once standard in physics.
2. **The FPS (foot-pound-second) system** was once standard in engineering, and is a gravitational system of units.
   A. The FPS is an incoherent system.

These three systems (MKS-SI, CGS, and FPS) are all mutually coherent for most branches of physics, especially mechanics (but not including electricity and magnetism). In mechanics, the equations have the same form in all three. In electromagnetics the International System of Units (SI) is used; the FPS system does not account for electromagnetics.

Take note that in the Metric/SI systems, each different kind (dimension) of measurement has a root name, from which other names may be constructed by combining the name with a metric prefix. For instance, the base measurements of an object(s) are:

1. **Edge measurement of an object(s):** Meter, a length unit, forms millimeter, centimeter, and kilometer. Units of length, often measured in meters (m), gauge the extent or distance between two points in space (i.e., between the edges of objects, or two edges on a single object).
2. **Weight measurement of an object(s):** Gram, a mass unit (weight), forms milligram, centigram, and kilogram. Units of weight measure the force of gravity's pull on an object, quantifying the mass of that object in relation to Earth's gravitational field. The standard unit for measuring weight in the International System of Units (SI) is the kilogram (kg).
3. **Volumetric capacity measurement of an object(s):** Liter, a unit of capacity (as volume, not energy), forms milliliter, centiliter, and kiloliter. Units of volumetric capacity (a.k.a., volume units, volumetric units) measure the amount of space or volume that a container or object can hold. They quantify the capacity or volume of a container, typically in relation to liquid or granular substances.

CLARIFICATION: *In mathematics, a 'metric space' is a set for which distances between all members of the set are defined. Those distances, taken together, are called a metric on the set. Therein, a metric space induces topological properties like open and closed sets, which lead to the study of more abstract topological spaces.*

5.9 The International System of Units (SI)

HISTORICAL NOTE: *The metric system of measurement was developed during the French Revolution and was first promoted in the U.S. by Thomas Jefferson. Its use was legalized in the U.S. in 1866. In 1902, proposed congressional legislation requiring the U.S. Government to use the metric system exclusively was defeated by a single vote. As of 2017, outside of the several States (including The United States and Great Britain), there is almost no need to convert metric units into something else, because they use metric units as their physical measurement system. In the United States and Great Britain, multiple measurement systems are used, which introduces the potential for confusion and error, and leads to an inefficient use of time and effort (due to the added necessity to convert).*

The International System of Units is generally seen written as either:

1. International System of Units (SI for Systeme international d'unites), or
2. International System of Quantities (ISQ).

The International System of Units (SI) is the most up-to-date version of the Metric System, and it is formalized as a State agreement that specifies a set of seven base (physical-quantity measurement) units from which all other State agreed upon units of measurement are formed.

The International System of Quantities (ISQ) is a system based on seven base quantities: length, mass, time, electric current, thermodynamic temperature, amount of substance, and luminous intensity. Other quantities such as area, pressure, and electrical resistance are derived from these base quantities by clear non-contradictory equations. The ISQ defines the quantities that are measured with the SI units. The ISQ is defined in the international standard ISO/IEC 80000, and was finalised in 2009 with the publication of ISO 80000-1.

The definitions of the terms "quantity", "unit", "dimension" etc., that are used in the SI Brochure are those given in the International vocabulary of metrology, a publication produced by the Joint Committee for Guides in Metrology (JCGM), a working group consisting of eight international standards organisations under the chairmanship of the director of the BIPM. The quantities and equations that define the SI units are now referred to as the International System of Quantities (ISQ), and are set out in the International Standard ISO/IEC 80000 Quantities and Units.

The Metric System (a.k.a., SI) provides a logical and interconnected framework for all physical measurements. The International System of Units (SI) is a modernized, State constructed, version of the Metric System established by international State/corporate agreement.

The SI unit system includes two types of units based on derivation location (axiomatic or sub-derived):

1. SI Base (Fundamental, Metric) Units.
   - Currently there are 7.
2. SI Derived Units.

The SI includes a coherent set of unit prefix multipliers.

1. Metric prefixes (prefix multipliers).
2. Currently there are +/- 24.
3. What about prefixes for other multiples, such as 104, 105, 10-4, and 10-5? The prefix myria- (my-) was formerly used for 104, but it is now considered obsolete and it is not accepted in the SI. Apparently, no prefixes were ever accepted generally for 105, 10-4, or 10-5, or others.

The seven defined constants are:

- The frequency of the ground-state hyperfine splitting of the caesium-133 atom - $\Delta\nu(^{133}\text{Cs})_{\text{hfs}}$
- The speed of light in vacuum - c
- The Planck constant - h
- The elementary charge - e
- The Boltzmann constant - k
- The luminous efficacy - Kcd
- The Avogadro constant - N_A

The seven defined SI units of measurement with their associated constants are:

1. Meter (m): The base unit for length (from edge-to-edge, distance).
   - The speed of light in vacuum - c
2. Kilogram (kg): The base unit for mass (as weight by gravity).
   - The Planck constant - h
3. Second (s): The base unit for time.
   - The frequency of the ground-state hyperfine splitting of the caesium-133 atom - $\Delta\nu(^{133}\text{Cs})_{\text{hfs}}$
4. Ampere (A): The base unit for electric current.
   - The elementary charge - e
5. Kelvin (K): The base unit for temperature.
   - The Boltzmann constant - k
6. Mole (mol): The base unit for amount of substance.
   - The Avogadro constant - N_A
7. Candela (cd): The base unit for luminous intensity; intensity of light.
   - The luminous efficacy - K_{cd}

5.9.1 The 2018 Update to the International System of Units

Updates to 2018 International System of Units include:

1. **Ampere (A)** - e is the elementary charge (which defines an ampere). The unit used to measure electrical current. An ampere is the current that, when flowing through two infinitely long, infinitely thin wires that are placed exactly 1 metre apart, would produce a certain amount of force. But infinitely long and thin wires are impossible to produce, so no one can actually test precisely what that value should be. Under the new proposal, an ampere will basically be defined based on the electrical charge of the electron and the proton - something that scientists will actually be able to measure.
   A. The Ampere is the only electrical unit among the seven SI base units. Hence, one might logically expect that all other electrical units, including the volt and the ohm, will be derived from it. But that is not the case. In fact, the only practical way to realize the ampere to a suitable accuracy now is by measuring the nominally "derived" volt and ohm using quantum electrical standards and then calculating the ampere from those values.
   B. In 2018, however, the ampere is slated to be re-defined in terms of a fundamental invariant of nature: the elementary electrical charge (e). Direct ampere metrology will thus become a matter of counting the transit of individual electrons over time.
   C. One promising way to do so is with a nanoscale technique called single-electron transport (SET) pumping. It involves applying a gate voltage that prompts one electron from a source to tunnel across a high-resistance junction barrier and onto an "island" made from a microscopic quantum dot. The presence of this single extra electron on the dot electrically blocks any other electron from tunneling across until a gate voltage induces the first electron to move off the island, through another barrier, and into a drain. When the voltage returns to its initial value, another electron is allowed to tunnel onto the island; repeating this cycle generates a steady, measurable current of single electrons.
   D. There can be multiple islands in a very small

space. The distance from source to drain is a few micrometers, and the electron channels are a few tens of nanometers wide and 200 nm to 300 nm long. And the energies involved are so tiny that that device has to be cooled to about 10 millikelvin in order to control and detect them reliably. (Stewart, 2016)

E. The ampere [A], is the unit of electric current; its magnitude is set by fixing the numerical value of the elementary charge to be equal to exactly 1.602 .10(-19) when it is expressed in the unit [As], which is equal to C. Thus we have the exact relation e = 1.602 .10(-19) [C]. The effect of this definition is that the ampere is the electric current corresponding to the flow of 6.242 10(18) elementary charges per second. The following is not true in SI: The present basic unit of electric current Ampere can't be basic unit because is defined with Coulomb and second. Ampere is not unique unit, because depends on other units. From this is obviously that the Coulomb has no relation whit any other units and because of that it's most convenient this unit to be proposed as basic units.

F. Previous to 2018: The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed 1 meter apart in vacuum, would produce between these conductors a force equal to 2 x 10–7 newton per meter of length.

2. **Kelvin (K)** - redefined by linking it to the exact value of the Boltzmann constant, k. Previously, the Kelvin was defined as the triple point of water - the obscure point where water coexists as a liquid, gas, and solid. kB is the Boltzmann constant (which defines a kelvin).
3. **Mole (mol)** - NA is the Avogadro constant (which will define a mole). It was redefined in 2018 by linking it to the exact value of the Avogadro constant.
4. **Meter (m)** - C is the speed of light (which will define a metre.
5. **Second (s)** - ΔνCs is the tick of a caesium atom clock (which defines a second).
6. **Kilogram (kg)** - h is the Planck constant (which will define a kilogram). The Planck constant is measured by placing a known mass on one end of a scale, and then, counterbalancing it by sending an electric current through a movable coil of wire suspended in a magnetic field. The electromagnetic force therein is used to measure Planck's constant down to an accuracy of 34 parts per billion.
7. **Candela (cd)** - Kcd is luminous efficacy (which will define a candela).

A dimension is a property that can be measured (e.g., length, time, mass, or temperature) or calculated by multiplying or dividing other dimensions (e.g., length/ time = velocity, length3 = volume, or mass/length3 = density).

5.10 Systems of units (in use today)

There are multiple systems of units, some of which are more intuitive and logical (depending on context), than others. There are four categories of unit [measurement] systems:

1. **Traditional unit systems**: Historically many of the systems of measurement which had been in use were to some extent based on the dimensions of the human body. As a result, units of measure could vary not only from location to location, but from person to person. Based on "arbitrary" unit values.
   A. **The Imperial System of Units** used in the United Kingdom and former colonies. It bases its measures on human anatomy (generally, the body parts of royals/imperials) and on common objects that humans use. Early on in human development, people used signifiers like body parts as their units of measurement. For instance, the imperial measurement unit known as a "foot" is about the length of a human foot. An "inch" is about the length of a human thumb. A cup is about the weight of a cup of water. A pound is about the weight of 2 cups of water. Note that there is no common base in the Imperial System. Conversely, in the Metric System, the base unit for all measurements is the number (the de-lineation) 10. The Imperial System includes, but is not limited to the following measurement sub-system units: the Foot, the Pound, the Gallon, and the Mile (statute mile and nautical mile).
   B. **The Market System of Units** used in the State of China.
   C. **The United States Customary Unit System** used in the United States
2. **The [Decimal] Metric Unit System**: A number of metric systems of units have evolved since the adoption of the original metric system in France in 1791. The current international standard metric system is the International System of Units (abbreviated to SI). An important feature of modern systems is standardization. Each unit has a universally recognized size. Both the imperial units and US customary units derive from earlier English units. Imperial units were mostly used in

the British Commonwealth and the former British Empire. Based on “arbitrary” unit values, formalized by standards.

A. **The [Decimal] Metric System of Units** (used for globally-coordinated projects): In the [decimal] metric system, every measure is a factor of 10 units from others. The metric (a.k.a., decimal metric) system uses base 10 for everything, which allows for easy calculation and scaling. It is, in terms of human-mind calculation, easier to work with direct powers of 10 proportions, than any other proportion, and particularly when units are of dissimilar proportion (e.g., inch, foot, yard, pound, ounce, etc.) and dissimilar by geographic location (e.g., UK gallon versus the US gallon). In other words, millimetres, centimetres, and kilometres are interchangeable, whereas feet, yards, and miles are not. When performing a mental calculation, someone doesn’t have to have in mind a table referencing how many inches are in a foot, how many ounces are in a pound.

B. In distance (reference is ‘meter’): 1M = 100centiM = 1000milliM = 0.001kiloM (or 0,001kiloM).

C. In volume (reference is ‘litre’ or ‘liter’): 10deciL = 1L = 1000milliL. 10cm x 10cm cube of water weighs about a kilogram, and is otherwise known as a litre.

3. **The Natural Unit Systems:** Unit values that have logically deduced or experimentally demonstrated to occur naturally in science.
   A. **Atomic units (au):** system of units of measured used in atomic physics.
4. **State/legal Weights and Measures**: To reduce the incidence of retail fraud, many national statutes have standard definitions of weights and measures that may be used (hence “statute measure”), and these are verified by legal State representatives.
   A. **Units of currency:** A unit of measurement that applies to money is called a ‘unit of account’ in economics and ‘unit of measure’ in accounting. This is normally a currency issued by a State, or a faction thereof.

5.11 Systems of units used by Community

A ‘measurement unit system’ is a group of related measurement units.

Currently, there are two active measurement systems:

1. Metric (Absolute) Measurement System.
   A. Contains Metric measurement units: Micrometer, Millimeter, Centimeter, Decimeter, Meter and Kilometer.
2. Graphics (Imaging, Visualization) Measurement System.
   A. Contains GDI measurement units: Pixel, Point, Display, Document, Inch and Millimeter. In graphics measurement units are typically used to express the length, size or location of objects (i.e. some object dimensions).

When multiple unit systems are in common use, it is often necessary to convert the magnitudes of quantities from one system to another. This is accomplished by using conversion factors. Only the defined conversion factors for the base units are required since conversion factors for all other units can be calculated from them. Conversion factors are necessary for interconversion (Read: conversion between systems).

5.11.1 Measurement device units

Currently there are four types of measurement device units:

1. Device - device measurement units are the units of measure of the output device. For instance, with a computer display system, there is only one device measurement unit, and it is called, ‘pixel’.
2. Absolute - absolute measurement units are units that do not depend on the device. For example: inches and meters are absolute units, because their length does not depend on the output device (as in, the LCD display, which understands only pixels).
3. Relative - relative measurement units depend on the size of “something else”. In a system, relative measurement units are those units that depend on the size of the parent or root objects containing the object.
4. And also, physical and abstract measurement units

5.12 Unit conversion

> **NOTE:** *Units of measurement are not ratios, but ratios are necessary to convert between one unit of measurement and another.*

It is possible to have units that may be converted within and between unit systems. Conversion within a system may be either:

1. *Between unit prefixes* (e.g., between milliseconds and nanoseconds for the dimensional unit ‘time’)
2. *Between units* (unit quantities) with the same dimension (e.g., between seconds and hours for the dimension ‘time’)

Conversion between systems is:

- Between units (unit quantities) with the same dimension (e.g., between feet in FPS and meters in IS for the dimension 'length')

Two units (as in, unit names) measuring the same thing, but from different systems, are referred to as equivalents. If a task works in one unit system, but requires input from another unit system, then equivalent units for the specific issue, from the other unit system, must be identified. For instance, if a task uses the imperial unit system, but a specific sub-task requires a metric measurement, then the two systems can be converted between once a metric equivalent (i.e., equivalent metric unit) is identified and its conversion factor is determined.

- **Conversion factors** are homogeneous, but may be incoherent. Their primary use is to transform equations from one coherent unit set to another.

Unit conversion is the process (technique) of exchanging one unit of measure for another unit of measure, while maintaining the associated value (or count).

It is possible to convert within and between unit systems wherever the units mean (measure) the same dimension, object, or event ("thing").

One way to avoid an additional conversion task (and hence, conversion formulas) is to design and apply a single, coherent, and updatable measurement system, such as, the metric system.

Therein, one way to avoid an additional conversion task (and hence, conversion formulas) is to not use unit scale [multiplication] prefixes. However, not doing this can make reading and calculation challenging for humans.

Hence, it is possible (given similar conception) to convert into and out of any other system, and between different levels-of-scales within a single [measurement] system.

5.12.1 Between unit [scale] prefixes

Converting [a quantity] within the metric system [to a different level-of-scale] is known as 'metric conversion' (i.e., intra-metric unit multiplier conversion vs. inter-metric unit multiplier conversion between different measurement systems).

In the metric system, conversion occurs between multiplication prefixes, which include, but are not limited to: kilo, mega, giga, milli, micro, and nano.

Scientific notation is: M x 10n

- M is the coefficient 1<M<10
- 10 is the base
- N is the exponent or power of 10

5.12.2 Unit commensurability and incommensurability

During a task that involves a non-unified unit system, there may be unit types (with unique names) that measure the same thing (same concept), but are based on different [reference] standards. One unit either has a common basis of measured meaning with another (or others), or it does not. If a single unit is present, then commensurability is not an issue.

1. **Commensurable units** have a common basis [for the transfer] of a set value. In order to transfer, a ratio that equals 1 must be present.
2. **Incommensurable units** do not have a common basis [for the transfer] of a set value, and hence, a set value (quantity) of that unit cannot be transferred.

The term 'incommensurable' means 'no common measure', having its origins in Ancient Greek mathematics, where it meant no common measure between magnitudes. In this context, magnitude is just another word for value or quantity. Incommensurable units measure concepts that appear to have no common basis (e.g. meters (length), radians (angle), and kilograms (weight) -- all measure different kinds of things, different concepts.

However, incommensurable [measurement] units can have relationships to each other, for instance, in the way that the weight of a substance might be related to its length, but that relationship may not be a simple ratio, as it is with commensurable units.

Insight: A magnet, for example, is a coherent mass with incommensurability of its atomic structure (its lattice work).

Commensurable means "a common measure". It is of course possible for unit names in different systems [of measurement] to measure the same concept. For instance, "feet" and "meters" both measure [the concept] 'length' (linear movement) in a given direction.

With two commensurable units, one unit can be used to measure the magnitude of another unit (e.g., the meter stick can be used to measure the length of the yardstick, both of which represent some specific magnitude of the same concept, length).

> **NOTE:** *Every conversion represents an inefficiency and the possibility for error.*

Commensurable units, because they measure the same concept, can be converted between. The concept, 'conversion [of units]' is the conversion between different units of measurement for the same quantity, typically through the input of a multiplicative quantity known as a 'conversion factor' or 'multiplication factor'.

There are a number of mathematical ways of actually making the conversions, but the one that is most likely to avoid errors involves making a ratio from the conversion units that equals 1.

The method for converting units comes right from one principle:

1. Numbers with units (e.g., 16.2 meters or 32 ft/sec²) are treated exactly the same as coefficients with variables (e.g., 16.2x or $32y/z^2$).
   A. Hence, it is not possible to add 32 ft to 32 ft/sec, any more than it is to add 32x to 32x/y. And, when 32 miles is divided (factored as a ratio) by 4 hours to get 8 miles/hour, which is exactly the same (i.e., conveys the same meaning) as dividing 32x by 4y to get 8x/y.

In mathematics, any number can be multiplied by 1, and its value will not change. Multiplying by 1 - a carefully chosen form of 1 - is the principal input required to convert[ing between] units with a different standards of measure[ment], but measuring the same thing (the same concept). A fractional (ratio) form of the real number 1 is required.

For example, imagine the requirement of converting a quantity of hours (e.g., 4 of unit 'hour') to minutes (e.g., ? of unit 'minute'). It is given by the metric system that 60 minutes = 1 hour. When both sides are divided by 1 hour. Herein, the unit hour is treated as a variable. As a variable, 60x = 1y, and both sides can be divided by 1y. After the act of dividing creates a ratio. When, for example, (60 min) / (1 hr) = 1, then any measurement can be multiplied by that fraction and its value does not change. If the quantity of the unit 'hour' is 4, then that quantity (4) is multiplied by the specified ratio form of 1:

- 4hr x (60min / 1hr) = 240min
- (4hr x 60min) / 1hr = 240min
- (4 x 60 min) / 1 = 240min

The initial unit quantity is not a dimensionless pure number (4.0), but is a number with dimensions (4 hours). And, the final result is not a dimensionless pure number (240), but is a number with dimension (240min). The dimension (or measurable concept) is the same for both units. A number with units is different from a number without units or with different units, just as 8x is different from both 8 and 8y. If the top and bottom of the fraction are equal, the fraction equals 1, and the value after multiplying is the same as the value before multiplying—but expressed in different units.

The conversion process has three steps:

1. **Identify conversion equation** - Identify (find and/or determine) a conversion factor between the given units and the desired units, which is expressed as a conversion equation.
   - For instance, 1 mi = 1.61 km or 1 km = 0.621 mi.
2. **Identify conversion ratio/fraction** - Determine the fractional form of the real number 1 by converting that equation to a ratio (fraction) with the desired units on top and the given units on the bottom.
   - For instance, 1.61km/1mi [=1] or 1km/0.621mi [=1]. In this case, the multiplication factor for converting from:
   - mi to km is 1.6 (1.61km/1mi)
   - km to mi is 0.621. (1mi/0.621)
   - Note: If the given units are raised to a power, raise the conversion fraction to that same power.
3. **Multiply** – Calculate the multiplication of the original measurement (the measured quantity as 1 unit of) with the multiplication factor (ratio/ fraction), and then, simplify [the units].

In the metric system, the zero point is the same for all units. Some other unit systems set their units zero point to zero too. For instance, 0 pounds equals 0 kilograms, 0 liters equals 0 cubic centimeters, and so on. Take note that between different common unit systems for temperature measurement, is not true: 0 degrees C is a different temperature from 0 degrees F. It is possible to apply the conversion technique to convert between temperature units with different zeros after relating them to a common zero point, and it is more efficient to apply the standard formula as a special case: F = 1.8C + 32. This formula is the slope-intercept form of the equation of a straight line. With other conversions, the intercept is 0 because the conversion line passes through (0,0); but with temperature there's a nonzero intercept because 0 degrees in one measure is not equivalent to 0 degrees in another.

Some conversions are completely impossible, not just impossible using the techniques on this page but impossible by any means at all, because of an axiomatic conceptual contradiction or technical impossibility. For instance, it is not possible to convert 'gallons' to 'square feet' (or liters to square centimeters) using any techniques. This is because gallons and liters measure volume, and square feet or square centimeters measure area. It's like converting x^3 to x^2: it's just not meaningful. A dimensional analysis can be used to show this in a formal way, but informally, remember that area is two dimensions of length and volume is three dimensions of length, and measurements you convert must always have the same number of dimensions.

The following terms mean the same thing: conversion ratio, unit factor, conversion factor, and multiplication factor. This ratio can then be used to multiply the original units to achieve the conversion. Since the ratio = 1 this multiplication does not change the item, it just changes the units.

A conversion ratio (or unit factor) is a ratio [that must be] equal to one. This ratio carries the names of the units to be used in the conversion.

1. **Factor** - It is a determining factor in the conversion.

2. **Ratio** - It is a ratio that carries the names of the units to be used in the conversion.
3. **Unit** - All conversion ratios (unit factors) must equal one.
4. **Multiplication** – The unit quantities are multiplied -- input of a multiplicative quantity. Multiply the measurement (# units you have) by the conversion ratio.

A conversion factor is a ratio (or fraction) that represents the relationship between two different units. A conversion factor or multiplication factor, originally known as 'unity bracket method', is a mathematical tool (a method) for converting between different units of measurement. It is sometimes referred to as a 'unit multiplier'. The method involves a ratio (fraction) in which the denominator is equal to the numerator. The conversion ratio is based upon the concept of 'equivalent values'.

A conversion factor is [a quantity] used to change the units of a measured quantity without changing its value (i.e., its known quantity). Because of the 'identity property' of multiplication, the value of a number will not change as long as it is multiplied by one. Also, if the numerator and denominator of a ratio (fraction) are equal to each other, then the ratio (fraction) is equal to one. So as long as the numerator and denominator of the ratio (fraction) are equivalent, they will not affect the value of the measured quantity.

For example, the unit [of measurement] 'days' may be converted to the unit [of measurement] 'hours', by multiplying the 'days' by the conversion factor 24 (a quantity).

Conversion factor examples include:

1. Quantity = [set equal to]= 1 day = 24 hours = 1440 minutes; therefore, 15 minutes (1 day/1440 minutes) = 15/1440 ~= 0.010416667 = ~0.01 days.
2. Quantity = [set equal to]= 1 hour = 60 mins = 3600 seconds; therefore, 7200 seconds = 120 mins = 2 hours.

Some unit systems do not have a common basis for their conversion/multiplication factor. In the metric system, however, conversion between units can be discerned by their prefixes (for example, 1 kilogram = 1000 grams, 1 milligram = 0.001 grams). Precision of language is important, and the presence of exceptions (e.g., 1 micron = 10−6 metre) are likely to cause confusion.

5.13 Instrumentation

> **NOTE:** *Measurement instruments are devices that replace the need for actual measuring units (i.e., objects) in making comparisons.*

There are three measurement instrumentation system unit types:

1. **Device** - device measurement units are the units of measure of the output device.
2. **Absolute** - absolute measurement units are units that do not depend on the device. For example: inches and meters are absolute units, because their length does not depend on the output device.
3. **Relative** - relative measurement units depend on the size of "something else". For instance, a measurement system's units may depend on the size of the parent or root objects containing the measurable object.

6 Measurement types and units

Measurement involves the utilization of types and units to precisely identify, quantify, and standardize the description of physical quantities in the real world. This practice enables accurate communication, comparison, and consistency across various contexts and disciplines.

6.1 Taxanomical hierarchy of units

> *A.k.a., Ontological hierarchy of units, order of units, classes of units, unit classes, unit class ordering, unit ontology.*

Taxonomies (and ontologies) are simplistic schemes that visually organize the [hierarchical] classification of concepts or objects. Taxonomies and ontologies are widely used in many scientific fields to classify and organize information, facilitate data retrieval, enable knowledge sharing, and support decision-making processes. Taxonomies present a hierarchical classification system used to categorize and organize items or concepts based on their similarities and differences. They provide structured frameworks for categorizing and understanding complex relationships among various entities, making them valuable tools. Additionally, taxonomies and ontologies help bridge the gap between human understanding and machine processing, facilitating the development of intelligent systems and data-driven applications in various domains.

Common taxonomies (of units) include, but are not limited to:

1. In physics, International System of Units (SI).
2. In biology, the Linnean taxonomy.
3. In geology, the BGS Rock classification scheme.
4. In subatomic physics, the Eightfold way.
5. In astronomy, the stellar classification system.
6. In pharmacology, the ATC drug classification system.
7. In genetics, the Gene Ontology (GO).

6.2 Taxonomy of physical measurement units

A structured classification system is required to provide a systematic organization of measurement units used in the sciences and engineering to quantify various physical properties of the real-world (inclusive of: matter, energy, and time). This taxonomy aims to facilitate the precise and consistent description of physical phenomena, enabling scientists, engineers, researchers, and educators to effectively communicate and work with a wide range of measurement units across diverse fields. Measurement units play a key role in quantifying, analyzing, and describing the physical world.

In the context of the International System of Units (SI) and related measurement systems, there are generally three top-level categories for units:

1. **Fundamental units (fundamental base units):** These are the base units from which all other units are derived. They represent fundamental physical quantities like length, mass, time, electric current, temperature, amount of substance, and luminous intensity.
2. **Derived primary units (derived measurable units):** These units are derived from fundamental units and represent measurable quantities such as energy, force, electric charge, and pressure. They are considered primary because they are essential for expressing other quantities.
3. **Derived secondary units (derived units specific to certain quantities):** These units are also derived from fundamental units but are specific to certain quantities, like temperature units (e.g., Celsius) or volume units (e.g., liters, milliliters), and are used to express those specific measurements.

These three categories cover the hierarchy of units used in the SI system and related measurement systems, and there are no additional top-level categories within this framework.

The foundational, primary physical measurement units are (a.k.a., axiomatic physical units):

> CLARIFICATION: *Some of the above primary units can be sub-divided using prefixes (e.g., deci-meters, centi-liters, etc.), and others cannot (e.g., hours, celsius, etc.).*

1. **Atomic matter unit (atomic unit):**
   - **Mole (mol; primary).**
     - Decimole (dmol).
     - Centimole (cmol).
     - Millimole (mmol).
     - Micromole (μmol).
     - Nanomole (nmol).
2. **Length units:**
   - **Meters (m; primary).**
     - Kilometers (km).
     - Centimeters (cm).
     - Millimeters (mm).
     - Micrometer (μm).
     - Nanometer (nm).
     - Picometer (pm).
3. **Mass units (weight units):**
   - Grams (g).
     - **Kilograms (kg; primary).**
     - Milligram (mg).
     - Microgram (μg).
     - Nanogram (ng).

    - Picogram (pg).
4. **Time units:**
    - **Seconds (s; primary).**
        - Millisecond (ms)
        - Microsecond (μs)
        - Nanosecond (ns)
        - Picosecond (ps)
    - Minutes (min).
    - Hours (hr).
    - Days (d).
    - Years (yr).
5. **Electric units:**
    - **Amperes (A; primary).**
6. **Temperature units:**
    - **Kelvin (K; primary).**
7. **Light units:**
    - **Candela (cd; primary).**

Derived primary units (measurable units derived from foundational units:

1. **Volume units:**
    - Liters (L = 0.001 m^3).
        - Kiloliter (kL = 1,000 m^3).
        - Hectoliter (hL = 100 m^3).
        - Decaliter (daL = 10 m^3).
        - Deciliters (dL = 0.0001 m^3).
        - Centiliters (cL = 0.00001 m^3).
        - Milliliters (mL = 0.000001 m^3).
    - Cubic meters (m^3).
        - Cubic kilometer (km^3).
        - Cubic hectometer (hm^3).
        - Cubic decimeter (dm^3).
        - Cubic centimeter (cm^3).
2. **Velocity units (a.k.a., speed units):** Units of speed or velocity are used to measure the rate of motion of an object with respect to time.
    - Meters per second (m/s).
    - Centimeter per second (cm/s).
    - Kilometers per Hour (km/h).
3. **Acceleration units:** Acceleration units measure the rate of change of velocity of an object with respect to time.
    - Meters per second squared (m/s^2).
    - Centimeters per second squared (cm/s^2).
    - Millimetres per second squared (mm/s^2).
4. **Energy units:**
    - Joules (J; primary).
5. **Electric current units:**
    - Coulombs (C; primary).
6. **Force units:**
    - Newtons (N; primary; pull or push).
7. **Forward pressure units:**
    - Pascals (Pa; primary; forward momentum).

NOTE: *For every one of these terms, the word "measurement" could be added to the label (e.g., volume measurement units, energy measurement units, pressure measurement units, etc.).*

Derived secondary units are derived from primary units. Examples of secondary units include, but are not limited to:

1. **Static object [derived] units:**
    A. **Temperature units:**
    - Celsius (°C; secondary).

    B. **Pressure units:**
    - Atmospheres (atm; secondary).
    - Bar (bar; secondary).

    C. **Area units:**
    - Square meters (m^2).

    D. **Volumetric density units:** Density measures the mass (as weight, not number of atoms) of a substance per unit volume in three-dimensional space. It measures the number of mass contained in a three-dimensional volume.
    - Kilograms per cubic meter (kg/m^3).
    - Grams per cubic centimeter (g/cm^3).

    E. **Linear density units:** Units of linear density measure mass (as weight, not number of atoms) per unit length along an edge (i.e., along a one-dimensional line or axis). It measures how much mass is distributed along an edge.
    - Kilograms per meter (kg/m).
    - Grams per centimeter (g/cm).
    - Grams per meter (g/m).
2. **Electromagnetic (atomic) motion object [derived] units:**
    A. **Electric current units:**
    - Ampere-Hours (Ah; secondary).

    B. **Electric units:**
    - Volts (V; secondary; for electric pressure).
    - Ohms (Ω; secondary; for electric resistance).

    C. **Electromagnetic inductance units:**
    - Henry (H; for EM inductance).
    - Siemens (S; for EM conductance).

    D. **Magnetic units:**
    - Teslas (T; for magnetic flux density).
    - Weber (Wb; for magnetic flux).
    - Gauss (G; for magnetic induction).

    E. **Light units:**
    - Lumens (lm; secondary).

    F. **Radiation units:**
    - Becquerel (Bg).
        - Gigabecquerel (GBq).
        - Megabecquerel (MBq).
        - Kilobecquerel (kBq)
    - Gray (Gy).

- Sievert (Sv).
  - Millisievert (mSv).
  - Microsievert (μSv).

3. **Motion of object [derived] units:**
   A. **Rope frequency units:**
   - Hertz (Hz).

   B. **Rope wavelength units:**
   - Meters (m).

   C. **Energy units:**
   - Calories (cal; secondary).
   - Kilowatt-Hours (kWh; secondary).

   D. **Force units:**
   - Dynes (dyn; secondary).

   E. **Radial motion units (angle units):**
   - Radian (rad; angular momentum).

   F. **Object flow units:**
   1. Mass flow rate units (kg/s).
   2. Volume flow rate units (m^3/s).

Derived tertiary units are derived from primary and secondary units. Examples of tertiary units include, but are not limited to:

1. The primary tertiary derived units related to mechanical, electrical, and thermal properties, such as:
   - Newton-meter (Nm; mechanical).
   - Coulomb-volt (C·V; electrical).
   - Joule-second (J·s; thermal).
2. The common force-based tertiary derived units:
   - Tension units (e.g., Newtons - N).
   - Compression units (e.g., Newtons - N).
   - Shear units (e.g., Newtons - N).
   - Torque units (e.g., Newton-meters - Nm).
   - Thrust units (e.g., Newtons - N).
   - Weight units (e.g., Newtons - N).
   - Spring constant units (e.g., Newtons per meter - N/m).

6.2.2.8 The temporal unit

A.k.a., The time unit.

The time scale units, from least precise (1) to most precise (4) include:

1. **Nominal time scale** (nominal time of day): The AM and PM of the 12-hour time clock. The 24-hour time clock does not have a nominal scale.
   A. Categories and no additional information.
2. **Ordinal time scale** (ordinal time of day): For example: morning, noon, afternoon, evening, night.
   A. Indicates direction or order of occurrence; spacing between is uneven.
3. **Interval time scale (interval time of day using the 12-hour clock):** The 12-hour clock has the following 12 by 2x interval scale -- 12,1,2,3,4,5,6,7,8,9,10,11,12 ,1,2,3,4,5,6,7,8,9,10,11,12.
   A. Equal intervals; difference between 1 and 2 pm is same as difference between 11 and 12 am.
4. **Ratio time scale (ratio time of day using the 24-hour clock):** The 24-hour clock has the following 24-hour scale -- 0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15, 16,17,18,19,20,21,22,23,24
   A. 24-hour time has an absolute 0 (midnight); 14 o'clock is twice as long from midnight as 7 o'clock. This is the most precise form of time.

6.3 Taxonomy of chemical system units

A.k.a., Units of chemical systems, chemical measurement units..

In chemical entities, it is possible to classify chemical entities similarly to biological entities (Feunang, 2016):

1. Kingdom.
   A. Organic compounds - chemical compounds whose structure contains one or more carbon atoms.
   1. Nucleosides, nucleotides, and analogues.
      i. (2'->5')-dinucleotides and analogues.
         1. (3'->5')-dinucleotides.
      ii. (5'->5')-dinucleotides.
   2. Lipids and lipid-like molecules.
      i. Fatty Acyls.
         1. Fatty acids and conjugates.

   B. Inorganic compounds - compounds that are not organic (i.e., that do not contain carbon), with a small number of exceptions (e.g., cyanide/isocyanide and their respective non-hydrocarbyl derivatives, carbon monoxide, carbon dioxide, carbon sulfide, and carbon disulfide).
   1. Mixed metal or non-metal compounds.
      i. Alkali metal salts.
      ii. Alkali metal chlorides.
   2. Homogenous metal compounds.
      i. Homogenous alkali metal compounds.
2. SuperClass.
3. Class.
4. SubClass.
5. Etc.

6.4 Taxonomy of biological [differentiation] system units

A.k.a., Units of biological systems, biological organism measurement units, biological units.

In biological and also chemical classification, rank is the relative level of a group of elements/organisms (a taxon) in a taxonomical hierarchy:

1. Kingdom.
2. Sub-kingdom.
3. Infra-kingdom.
4. Division.
5. Subdivision.
6. Infra-division.
7. Class.
8. Order.
9. Family.
10. Genus.
11. Species.

6.5 Taxonomy of temporal system units

A.k.a., Temporal measurement units, time units, temporal units.

Time has to do with description; time can only be used to describe. Time can only be a measurement of something. For instance, how long it took something to run, how long it took to measure the length of something (how long it took something to happen). Time is event driven and experienced in a linear (counting) manner. Events occur and are ordered in a sequence, and therein, perception of time passing is experienced by individuals. In mathematics, 'time' is a [count along a] number line. Each event is a movement along the number line, and there are durations/separations between events (i.e., there are events and there are intervals between events on the number line). Here, both the length of change and interval at which change occurs can be counted.

Hence, time has the following characteristics:

1. **Personal perception of time:** The assertion that events occur sequentially and that this sequence gives rise to the perception of time, a subjective experience of time. Consciousness perceives events (frames in the universal move) one after the other, and this perception constructs the sense of time passing. In this way, time has direction (past to future).
   A. Consciousness self-reflects upon itself and thus creates an experience of itself in time. It creates the experience of time within itself. Time is the self-reflection of consciousness. The brain integrates signals to create an experience. Time is our own consciousness reflecting upon itself.
2. **The mathematical representation of time:** In mathematics, time is represented as a number line, which allows a user to use it as a tool to map events along it. In the realm of mathematics, time is conceptualized as a scalar quantity and is often represented along a one-dimensional number line, where specific points correspond to particular moments or events. This representation permits the chronological ordering of occurrences, thereby facilitating their analysis in relation to one another. While it is common to associate number lines with magnitude alone, they inherently possess a directional component when used to represent time—progressing from the past, through the present, and into the future. However, the characterization of time as a vector requires some refinement. In physics, vectors are quantities described by both a magnitude and a direction in space. While time does have a directionality in its forward movement, it is not a vector in the strict physical sense, as it does not have a spatial direction. Instead, time is considered a scalar because it has magnitude—duration—but no spatial orientation. Motion can be described using magnitudes that specify how much (time), where (vectors), and how fast (velocity) an object travels from location A to location B. In this sense, vectors are the mathematical tools that capture the full essence of motion through space, but "time" itself, as a concept only, only has magnitude and no spatial direction (pother than forward / backward along the number line itself). To make this understanding most clear, when "you" are counting 2,3,4,5, there is no direction; it is possible, however, to reverse a count and start counting backwards (but, this still just represents magnitude and has no direction 4,3,2,3,4,5. Number 2 is not east or west (right or left) of number 5. However, 5 is 3 magnitudes higher than 2. Technically, if a user of the numberline tool were to go "backwards" on the numberline, that would be an operation, such as 5-2 = 3; still, nowhere here is there direction (the "-2" is a magnitude operation).
   A. **Time as a measure of change:** Time, in the context of physics and mathematics, is a measure of change. Timing is a way of describing change. Each event can be considered a record along the timer axis (Read: timeline axis), and the interval between events can be measured.
   B. **Counting time:** Time can be counted by considering the following:
      1. The change in the shape of an object over time.
      2. The change in location of an object (relative to another/other objects) over time.
      3. The temporal distance or duration between two events, which is the time interval.
      4. The rate of change, which is the speed or velocity.

There is are two known categories of time:

1. **Now time** (the experience of now, right now).
2. **Relative time:**
   A. **True relative time (a.k.a., timer time)** - starting a count from zero. "True" time is mathematical and independent of the movement of real-world objects. It is a magnitude away from a zero count. Whenever a timer is starting, there is "true" relative time (i.e., "true" relative counting, sequencing). Here, the time (count) is relative to when someone started the timer.
   B. **Object relative time (a.k.a., objective time)** - count of motion between objects; time-counting the movement of bodies. Here, the time (count) is relative to the movements or positions of physical objects or celestial bodies. Here, there is a measured count of the movement of objects (bodies). Object relative time is the measurement of time based on the movements or positions of physical objects or celestial bodies. It is the time as we measure it by the position of bodies that we know are in motion (e.g., the sun, the earth, the moon, etc.). An example of object relative time would be measuring the time it takes for the Earth to complete one full rotation on its axis, resulting in a 24-hour day. This measurement of time is based on the movement of the Earth, a physical object, and is independent of anyone's immediate perception of "now time."

In rational physics, the physical world can be explained and visualized by showing a [universal] movie composed of many individual "static" frames. In the analogy, "time" requires at least two frames of the universal move. In other words, visualizations that can be said to involve "time" must include two or more frames within the full universal movie. Each frame in the universal movie is a slice of location (of one or more objects), and not a slice of "time".

6.5.1 Time measurement system

A.k.a., Timing measurement system.

A time measurement system is a sequence of data ordered in time; an ordered sequence of data in the time domain. Data that are not time series are usually called cross-section. A time series of cross-sectional data is called panel data – for example, studying weight or income of a particular group ['cohort'] over time is panel data. There are three common graphical representations of time sequenced data:

1. **Step-wise constant:** Each step represents a new value.
   A. **Second (S):** For example, a human understandable and countable axiomatic time duration that can be counted precisely with tools, one of the most accurate being the detection of the fixed numerical value of the caesium frequency Δν, the unperturbed ground-state hyperfine transition frequency of the caesium 133 atom, to be 9,192,631,770.000, expressed in the unit Hz, which is equal to s^{-1}.
   B. **Price (P):** For example, the cost of some item over time.
2. **Discrete (count, quantity):** For example, the number of items sold per day (a discrete-daily count).
3. **Continuous (flux, F):** For example, a temperature measurement over time; a continuous-flux count.

6.5.2 Timekeeping

A.k.a., Timing, time recording, time sequencing, clocking, timekeeping, temporal accounting.

Time is what clocks measure. Remember here that both a clock measure and a tape measure are counting/sequencing tools. A clock is an instrument to indicate, keep, and co-ordinate time. The word clock is derived (via Dutch, Northern French, and Medieval Latin) from the Celtic words clagan and clocca meaning “bell”. In general usage today a “clock” refers to any device for measuring and displaying the time. Timekeeping instruments are pivotal in the quantification of temporal intervals and the synchronization of human activities with natural cycles. Historically, the development of timekeeping has been closely aligned with the observation of celestial bodies, leading to the creation of sundials and later more intricate mechanical clocks, each relying on the consistent motion of the Earth in relation to the Sun. Whereas sundials use the Earth-Sun relationship to demarcate the passage of daylight hours, the hourglass uses a known fixed amount of flowy mater (e.g., sand) and gravity to record time. In modern times, the precision of timekeeping has improved with the advent of atomic clocks, which measure the vibrations of atoms, typically cesium or rubidium, to maintain a time standard of astonishing accuracy. These molecular clocks, unhindered by environmental variables, have become the cornerstone for global timekeeping standards, enabling high-precision applications ranging from satellite navigation systems to international time synchronization. Together, these devices form a diverse array of timekeeping tools, each leveraging different principles—from the astronomical to the quantum—to provide us with a reliable measure of time's passage.

The timekeeping element in an every modern digital clock is a harmonic oscillator, a physical object (resonator) that vibrates or oscillates repetitively at a precisely constant frequency. This object can be a pendulum, a tuning fork, a quartz crystal, or the vibration of electrons in atoms as they emit microwaves. Digital clocks display a numeric representation of time. Two numeric display formats are commonly used on digital clocks: 24-hour notation and 12-hour notation. Analog clocks usually indicate time using angles from a central point displayed as lines ("hands").

The term "analog" in "analog clock" is derived from the word "analogous," which means comparable or similar to. In the context of an analog clock, the display of time is analogous to the motion of time in the natural world. An analog clock typically has visible moving indicators ("hands") that rotate around a dial to indicate the hours, minutes, and sometimes seconds, with the positions of the hands representing the passage of time. The movement of the hands on an analog clock is continuous, mimicking the continuous passage of time, and is thus why they are called analog, analogous clocks. Alternatively, digital clocks visualize time with numerals (Read: numbers) that change in discrete, incremental steps. The continuous motion in analog clocks is analogous to the natural, cyclical movements observed in celestial bodies, such as the Earth's rotation and the apparent movement of the Sun across the sky, which were the basis for measuring time long before mechanical clocks were invented.

The two most precise time clocks are:

1. **The earth sun relationship clock (a.k.a., solar time, solar clock):**
   A. **The solar year clock** - one revolution of the earth around the sun equals 1 year.
      1. 1 revolution of earth around sun = 1 year.
   B. **The mean solar day clock** - the average solar day; that is, the average time for Earth to make one complete rotation relative to the sun.
2. **Molecular decay clock (a.k.a., atomic clock, atomic time)** - sensing the rate of radiation emission from a radioactive atom. The source of light is sensed emitting from a radioactive atomic material at some phenomenologically set interval. In quantum physics, decay = data = time. Here, time is molecular decay (i.e., time is measured as molecular decal.
   1. For example, gamma radiation from caesium-137 atoms.

6.6 Temporal units

A.k.a., Time units, units of time.

Timekeeping at the micro-level is counted in seconds; wherein prefixes indicate fractions of a second (e.g., micro-, nano-) and sets of counted seconds (e.g., kilo-, mega-). Herein, counted seconds add-up to human recognizable durations of time (as in, the minute, the hour, the day, etc.).

In the early 21st century, units of human recognizable time include:

1. A **second** is:
   A. A fraction of the time it takes for the Earth to complete one full rotation on its axis, which is approximately 86,400 seconds per day (1/86,400). This definition is based on the division of a day, which is divided into 24 hours, each consisting of 60 minutes, and each minute further divided into 60 seconds.
   B. Radioactive decay, specifically in the context of the caesium atomic clock. In atomic clocks, the second is defined by the vibrations of caesium atoms. When caesium atoms transition between energy levels, they emit electromagnetic radiation at a specific frequency. By counting the cycles of this radiation, we can precisely measure time, and one second is defined as the duration of 9,192,631,770 cycles of radiation emitted by cesium-133 atoms during this transition.
2. **Minutes** measured in 60 seconds.
3. **Days** measured in 1440 minutes.
4. **Months** measured in days (as 28, ~30).
5. **Years** measured in days (as ~365).
6. **Years** measured in months (as 12/13).
7. **Decades** measured in years.
8. **Centuries** measured in decades.
9. **Millennia** measured in centuries.

6.7 Taxonomy of human anatomical system units

A.k.a., Human anatomy measurement units.

The significant human anatomical measurements include, but are not limited to:

1. **Human locomotion (i.e., walking) time and distance (average):**
   A. **Walking distance and time:** The adult human walks about 1 kilometer in about 15 minutes.
   B. **Walking pace:** The adult human walks at a pace of about 1.4 to 1.6 meters per second.
   C. **Walking speed:** The adult human walks approximately 84 to 96 meters per minute.
2. **Human height (average):**
   A. For a male: Approximately 1.7 meters.
   B. For a female: Approximately 1.6 meters.
3. **Human weight (average):**
   A. Male: [Specific weight range or average].
   B. Female: [Specific weight range or average].
4. **Body mass index (BMI) range (average):**
   A. Specific BMI range: [Specific measurement or range].

5. **Skeletal muscle mass body composition:**
   A. Healthy D3 creatine dilution: [Specific measurement or range].
6. **Muscular system:**
   A. Muscle mass percentage: [Specific percentage].
   B. Average strength capacities: [Specific measurement or range].
7. **Skeletal system:**
   A. Bone density averages: Macro-structural property.
   B. Bone quality averages: Micro-structural properties.
   C. Common variations in bone structure: Geometry and architecture).
8. **Cardiovascular system:**
   A. Average heart rate: [Beats per minute range].
   B. Blood pressure ranges: [Specific ranges].
9. **Respiratory system:**
   A. Lung capacity: [Specific volume or range].
   B. Average breathing rate: [Breaths per minute].
   C. VO2 max: [Specific volume or range].
10. **Digestive system:**
   A. Metabolic type: [Specific measurement or range].
   B. Average metabolic rate: [Specific rate or range].
   C. Common digestive capacities: [Specific capacities].
11. **Metabolic system:**
   A. Digestive organ assimilation capacity: [Specific capacity].
   B. Digestive organ excretion capacity: [Specific capacity].
   C. Body cellular-tissue process capacities: [Specific capacity].
      1. Repair (maintenance) capacity: [Specific capacity].
      2. Power (energy, atp) capacity: [Specific capacity].
12. **Neurological system:**
   A. Average reaction times (cognitive and muscular throughput and speeds).
   B. Cognitive function metrics (cognitive capabilities).
13. **Skin system:**
   A. Thickness and elasticity: Measurement of the epidermis and dermis layers, and skin's ability to return to its original state after stretching.
   B. Pigmentation levels: The concentration of melanin which determines skin color and reaction to sun exposure.
   C. Moisture content: The level of hydration within the skin, affecting texture and suppleness.
   D. Sebum production: Rate of oil secretion that influences skin's moisture barrier and overall health.

6.8 Taxonomy of electromagnetic system units

A.k.a., Electromagnetic measurement units, electricity, light, tense rope torsion.

Electricity is a form of light; it is guided electromagnetics. For electricity to "flow", there must be matter. Electricity is the twirling of strings of atoms in place; it is the torsion string of atoms, the torsion of a conduit of interconnected atoms. Light is mediated by a rope-like entity. There is a mediator for light, which looks like a rope (a pair of twined threads, like DNA). Light is a torsion along a physical entity, a two stranded rope, between all atoms. The two stranded rope is a physical object, similar to a DNA molecule, that binds all atoms to all other atoms; and, light is a torsion (torquing) of the rope. You may not be able to see it, but antenna "put out" light (Read: electromagnetic radiation, rope torsion). The reason an antenna is used for radio waves (a frequency category of light) and a filament for visible light is the relative wave-length of the two waves. The rope is made of two braided strands, forming a helical shape. A two stranded rope shape. Light is a DNA-like entity that is between any two atoms (and is tense in every case, and torqued when there is light). Here, there is a DNA-like physical entity from atom-to-atom (which is always tense, and may be torqued to produce light). The rope is torqued and the result is light. When the speed of light is measured, what is measured is the torsion. All entities are bound together by an electromagnetic rope. Light is a torsion of the rope. Light looks like the twirling a two stranded electro-magnetic rope, torquing in place. A single torque of a rope is the complete revolution (of rotation) of a rope. And, torsion is the fastest torque ("wave") that can be imagined/experienced (given what is known). Visually, the electric and magnetic names are the names for each of the strands of the two stranded thread. Its two threads that form a physical rope that torques (the action of which is light). Herein, low frequency equals "cold", and increased frequency (i.e., "hot" frequency) equals "hot" (a.k.a., thermals unit, temperature unit). The higher the frequency, the hotter it is, and the lower the frequency, the colder it is. The longer the link length the colder the substance. The more torque there is ("high frequency") with shorter links the hotter it is (higher the temperature). Touch is the macro-touchable physical world, and therein, electromagnetic threads is the invisible physical world. More links per unit of time or distance invisible physical world will have more impact on the macro. Imagine a hydrogen bond. What is a bond? The "bond" is a rope with two threads. The rope intersects and becomes all atoms; it is an electromagnetic rope that interconnects all atoms. If matter is heated, it's temperature rises more and more. It can be seen that particles contained in it move ever faster. Whatever the substance is made of (molecules, atoms, etc.), when it is heated, the substance (object of molecules, atoms, threads) it is vibrating faster. The "pumping" of some object (composed of the ropes) is what is making the molecules move faster. In other words, the assembling and disassembling of the ropes of an atom(s) "pumps the atom", thus, torquing the ropes between all atoms (at the speed of light). The atoms expand and contract, and when doing so, they open and close the two threads of the rope. By doing so it torques the rope and light flows in both directions. The torque of a rope refers to the rotational force (moment) that the rope does when it turns (a.k.a., rotates) around the central axis of itself as an object. In simpler terms, it's the force that causes an object to rotate. (Gaede, 2014)

> **CLARIFICATION:** *Touch (contact surfacing) is an emergent property that results from bundling of threads into an atom.*

The formula for the speed of the torsion of a rope is:

torque of a rope (τ) = frequency (F) x distance (r)

$\tau = F \cdot r$

- where,
  - F = force applied.
  - r = distance from the point of rotation (or the axis) to the point where the force is applied.

The formula for the speed of light is:

speed of light (C) = frequency of rope (f) x wavelength of thread (λ)

$C = f \cdot \lambda$

- where,
  - frequency (f) is the rate at which current changes direction per second (how many times?). The links on the rope, the shorter they are the higher the frequency (i.e., higher frequency equals many links and shorter links). When the links are longer (in distance from one peak to the other), there are fewer links, a lower frequency.
  - wavelength (λ) is the distance between the top-to-top, equivalent to bottom to bottom (i.e., from crest to crest). Wavelength is the distance between two successive points on a twisted rope (i.e., of a wave) that is in phase, such as between two consecutive peaks (or troughs) of a sine wave. When discussing wave-like forms (a.k.a., waveforms), one cycle of a wave is completed when it goes through a full oscillation from its starting point, reaching a maximum value, returning to its starting point, reaching a minimum value, and then returning to the starting point again.
  - a [single] "cycle" refers to a [single] complete oscillation or a full revolution (of rotation) of a periodic waveform, or of the rope as an object rotating around a central axis. One cycle of a "wave" is completed when it goes through a full oscillation from its starting point, reaching a maximum value, returning to its baseline, then reaching a minimum value, and then finally, returning to the starting point again. Simply, the wavelength corresponds to the spatial length (or distance) over which one cycle of the wave occurs.

The wavelength (λ) is related to the wave's speed (v) and frequency (f) by the equation:

wavelength (λ) = speed of torsion-wave (v) / frequency-count of waves per distance-count (f)

$\lambda = v / f$

- where,
  - λ (lambda) represents the wavelength
  - f represents the frequency of the wave (using a "peak-count" unit)
  - v represents the speed of the wave (using some "time-count" unit)

Wave speed (v) = frequency (f) x wavelength (λ)

$v = f \cdot \lambda$

A 2D wave oscillation has vector magnitudes, and the frequency of these vector magnitudes equals "light", radiating perpendicularly to each other along a perfectly straight line. Vectors represent quantities of displacement, velocity, and de-/acceleration associated with a wave's motion, while magnitudes describe the sizes or quantities of these vectors:

1. Vector: a quantity that has both magnitude (size or quantity) and direction.
2. Magnitude: The magnitude of a vector is its size or numerical value, ignoring its direction.

The formula relating wave vector to wavelength is:

wave vector (k) = 2π / wavelength (λ)

$k = 2\pi / \lambda$

- wherein,
  - 2π (2 times pi) is two times the value of the mathematical constant pi (π)
    - The approximate value of pi is commonly rounded to 3.14, but its decimal expansion continues infinitely without a repeating pattern: 3.14159...

All light is electro-magnetic torsion (i.e., radiation or induction). Radio typically has a frequency between 100kHz and 100GHz, and hence, it has wave lengths between 3mm and 3km. Visible light (ROYGBV) in the green is about a 500nm (or 0.0005mm) wavelength. Visible light can be torqued (i.e., radiated and induced) with an antenna as low as a nanometer range of 250nm long, but this is only recently possible with nanosonic fabrication.

Note that there are three different axiomatic signaling/changing wave-like motions (i.e., that form the patter of an object "waving") that an object can perform/do:

> **CLARIFICATION: "***Wave-like" means that they have values for frequency and wavelength.*

1. **Transverse waves** are the slowest; because, the internal waving of the object goes up and down as it moves forward. Here, there is particle motion perpendicular (at right angles) to the direction of the wave's propagation.
2. **Longitudinal waves (a.k.a., sound waves, compression waves)** are a little faster than transverse; because, the internal waving (of the objects doesn't go) up and down, only backward and forward. Here, there is particle displacement parallel to the direction of wave propagation. Sound waves in air or compression waves in a spring are examples of longitudinal waves.
3. **Torquing a rope (a.k.a., torsions of a rope)** looks like a wave from a 2D representation when it is torqued. Torquing a rope involves applying a twisting or rotational force to it. Is the fastest wave/signal, because the whole object moves in rotation, and the internal object does not go up and down or backward and forward. In other words, a torsion motion "wave" is much faster than a transverse or longitudinal (sound) "wave" (as a type of signal), because the rope (object) twirls in place and nothing goes anywhere. Nothing is faster than torsion, because nothing goes anywhere, it moved in place.

> **CLARIFICATION:** *A wave is a movement within an object (i.e., what is "waving" is an object). A wave is what something does, not what something is. A rope, in physics, has been traditionally mistaken for a wave.*

6.8.1 Gravity

A.k.a., Gravity measurement units

It is likely that gravity is not a force; gravity is a tension, and tension is not a force. Atoms are made of the ropes that interconnect all atoms. At large distance, all [tense] ropes are aligned, and at small distance, the tense ropes separate and become an effective source of "pull" (a.k.a., attraction, gravity). Two objects far apart have all their ropes superimpose; they act as one and gravity is weak. When two objects are brought closer together, all the ropes separate. Imagine tense ropes between two bodies of atoms fanning out, pulling the center of the smaller body to the center of the larger body. When the tense ropes fan our they work/act individually. Each rope acts Individually, thus giving the mechanism for the acceleration of gravity; because there are more ropes acting individually.

When multiple ropes are attached between two objects and fan out, the tension in each rope can be calculated using the principles of equilibrium. If n ropes fanning out between two objects, and the angle between each rope and the horizontal direction is θ. If the tension in each rope is uniform, the formula for the tension (T) in each rope can be calculated.

The formula for the tension (T) in each rope is:

tension (T) = force (F_{total}) / number of ropes (n)

$$T = F_{total} / n$$

- where,
  - F_{total} is the total force acting along the direction of the rope
    - If the objects are in equilibrium, this force can be the total force applied horizontally or vertically that needs to be balanced by the tension in the rope
  - n is the number of rope
  - T is tension of the rope

When the ropes fan out symmetrically at equal angles (each angle is θ), and the force is applied horizontally or vertically, the total force (F_{total}) can be calculated using trigonometry:

1. Where the force is horizontal:

   $$F_{total} = T \cdot (1 / \sin(\theta))$$

2. Where the force is vertical:

   $$F_{total} = T \cdot (1 / \cos(\theta))$$

The force of gravitational attraction between two objects (masses) can be shown with the following formula that includes distance (d), as separation only:

force (f) = gravitational constant of planet (G) x ((multiplication of masses as weights, $m_1 \cdot m_2 \cdot \ldots$) / distance of separation squared (d^2))

$$F = G((m_1 \cdot m_2) / d^2)$$

- Where,
  - F = force

- G = the gravitational constant, (a fundamental constant approximately equal to 6.674×10^{-11} 6.674×10^{-11} N m²/kg²)
- m_1 = the mass of object 1 (at current location)
- m_2 = the mass of object 2 (at current location)
- distance = count of separation
  - each computation depicts a static distance
- For a rope, feplace F (force) with T (torsion)

NOTES:

1. A third (m_3), fourth (m_4), and so on, mass, can be added to the masses section and multiplied.
2. Each frame (calculation) depicts a static distance.
3. Distance decreases (d_1, d_2, d_3, etc.) when acceleration increases.
4. Distance is toward the other object.
5. Distance is a measure of weight.
6. Force increases when distance decreases.

The force of gravity is also calculated by Distance-traveling in Newton's 2nd Law is a formula that does not show separation, but does show an increase or decrease in movement over time:

force (F) = mass (m) x acceleration (a)

$F = m \cdot a$

- Where,
  - F = force
  - m = total mass (as weighted pull of gravity, a.k.a., weight)
  - a = acceleration (rate of increase of movement of distance)

NOTES:

1. Distance increases (d_1, d_2, d_3, etc.) when acceleration increases.
2. Distance travelled occurs because of a "pushing" force away from an unspecified point.
   A. Distance travelled is away from an unspecified point.
3. Distance is a measure of velocity.
4. Force increases when distance increases.

By using both gravitational equations one can determine the acceleration of an object due to gravity (G) when it's falling near the surface of the Earth.

6.9 Taxonomy of temperature [differentiation] system units

A.k.a., Temperature measurement units.

Temperature is measured in Kelvin (K), and intensity in nanometers (nm). These units are also related to the concepts of spectrum and wavelengths. For instance, the sun's surface temperature is approximately 5780 degrees Kelvin, which corresponds to a peak intensity of about 501 nanometers, in the blue-green region of the spectrum. Although the sun emits a broad range of wavelengths, its overall color appears white. However, when viewed from Earth, the sun often seems yellow due to atmospheric scattering of its light.

In concern to "temperature", there are three categories of units:

1. **Fundamental physical temperature unit:**
   A. **Thermal temperature (K):** This is a measure of the temperature of an object in the context of thermal radiation. It is related to the color of an object when it is heated to incandescence. For example, as an object becomes hotter, it may change color from red to orange to white, indicating higher thermal temperature.
2. **Secondary derived quality units:**
   A. **Color rendering index (CRI):** CRI is a measure of how accurately a light source can render colors (compared to a reference light source with the same color temperature). It assesses the ability of a light source to reveal the true colors of objects it illuminates. A higher CRI indicates better color rendering. This is a specialized unit related to the quality of light and color rendering. It can be categorized under "Quality units" or "Light units" as it pertains to the characteristics of light sources.
   B. **Color temperature (K):** This is a measure of the color appearance of light, indicating whether it appears "warm" (reddish) or "cool" (bluish). It is not directly related to thermal temperature but is often used to describe the color of light sources, such as incandescent bulbs (warm) and fluorescent lights (cool).
   C. **Correlated color temperature (CCT):** This a measure used to characterize the color appearance of a light source. It relates to the temperature of an ideal black body radiator that emits a similar spectrum of light. Higher CCT values correspond to "colder" or bluer light, while lower values indicate "warmer" or more yellow-red light. For example, sunlight has a yellowish tint, while blue giants like Sirius, with surface temperatures exceeding 10,000 Kelvin, appear bluish to the naked eye.

Unfortunately the term, color rendering index (CRI), is often interpreted wrongly. It characterizes the influence of light source on the perception of an object’s color. This parameter shows how correctly a light source with a particular CCT will deliver the color of an illuminated object, compared with an ideal source - an absolutely black body with the same color temperature. To determine the CRI, a set of 8 standard color samples is illuminated with the source and with the light of a back body with the same color temperature. If none of the samples change their color, CRI is equal to 100. The index reduces in inverse proportion to the number of color changes in samples. It is usually believed that a CRI above 80 is good. It is important to know, however, that CRI is calculated for light sources with a particular color temperature. It is not appropriate to compare a 2700K, 82 CRI light source with a 5000K, 85 CRI source.

Also note that CCT and CRI are only defined for full-spectrum light sources. The CRI of monochromatic light is close to zero, and its CCT cannot be calculated.

6.10 Taxonomy of radiation system units

A.k.a., Units of measurement for radiation, radiation measurement units.

There are 4 [different] types of [physical] measurement for radiation:

1. **Exposure duration:** This category focuses on measuring the length of time during which an object or organism is exposed to radiation. The unit for exposure duration is typically represented in seconds (s) or multiples thereof, such as minutes (min) and hours (hr).
2. **Absorbed dose:** Absorbed dose measures the amount of radiation energy deposited in a material or tissue. The unit for absorbed dose is the gray (Gy), where 1 Gy represents the absorption of 1 joule of radiation energy per kilogram of the absorbing material.
3. **Dose equivalent:** Dose equivalent accounts for the type of radiation and its potential biological effect on living organisms. It is measured in sieverts (Sv), which take into consideration the absorbed dose and the radiation type's relative biological effectiveness.
4. **Radioactivity:** Radioactivity measures the rate at which radioactive materials decay and emit radiation. The unit for radioactivity is the becquerel (Bq), which corresponds to one decay event per second.

Within this context, there are base/fundametal units for radiation and also, derived units:

1. Second (s): The base unit for exposure duration.
2. Gray (Gy): The base unit for absorbed dose.
3. Sievert (Sv): The base unit for dose equivalent.
4. Becquerel (Bq): The base unit for radioactivity.

6.11 Taxonomy of energy system units

A.k.a., Energy measurement units.

Energy is an umbrella term for the various different forms of work as the thing that is actually being measured to say how many "energy units" are being used. Energy can be described in terms of calorie, joule, etc. A calorie is specifically a measurement of how much "energy" in the form of heat could be released when heated in a bomb calorimeter. In rational science (a.k.a., rational physics) "energy" is a dynamic concept (a process visible with animation only) with the following definition (with context dependent words): the capacity [to do something]; the ability [to do something]; workability [to do something; doing some action (of the electromagnetic torsion type) with an object-resource].

Energy is a quantity that a given substance or system state contains that can be used for [the work of] electromagnetic torsion. An energy system is a sequence of energy calculations and energy transfers (“conversions”) ... of the unified electro-magnetic (EM) atomic continuous rope. The components of an power system that uses energy (i.e., does EM work) must work together to "transfer" energy (via a torque of the rope) and [transform] power, in such a way as to provide for higher functioning and the fulfillment of energy/power requirements.

The concept of energy can be applied to any existent system, wherein the following principles apply:

1. Energy is a derived quantity that may be assigned as a property of any existent system.
2. The total quantity of energy in a closed system is fixed.
3. The total quantity of energy in an open system is not fixed. In an open system, energy is brought into the system from the environment.
4. More ‘energy’ is required to transfer something across a system boundary, than within the system boundary.
5. Systems maintain themselves by cycling energy and matter. Ecosystems maintain themselves by cycling energy and material nutrients [obtained from external sources].

An energy process is any change that a system undergoes from one equilibrium state to another. Therein, a ‘path’ is the series of states through which a system passes during a process. To describe a process completely, one should specify the initial and final states, as well as the path it follows, and the interactions with the surroundings.

In any given service system, energy has the following characterizations:

1. Energy is *expressed/experienced* as: effect, change, action, movement (or motion), behavior.
2. Energy is *carried/possessed* by: substances and systems.
3. Energy is *transferred* as: work or heat.
4. Energy is *required* for all: structures, processes, operations, functions.

Energy systems involve [at least] the following process stages/phases:

1. **Harvesting, harnessing, and/or collecting** natural energy sources/carriers.
2. **Transferring/transceiving** between different carriers of energy in order to store the energy or produce power. These transferring/transceiving processes are sometimes, and inaccurately, referred to as energy "transformation" and/or "conversion" processes. In actuality, the energy does not change form, it simply transfers carriers.
3. The **distribution** of energy carriers to their end-use application.
4. The **utilization** ("consumption") of energy by a service application.

Energy is a unifying abstract quantitative property that may be assigned to any region, system, object or substance in space-time (existence) via calculation, indicating a change to space-time (existence). The value of the property 'energy' is derived via a measured formulaic (algebraic) expression relative to the region of space (system) under consideration and the theorized principles-attributes that make up existence. The quantized value that is 'energy' indicates the relative degree to which motion is present and/or change of motion is possible in a given area of space-time. The formulas for deriving energy are human inventions -- the description of the natural law of energy conservation by means of a set of algebraic formulas is a human invention. Objects and systems have energy that can only be indirectly observed - by observing what the object or system does.

> **NOTE:** *Although 'energy' may be the most important concept in physics to define, it is also the most difficult to define, because it is axiomatic to the study of existence, which is not yet fully understood.*

Energy is not a thing; it is not matter and it cannot be reified. But, existence may be said to "carry" a property called 'energy'. 'Energy' is an abstract value of a system, and when calculated in "appropriate" ways, always turns out to be conserved.

> **INSIGHT:** *When energy is present, change is occurring or is possible.*

It is incorrect to conceive of energy as a substance-like entity that occupies space, but there are entities called "fields" which occupy space. There are electric and magnetic fields which occupy space, and are described by the "classical" electromagnetic theory of Clerk Maxwell and others, way back in the 19th Century. To conceptualise energy as having form or substance, you should be aware that such conceptualisations are not required by the mathematical structure of physics. There is nothing in the equations or laws which says that energy has either form or substance. It is nothing more than an abstract entity which can be calculated according to rules which it is the business of physics to discover.

> **NOTE:** *Magnetic fields are really electric fields under a Lorentz transformation. Electric fields do not occupy space in the sense that matter does. Instead, they occupy "counterspace". You cannot put two matter-objects (e.g., clay bricks) in one place, but you can superimpose two magnetic fields in the same space to get a total magnetic field (in "counterspace").*

Characteristics of a broad conception of energy:

1. Energy is associated with the action of organisms.
2. Physical systems and objects possess and expend energy.
3. Energy of itself does not cause anything.
4. Energy is associated with activity.
5. Energy is transferred/exchanged between carriers by processes.
6. Energy is a generalised kind of fuel associated with making life comfortable.
7. Energy is a kind of fluid which is transferred in some processes.

There is an inaccuracy in the following commonly seen definition of energy: **"**Energy is the ability to do work, where work is force times distance." The idea that energy is the ability to do work dates back to the seventeenth century and was put into question when energy was defined quantitatively as a conserved quantity in the 1840s. Within ten years, the enunciation of the second law of thermodynamics had shown this definition to be false. In thermodynamics, 'work' takes on a meaning which is broader than the "force times distance" concept of classical mechanics. Herein, work refers to either (1) a process of energy transfer, or (2) the energy being transferred. Not all energy can produce work -- according to the second law of thermodynamics there is always some part of the energy of a system (disordered) that cannot produce work.

Every time energy is transferred, some of its ability to do "work" is irretrievably lost. However, no such limitation applies to the conversion of work to heat; if a simplified definition of energy is needed, it might be described as the ability to produce heat (heating). While this definition is neither elegant nor useful, at least it is true. It is therefore misleading to leave heat out of any definition of energy. Thus, in every transfer of energy, there is energy available [given appropriate technology] to do "work", and energy not available to do "work" -- energy is the capacity to do 'work' and/or supply 'heat'. Therein, the specific expression/definition of 'work' is dependent upon the contextual medium possessing or transferring energy, and 'heat' is energy transfer between two objects of different temperatures:

- **Available energy**, that is energy which can, in principle, be transferred between systems by the process called "work".

Additionally, without the idea of "conservation", energy would mean nothing. Conservation of energy means that energy calculations, correctly performed, always balance to give a constant total. Note that the term 'conservation' does not mean the "saving of energy" or "not wasting energy".

The amount of work that can be obtained from energy depends on the degree of organization of the energy. Organization means all the molecules are moving in the same direction. If the same amount of energy is added to the random motion of the molecules, the result will be a rise in temperature.

Energy and mass are two different ways of expressing a certain property of a system, and that property is a conserved quantity. The equation $E = mc^2$ does not state that mass can be converted into energy. What it does say is that the total energy of a system can be found by multiplying its mass by a universal constant (or consistent). In a frame of reference affixed to the object, multiplying its mass by c^2 yields a quantity called 'rest mass energy'. All mass carries energy.

INSIGHT: *Mass can only be determined when a particle is at rest. This is called 'rest mass'. Electromagnetic emissions cannot be put to rest, and therefore, the mass of these "particles" (if they even have mass) cannot be determined.*

Mass and energy are scalar quantities, while momentum is a vector quantity. Kinetic energy is scalar, it does not have direction. A scalar quantity has only magnitude, while a vector quantity has both magnitude and direction. Momentum is a vector quantity, because it has magnitude and direction. Although a scalar quantity may be separated into components, that doesn't make it a vector quantity. A vector is defined by how those components add up to a total. Vectors also follow specific coordinate transformation laws. As viewed from different coordinate systems, the magnitude of a vector would be the same, but the values of its components would be different. There are requirements for a physical quantity to be a vector: 1) it should have a direction; and 2) it should be added by laws of vector addition.

Vector quantities are often represented by scaled vector diagrams. Vector diagrams represent a vector by use of an arrow drawn to scale in a specific direction. Observe that there are several characteristics of such diagram: (1) a scale is clearly listed; (2) an arrow is drawn in a specified direction, therefore, the vector has a head and a tail, direction; (3) the magnitude and direction of the vector are clearly labeled (the magnitude is 100 newtons of force and the direction is 35 degrees).

INSIGHT: *We understand that matter is made of "atoms". We understand that atoms have "mass". We understand that there is a relationship between mass and energy. We understand that there is a relationship between vacuum and energy.*

At the center of all things with magnitude (e.g., magnetism), there is not that force (or inertia) modality. At the center of gravity there is zero gravity. At the center of magnetism there is zero magnetism. At the center of charge there is zero charge. Where there is not that force there is a "plane of inertia". There is no midsection to any magnet. Each new slice of a magnet will have its own plane of inertia. That tells you that there is no thing that is a plane of inertia. That tells you that the "block wall" or plane of inertia is not located there.

6.11.1 Energy as work by the system against entropy

NOTE: *If energy were defined as the ability of a system to cause external action, then such action becomes sensible by force (displacement), heat (temperature), and light (EM radiation).*

If energy is the ability to do work, then without energy there is no ability to maintain structure against the entropic randomization of the universe -- without energy there is no ability to do anything. Here, we take high energy molecules or molecules in motion that ultimately derive their energy from the sun (i.e., the basic economy of the planet is energy from the sun, is photosynthesises) and transformationally redirect it into something we can use. In other words, we take that high potential environmental energy and convert it through a process of some kind into directed high potential [information] energy that allows our habitat (and bodies) to be powered. At a biological level this occurs through a quantum transducer known as 'mitochondria'. Biologically speaking, our organisms strip electrons off food in a similar, though significantly more complex, manner to the functioning of turbines in a hydroelectric dam through which water flows. When water goes through the turbines electrons are taken [by us] and fed into an electric grid through electron transmission. In fact, our mitochondria is a miniature example of this electron transport chain seen in hydroelectric or nuclear generating power systems. Our organisms take high energy [macro]nutrients as proteins, lipids, and carbohydrates and process them through an energy "powerhouse" we know as mitochondria to produce a set of high-energy intermediaries (e.g., atp, nadph) that are then directed and delivered to regions of the cell(s) that maintain function (i.e., muscles to contract or neurons to fire or digestive juices to be released or cells to replicate. This process is technically known as mitochondrial bioenergetics. At a practical level our diet and lifestyle play an important role in functionally maintaining the ability of these powerhouses to do that work. Fundamentally, matter is a form of coalesced energy (remember e = mc2), and molecules are essentially information rich “data packets” of energy.

6.11.2 Energy and thermodynamic systems

It is possible to associate energy and thermodynamics within a system's model in the following ways:

1. Whereas "energy" is vibratory potential "thermodynamics" is electromagnetic heating;
    A. wherein, there are (in order):
        1. **electromagnetic action models** and explations for the "light-/radiation-energy" part (a.k.a., torsion of light-rope),
        2. **atomic action models** for the "pumping-/electron-energy" part,
        3. **thermodynamic action models** for the "thermal-/heating-energy" part (a.k.a., thermal-sensed vibration of atomic compositions of light-ropes),
        4. **mechanical action models** for the actual, obejct-ive moving parts.

Here, 'heat', 'friction', and 'sound' are human sensed, physically associated phenomena. These phenomea occur where action occurs at these levels four levels. At this level, there is also the universally observed and constrained, also physically sensed and associated phenoma of 'gravity' (a.k.a., universally constrained object-to-object pulling/attraction). In this case, friction is universally constrained pushing (a.k.a., forced and constrained object-to-object separation). And herein, heat is the macro-physically sensible vibration of atomic object (a.k.a., constrained object-bound structures, bodies).

Thermodynamics does not have a direct etymological meaning, but it could be named the study of heat transfer. Anything in physics related to heat is classified [at least] as part of study of thermodynamics, and follows thermodynamic principles. There are four principles (or “laws”) of thermodynamics (zero through three):

1. **The zeroth law of thermodynamics** - if a system A is in equilibrium with system B, and system B in turn is in equilibrium with system C, then systems A and C are in equilibrium with each other.
2. **The First Law of Thermodynamics** - the change in internal energy of a system is equal to the sum of the energy transferred to the system by “heat” and the “work” done on the system. This principle claims that energy is conserved.
3. **The Second Law of Thermodynamics** - the efficiency of heat engines must always be < 1.
4. **The Third Law of Thermodynamics** - the temperature of a system cannot reach absolute zero (0 K); as the system approaches absolute zero, entropy approaches a constant.

Thermodynamics divides the universe/reality into two parts: a system and its environment. Therein, there are three distinct types of thermodynamic system:

1. **Isolated systems** - no transfer/exchange of energy or matter with the environment.
2. **Closed systems** - transfer/exchange only energy, but not matter with the environment.
3. **Open systems** - transfer/exchange both energy and matter with the environment.

Thermodynamics concerns equilibrium states. Thermodynamic equilibrium is an axiomatic concept of thermodynamics. It is an internal state of a single thermodynamic system, or a relation between several thermodynamic systems connected by more or less permeable or impermeable boundaries. In non-equilibrium systems, by contrast, there are net flows of matter or energy. Equilibrium is a state of balance (no change). In an equilibrium state there are no unbalanced potentials (or driving forces) within the system.

1. **Thermal equilibrium** is if the temperature is the same throughout. The point at which heat transfer stops.
2. **Mechanical equilibrium** is if there is no change in pressure at any point of the system with time.
3. **Phase equilibrium** is if a system involves two phases and when the mass of each phase reaches an equilibrium level and stays there.
4. **Chemical/atomic equilibrium** is if the chemical/atomic composition of a system does not change with time, that is, no chemical or atomic reactions occur.

The prefix iso- is often used to designate a process for which a particular property remains constant.

1. **Isothermal process** - a process during which the temperature remains constant.
2. **Isobaric process** - a process during which the pressure remains constant.
3. **Isochoric (or isometric) process** - a process during which the specific volume remains constant.
4. **Cycle** - A process during which the initial and final states are identical.

6.11.3 Thermodynamic energy flow types

A system and/or region of space can “gain” energy from its surroundings or “lose” energy to its surroundings.

Technically, the system or region of space isn't actually gaining or losing some real thing called 'energy'; instead, the property, 'energy', which is assigned to that region of space or system is increasing or decreasing in value. As energy flows through systems it acquires different qualities:

1. **Enthalpy** - The amount of heat content used in a system at a constant pressure. In any system how much heat is used at the constant pressure termed as enthalpy. Enthalpy (h) is the measure of total energy content of a substance in a thermodynamic system. The SI unit for 'specific enthalpy' is joule per kilogram. It can be expressed in other specific quantities by $h = u + pv$, where u is the 'specific internal energy', p is the pressure, and v is specific volume, which is equal to 1ρ, where ρ is the density.
2. **Entropy** - Entropy is the measure of disorder, or a measure of "randomness". Entropy is a quantitative measure of the unavailability of a system's energy [to do work]. When a system receives an amount of heat (ΔQ), the system gains an entropy in the amount given by $\Delta Q/T$, where T is the absolute temperature at which the heat transfer takes place. Entropy is a measure of the disorder of a thermodynamic system. Enthalpy is a measure of the total energy of a thermodynamic system. Entropy is a quantitative measure of the molecular disorder of a system. Entropy of the system increases when temperature gradients disappear or dissipate. Entropy of the system increases when concentration gradients disappear or dissipate. As energy is expended to do work, entropy decreases. If no energy is available in the system, its entropy level will remain constant or increase.
   A. There are at least two kinds of entropies - thermodynamic and information-theoretic entropies. Thermodynamic entropy should not be confused with the so-called 'information theoretic entropy' (a.k.a., intropy). 'Information theoretic entropy' is a measure of variety of message sources in communication systems.
3. **Exergy** - The generic name for the amount of work obtainable when some matter is brought to a state of [energetic] equilibrium with its surroundings by means of reversible processes. In thermodynamics, the exergy of a system is the maximum useful work possible during a process that brings the system into equilibrium with a heat reservoir. When the surroundings are the reservoir, exergy is the potential of a system to cause a change as it achieves equilibrium with its environment. Exergy is the energy that is available to be used. After the system and surroundings reach equilibrium, the exergy is zero The maximum useful work which can be obtained in a process in which system obtains dead state. For example, when a new source of energy, such as geothermal well, is discovered, the first thing the team does is estimate the amount of energy contained in the source. However, this information alone is of little value in deciding whether to build a power plant on the site. Additional information is needed in order to determine the work potential of the source; that is, the amount of energy that can be extracted as useful work. This property is called exergy. Note that destroyed exergy has been called anergy.
4. **Emergy** - is defined as the available energy of one kind required directly and indirectly to make a product or service. It is measured in emjoules (a unit referring to the available energy consumed in transformations). In energy systems, energy sources and components are connected with energy flows and arranged from left to right (generally), thus describe the order of increasing transformity. The transformity is defined as the emergy (in emjoules) of one kind of available energy required directly and indirectly (through all the pathways required) to make one joule of energy of another type. Transformity is the ratio of emergy to available energy.

7 Fundamentals of: Energy

INSIGHT: *Energy is a mathematical principle, not a description of a mechanism or anything physical. Mathematics describes motion; measurement is motion.*

There is no equation that represents a static concept. "Energy" is a physics term describing a mathematical principle - something that cannot be held or seen. Energy is simply a value that is algebraically calculated. Therein, energy is an abstract and quantized value (a property) that may be assigned to any given region of space-time, implying the presence of change or the possibility for change. The property, 'energy', is the result of a mathematical expression in a run calculation, and cannot be reified. There is no such thing as "a form of energy", because energy does not have form - it is not an existent substance. Energy does not come in different forms. Hence, 'energy' is not capable of being transformed or converted. Instead, energy is an abstract, calculated value implying the transformation of existence, or potential for the transformation of existence, but it itself does not have existence or form. All systems in existence "carry" energy (i.e., have energy as a property assignable to their existence).

CLARIFICATION: *Energy is not a physical substance; it is not made of atoms. Matter is made of atoms. The distinctive names of energy, such as kinetic energy, potential energy, electrical energy, mechanical energy, thermal energy, arise because of the different systems by which energy is assigned as a property, not because there are different forms or types of energy. Energy is just energy. Different physical "storehouses" result in the different names, not different kinds of energy. Many papers cite the approach in the Feynman Lectures: there are a number of different physical quantities whose sum is always constant (as a physical law), so we call that sum "energy". These various physical quantities are typically called "forms of energy".*

The value of the property, 'energy', can be calculated for any region of space-time and/or system given the data available to complete the calculation. 'Energy' cannot be calculated in isolation, or measured directly. Conceptually, energy only exists in the context of two or more objects and the occurrence of a change (i.e., in the context of a system).

CLARIFICATION: *"Energy" is a concept that means "capacity". There is no physical stand-alone object called 'capacity'; instead, "capacity is a concept. Therefore, energy cannot be transferred; only objects can be transferred.*

Energy is a universal property of every existent system that implies the calculated ability to change [given a cause in the real world]. And, all change in the universe implies the transfer of energy (objects). A change in a system's state implies a transfer of energy (some object), and a transfer of energy (objects) implies a change in a system's state. The presence of energy (objects) and its transfer underlies all change of existence in the universe. Its presence, as an expressed property (object), is a calculable necessity for the existence of movement, heat, electricity, and all life.

NOTE: *In physics, the presence of energy is required for change, but energy does not cause change. Differences in the real world (e.g., pressure and temperature gradients) cause change, and when change occurs, energy transfers (i.e., is recalculated). In other words, differences in pressure concentration and unbalanced forces cause change, not energy. But, when change occurs, energy is transferred. And, the quantity that is 'energy' can be calculated to determine the value required for an expressible change to occur. For instance, the energy requirement for lifting an object a set height can be calculated.*

Energy is not made of anything, energy is a term used to describe a trait of matter and non-matter fields. When matter has velocity, for example, it is said to have kinetic energy. Energy isn't 'stuff', it is a calculated quantity based on an equivalence relation; a property that systems have. It is a scalar value that is assigned to the state of a system, (i.e., energy is a tool or mathematical abstraction of a property of physical systems). This quantity is involved in (i.e., can be associated to) all processes of change.

Mathematically, energy is a conserved quantity, and hence, it is not possible to create new energy that is not already present (mathematically speaking) in the universe. Many different kinds of change take place in the real world, and for each kind of change the total energy before is calculated to equal the total energy after.

NOTE: *In common parlance, the terms "energy generation" and "energy utilisation" are confusing because, in fact, no energy can be created or destroyed.*

A classic textbook definition of energy is "the ability (or capacity) to do work". Even though this definition is now deprecated, it seems to have enduring power "Energy is the capacity to do work" is not only incomplete, but incorrect, because it ignores the 2nd Law of thermodynamics, which states that not all energy has the ability to do work. The 1st law says that energy is conserved, yet the 2nd law says that the ability to do work is not conserved, so this definition of energy leads to a logical contradiction. Further, although at a conceptual level the idea that energy is "the capacity to do work" makes sense for mechanical energy, but not for thermal and other "forms" of energy.

The total energy of a system can be classified in a variety of ways. Hence, there are multiple "types" of energy, which depend upon the context of the classification. As a measure/property of the expression of something that exists, the presence of energy can be classified according to:

1. Spatial motion (of carrier/system).
2. Spatial length (of carrier/system).
3. Spatial medium (of carrier/system).
4. Pressure gradient (within carrier/system).
5. And, any combination thereof.

7.1 Energy units classified by: Spatial motion

Stating that an object "possesses" energy means that it is moving right now or has the ability to move due to its position [in a force field]. The part of the measure that is not currently represented as motion, but stays in the form of an ability to move due to its position is called, potential energy. While, the part corresponding to the motion right now is called kinetic energy.

In general, motion and the potential for motion is described as mechanical energy. Mechanical energy is the total energy an object has (when building up energy or when using it). The two known types of energy as per motion are: kinetic energy (current motion) and potential energy (potential for motion). Hence, the sum of potential energy and [macroscopic] kinetic energy is called mechanical energy.

Hence, from the perspective of spatial motion, energy can be classified in two fundamental ways:

1. As a flow: Energy *expressed* as motion is called **kinetic energy (mass and velocity)**. Kinetic energy is the energy an object "possesses" due to its motion. A force, driven by a cause, is required to accelerate a mass to its stated velocity. Kinetic energy is "gained" during acceleration and remains during motion. Kinetic energy represents explicit change.
2. As a potential for flow: Energy *associated* with position [in an electric or magnetic field] or condition is called **potential energy (position and condition)**. Potential energy is the energy associated with an object as a result of its position or condition inside a "force" field. Note here that potential energy is not stored energy. Energy can be stored in motion just as well as it can be stored in position. Potential energy represents a potential for future change (or motion). Energy due to position in space.

And yet, this arrangement of motion associated energy concepts could also be viewed from the following perspective classification:

1. How energy flows: electromagnetic energy, electrical energy, heat, work, etc.
2. How energy is stored: internal energy, kinetic energy (stored in motion), potential energy (stored in condition), energy density (stored in fuel), etc.

Simplistically, kinetic energy is energy "in motion" and potential energy is energy "at rest". Potential energy is often measured as positive or negative depending on whether they are greater or less than the energy of a specified base state or configuration, such as two interacting bodies being infinitely far apart.

When energy is present, then there ongoing change (i.e., movement) or the possibility of future change (i.e., future movement). That potential for future change can be "absorbed" by some sort of reservoir-like capability in existence (as potential energy), retained for a length of time (permittivity), then released again in the future as explicit change (as kinetic energy).

A existent\material system can have any combination of kinetic and potential energy, and both potential and kinetic energy can be "stored". Over time, energy is transferred from potential energy to kinetic energy, and then, back to potential energy constantly. This is referred to as the "conservation of energy" (or, "conservation of ether").

Potential energy only exists in the presence of a system. When a brick, for instance, is lifted, its potential energy is not increased. Instead, the potential energy of the system that consists of the two objects: the earth and the brick. Potential energy is not stored in either Earth or the brick, nor is it possible to apportion the potential energy between the two interacting objects. The first step to enlightenment is to learn not to speak or think about gravitational or electrical potential energy of electrons (or of any other kind of particle) and think instead of energy as a property of the whole system.

> **NOTE:** *Technology takes forms of potential energy and turns them into kinetic energy. Whenever energy is "used", it is kinetic energy.*

The material expression of kinetic and potential energy can take multiple forms. These forms represent a contextual measure (quantity) of the ability of a system or object to do work on another system or object in material reality. The interaction between energy and matter is described by its multiple forms of energy.

> **QUESTION:** *Energy is not a thing, it is a property of something; hence, how can it exist in different forms? Simply put, a "form" of energy is a mathematical expression, an equation that evaluates a quantity of energy in a given context. Thermodynamics is the study of any energy transformation that involves heat.*

Kinetic energy is calculated using the following formula:

- $E = 1/2mv^2$

- where,
  - E is energy, measured in joules (J)
  - m is mass, measured in kilograms (kg)
  - v is velocity, measured in meters per second (m/s)

Notes about the expression:

1. The more mass a moving object has, the more kinetic energy it will possess at the same speed.
2. Because the velocity term in this formula is squared, velocity has a much larger effect than mass does on kinetic energy.
3. The larger an object (m) is and the faster it moves (v), the more kinetic energy (KE) it has.

Ways of harnessing macroscopic kinetic energy include, but are not limited to:

1. Wind power harnesses the kinetic energy possessed by moving bodies of air (wind) as they flow between atmospheric pressures.
2. Hydropower harnesses the kinetic energy of moving water as it moves (i.e., falls) in a "gravitational force" field.

Potential energy is calculated using the following formula:

- E = gmh
- where,
  - g is the acceleration due to "gravity"
  - h is height above inertial ground plane
  - m is the mass of a body

Notes about the expression:

- The larger an object is (m) and the more displaced it is (h) in a "force" field, the more potential energy (PE) it possesses.

7.2 Energy units classified by: Spatial length

All energy types detectable in space-time may be classified by the length-dimension of the system or object (i.e., mass) under observation. Generally speaking, there are two principal categories of length: the macroscopic and the microscopic. The prefixes "micro-" and "macro-" come from Greek words that mean "small" and "large," respectively. The suffix "-scopic" originates with the word "scope," which in turn originates with the Latin word "scopus," which can mean aim, target or object of attention.

> **NOTE:** *The terms 'microscopic energy' and 'macroscopic energy' could be replaced here with 'microscopic viewpoint or approach' and 'macroscopic viewpoint or approach'.*

The macroscopic context considers a certain quantity of matter without considering the events occurring at the molecular level. The macroscopic approach is based on the study of the overall behaviour or gross behaviour of a number of molecules. Hence, the macroscopic "forms" of energy are those a system (or object) possesses as a whole with respect to some outside reference frame (e.g., the earth). The macroscopic viewpoint maintains:

1. The energy expressed/possessed by the gross or average behavior of multiple molecules that can be explained based on the continuum assumption.
2. Time average influence of multiple molecules.
3. Effects can be perceived by senses and/or measured by instruments, such as the effects of pressure and temperature.
4. Substances perceived as infinitely divisible or existing along a continuum.

The microscopic "forms" of energy, on the other hand, are those related to the molecular structure (architecture) of a system, its molecular bonding, and the degree of the molecular activity, which are independent of outside reference frames. The microscopic context maintains:

1. The energy expressed/possessed atoms or molecules are considered based upon statistical considerations and probability theory in connection with a model of the atom.
2. The 'internal energy' of a system is the sum of its microscopic forms of energy.

The macroscopic and microscopic energy value of a system can be combined to express the 'total energy' of a system - the sum of its macroscopic energy and microscopic energy.

Kinetic energy and the spatial length of a system in question can be combined in value. Kinetic energy is the energy of motion: the motion of large objects (macroscopic kinetic energy), or the movement of small atoms and molecules (microscopic kinetic energy). Macroscopic kinetic energy is sometimes referred to as "high quality" energy, while microscopic kinetic energy is more disordered and "low-quality". Macroscopic kinetic energy can become microscopic kinetic energy through 'friction'.

7.3 Energy units classified by: Spatial medium

It is customary to say that energy exists in different forms which are transformed or converted into one another during physical processes. However, using the term "energy form" for the respective categories is unsatisfactory because it easily leads to the misinterpretation that there are different kinds of energy. The term 'energy carrier' more accurately accounts for the well-known but little recognized natural law that energy always flows simultaneously with at least one other existent (physical) quantity. Hence, the term 'energy carrier' is able to provide clear language of how energy is transported, exchanged, and stored. The substance-like physical quantity which flows while energy is flowing, "carries" the energy. It is imprecise to speak about the forms of something that itself does not change, but rather, which only changes carriers.

Of course, there are limits as to how literally the expression "energy carrier" should be understood. The word "carry" implies here only a temporal relationship between the flow of energy and the flow of an energy carrier. It is not meant to imply that energy and its carrier necessarily occupy the same position in space or even flow with the same velocity. An energy carrier can be "loaded" with more or less energy in the same sense that a carrier of commodities, say a pickup truck, can be loaded with more or less of a commodity.

The picture of energy carriers and energy load factors is especially useful to describe devices which are traditionally called "energy transformers" or "converters." Traditionally speaking, energy flows into an energy transformer in one form and out in another. Unfortunately, this way of speaking suggests that one physical quantity is transformed into another within such a device. Actually, however, the energy simply changes its carrier within the device. In other words, the energy is transferred from one carrier to another within the device. Accordingly, the name energy transceiver is more appropriate to the actual function of such a device.

It is easy to graphically represent the energy transport from one device or region of space to another with the help of an energy flow diagram. Such diagrams provide the means for a simple, graphical calculus applicable to the solution of energy-related problems. A

7.4 Energy carriers, mediums, and forms

> **CLARIFICATION:** *Energy can be absorbed by carriers and transferred between carriers.*

Energy can be classified according to the spatial medium (form or source) for which the quantity is being calculated. The following are not different forms of energy -- in physics, there is just energy, not different forms of energy. In particular, in physics, the conservation law states that there are no sources and there are no sinks of energy. There is such a thing as 'dissipation', which is covered by entropy per a thermodynamic system.

Energy may be classified for the following systems:

1. **Mechanical energy** - energy possessed by the mass of an object due of its motion and/or potential to move. Energy in the mass of an object due to its motion and gravitational position - the sum of the kinetic energy and potential energy of a mass.
   A. Mechanical kinetic energy - energy due to motion (moving objects)
   B. Mechanical potential energy - energy due to tension of objects.
2. **Chemical energy** - energy possessed by the composition of a chemical substance due to the condition and/or potential condition of its atoms. Energy in the chemical bonds of atoms and molecules. Chemical energy is released out of the reaction taking place between elements/molecules to form a more stable compound.
   A. Chemical potential energy - energy due to molecular position in a chemically-bonded "force" field (i.e., due to chemical bonds).
3. **Nuclear energy** - energy possessed by the composition of an atom due to the condition and/or potential condition of its binding nucleons. Energy in the nuclear bonds of an atom. Nuclear energy is the energy released by either a fission or a fusion process. Here again the resulting products assume a more stable condition.
   A. Nuclear potential energy - energy due to dielectric position in an atomically-bonded "force" field (i.e., due to nucleus of atoms).
4. **Electric[al] energy** - energy possessed by the electric composition of an atom due to the condition and/or potential condition of its polar charge. Energy expressed in/as charged motion is electrical energy.
   A. Electric[al] potential energy - energy due to atomic position in an electrically-bonded "force" field.
   B. Electric[al] kinetic energy - when matter that carries a charge moves in an electric field it carries kinetic energy.
5. **Electromagnetic energy** - energy possessed by the composition of ether (electric and magnetic fields) due to the condition and/or potential condition of its dielectric inertial plane. Electromagnetic energy is a dynamic form of energy that is caused by the acceleration or oscillation of a charged particle. All substances above absolute zero (0 Kelvin) emit a range of electromagnetic energy.
   A. The acceleration/oscillation of electrical charges produces dielectric radiation.
6. **Gravitational energy** - energy possessed by the mass of an object due to its motion and/or potential to move toward a zero inertial plane.
   A. Gravitational potential energy - energy due to mass position in a gravitationally-bonded force" field (i.e., due to height and weight in gravity field).
7. **Thermal energy** - the total energy of motion, rotation, and vibration of the atoms and molecules inside an object. Thermal energy is not the energy

of a whole object itself (mass) moving. In a gas or gas mixture, like air, the motion (and rotation) of individual gas particles makes up this energy. In a solid, like a table, the thermal energy exists as vibration of atoms or molecules. Note that total thermal energy also includes some atomic forms of potential energy. The temperature of an object is determined by its total microscopic kinetic energy. Thermal energy is the result of molecular agitation causing rise in temperature. It is the basic energy form, in the sense all other forms of energy can be completely converted into thermal energy. The other way, i.e., the complete conversion of thermal into other forms of energy is not possible and is governed by the Second law of thermodynamics. Thermal energy is the energy of a vibrating molecule in all degrees of freedom (translational, vibrational, rotational, potential).

7.4.1 Movement and oscillation of energy carriers

The oscillation and/or acceleration of an energy carrier will produce a related type of energy transfer:

1. Atomic and molecular oscillation generates thermal radiative electromagnetic energy (heat).
2. Mechanical oscillation generates acoustic/cymatic radiative energy (sound).
   A. Linear acceleration of matter results in force (thrust or propulsion).
   B. Circular acceleration of matter results in torque.
   C. Divergent acceleration of matter results in pressurization or explosion.
   D. Convergent acceleration of mater results in depressurization or implosion.
3. Electric [charge] oscillation generates electromagnetic radiative energy (light).
   A. Moving charges have a magnetic field.
   B. Linear acceleration of electric charge generates a pulse of electromagnetic radiative energy.
   C. Circular acceleration of electric charge generates electromagnetism.
4. Magnetic oscillation [in the presence of a conductor] generates electrical radiative energy [around the conductor].
5. Changing magnetic fields generate electric currents in a conductor.

> **NOTE:** *All digital communications and wireless charging, at the present, are based on electron oscillation. Therein, the term 'signal' is another word for the propagation of energy conveying communicative information (i.e., a communication)*.

7.5 Energy units sub-classified by: Pressure gradient

> **NOTE:** *There are pushing pressures and there are pulling pressures.*

Every aspect of power production and/or energy transfer in the world is about moving pressures from one place to another. Therein, flow exists because of a difference in pressure -- a difference in pressure between one point\location [in a conduit/medium] and another point\location [in the conduit/medium]. When there is no pressure [gradient], there is no flow of energy, and hence, no power.

> **INSIGHT:** *Without pressure, there is no movement. Without cause, there is no pressure. Without intention, there is no cause. Without movement, there is no intention. Without desire, there is no suffering.*

When a pressure gradient has been established, energy always flows spontaneously, and without the need for work, from areas of high to low pressure (given a conducive medium for flow).

Pressure gradients:

1. Mechanical pressure gradient (strain).
2. Molecular pressure gradient (temperature, thermal).
3. Atomic pressure gradient.
4. Electrical pressure gradient (voltage).
5. Magnetic pressure gradient (gauss).
6. Electromagnetic pressure gradient (electron-volt).
7. Electrochemical pressure gradient.

Pressure types:

1. Electrical pressure (voltage) = energy / unit charge.
2. Mechanical pressure (stress) = force / unit area.
   A. Acting parallel (shear stress, the force is termed 'shear force').
   B. Acting perpendicular (normal stress\fluid pressure).
   C. The degree of mechanical deformation is termed 'strain'.
3. Fluid pressure = energy / unit volume.

Absence of pressure:

1. No hydro pressure = no flow of water = no hydro current = no hydro power.
2. No electric and/or magnetic pressure = no flow of charge = no electric current = no electricity or electrical power.
3. No mechanical pressure = no force or torque = no change of position = no mechanical power.

4. No molecular pressure = no temperature = no thermal current = no thermal power.

Water analogy describing the same principle, but different processes:

1. Matter flowing as water molecules (water molecules are flowing) - There are “excess” water molecules on one end of a conduit that are able to flow to the other end that has less molecules.
2. Matter flowing as charged particles (electron or proton particles are flowing) - There are “excess” charged particles (electrons) on one end that are able to flow to the other end that has less charged particles (electrons).
3. Ether flowing as dielectric fields - There are “excess” fields on one end that are able to flow to the other end that has less dielectric fields.

7.6 Energy Transfer modes

> **CLARIFICATION:** *It is not “the energy” being transported through the electromagnetic field, a fuel line, or a house wall which has different characteristics, but rather, a substance-like physical quantity which flows simultaneously with the energy in each case. Consequently, energy is not actually transformed or converted within a so-called “energy transformer” or “energy converter.” Rather, it is correct to say that the other substance-like physical quantity that flows along with the energy is exchanged/transferred/converted within such a device. For example, energy is brought into a power plant together with coal and oxygen or, scientifically speaking, together with the amount of substance (the quantity measured in moles) of coal and of oxygen, and energy always flows out of the power plant simultaneously with electric charge.*

Energy transfer refers to the movement or flow of energy from one area of space-time to another without changing its form. There are different processes that allow for the transfer of energy; these different processes are otherwise referred to as ‘modes of energy transfer’ (or ‘energy transfer modes’). These transfer modes (processes) are generally signified linguistically as gerunds (verbs functioning as nouns). The presence of the process (or mode) means the transfer of energy. Recall that the time rate of energy transfer is called ‘power’.

> **NOTE:** *Although every transfer will mean some conversion to heat, the transfer of energy may or may not mean the complete conversion of the medium participating in the transfer. Whereas a combustion system involves some conversion of the input medium, a wind turbine system does not involve conversion of the wind to some other medium. Energy can be transferred without changing carrier, such as when [electrical] energy “moves” along a wire, or [thermal] energy “moves” from the inside of a hot cup to the outside.*

The mechanisms of energy transfer at a system boundary are:

1. Temperature (heat or heating) - heat transfer
2. Pressure (work or working) - work transfer
3. Volume (mass flow or permeating) - mass transfer

> **NOTE:** *In a closed systems (i.e., systems with a fixed mass), energy can only transfer across the boundary as heat and/or work, not mass flow. The boundary of an open systems allows for energy transfer by mass flow, as well as temperature (heat) and pressure (work).*

Systems may be said to “possess” energy, but they cannot be said to “possess” heat or work. These are modes of transfer, otherwise known as ‘boundary phenomena’, because they are recognized at the boundary between the two or more systems. The transfer modes are associated with a [boundary] process, not a state of the system. Also, they are path dependent functions (i.e., their magnitudes depend on the path followed during a process as well as the end states).

Heat and work are energy in transit. Thus, heat and work are not properties of state, but energy that is in transport across system boundaries, to or from the environment. It is not possible to measure how much heat or work are present in an object, but rather only how much energy is transferred among objects in certain ways during the occurrence of a given process. Work and heat are, in a way, transport concepts for energy.

Heat and work are measured as positive (additive) or negative (subtractive) depending on which side of the transfer they are viewed.

These transfer processes can be viewed from several perspectives. From the perspective of gradient flow, there are two primary transfer modes:

1. Differences in temperature lead to the transfer of energy.
2. Differences in pressure lead to the transfer of energy.

The are a fixed number of ways that energy can be transferred (i.e., “exchanged”). These transfer processes can be viewed from the motion of a medium:

1. **Displacing matter** - by accelerating matter through a pressure differential.
2. **Permeating matter** - by displacing the location of some matter into other matter through pressure differential.
3. **Pressurizing matter** - by compressing matter through pressure differential.

4. **Heating matter** - by [rapidly] accelerating the atoms and molecules of matter through pressure differential.
5. **Waving matter (mass radiation)** - by colliding matter, creating compression and rarefaction of mass (i.e., "waves"). By accelerating an interface to a closed and non-displaced system.
6. **Waving ether (electromagnetic radiation) -** by accelerating charges, creating compression and rarefaction of ether (i.e., "waves").

   NOTE: *Waving is transfer of energy without the transfer of matter. A wave is a vibration (vibratory pressure as compression and rarefaction) that transfers energy from one place to another without transferring matter (solid, liquid or gas).*

Energy can be transferred into our out of a system in several ways:

1. Through mechanical interactions - energy transferred mechanically as work (i.e., in a coherent manner)
2. Through thermal interactions - energy transferred thermally as heat (i.e., in an incoherent manner)
3. Through radiation interactions - energy transferred

   NOTE: *Any of these transfers increase the system's internal energy (per ΔE).*

Energy can be transferred into our out of a system in several ways:

1. **Working - work transfer mode**: The coherent and directed transfer of energy by a force causing a displacement at the point of application of the force. Work transfer (working) may be contrasted with heat transfer (heating). Work transfer refers to all transfers that do not involve a temperature difference. May be viewed as the flow of "non-thermal energy transfer". If work is *done on* a system, then the energy of the system increases (input energy transfer). If work is *done by* a system, then the energy of the system decreases (output energy transfer).
2. **Heating - Heat transfer mode:** The transfer of energy driven by a temperature difference between two regions in space. Heat transfer takes place due to the presence of a difference in temperature. Heat always flows from the system with a higher temperature to the system with a lower temperature. Heat is the quantity of energy which crosses the boundaries of a thermodynamic system. When added to a system heat transfer causes the energy of a system to increase, and heat transfer from a system causes the energy to decrease.

There are several important principles to note when discussing these two transfer modes:

1. Work transfer can be completely converted into heat transfer.
2. Heat transfer cannot be completely converted into work transfer, because some of the "energy" will disperse irrecoverably. The degree to which the "energy" is dispersed is known as the entropy of the system.
3. Work transfer will always produce some heat transfer.
4. Both heat and work are path functions, and vary with the manner in which the process is carried out.
5. A system cannot contain or store either heat or work.
6. Heat into a system and work out of a system are considered positive quantities.

Energy can be transferred into our out of a system in several ways (modes) - it must flow or it is not energy transfer:

1. **Mechanical radiative transfer (wave flow)** - energy is "transferred" by the propagated disturbance of a physical medium (flow of "mechanical energy" as wave collisions). The flow of a propagating [contraction and rarefaction] disturbance of space. Matter does not flow with the transfer of energy.
2. **Matter transfer (mass flow)** - energy is transferred by the movement of physical matter through the boundary of a system, carrying energy with it. The flow of matter as volume transfer. As mass flows into a system, the energy of the system increases by the amount of energy carried with the mass into the system. Mass leaving the system carries energy with it, and the energy of the system decreases. Since no mass transfer occurs at the boundary of a closed system, energy transfer by mass is zero for closed systems.
3. **Electromagnetic transfer (field flow)** - energy is transferred by the propagation of an electromagnetic field (Read: electromagnetic induction or radiation). The flow of "electromagnetic energy". Or, the flow of ether as a propagating [contraction and rarefaction] disturbance of counterspace. The transfer processes are known as:
   A. Electromagnetic induction.
   B. Electromagnetic radiation.
4. **Electrical transfer (charge flow)** - energy is transferred by electric charge/current propagating through conductive matter. The flow of "electrical

energy". The transfer process is known as:
A. Electrical [charge] conduction.

7.6.1 Transfer types

Energy can be transferred from one point in space-time to another in three ways:

1. Through the *action of forces*.
   A. **Electric and magnetic force fields** - Charged particles, upon which electrical fields exert forces, possess potential energy in the presence of an electric field in a way similar to that of an object in a gravitational field. These force fields can accelerate particles, converting a particle's potential energy into kinetic energy. Likewise, charged particles can interact via the electric and magnetic fields they create, transferring energy between them, and in the case of an electrical current in a conductor, cause molecules to vibrate, i.e. converting electrical potential energy into heat.
   B. **Frictional Forces** - The macroscopic (large-scale) energy of an object, that is, the potential and kinetic energy associated with the position, orientation, or motion of the entire object, not counting the thermal or heat energy of the system, can be converted into thermal energy (heat), whenever the object slides against another object. The sliding causes the molecules on the surfaces of contact to interact via electromagnetic fields with one another and start vibrating.
   C. **Gravitational force (possibly, magnetic)** - When gravity accelerates a falling object it converts its potential energy to kinetic energy. Likewise, when an object is lifted, the object stores the energy exerted by the lifter as a potential energy in the earth-object system.
2. When *atoms absorb or emit electromagnetic radiation* (i.e., photons of light). When light falls on an object, an incident photon may either pass through the object, be reflected by the object, or be absorbed by the atoms making up the object. If most of the photons pass through, the object is said to be transparent. Depending on the smoothness of the surface on the scale of the photon's wavelength, the reflection may be either diffuse (rough surface) or coherent (smooth surface). If the photon is absorbed, the photon's energy may also be split up and converted in the following ways:
   A. **Photothermal effect:** the energy absorbed may simply produce thermal energy, or heat in the object. In this case the photon's energy is converted into vibrations of the molecules called phonons, which is actually heat energy.
   B. **Photoelectric effect:** the energy absorbed may be converted into the kinetic energy of conduction electrons, and hence electrical energy.
   C. **Photochemical effect:** the energy may bring about chemical changes which effectively store the energy.
3. When *nuclear reactions* occur, that is, when there are rearrangements of the subatomic particles that make up the nuclei of atoms. There are two basic types: **Fission** - when nuclei combine, and **Fusion** - when nuclei split apart.

7.6.2 Transfer (carrier) interactions

Electromagnetic waves (light) and mechanical waves (sound) interact with physical materials in various ways that impact their "transfer" of energy. There are three principal ways in which waves (compression and rarefaction of space or counterspace) interact with matter; these are known as wave behavior interactions:

1. **Transmission (light wave transmission or mechanical wave transmission):** The passing of a wave through a material. For instance, light passes through an object - an object is either transparent (the light passes straight through), or translucent (the light passes through, but its direction "scattered" by the material). Light rays that pass through an interface are transmitted rays. These rays bend. This bending is called refraction. The direction and magnitude of refraction depends on the relative densities of the two media and the angle of incidence.
2. **Reflection (light wave reflection or mechanical wave reflection):** The bouncing back of a wave after it strikes a barrier. For instance, light bounces off a surface. Reflection can either be coherent (the angle of incidence equals the angle of reflection) or diffuse (the reflected direction is scattered).
3. **Absorption (light wave absorption or mechanical wave absorption):** The transfer of energy from a wave to matter as a wave passes through it. For instance, light enters a material and does not pass through. Instead, its energy is converted into "thermal energy" as microscopic vibrations of the material, or is absorbed by chemical reactions triggered by the light (the photochemical effect).

Consider a passive solar home in the winter with sunlight propagating to a window on the home. The following may be said about the system:

1. Light is transmitted through the window (which is

either translucent or transparent) .
2. The light contacts the floor and is either reflected or absorbed (after several reflections around the room, almost all is eventually absorbed. A tiny bit is reflected back out the window.
3. The floor (and other surfaces where the light contacts), are "heated" by the absorption of light.
4. Some of this heat conducts into the material.
5. Some of this heat is re-radiated (at infrared wavelengths), back into the room.
6. Air near the surfaces is "heated" by this re-radiation and by contact (conduction) with the wall.
7. The "heated" air rises (convection).

7.6.3 Work transfer mode

> **IMPORTANT:** *Modern physics is still confused over the concepts here as is visible in the following: Work and energy are in the same units (joules), but work is always a change in energy.*

Work describes a transfer change in energy; it's not a conserved quantity in itself unless embedded in the concept of energy, which is conserved. With the above said, the "ability/capacity of a system to perform/do work" is a common and imprecise definition of energy. As a measure, energy is the total amount of work that can be done.

Work is the difference in energy between when you started, and when you're done. "Work" is just the amount of energy added (the amount of energy it has at the end, minus the amount of energy it had when you started).

In physics, it is said that whenever a force is applied that causes motion, then "work" is done. Work is a mode of transferring energy; it is an energy interaction between a system and its surroundings. Work is the use of force to act on an object in order to move that object in the same direction as the force. As a principle, work has two expressed attributes. Firstly, work is a transfer of directed/ordered energy, as contrasted with "disordered" energy (i.e., heat). Work refers to an activity involving a force and movement in the direction of the force.

Work is done on something or by something. Another way of understanding work is that work is a change in energy via a force. There are other ways of changing energy, such a through thermal contact. The point is that work changes the energy of something and the change is through application of a force (or torque).

Hence, if there is force, but no movement of distance/displacement, then there is no work. Here, a **force** is an action that pushes or pulls (applies a pressure to) an object or material substance or physical system.

- Work (J) = force (N) x distance (m)
- 1 Joule = 1 newton x 1 meter
- In units energy = joules (J)
- Work = joules (J)

Work is scalar. Work is not a vector, but force and displacement are vectors. Work is the product of a component of a force on an object times the displacement of the object, while the force is being exerted in the direction of displacement.

- $W = {}^{+}F \times {}^{+}d$ - when force causes a displacement, work (energy) is positive (F x d = work)
- $W = {}^{+}F \times {}^{-}d$ - when force hinders a displacement, work (energy) is negative ($F \times {}^{-}d = {}^{-}$work).
- $W = {}^{+}F \times {}^{0}d$ - when force results in no displacement, there is no work (F x 0 = 0 work).

Secondly, work (W) is accomplished by a force (f) acting through a distance (d).

- $W = \int f_i \bullet \Delta x_i$ (i.e., Work = Force x Distance)
- $W = F \times \Delta x$
- where, x is displacement

For a constant force; the work done formula as force x distance, only applies if you have a constant force:

$$W = f_i \bullet \Delta x_i$$

From a systems perspective, work is the amount of directed energy transferred into or out of a system. Work can increase or decrease energy. In most classical scenarios, work will change either the kinetic or potential energy. In concern to work as a factor of potential or kinetic energy:

- $W = \Delta K$ (kinetic)
- $W = -\Delta U$ (potential)

7.6.4 Heat transfer mode

> **IMPORTANT:** *Modern physics is still confused over the concepts herein as is visible in the circularity of their definitions: (1) Energy does work or produces heat; (2) but, heat is a transfer of energy.*

Heat, like work, is neither a thing, nor a form of energy. Heat is not a substance that is being transferred [between any two things]. Heat is the energy in transit from one body to another under the influence of a temperature gradient. Heat cannot be stored as such. Heat flowing into a body merely changes the internal energy of the body. The internal energy of the carrier is increased after heating. The temperature of a body gives a measure of the intensity of heat.

> **NOTE:** *The enthalpy of a system is the sum of the internal energy and the pressure-volume of the system. It is a function of the state of the system and depends on the temperature and pressure of the system. The absolute value of the enthalpy of a substance cannot be calculated, but values relative to some arbitrary chosen reference state can be determined.*

When a temperature difference exists across a boundary, the second law of thermodynamics indicates the natural flow of energy is from the higher temperature body to the lower temperature body.

> **DEFINITION:** *The* **specific heat capacity** *of a substance is defined as the amount of heat required to increase its temperature by one degree. Specific heat capacity is measured in joules per kilogram degree-celsius.*

Before it is transferred, the energy which remains within the boundary of the system is not heat, but 'internal energy' or 'total available energy'. Once a system absorbs heat, the latter is no longer heat, but internal energy of the system. In other words, it stops being heat because heat is no longer being transferred between two systems at different temperatures. For it to be heat it must be in the process of being transferred from one system to another system. Heat cannot be stored nor contained by any system because heat is a process function.

> **NOTE:** *An adiabatic process is one in which the system is perfectly insulated and the heat transfer is zero.*

A process function, or process quantity, is a physical quantity that describes the evolution or shift through which a thermodynamic system passes from an initial equilibrium state to another equilibrium state. It is a category error to use the expression "heat stored" if one does not clarify that it is not heat (a process) which is being stored, but energy which has been transferred from one system to another transposing the boundary of the acceptor system. The proper expression for this is "energy stored by heat transfer"; or simply "energy stored".

The energy emitted or released by the system becomes heat the moment it crosses the boundary of the system (i.e., the moment it becomes energy in transit). Remember, process quantities cannot be stored or contained because they describe the trajectory by which a system acquired an equilibrium state. A process function or process quantity is not a state function. A state function is a property of a thermodynamic system which depends only on the current state of the system. Internal energy is a state function.

There is no such identifiable thing as "heat energy" in an object. Hence, "hot" is not a substance. Instead, heat is a mode of energy transfer representing the flow/transfer of energy spontaneously (across systems or within a system) due to temperature differences. When a suitable physical pathway exists, energy flows spontaneously from a hotter to a less hot (i.e., "colder") body. The name of the transfer process is heat transfer. What gets transferred is a quantity of energy. Heat describes what energy is doing at a given time. Essentially, heat is any energy transfer that is not macroscopically ordered (i.e., an energy transfer expressing all degrees of freedom; it "disperses"). When energy disperses, it is not destroyed, but rather, that it is lost for useful purposes.

7.6.5 Temperature (direction of heat transfer)

Temperature is a property of matter that determines the direction heat will flow when two mediums are brought into contact. The direction of heat transfer is based on temperature. In order to have a change in temperature there must be a transfer of energy between systems.

Temperature is a property which is directly proportional to the kinetic energy of the substance under examination.

Temperature is measured in either:

1. Kelvins (K) with zero motion as its reference point (0°K).
2. Celsius (C) with the freezing point of water as its reference at (0°C).

The Celsius scale is a derived scale, defined in relation to the Kelvin temperature scale. The Celsius scale is an interval system, not a ratio system; it follows a relative scale and not an absolute scale. This can be seen because the temperature interval between 20 °C and 30 °C is the same as between 30 °C and 40 °C, but 40 °C does not have twice the air heat energy of 20 °C. A relative scale adds an unnecessary degree of abstraction (generating the potential for confusion) over an absolute scale. An absolute scale represents as close [an expressed] alignment with reality as is possible given what is presently known.

Heat is energy in transit, it is dynamic in nature and heat flow stops only at their equilibrium temperature state (i.e., thermal equilibrium).When two bodies are in thermal equilibrium with a third body, then they must be in thermal equilibrium with each other. This is called the Zeroth Law of Thermodynamics and is the basis for temperature measurements, since the thermometer must come to thermal equilibrium with the object being measured.

7.6.6 Modes of heat transfer

Heat transfer is energy in transition across the system boundary due to a temperature difference, there are three modes of heat transfer at the boundary that depend on the temperature difference between the boundary surface and the surroundings. These are:

1. Conduction.
2. Convection.
3. Radiation.

There are three types of heat transfer (i.e., three mechanisms by which energy is transferred via heat). The first two (conduction and convection) refer to the direct transfer of energy, whereas the radiation is a conversion of energy to a different form (electromagnetic radiation, light), and the subsequent travel (transfer/transport) of that radiation. These heat transfer processes may also be referred to as modes:

1. **Conduction (conductive heating/thermal conduction)** - transfer of thermal energy through an object/substance by atomic movement. Direct transfer by contact through a solid or stationary fluid. When a temperature gradient exists in a stationary medium, which may be a solid, liquid, or gas, the term "conduction" refers to the heat transfer that will occur across the medium.
   A. A **thermal/heat conductor** is a substance/material that allows thermal energy to move through itself easily. Materials that do not allow thermal energy to move through them easily are called **thermal/heat insulators**. Similarly, electrical conductors allow electrical energy to move through easily, while electrical insulators do not allow electrical energy to move through easily.
2. **Convection (convective heating/thermal convection)** - transfer of thermal energy from a surface to a moving fluid by movement of groups of molecules. Convection refers to the heat transfer that occurs between a surface and a moving fluid when they are at different temperatures. Simplistically, convection is the movement of a fluid in response to heat. A substance experiencing convection will move in the form of a [convection] current. Convection takes place through advection, diffusion, or both.
   A. **Advection** is the movement of some material dissolved or suspended in the fluid. For instance, if pure water is heated, there will occur convection of the water. Advection cannot occur because there is nothing dissolved or suspended in the fluid to advect. If silt is suspended in the water, and the liquid mixture is heated, then there will occur convection of the water and advection of the silt.
   B. **Diffusion** is the net movement of particles from high concentration to low concentration.
3. **Radiation (radiative heating/radiant heat/thermal radiation)** - transfer of thermal energy through space-time from the emission and absorbance of electromagnetic waves - the emission of electromagnetic radiation and its absorption. All objects, even those that are in equilibrium (at equal temperature) with their surroundings, continuously emit/radiate electromagnetic waves (i.e., "light waves") into their surroundings. The source of this radiation is the thermal energy of the materials, the movement of the object's molecules. Radiation does not require matter, unlike convection and conduction.

7.6.7 Electromagnetic transfer mode

Electromagnetic transfer mode is the transfer of energy as electromagnetic fields at near the speed(s) of light. Electromagnetic energy can be reflected or emitted from objects through electric and/or magnetic waves traveling through space. The electromagnetic spectrum is the range of all types of electromagnetic radiation (electromagnetic radiation being a type of electromagnetic energy). Electromagnetic radiation is a kind of energy that travels and spreads outward as it travels. The electromagnetic spectrum is a categorization of all electromagnetic waves by frequency, wavelength or photon energy. Electromagnetic frequencies are produced where electricity flows. One does not exist without the other. Electricity, understood as the movement of electrical charges, generates an EM-waves, relative to the geometric conditions of the circuit and frequency conditions in the current flow. Conversely, an electromagnetic wave can generate electricity (photoelectric effect). Electromagnetic radiation can be described in terms of its wavelength — the distance between the crests of the waves — or its frequency — the number of crests that pass by a fixed point during a fixed time interval.

> **DEFINITION: Coupling** *is the transfer of energy from one medium, such as a metallic wire or an optical fiber, to another medium (which may be of the same composition, but separated by space). In an electrical circuit, coupling is the transfer of electrical energy from one circuit segment to another.*

Electromagnetic transfer mode refers to the transfer of energy between two spatially separated objects -- the energy is transferred without contact. Electromagnetic "wireless" power (wireless energy transfer) techniques fall into two categories:

1. Radiative (radiation-based).
2. Non-radiative (induction-based).

Therein, there are three kinds of wireless power transfer technology (wireless transmission of electricity and/or "energy") in accordance with its working principles (technically, these are all forms of electromagnetic transfer):

1. **Electromagnetic and electrodynamic induction (non-radiative):**
   A. **Magnetic induction** - magnetic field coupling mode.
2. **Electrostatic induction (non-radiative):**
   A. **Electric induction** - electric field coupling mode.
3. **Electromagnetic radiation (radiative)** - electromagnetic field coupling mode.

Take note that each mode/method listed above has multiple different names in the literature and in application.

7.6.8 Magnetic induction mode

A.k.a., Magnetic field coupling mode; direct induction; electromagnetic induction

This is a method of producing electromotive force (voltage) and/or heat across an electrical conductor due to its dynamic interaction with a magnetic field. The magnetic field may come from either moving permanent magnets or alternating current electromagnets.

Electromotive force causes the movement of electric charge. How much electromotive force is present between two points in a circuit is measured in units of 'volts'. The electrical current that flows in this situation is known as an 'induced current'. Electromagnetic induction occurs when a changing (moving/dynamic) magnetic field induces an electrical current in a closed loop. Note that any change in the magnetic field around a conductor will induce a voltage. The more voltage induced, the more electrical current produced (if an electrical circuit is present).

CLARIFICATION: *Induction refers to energy transfer without contact (versus conduction, which is by contact). The basic process of generating electrical power with magnetic fields (and without contact) is known as* **induction***. This specific type of induced current process is also called magnetic induction to distinguish it from charging by induction, which utilizes the Coulomb force. Inductive charging is also known as wireless charging.*

Electromagnetic induction relies on 'magnetic flux'. Magnetic flux refers to how a conducting material (or any material) is affected by a magnetic field. Magnetic flux is the product/strength of the magnetic field multiplied by the conductive surface area perpendicular to that magnetic field. Electromagnetic induction occurs when there is a change (change only) in the magnetic flux (over time). By continuously varying the magnetic field or surface area (angle or volume) a continuous electromagnetic induction will occur. Wrapping/coiling wire is a good way to increase magnetic flux.

CLARIFICATION: Electromagnetic flux *can be classified into 2 types: (1) Electric flux is defined as the number of field lines or the concentration of field lines of an electric field perpendicular to a surface. (2) Magnetic Flux is the number of magnetic field lines or the concentration of magnetic field lines perpendicular to a given surface.* **Electrodynamics** *is the branch of physics which deals with rapidly changing electric and magnetic fields. A current moving through a conductor creates both magnetic and electric fields. A time-varying current will produce time-varying fields. Time-varying currents are nothing more than a macroscopic series of charges undergoing time-varying acceleration.*

Magnetic induction is used in the following energy transfer applications:

7.6.8.1 AC electricity (in conductive coils)

AC electrical generators (alternators) - devices that use [electro]magnetic induction to produce electricity (as the flow of electric charge, electric power).

7.6.8.2 Heating (in ferrous metals)

Induction heating (e.g., induction cooking) - the process of heating an electrically conducting object (usually a metal) by electromagnetic induction (specifically, magnetic inductive coupling), through heat generated in the object by eddy currents (also called Foucault currents). Induction heating occurs due to electromagnetic force fields producing an electrical current in a part. By applying a high-frequency alternating current to an induction coil, a time-varying magnetic field is generated. The parts heat due to the resistance to the flow of this electric current. An induction heater consists of an electromagnet, and an electronic oscillator that passes a high-frequency alternating current (AC) through the electromagnet. The rapidly alternating magnetic field penetrates the object, generating electric currents inside the conductor called eddy currents. The eddy currents flowing through the resistance of the material heat it by Joule heating. Induction heaters are used to provide alternating electric current to an electric coil (the induction coil). The induction coil becomes the electrical (heat) source that induces an electrical current into the metal part to be heated (called the workpiece). No contact is required between the workpiece and the induction coil as the heat source, and the heat is restricted to localized areas or surface zones immediately adjacent to the coil. This is because the alternating current (AC) in an induction coil has an invisible force field (electromagnetic, or flux) around it. Furnaces (as an alternative method of heating) tend to be large, have long start-up and shut-down times, and emit fumes and by-products of combustion, both a pollutant and a potential safety hazard. The induction heater can be small and, as all electric devices, is immediately turned on and off. It is a "clean" process and safer for those operating the system. It also has fewer maintenance costs than furnaces. As with conduction heating, induction heating has the benefit that all of the power supplied goes directly into the workpiece and heating times are short. They fit well into automated production methods, are easily controlled, and the process is highly repeatable. There are some surprising benefits to induction heating. For example, alloys are easily mixed in induction heating processes because the induced field automatically stirs the melted metal! Also, special techniques— precision melting, hardening of surface— can be implemented in the process. Induction heaters require electricity.

7.6.8.3 Voltage transformation (between electrically conductive circuits)

Electrical transformers (a.k.a., non-resonant inductive coupling; i.e., conventional transformer or electrical power distribution transformer) - devices that use electromagnetic induction to change the voltage of electric current. Electrical transformers transform one voltage into another voltage through electromagnetic induction. In other words, it is a device in which an input alternating current produces an output alternating current of different voltage. Note here that transformers work with AC, not DC. It is called an electrical transformer, because it transforms electrical energy into magnetic energy, then back into electrical energy again. A transformer's main purpose is to transfer electrical energy from the primary coil to the secondary coil. A transformer's basic operating principle: the transfer of power from the primary to the secondary circuit occurs via electromagnetic coupling. An electrical transformer is a form of wireless energy transfer. The primary and secondary circuit of ta transformer are not directly connected. Here, energy transfer takes place through a process known as mutual inductance (without any physical contact in between). In transformer theory, electromagnetic (EM) induction refers to the phenomena that electromagnetic changes in one place induce (EM) changes in another place.

7.6.9 Electrodynamic induction mode

> **Also known as:** *Magnetic field coupling mode (a.k.a., inductive coupling; magnetic coupling; magnetic inductive coupling; inductive power transfer; resonant magnetic induction; resonant inductive coupling*

This is the near field wireless transmission of [electrical] energy (by the transfer of electromagnetic energy) between two magnetically coupled coils that are part of resonant circuits tuned to resonate at the same frequency. The resonant inductive coupling process occurs in a resonant transformer, an electrical component which consists of two coils wound on the same core with capacitors connected across the windings to make two coupled LC circuits. Resonant transformers are widely used in radio circuits as bandpass filters, and in switching power supplies. Resonant inductive coupling is also being used in wireless power systems. Here the two LC circuits are in different devices; a transmitter coil in one device transmits electric power across an intervening space to a resonant receiver coil in another device. It is the transfer of energy between a current-carrying conductor and nearby conductors due to a time-varying magnetic field that is created by time-varying current in the energized conductor. Magnetic induction concerns electric currents generated by the motion of a magnetic flow along a conductor. In other words, magnetic field coupling is caused by the current flow in conductors. Magnetic field coupling is created by inductive means (inductive coupling). The magnetically induced current in each nearby conductor will be slightly different since it depends on the relative location of each individual conductor to the energized conductor. The coupling mechanism can be modelled by a transformer. According to the transfer distance, the magnetic field coupling mode can be mainly classified into short-range electromagnetic induction and mid-range strongly coupled magnetic resonance (SCMR). The transfer efficiency and transfer power of electromagnetic induction are normally high, but the transfer distance is limited to centimeter level. In contrast, the transfer efficiency and transfer power of SCMR are a marginally lower, but the transfer distance can achieve meter level to realize mid-range power transfer. Optimal for mid-range wireless power transfer. This technology is being developed for powering and charging portable devices such as cellphones and tablet computers at a distance, without being tethered to an outlet. Inductive power transfer works by creating an alternating magnetic field (i.e., an electromagnet; flux) in a transmitter coil and converting that flux into an electrical current in the receiver coil.

> **NOTE*:* Non-dynamic magnetic induction (induced magnetism)** *is the production of a magnetic field in a piece of unmagnetized iron or other ferromagnetic substance when a magnet is brought near it. The magnet causes the individual particles of the iron, which act like tiny magnets, to line up so that the sample as a whole becomes magnetized. Most of this induced magnetism is lost when the magnet causing it is taken away.*

7.6.10 Electrostatic induction mode

> **Also known as:** *Electric field coupling mode capacitive coupling; electrostatic influence*

This is the near field transfer of energy between an energized conductor and the nearby conductors due to a time-varying electric field that is created by moving charge in the energized conductor. It pertains to magnetic flows produced by an electric charge (voltage). It is caused by an electric field gradient (voltage difference) or differential capacitance between conductors. The phenomenon of producing induced charges is known as electrostatic induction. The principle itself refers to the redistribution of the surface charges on the object. In other words, it is the production of an unbalanced electric charge (i.e., static electricity) on an uncharged conductor as a result of a charged body being brought near it without touching it. In other words, it is a redistribution of electrical charge caused by the influence of nearby charges. If the charged body is positively charged, electric charge in the uncharged body will flow toward it; if the opposite end of the body is then grounded, electric charge will flow onto it to replace those drawn to the other end, the body thus acquiring a negative charge after the ground connection is broken. A similar procedure can be used to produce a positive charge on the uncharged body when a negatively charged body is brought near it. Electrostatic induction is an efficient way of using a charged object to give something a charge, of the opposite sign, without losing any of the original charge. Electric field coupling is capacitive in nature (capacitive coupling). Hence, the coupling mechanism can be modelled by a capacitor (a capacitor is defined as two conductors separated by a dielectric, and may be used to store charge, "electrical energy"). A high-frequency and high-voltage driver source excites the resonant transmitter to generate an alternating electric field which can couple with the resonant receiver. Energy will be delivered as soon as this coupling relation is set up. The transfer efficiency of this mode is affected by surrounding objects. Optimal for short-range wireless power transfer.

> **NOTE:** *Electromagnetic resonance uses "antennas", and electromagnetic induction uses "transformers".*

7.6.11 Electromagnetic radiation mode (EMR)

> **Also known as:** *Resonant coupling; electromagnetic resonance*

This is the far field transfer and receiving of electromagnetic energy. Electrical energy is generally converted into electromagnetic energy, which can be radiated outward (as "EM waves"), which are then received and converted back into electric energy with using a silicon rectifier antenna in the receiver. Electromagnetic radiation (EMR) is the emissive transmission of electromagnetic energy between two bodies not in contact (source to receiver). Electromagnetic radiation is used to transfer electrical energy (which may carry power and/or data) without an electrical conductor or inductive coupling.

> **NOTE:** *An antenna can be designed to react with either the electric or magnetic field of a an electromagnetic radiative wave.*

The transmitter and receiver are tuned to the same resonant frequency (to a mutual frequency). In general, this is accomplished through "radio waves" or optical laser devices. Electromagnetic radiation (i.e., "light") propagates by itself in a vacuum at very high speed (the speed/s of light). Because of its high power density and good orientation features, electromagnetic radiation mode is usually suitable for the long distance transfer applications. However, its transfer efficiency is severely affected by the material conditions (e.g., meteorological or topographical conditions), and the impacts on creatures and ecological environment are unpredictable. Optimal for long-range wireless power transfer.

> **NOTE:** *In electric circuits, this motivating force is voltage (a.k.a. electromotive force, or EMF). In magnetic circuits, this motivating force is magnetomotive force, or mmf. Magnetomotive force (mmf) and magnetic flux (Φ) are related to each other by a property of magnetic materials known as reluctance.*

7.6.12 Electrical transfer mode

Electrical conduction mode (a.k.a., electrical transfer mode; electrical conduction coupling, electron mode) is the transmission of electrical energy (as electricity - flow of electric charge carried by electrons conserved in a circuit) from a power source to an electrical load, such as an electrical power grid or a electrically powered device with the use of a conductor (physical contact). An electrical conductor is a substance in which electrical charges (e.g., electrons) move easily with the application of voltage (i.e., contains movable electrical charges). Electrical conduction can occur in a "wired" or "wireless" manner. Wireless power transfer (WPT; a.k.a., wireless energy transfer, wireless energy transmission, and wireless electrical transmission) is the transmission of electrical energy (as electricity) without the use of a discrete human-made (synthetic) conductor (e.g., atmospheric plasma channel coupling - air method; ground channel coupling - ground method. Electrical power transfer (EPT; wired power transfer) is the transmission of electrical energy (as electricity) with the use of a discrete human-made (synthetic) conductor (e.g., hard-wire using a wire; resistive using a resistor).

Energy can be transferred by electrical transmission. Within a wire this is accomplished through electric fields associated with electrons in the metal wire. The electrons literally push on each other, and convey force through the wire, which thereby transfers energy. For example, the electro-chemical processes in a battery create positive and negative electric charges at the battery contacts which push on, and hence force, the movement of electric charge. Electrical energy is converted to heat when some of the electrons encounter resistance - that is, when the electrons are pushed through materials causing heat, that is, cause the atoms of the material to start vibrating. Alternatively, the movement of electrons may give rise to electric and magnetic fields (such as in coils of a motor), which do work, such as turning the motor shaft.

> **NOTE:** *Bearings provide a convenient support for rotating shafts.*

Electrical energy can be transmitted by means of electrical currents made to flow through naturally existing conductors, specifically the earth, lakes and oceans, and through the upper atmosphere starting at approximately 35,000 feet (11,000 m) elevation — a natural medium that can be made conducting if the breakdown voltage is exceeded and the constituent gas becomes ionized. For example, when a high voltage is applied across a neon tube the gas becomes ionized and a current passes between the two internal electrodes.

> **NOTE:** *Whenever an electric current flows through a conductor, a magnetic field is immediately brought into existence in the space surrounding the conductor. It can be said that when electric charges are in motion, they*

produce a magnetic field. The converse is also true (as in, when a magnetic field embracing a conductor moves relative to the conductor, it produces a flow of electric charge in the conductor).

8 Fundamentals of: Power

INSIGHT: *From the actualization of potential comes power.*

In the context of power, while 'energy' measures the total amount of energy transferred (i.e., work that is or can be done), it doesn't say how fast the energy is transferred (i.e., how fast the work is or can be done). Herein, power is the rate of transferring, producing, or consuming, energy (i.e., the rate at which energy is transferred, produced, or consumed). Take note that 'power' is not an amount of energy itself; it is a rate of change occurring to the presence of energy. Power is the rate at which a quantity of energy is transferred or otherwise changed in time. It could be the rate at which a quantity of energy is transmitted, as in the case of a power generator, or the rate at which it is received, as in the case of a load. It could also be the rate at which a quantity of energy is transferred between a transmitter and a receiver, such as across a power line between a transmitter and receiver. Thus, power can be described in the following ways, which all amount to the same definition:

1. Power = the [time] rate of energy transfer (or conversion) [within or between energy carriers].
2. Power = the [time] rate of change in energy [in a system].
3. Power = the amount of energy required or expended in a time interval (i.e., for a given amount of time).
4. Power = energy flow per unit time. In other words, power is the time rate of an energy flow. Power can be modelled as an energy flow, equivalent to the rate of change of the energy in a system(s) per period of time.
5. Power = energy "produced", "transformed", or "consumed" per amount of time (i.e., per time interval).

Take note that it is sometimes said that power is "a rate of *energy* generation (production) or consumption (utilization)". Technically, this is not accurate because energy cannot be generated or consumed, it can only be transferred. However, because power is a rate [of transfer], power can be said to be "generated" and "consumed". Power is generated, in the sense that energy transmission is occurring, and it is consumed, in the sense that an end device (load) is using it to function; and that transfer can be started and stopped, slowed or sped up. Hence, although it is not technically accurate to say that "power is a rate of *energy* generation and/or consumption", it is understandable.

DEFINITION: *In mathematics, a 'rate' is the ratio between two related quantities (e.g., A/B, where 'A' is the numerator and 'B' is the denominator). 'Rate' refers to a <u>rate of change</u>. The most common type of rate is "per unit of* *time" (time denominator), such as speed, heart rate and flux. Ratios (or rates) that have a non-time denominator include: exchange rates; literacy rates; and an electric field (in volts/meter). Often, 'rate' is a synonym of rhythm or frequency, a count per second (i.e., Hertz; e.g., radio frequencies or heart rate or sample rate). 'Power' is a ratio with a time denominator; it is energy per unit time (energy/time = power). Using the signifier "watt" for power is confusing since the "per hour" is not signified by the term itself; instead, it is inside the term "watt". Hence, to make the rate into an amount, it needs to be multiply by a time unit to cancel it out. It would be more intuitive if we worked in joules (energy) and joules per hour or joules/sec (power).*

When the quantity or location of energy changes, then power is present. Therein, as mentioned in the previous paragraph, it may be said that power is the rate at which energy is produced ("generated"), transferred ("transformed"), or used ("consumed") in a given amount of time. For instance, power is the rate at which an system (e.g., electrical) can produce, use, or transfer [electrical] energy. Hence, there are three basic power processes:

1. **Power is produced or converted -** how much energy is a system producing ("generating" or "transforming") or converting per time interval (e.g., second)? Or, how much power is a system producing from it source of power (energy)?
2. **Power is transmitted** - how much energy is a system transferring (or delivering) per time interval (e.g., second)? Or, how much power is a system transferring from its source to its usage point?
3. **Power is used or dissipated -** how much energy is a system using ("consuming") or dissipating per time interval (e.g., second)? How much power is a system using?

In every context, power includes a parameter for 'effort' (or energy) and for 'rate' (time). It is essential to recognize that power is a rate -- a time rate. Thus, regardless of the transfer process, the faster the transfer occurs, the more power is produced. A small amount of energy used extremely quickly can have a lot of power. Similarly, a large amount of energy used very slowly could have very low power. High energy does not necessarily mean high power. The power of any given energy transfer process depends on the time-rate (i.e., "how quickly") a given amount of energy can be transferred. The more energy transferred per time (e.g., /seconds), the greater the power of the transfer.

NOTE: *Power is a widely used measurement. When people speak of the loudness, volume, or level of a signal, they probably mean its power.*

Power is always delivered through pressure (force) and flow [rate] (speed or velocity). Hence, in both mechanical and electrical systems, power delivered may sometimes be calculated by multiplying pressure (force) times flow (speed or velocity). Herein, the rate is included in the flow (speed or velocity) measurement. In mechanical power systems, many terms describe the pressure or force (Newton, Newton per square meter, etc.) and many terms describe the speed or flow (meters per second, litres per second, etc.). In electric power, two terms [at least] describe the pressure or force (voltage and EMF) and two terms describe the speed or flow (current and amperes).

INSIGHT: *All life in the solar system exists because of the power output of the sun.*

Power is absorbed (by a load) and/or transferred (to a load). Power may be dissipated. Power dissipation is the amount of energy per given time period emitted to the outside world by something. In physics, dissipation embodies the concept of a dynamical system where important mechanical modes, such as waves or oscillations, lose energy over time, typically due to the action of friction or turbulence. The lost energy is converted into heat, raising the temperature of the system. Such systems are called dissipative systems. A 60 watt light bulb "dissipates" ~60 watts of power.

There is an upper limit to how much power a power generating system (i.e., energy transformer or transceiver) can output. For instance, a 10 kW wind turbine (provided it has the optimum level of wind), can generate a maximum of 10 kW of power. Hence, 10 kW is the rate at which the wind turbine can generate power, and not the amount of energy that it can generate in a certain period of time. Frequently, the upper limit power output of a power generating system is simply referred to as its "output".

It is frequently said that an electrical device is a device that uses electrical energy. However, such devices are actually transferring the energy to other carriers (i.e., "converting it to other forms") such as heat, motion, electromagnetic radiation, etc., and in the process they are performing a useful function. The rate at which these devices "use" energy is their power [rating]. Depending upon the device and the context in which the power rating is being described, the terms 'load' and 'demand' are synonyms for power [rating]. Take note, however, that while the term 'power' can refer to the power that something is using or generating, the terms 'load' and 'demand' only ever refer to the power that something is using.

NOTE: Wattage *is the maximum power drawn by a device.*

In concern to measurement, electrical devices "use" electrical power measured in units of watts or joules per second (i.e., are powered by watts). As a measure, the watts aren't affected by how long the device is running: a second, an hour, a day - no difference - as long as it's switched on it will be using a certain number of watts of power. If it's not switched on it won't be using any power (i.e., 0 W).

> **NOTE:** *A heat signature always indicates the presence of power (i.e., the presence of the time rate transfer of energy).*

Take note that for some devices it is more complicated to determine power usage/demand. For instance, the watts of power used by a laptop or other computing device may vary from moment to moment depending upon what the system is doing (e.g., how many programs are running). It may be using 50 W of power one moment, 30 W of power the next, and then 43 W of power the next. Hence, the need for a distinction between instantaneous power and average power.

> **HISTORICAL NOTE:** *Why is 'watt' a signifier for a unit of power? For equations, it is simpler for power to have its own unit (instead of being expressed using units of energy and time together). However, some idiot decided to name it after James Watt, the Scottish inventor who facilitated the development of the steam engine, with no relation to earlier energy-associated signifiers.*

Power can be measured (or calculated) in several ways. It can be measured at any instant in time, it can be averaged over a time interval, and its maximum value over a time interval can be determined:

1. **Instantaneous power** (P_i) - Instantaneous power is the power measured at a given instant in time. The instantaneous power (or instantaneous demand, or instantaneous load) is the power that something is using (or generating) at any one moment in time. For example, a 60W light bulb uses 60W every second, and a 60W power generating source can generate a maximum of 60W every second.
2. **Average power** (P_{avg}) - average power is the power measured over a long period (i.e., when t in the equation for power is very large). This is simply the mean, average of the instantaneous power over a longer period of time. Average power may also be referred to as "average load" ("mean load"), or "average demand" ("mean demand"). The average power represents the power that something uses or generates, on average:
   A. Over a specific period of time (e.g. yesterday); or
   B. Over multiple periods of time (e.g. across all the weekends on record); or
   C. Throughout a certain type of operation (e.g. typical laptop usage, or typical building usage - Monday to Friday 09:00 to 17:00, or typical efficiency for something that's generating power).
3. **Peak power** (P_{pk}) - Peak power is the maximum value the instantaneous power can have in a particular system over a long period.

8.1 Power units and formulas

> **CLARIFICATION:** *Joules per second (J/s) is a clearly signified unit of power. Joules per second makes it obvious that power is the rate at which energy is being generated or used. It's like how kilometres per hour (kph) makes it obvious that speed is the rate at which distance is being travelled. Watt as another unit of power; and, as a signifier of [a unit of] power, it does not make it obvious what power means. In other words, the usage of the term 'watt' as a signifier for power, does not make it obvious that power is the rate at which energy is transferred. But, the watt is actually just another name/signifier for Joules per second. J/s and W are the same thing.*

Energy is an amount (i.e., quantity), while power is a rate at which energy is used.

- Energy = Watt (Power) x time
  - E.g., kWh = kW x t
- Power = Work (Energy) / Time
  - E.g., kW = kWh / t
- Time = Energy / Power
  - E.g., t = kWh / kW

In concern to units of energy and power:

- Energy is measured in watt-hours (W·h) or joules (J).
- Power is measured in watts (W) or joules per second (J/s).

Watts may be used for [at least] the following power measurements:

1. Watts are used to measure the output of a power generating system.
2. Watts are used to measure the power production capacity of a power generating system.
3. Watts are used to measure the amount of power required by a power consuming system (load).

Watt-time (e.g., watt-hours) may be used for [at least] the following energy measurements:

- Watt-time measures the total amount of energy used over time -- watt-hours is a combination of how fast the energy is used (watts) and the length of time it is used (hours).

Power generating system can be said to produce watt-hours [of energy] per given timeframe (e.g., megawatt-hours per year, and not megawatts per year). Therein, power generating system may be said to produce a specific amount of energy (e.g., Wh) per a given timeframe.

The relationship between energy and power is a lot like the relationship between distance and speed:

1. Energy is like distance - The amount of energy that is used over a specific period of time is like the distance that is travelled over a specific period of time. For example, the vehicle travelled 3 meters, or the electrical device used 3 joules (or 3 watt-hours).
2. Power is like speed - Instantaneous power is like the speed at a specific instant in time (e.g. right now). The average power over a specific period of time is like the average speed over a specific period of time. For example, the vehicle travelled at a speed of 3 meters per second (m/s), or the electrical device used 3 joules per second (or 3 watts).

In concern to watts, a quantity of energy is measured in watt-time (e.g., watt-seconds, or more commonly, watt-hours). Watt-hours means watts multiplied by the hours the watts are transferring energy (i.e., doing work) to form a total quantity of energy transferred, or potentially transferred. Similarly, watt-seconds means watts multiplied by the number of seconds the watts are transferring energy. Watt-hours are a measurement of energy, describing the total amount of energy (electrical, mechanical, etc.) used over time. Watt-hours are a combination of how fast the energy is used (watts) and the length of time it is used (hours).

> **QUESTION:** *How much energy does a system require to operate for one second, and one hour? The answer will come in units of watt-seconds and watt-hours.*

Watt-time (e.g., watt-hours) is a quantity of energy -- the quantity of energy transferred (or, work done) in a given amount of time. For example, watt-hours is a combination of how fast the power (e.g., electricity) is used (watts) and the length of time it is used (hours):

- Watt-time = Watts x time
- Wt = W • t

In hours:

- Watt-hour = Watts x Hours
- 1 Watt-hour = 1 Watt x 1 hr
- 1Wh = 1W • 1hr
- Wh = W • hr

> **NOTE:** *The unit for watt-hour may be abbreviated: Wh, W.h, or W-h (or in seconds, Ws, W.s, or W-s).*

More commonly, energy is measured in kilowatt-hours, the equivalent of 1000 watts of power for 1 hour.

- Kilowatt-hour = Kilowatts x Hours
- 1 Kilowatt-hour = 1 Kilowatt x 1 hour
- 1kWh = 1kW • 1hr
- kWh = kW • hr

In concern to the quantity of energy used by a load, for instance, a 60-watt (power) light bulb running for 1 hour (time), will have used 60 watt-hours of energy.

1. A 60W light bulb - requires 60W of power to run for 1 second.
2. Running for 1 hour.
3. Will use [a quantity of] 60 watt-hours of energy:
   - 60W x 1hr = 60Wh = .060kWh
4. 1 second is 1/3600 of an hour; hence, in 1 second a 60W light bulb uses:
   - .060kWh x 1/3600s = .00001666kWh

In other words, a light bulb with a power rating of 60 watts will use 60 watt-hours per hour, or 60 watt-seconds per second, or 60 watt-microseconds per microsecond, or 60 watt-centuries per century. However, watts do have an embedded reference time unit as part of their joule-based definition: 1 watt equals 1 joule in 1 second (W = J/s). Take note, however, that a joule is the amount of energy required to move an object against a static force of one newton, by the distance that light would travel in 1/299,792,458 second. Consequently, a watt is the amount of power required to push an object against a static force of one newton, at a constant velocity of 1/299,792,458 the vacuum speed of light.

As a measure of the most common unitized form, 1000 units (kilo units), energy is:

- Energy: 1kWH = 1000WH = 1000Wx3600sec = 3600kW−sec = 3600kJ1kWH = 1000WH = 1000Wx3600sec = 3600kW−sec = 3600kJ

The units of power are units of energy (in a particular system or context) divided by time. The SI unit of power is the watt. The unit of power measurement, the watt, represents energy per unit time. As a rate of change of energy, power is:

- power = change of energy / change of time
- power (P) = ΔE / Δt
- watt (W) = ΔE / Δt

When the rate of energy transfer is constant, power is:

- power = energy transferred / time
- power (P) = E / t
- watt (W) = E / t

The unit of power is joules per second or J/s when work is measured in joules and time in seconds. A watt is the consumption of one joule of energy per second. One watt is equal to one joule of work done per second. Or, said another way, one watt is equivalent to an energy transfer rate of 1 J/second. When energy is measured in joules, then:

- Wattage as J/s = rate of power in Joules per second
- 1 Watt = 1 Joule in 1 second
- 1 W = 1J / 1s
- W = J/s

When energy is measured in newton-meters, then:

- Wattage as Nm/s = rate of power in Newton-meters per second
- 1 Watt = 1 newton-meter in 1 second
- 1W = 1Nm / 1s
- W = Nm/s

Take note that a joule is another term for a force of 1 newton over a distance of 1 meter:

- Joule = Force (1 Newton) x distance (1 Meter)
- 1 Watt = 1J/s = 1Nm/s

As a measure of the most common unitized form, 1000 units (kilo units), power is:

- Power: 1000 Watts = 10^3W = 1kW = 1000J/s = 1kJ/s

Table 6. *Table of unit prefixes of watts (wherein, P = power).*

Name	Symbol	Conversion	Example
Picowatt	pW	1pW = 10^{-12} W	P = 10 pW
Nanowatt	nW	1nW = 10^{-9} W	P = 10 nW
Microwatt	μW	1μW = 10^{-6} W	P = 10 μW
Watt	W	-	P = 10 W
Kilowatt	kW	1kW = 10^3 W	P = 2 kW
Megawatt	MW	1MW = 10^6 W	P = 5 MW

8.1 Power modes

Every energy transfer mode (or power generation/ consumption system) has its equivalent calculation for power.

1. **Mechanical power** is the rate at which mechanical work is done. Mechanical power is the rate of change of mechanical energy. Mechanical power is the rate at which mechanical energy is converted. In a mechanistic sense, 'power' refers to how far an object can be moved in a given period of time, and hence, how much energy is transferred in that time period.
2. **Electrical power** is the rate at which electrical work is done. Electrical power is the rate of change of electrical energy. Electric power is the rate at which electrical energy is converted. Electrical power is the rate at which electrical energy is "produced" or "used" (or "consumed").
   A. Since current is the rate of transport of charge, electric power is given by the above expression, but using current I instead of charge Q:
      - P = IV
3. **Electromagnetic power** is the rate of work done by the electromagnetic forces. Electromagnetic power is the rate of change of electromagnetic energy (Read: electric and magnetic fields).

8.1.1 Mechanical power mode (Work transfer)

In concern to work transfer mode, power is the amount of work done (or, can be done) per unit of time. Power is the time rate at which work is done -- power is the rate of doing/performing work. In other words, power is the amount of work that can be done in a certain amount of time, "the rate of working". Power is the rate of energy transfer by [doing] work per unit of time. Power is work over the amount of time it took to do that work. Regardless of the work being done, the faster the work is done, the more power is produced.

1. Working faster = more power.
2. Working slower = less power.

Whereas energy is the total amount of work that is or can be done, power is how fast the work is or can be done. Power is also often thought as the amount of work performed (or energy transmitted) in time.

Power is work (energy) per unit of time. Thus, as a rate of change of work done, power is:

- power = change of work / change of time
- power (P) = ΔW/Δt = ΔE/Δt
- where, work (W) and time (t)
- power = work done (J) / time (s) = energy used (J) / time (s).

When the rate of work is constant:

- power = work / time
- power (P) = W/t = E/t

8.1.2 Principal types of mechanical working power

There are two principal types of mechancal power, solid and fluid:

1. Mechanical power system (solid mechanics) - linear or rotational motion. Mechanical power systems are used for the generation, control, and transmission of power by the use of solid mechanical objects.
   A. Linear mechanical systems produce linear motion.
   B. Rotational mechanical systems produce angular

motion.

2. Fluid power system (fluid mechanics) - linear or rotational motion. Hydraulics are used for the generation, control and transmission of power by the use of pressurized liquids. Pneumatics are used for the generation, control, and transmission of power by the use of pressurized gases.
   A. A hydraulic cylinder or pneumatic cylinder, provides force in a linear fashion.
   B. A hydraulic motor or pneumatic motor, provides continuous rotational motion or torque.
   C. A rotary actuator provides rotational motion of less than 360 degrees.

8.1.3 Linear working power

The full decomposition of the power formula for linear [solid] mechanical work transfer mode has the following sub-parts:

1. In [linear] work (W) transfer mode, energy (E) has the units of force times distance or displacement (F • d). In other words, linear work is force (F) times distance (d). Therein, power is force times distance over time:
   - P = E/t = W/t = (F • d) / t
   - Linear work = Force x Distance
   - W = F • d
   - power = linear work / time
   - P = W/t = F • d / t
   - where, work is in watts, force is in newton, and distance is in meters.

2. Force (F) is mass (m) times acceleration (a) is (m•a):
   - P = E/t = W/t = (F•d)/t = (m•a•d)/t

3. Acceleration (a) is an exponential increase in distance over time (d/t^2):
   - P = E/t = W/t = (F•d)/t = (m•a•d)/t = $(m•(d/t^2)•d)/t = (m•d^2)/t^3$

4. Alternatively to #2, distance (d) over time (t) is velocity (v): (note that speed is another word for velocity)
   - P = F•d/t = Fv
   - where, velocity is a length measurement per time (e.g., meters per second). The rate is included in the velocity measurement.
   - Note: (1) there must be both force and velocity, and (2) the force must be applied in the direction of the velocity. A static force without velocity does not require power to maintain itself, and velocity (including rotational velocity) without force also does not require power.
   - Note: in electrical systems, power = VI, which is the equivalent in mechanical systems to P = Fv. Therein, voltage (V; a.k.a., electromotive force, EMF) is the force (F), and current (I; a.k.a., amperage) is the velocity (v) .

8.1.4 Rotational working power

The full decomposition of the power formula for rotational [solid] mechanical work transfer mode has the following sub-parts. Note that torque causes objects to spin or rotate.

1. In [rotational] work (W) transfer mode, energy (E) has the units of force (F) times the swept angle (Θ) times the radius (r).
   - P = E/t = W/t = FΘr/t

2. Therein, force (F) times radius (r) is torque (T). Hence, energy (E) has the units of torque times the swept angle in radians (T • Θ).
   - P = E/t = W/t = FΘr = T•Θ/t
   - Rotational work = torque x the swept angle
   - W = T•Θ
   - Power = rotational work / time
   - P = W/t = T•Θ/t
   - where, work is in watts, torque is in newton-meters, and swept angle is in radians.

3. Swept angle (Θ) over time (t) is equivalent to angular velocity (Ꞷ).
   - P = E/t = W/t = FΘr =T•Θ/t = T•Ꞷ

8.1.5 Electrical power mode (Electrical transfer)

> **CLARIFICATION:** *The symbol for amperes is generally the letter 'I' (capital 'i'). Before being named amps, the letter 'I' traditionally stood for the "Intensity of current flow", hence, the first letter of the word intensity (I).*

Electric power is the rate, per unit time, at which electrical energy is transferred by an electric circuit (as electricity). In other words, electrical power is the rate of change of electrical charge (electrical energy). The electrical power drawn by an electrical device is expressed in Watts or Volt-Amps (VA). Electrical systems "draw" watts of power. Electric power systems are used for the generation, control, and transmission of power by the use of electricity.

> **NOTE:** *Many electrical devices that dissipate power, do so by converting the electrical power into thermal energy, or heat. This is true for wires and resistors.*

The SI unit of electrical power is the watt, which equates to:

1. An energy transfer rate of 1 joule per second.
   A. One watt is defined as the energy consumption

rate of one joule per second (J/s).

2. A current flow of 1 ampere through an electric potential difference of 1 volt.
   A. One watt is one ampere of current flowing at one volt.
   B. Hence, electrical power is described by the formula:
      - volts × amps = watts

As a rate of doing electrical work in one direction (e.g., DC voltage), power is:

- power = volts x coulombs / time = volts x amps
- power (P) = VQ/t = VI
- where, electric current (I) consisting of a charge of coulombs (Q) every t seconds passing through an electric potential (voltage) difference of V.
- Note, the time interval required for the calculation of power (P=E/t), is included in the electric current parameter (I). Electric current (I) is measured in ampere, and one coulomb per second is equivalent to one ampere (1I).
- Herein, electrical work is done by a voltage (v) moving an amount of electrical charge (q).
  - Electrical work done = voltage difference x charge
  - $W = \Delta V \cdot q$
  - where, the rate of movement of electrical charge is current (I), measured in amperes (I = q/t).

Technically, power in electrical conduction is not transported through electrons pushing length ways just like water in a pipe. It is transported by electro-magnetic fields which flow partly inside, partly outside the wire. Electrical energy flows wherever electric and magnetic fields exist together and fluctuate in the same place. The simplest example of this is in electrical circuits, as the preceding section showed. In the general case, however, the simple equation P = IV must be replaced by a more complex calculation, the integral of the cross-product of the electrical and magnetic field vectors over a specified area, thus:

- power (P) = $\int_s (E \times H) \cdot dA$
- where, the result is a scalar since it is the surface integral of the Poynting vector.

A system may take in power (power input) or put out power (power output):

- Input power (power in[put], P_{in}) = voltage x current
- Output power (power out[put], P_{out}) = voltage x current

8.1.6 DC voltage electrical power

In DC circuits, all voltages and all currents are constant, which makes calculation of power simple. A watt is defined as a current of one ampere, pushed by a voltage of one volt.

- Wattage = Volts x Amps
- 1 Watt = 1 Volt x 1 Amp
- 1W = 1V • 1I
- W = VI

In a resistor, the current, voltage and resistance are related by Ohms law as:

- Voltage = Amps x Resistance
- 1 Volt = 1 Amp x 1Ohm
- 1V = 1I • 1R
- V = IR
- where, V is voltage in volts, I is current in amps (traditionally stood for Intensity of current flow), and R is resistance in ohms.

Therein, the power dissipated by a resistor is:

- P = VI
- where, P is power in watts.

Take note that resistors are often rated in both ohms and watts. For a circuit with a single DC power supply, and a single resistor, the power dissipated by the resistor can be written as any of the following forms:

- $P = VI = I^2R = V^2/R$
- where, P is power in watts.

Power cannot be radiated without accelerated charges (i.e. time varying currents). Direct current is time invariant and cannot radiate power.

8.1.7 AC voltage electrical power

AC voltage has phases, and the number of phases may change how power is calculated:

- Single phase, P = IV
- Dual phase, P = IV
- Three phase, P = IV • 1.732
- where, 1.732 is the square root of 3.

8.1.8 Electromagnetic power mode (Electromagnetic transfer)

The watt specifies the rate at which electromagnetic energy is radiated, absorbed, or dissipated.

9 Fundamentals of: Force and motion

> **NOTE:** *To precisely describe motion, the position of an object must be located within a given reference frame. When we say space is three dimensional, we mean we need three numbers to completely locate the position of an object or point. A system for assigning these three numbers, or coordinates, to the location of a point in a reference frame is called a coordinate system. Most frequently, a Cartesian (rectangular) system is used to describes the position in terms of x, y, z coordinates.*

Force is the ability to transfer energy (e.g., a push or pull, a pressure). It is frequently said that a force is a push or pull that one body exerts on another. Thus, a force is always an [inter]action, an influence. It represents the interaction of one body with another, which may be recognized by actual contact or by action at a distance. It is the influence of that which is a 'force' (or 'torque') that produces a change in a physical quantity (i.e., on an object or in a system). When forces are balanced they are said to be in a state of equilibrium. Force is a vector quantity - it has magnitude and direction. Hence, a force is has the following parameters (i.e., is characterized by its):

1. **Point of action** - external power.
2. **Magnitude** - amount/separation.
3. **Direction** - spherical degree.

In concern to force, there are only two (plus one) forms of contact [forces]:

1. **Push** *(contact force)* - pressure outward (i.e., out).
   A. The "weak force" and "electromagnetic force" are both push forces.
2. **Pull** *(contact force)* - contraction inward (i.e., in).
   A. The "gravitational force" and "strong force" are pull forces.
3. **Tension** *(equalized contact force)* - equal inward and outward action simultaneously (i.e., in & out equally together). Tension is nether pull nor push. In a state of tension, neither push nor pull wins the "tug of war".

It is commonly said that force is the "ability to do work". It must be noted that a force is required to do work, but every force does not necessarily do work. To apply a force, an amount of energy is required. This energy is then transferred to the object upon which the force has acted. This force does work on the second object. In this sense, force is a method to transfer energy, thus affecting the motion of a secondary object or system.

Newton's second law of motion states that a force, acting on an object, will change its velocity by changing either:

1. Its speed,
2. Its direction,
3. Or, both.

There are three principle types of motion due to force (i.e., all motion can be classified into three basic types):

1. **Translational/linear motion:** Object moves in a straight line. Translational motion is the motion by which a body shifts from one point in space to another. An object has a rectilinear motion when it moves along a straight line. Translational/linear motion is affected by force. Force causes linear acceleration. Note that "to translate" is "to have linear motion".
2. **Rotational motion:** Object spins. Rotational motion is the motion by which a body rotates in space. Rotational motion is affected by torque. Torque causes angular acceleration.
3. **Vibrational motion:** Object oscillates. Vibrational motion is the motion by which a body moves backwards and forwards (oscillates in two or more degrees of freedom) in space. Vibrational motion is affected by waves (compression and rarefaction). Waves cause vibrational acceleration.

An object can have any combination of these types of motion. For instance, the earth translates around the sun in an elliptical path, rotates about its axis, and vibrates during an earthquake. And, the three types of motion can be separated and analyzed.

In physics, a force is an influencing interaction that causes an object of mass (or charge) to change its velocity. Force can be categorically understood in relation to its physical application.

1. For a **mechanical system**, when force is applied, mass is displaced (some distance), and work is done (energy is transferred). Or, when torque is applied, mass is rotated, and work is done (energy is transferred). Therein, power is present as linear or rotational movement occurs.
   - Work (W) = force (F) x displacement (d)
     - Work = force x distance
     - Work = force x distance x cos0(theta)
       - Note: Theta is an angle against or with gravity. Gravity has an influence, so the equation should be with cosine.
   - Work (W) = F x rΘ = τΘ
2. For an **electrical system**, when force is applied, charges flow, and work is done (energy is transferred). Therein, power is present as charges flow.
3. For an **electromagnetic system**, when force is applied, electromagnetic waves (perturbations) propagate, and work is done (energy is

transferred).

A force can cause any of the three types of motion. Therein, it could be said that there is one principal type of motion instantiation, and one principal sub-type of motion instantiation. The principal type [of motion] is force, and the principal sub-type [of motion], which is caused by the principal type (force) is torque.

1. [Principal type] **Force** as that which causes linear (translational) motion. Translational motion is affected by force.
2. [Sub-type] **Torque** (twisting force, moment, moment of force) as that which causes rotational motion. Rotational motion is affected by torque. Torque is a measure of how much a force acting on an object causes that object to rotate. Torque is the counterpart of the force in angular motion.

A force can be acted as a force alone or as a torque. A force can be present without a torque, but a torque cannot be present without a force. A force is necessary in order to create a torque. Torque is created by a force. The specifics of the torque depend on the location of the force and the center of rotation (i.e., point about which an object rotates, the pivot point). One important distinction between force and torque is direction. Positive and negative signs are used to represent forces in the two possible directions along a line. The direction of a torque, however, is clockwise or counterclockwise, not a linear direction.

Take note that it is possible [for an object] to have a zero total torque with a non-zero total force. For instance, an airplane with four propeller engines -- two on either side of the fuselage, each side's propellers spinning in opposite directions to cancel out the total torque. Conversely, it is possible to have a zero total force and non-zero total torque. A merry-go-round's engine(s) need to supply a non-zero torque to bring the go-round object up to speed, but there is a zero total force on it. If there was not zero total force on it, its center of mass would accelerate.

> **NOTE:** *The farther away from the center of rotation that the force is applied, the easier it is to rotate, the greater the torque.*

A simplistic way of classifying force is as follows:

1. **Applied force** is a push or a pull that is exerted on an object by another.
2. **Force of gravity** is the natural force that draws any object that is thrown to the sky towards the center of the earth.
3. **Normal force** is the magnitude of push that is brought about by an object's own weight.

A force is the fundamental result of an interaction between two objects, whereas power is an expression of the rate of energy transmitted over time (e.g., work), of which force is an element. Force and power can both be described and measured, but a force is an actual physical phenomenon, and power in itself is not.

> **NOTE:** *Heat transfer by friction involves force. Heat transfer by conduction does not involve force. The definition of work could thus be restated as the amount of energy transferred by forces. No work is done without motion.*

9.1 Mechanical force

Mechanical force includes several possible sub-types of force.

In concern to the mechanics of motion, there is the category of force and the category of tension (not force), and when there is force, their is either push or pull:

1. Dynamic concept of force: The force of inertia (a.k.a., force, motion, push or pull, a verb) - a force is an [objective] influence that causes the motion of an object (accelerating it to a highest potential value in speed, a.k.a., inertia; someone wins the tug of war, either pushing or pulling some object):
   - Force (F) = Mass (m) x Acceleration (g)
   - Newtons (F) = mass (*m* in kg) • planetary gravity (*g* in m/s^2)
   - N = kg • m/s^2
   - where,
     - The measured value [on a scaling tool] at the point of a lack of inertia is: kg
     - The acceleration of the object to the center of a planet is "gravity" (g), and for the planet Earth it is: 10 m/s^2
2. Static concept of force: Tension (not a force) - is not a force, and occurs when acceleration is zero; the system is in equilibrium (a system is in equilibrium when the sum of all forces is zero; no one wins the tug of war, neither pushing nor pulling some object):
   - Tension [weight]
   - ~~Force~~ tension (weight) = gravity (g is acceleration) * ($mass_1$ (object, not planet earth) x $mass_2$ (planet earth object) / $distance^2$)
   - ~~F~~ T [w] = g (m_1 • m_2 / d^2)
   - Where,
     - Force ≠ tension (weight)
     - Tension = weight
     - gravity (g) = meters per second squared: m/s^2
     - Mass (*m*) = amount of matter (in hydrogen 1 units, *h*); count atomic hydrogen 1 units in object
       - m_1 = amount of matter in non-planetary

object
    - m_2 = amount of matter in planetary earth object (or, other non-planetary object)
    - *Mass 1 and mass 2 are the number of roes that interconnect the cube and the cylinder*
- Distance (*d*) = distance between the two objects in metric meter units (m); measuring distance separation

Tension is not a force; because, a force is: an influence that causes the motion of an object. Tension is a static concept; because, there is no motion once something is completely tense. Once a [state of] tension is reached between objects, there is no motion, just equilibrium (Read: no pushing or pulling, no force).

Note that there are two branches of physics, given the way they define tension. Tension is either:

1. Two equal forces (motions) in opposite directions.
2. Zero acceleration.

In this later branch, the word "force" (F) is replaced in Neuton's equation with weight, and gravity (g, the gravitational constant) is omitted, because the system state is at a point of equilibrium and there is no inertia (force or movement). The results of multiplying two masses and dividing their distance in separation is weight, tension. When all atoms in two objects have their ropes aligned, then you only have no tug of war, and only overlap. If "you" want to feel atoms 3,4, and 5, then you have to move the mass 1 (m_1, the cylinder object) closer to mass 2 (m_2, the sphere object), and then you can see the ropes go out of alignment between the interconnecting atoms of both objects. When they are no longer on the same axis "you" feel atoms 2,3,4,5; because, they are fanned out and pulling; one object has more mass than the other). What has changed is the number of effective (i.e., non-tense) ropes.

9.1.1 Linear motion (linear/translational force)

Mass times acceleration (m • a) is not a force; it is the sum of all forces:

- Sum of all forces (f) = mass (m) x acceleration (a)

The sum of all forces on an object equals the product of its mass times its acceleration. Then, if every part of a system moves in a straight line at a constant speed, the system is in translational equilibrium (note: this means being at rest). For a body to be in translational equilibrium, the resultant forces in any two perpendicular directions must be zero.

9.1.2 Torque (rotational force)

A force that produces a twisting or turning effect, or rotation, is called torque. Torque is also called a "rotational force" or a "twisting force". It is a "force" that makes anything rotate, twist, or turn. Any time anything rotates, there is a torque involved. Torque is the rotational equivalent of linear force. Torque can be used to create a force at a distance, but it does not cause an object (directly) to move along a distance. Torque is defined as a force around a given point (axis), applied at a radius from that point. A force applied at a non-zero distance from an object's centre will tend to rotate the object. This is easily seen in real life. If a wrench is placed on a bolt and a force is applied to the end of the wrench, the bolt will turn. If the same pulling force was applied directly to the bolt, it would not turn because the force's direction passes through the object's centre. The amount of torque is determined by multiplying the magnitude of the force by the force's distance from centre.

The ability of a force to rotate an object about an axis depends on two variables:

1. The magnitude of the force (F).
2. The distance (r) between the axis of rotation and the point where the force is applied.

The "turning ability" of a force is the product of F and r. The technical name for this "turning ability" is torque. Hence, the torque τ exerted by a force F that is applied at a point r relative to the origin is the cross product of r and F. Thus, the formula for torque is:

- torque (τ) = force (F) x perpendicular distance (r)
- $\tau = F \cdot r$

The magnitude of a torque depends on three quantities:

1. The force applied.
2. The length of the element (e.g., lever arm) connecting the axis to the point of force application.
3. The angle between the force vector and the lever arm.

Note that the units for both torque and work are the product of force and distance, yet torque and work are two different things. Torque is a force that tends to cause a rotation, which means that it does not actually cause an object to move along a distance. Work is a measure of energy transfer between systems, which may or may not have been done by a force from torque.

Mathematically, for rotation about a fixed axis through the center of mass, the formula is:

- $W = \int^1{}_2 \tau d\theta$
- where,
    - W is work, τ is torque, and
    - ∫ (θ1 and θ2) represent (respectively) the initial and final angular positions of the body.

Whereas torque is measured, power is calculated. The power of a torque (rotational force) is a product of torque and rotational speed (i.e. cadence). The power (work per unit time) of a torque is given by:

- power (Pm) = torque (τ) · angular velocity (ω)
- where,
  - ω is angular velocity or angular speed.

Here, power is notated as a mechanical parameter, hence, mechanical power (Pm).

The terms “moment” and “torque” are often used interchangeably. By definition, however, moment is a quantity that represents the magnitude of force applied to a rotational system at a distance from the axis of rotation.

9.1.3 Pressure

Pressure is the force applied perpendicular to the surface of an object per unit area over which that force is distributed. Pressure is the ratio of force to area over which it is applied. Pressure is a scalar quantity as it has magnitude but no direction, while force is a vector quantity, because it has both magnitude and direction.

- pressure (P) = force (F) / area (A)
- F/A = ΔF/ΔA = work/volume = energy / volume

Pressure in a fluid can be seen to be a measure of energy per unit volume by means of the definition of work. This energy is related to other forms of fluid energy by the Bernoulli equation. Pressure in a fluid may be considered to be a measure of energy per unit volume or energy density. For a force exerted on a fluid, this can be seen from the definition of pressure:

9.2 Electrical force

When two bodies of matter have charges and are near one another, an electric force (F) is exerted between them. The existence of such force, where current does not flow, is referred to as static.

The force of attraction or repulsion exerted between two charged bodies is directly proportional to the product of their charges (Q) and inversely proportional to the square of the distance (d) between them.

This relationship between attracting or repelling charged bodies was first discovered by a French scientist named Charles Coulomb and accordingly is known as Coulomb’s Law:

- Vector quantity (F) = â $(Q_1Q_2 / 4\pi\varepsilon_0 d^2)$
  - where,
    - F is a vector quantity, which represents the electrical force acting on charge Q_2 due to charge Q_1 measured in newtons (N).
    - â is a dimensionless unit vector with a unity magnitude pointing from charge Q_1 to charge Q_2.
    - q1 and q2 are charges (scalar values).
    - ε_0 is a universal constant called the electrical permittivity of free space [$\varepsilon_0 = 8.854\text{x}10^{-12}$ farad per meter (F/m)].
- Electric force (F) = k (q_1q_2 / r^2)
  - F is the electric force.
  - k is coulomb's constant.
  - q1 and q2 are charges (scalar values).
  - r is the distance of separation between the two charges.

10 Fundamentals of: Electricity

Electricity is the set of physical phenomena associated with the presence and flow of electric charge. Electricity gives a wide variety of well-known effects, such as lightning, static electricity, electromagnetic induction and electric current. In addition, electricity permits the creation and reception of electromagnetic radiation such as radio waves.

In electricity, charges produce electromagnetic fields which act on other charges. Electricity occurs due to several types of physics:

1. **Electric charge:** a property of some subatomic particles, which determines their electromagnetic interactions. Electrically charged matter is influenced by, and produces, electromagnetic fields, electric charges can be positive or negative. Electric charge is measured in coulombs.
2. **Electric force:** the force of attraction or repulsion between objects due to charge.
3. **Electric field:** charges are surrounded by an electric field. The electric field produces a force on other charges. Changes in the electric field travel at the speed of light. Electric fields are measured in kilovolts per metre (kV/m).
4. **Magnetic field:** these fields are toroidal/spiral in form, near instantaneous, and feedback into/onto themselves. They are not as well studied as electrical fields. A changing/fluctuating (in flux) magnetic field will induce an electric field [at a distance] in a material capable of conducting an electric field (i.e., in a conductive material). A magnetic field can be generated in one of two ways (either / or): directly through a permanent magnet; or indirectly by passing an electric current through conductive coils/windings to produce an 'electromagnet'. and Magnetic fields are measured in milligauss (mG).
5. **Electromagnetic field:** The synchronized and perpendicular propagation of electric and magnetic fields at a specific frequency. Electromagnetic field are typically measured in electron-volts (eV). The frequency is typically measured in hertz (Hz).
6. **Electric potential:** the capacity of an electric field to do work on an electric charge, typically measured in volts.
7. **Electric current:** a movement or flow of electrically charged particles, typically measured in amperes.
8. **Electric conductor**: a material that can carry an electrical current, and through which charges move freely. Conductivity is determined by the atomic makeup of a material. Materials with high electric charge mobility (many free electrons) are called conductors, while materials with low electron mobility (few or no free electrons) are called insulators. For electrons to flow continuously (indefinitely) through a conductor, there must be a complete, unbroken path for them to move both into and out of that conductor. Note that when a current carrying conductor is placed in a magnetic field it experiences a force (specifically, an electromagnetic force).
9. **Electromagnets:** moving charges produce a magnetic field. Electric currents generate magnetic fields, and changing magnetic fields generate electric currents.

In electrical engineering, electricity is used for:

1. **Electric power** where electric current is used to energise equipment.
2. **Electronics** which deals with electrical circuits that involve active electrical components such as vacuum tubes, transistors, diodes and integrated circuits, and associated passive interconnection technologies.
3. The **electromagnetic spectrum** is the range of all possible frequencies of Electromagnetic radiation and is sorted by frequency. The electromagnetic spectrum is a categorized spectral representation of electromagnetic waves by their wavelength (frequency) location within the whole set of known electromagnetic waves, which is most commonly measured in micrometers. Names are often assigned to regions of the electromagnetic spectrum, but there is no clear cut dividing lines from one region to the next. Electromagnetic waves can be characterized by either the frequency or wavelength of their oscillations, which determines their position in the electromagnetic spectrum, which includes, in order of increasing frequency and decreasing wavelength. The electromagnetic spectrum is a unified spectrum of photonic energy patterning that humans, for purposes of functional service specialization, have split into "frequency bands". Individual photon energies in the frequency band known as "radio frequency" (RF) are so small that its not useful to describe RF waves in terms of photons, but one could do so. Each "band" represents electromagnetic radiation along a continuous spectrum, split into wave segments with different, upper and lower, frequency boundaries (a.k.a., "bands"). So, visible light and RF are the same thing, EMR; its only a matter of how much energy each of them (i.e., each frequency instantiation) is carrying. Because of its frequency, the "RF" band is has lower photon energy than visible light.