SI Metric System Demystified

This article examines the well-defined SI Metric System used to numerically described our Universe. Unlike an averaged score from a panel of expert judges in a field of sports, values with these units of measure require specific tools which determine a useful number from which further deductions & conclusions can be made. Judgments are then drawn from these measurements based on Science, Mathematics, Statistics & other forms of logical reasoning.

Colloquial phrases appear to use Scientific words:

"the ***gravity*** of the situation"
"a ***quantum*** leap"
"an idea with ***momentum***"
"the ***power*** of the office"
"a person under ***pressure***"
"may the ***force*** be with you"

"boundless ***energy***"
"good ***work***"
"going the extra ***mile***"
"the ***potential*** to succeed"
"***weighs*** heavily on my mind"
"***time*** flies"

Many times, Science borrows these words & assigns more specific mathematical meanings to measurements of well-defined recurring phenomena. These measured data points generate objective statements & conclusions. Because of accurate well-defined measurements, technology improves & knowledge of our Universe progresses.

Need for Definitions

As far back as 5000 year ago, between the Tigres & Euphrates Rivers of Babylon, the 1st great civilization of humankind, commerce was the driving force in defining constant units of measure. Specialization of trades in this early society allowed for barter of goods & services. The idea of fairness in food distribution can even be understood by our canine friends. If you have two dogs & give one a treat, the 2nd dog will expect the same snack.

Miniature clay symbols in the shape of bread loaves, were discovered in Iraq that archaeologists believe counted loaves of bread for Uruk city merchants (ref [1]). If one person bartered for a loaf of bread, his neighbor would expect a similar barter. Fast forward several millennia & we can define the mass of a loaf of bread in milligrams (mg) (or millionths of a pound) (ref [2]).

Fido will not complain if you short-change him a few milligrams in snacks that you gave his pal *Lucky*. However, Experimental Science has progressed far beyond simple commerce. The units of measure that are rigorously defined today are @ the very heart of Physics, theoretical, experimental & applied. These units are specified to such a degree to allow modeling of transistors on the scale of nanometers (nm or tens of billionths of an inch) in computer chips. Such precision in measurement is also required for “demanding needs of modern measurement science, device manufacture, material science, pharmaceutical research and testing, and environmental monitoring.” (ref [2])

The fundamental constants discussed here, have such precision because they are “constants” of nature. Science repeatedly remeasures these constants in the course of other experimentation & counts on these constants to be constant (ref [3]). If they did change in value, major upheavals in Physics would occur!

SI Base Units

Through the centuries, Physics has collected 6 fundamental units of measure (ref [4]) by which other derived units of measure are defined. These units of measure are incorporated into the SI metric system & given below in the table on the left. The SI Fundamental Constants (siData.pdf) that are proposed to define these SI Base Units of measure are listed in the table on the right.

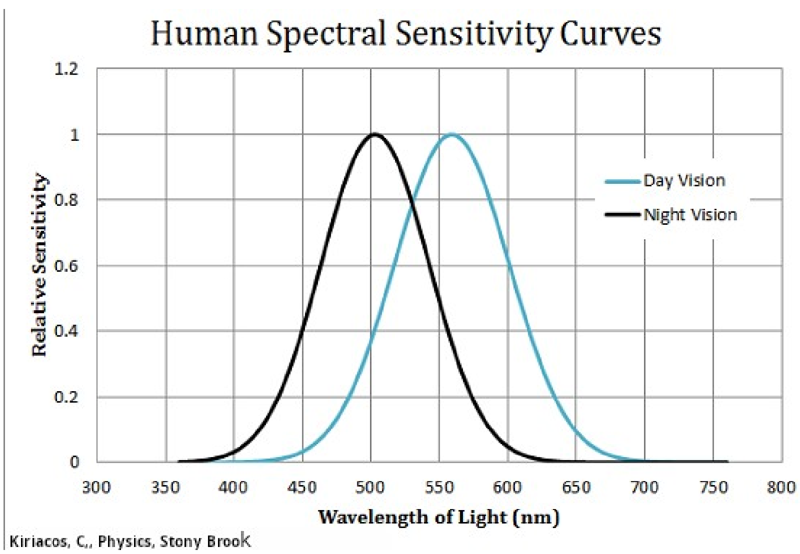
SI Base Units

quantity	units	abr	basis
mass	kilogram	kg	$h \bullet \nu_{Cs}/c^2$
length	meter	m	c/ν_{Cs}
time	second	s	$1/\nu_{Cs}$
temperature	Kelvin	K	$h \bullet \nu_{Cs}/k_B$
electricity	Ampere	A	$e \bullet \nu_{Cs}$
amount	Mole	mol	$1/N_A$

SI Fundamental Constants

quantity	sym	units
^{133}Cs transition frequency	ν_{Cs}	Hz
speed of light in vacuum	c	m/s
Planck constant	h	J/Hz
Boltzmann constant	k_B	J/K
elementary charge	e	C
Avogadro constant	N_A	1/mol

In the above table on the left, the 1st three units (mass, length, time) have been repeatedly applied in commerce since ancient times. The question: “How cold was it last night?” did not have a reliable answer until 1724. At that time, Daniel Fahrenheit developed a sealed mercury-filled glass thermometer with a scale that could be reproduced in volume (ref [5]). Across the decades, Experimental Scientists have investigated phenomena further. Parameters of electricity were 1st isolated & measured in 1785 (ref [6]). Beginning in 1811 (ref [7]), the unit Mole was developed to help cope with the extreme minutia of the atom.



Optical Brightness: One SI Base Unit of measure that is not emphasized in this article is the lumen (lm) & its closely related units of candela (c) & lux (lx) (ref [8]). These units are measures in optics & are incorporated into the light bulb ratings one purchases. A lumen relates the optical brightness as perceived by humans to radiative power or Watts from a light source. A Watt of specific spectral radiation emitted in all directions is equivalent to 683 lumens (siData.pdf) emitted in all directions.

Empirical filter functions integrate & convert spectral electromagnetic (EM) radiation of a light source from Watts to lumens. The graph above gives filter functions of human sight in bright & low light as a function of relative intensity This data is given within the measured spectral frequency range of humans (ref [9]) & “normalized” to unity. Different filter functions give spectral responses for human perceived colors of red, blue & green. The others senses of homo sapiens (hearing, taste, smell & touch) can be more difficult to measure numerically & are not given special SI status.

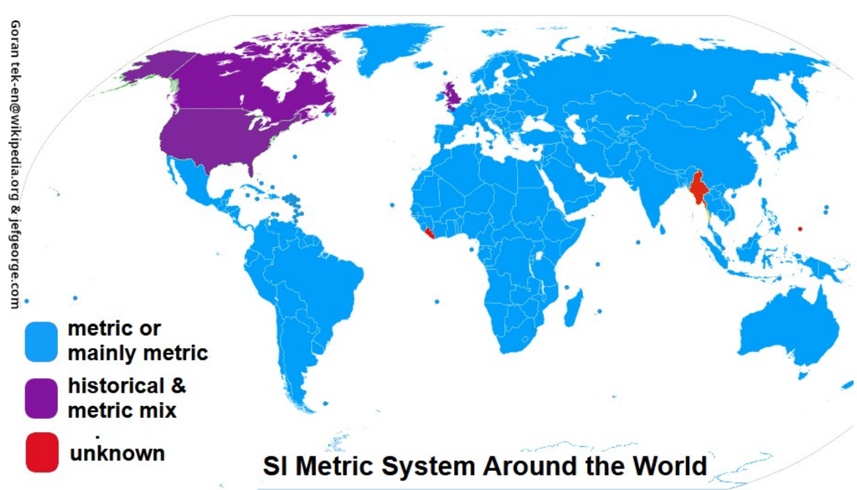
A Decimal Monetary System: When the United States (US) founding fathers Benjamin Franklin (1706 – 1790) (ref [10]) & Thomas Jefferson (1743 – 1826) (ref [11]) were building a new nation, the choices of British coinage were as follows (ref [12]):

1 pound = 20 shillings
1 shilling = 12 pence
1 mite = 1/8 penny
1 farthing = 1/4 penny
2 farthings = 1 halfpenny (‘haypenny’)
2 halfpence = 1 penny (‘copper')
2 pence = 1 tuppence (‘half-groat’)

3 pence = 1 thruppence
4 pence = 1 groat
6 pence = 1 sixpence (‘tanner')
12 pence = 1 shilling (‘bob’)
2 shillings = 1 florin (‘two bob bit')
2 shillings & 6 pence = 1 half crown
5 shillings = 1 crown

Along with others, Franklin & Jefferson advocated & received a decimal monetary system (1787) (ref [13]). Early on, the US Dollars ($) & Cents (¢) decimal currency ($1 = 100¢ ⇨ $0.01 = 1¢) more easily supported the US commerce of the 13 states.

The Metric System: The French Revolution (1789 – 1799) occurred a decade later (ref [14]). Partly due to the US improvements in British coinage, “in 1790, the Prieur du Vernois (1763 / 1832) … presented a suggestion to the National Academy of France for a single uniform set of weights and measures.” (ref [13]) As a results, French authorities mandated that all types of measurement incorporate a decimal system.



The 6 SI Fundamental Constants have been redefined as new technology becomes available. Today, 7 Fundamental Constants

of nature & 7 Base Units are termed the "International System of Units" (ref [15]). As a nod to their original language, the Metric System is termed SI (Système International) Units of Measure. "Established and maintained by the General Conference on Weights and Measures (CGPM), it is the only system of measurement with an official status in nearly every country in the world."

The US still uses a customary system that is a blend of old English units (pound, inch, Fahrenheit) & metric units (amps, volts, watts). However, all unique units of measure in the US have exact conversion factors to metric standards as decreed by the US Congress in 1988 (ref [16]). For example, 1 inch = 2.54 centimeters (exactly).

From the above global map (ref [15]), the British & Canadians also use an imperial / metric mix of units. Two countries listed as "unknown" are Bangladesh (ref [17]) & Liberia (ref [18]). Both countries have English-speaking colonization in their past.

Mass: Equivalent weights of a merchant's product were fundamental in selling that commodity to the public. The use of standard weights in calibrated stones & weighing scales date as far back as 2600 BC along the Nile River in Egypt (ref [19]).

Gallo-Roman Museum, Tongeren, Belgium

Balance scales were fundamental in commerce from the Bronze Age onward. The steelyard balance to the right with bronze reference weights (ref [19]), was typically used in Western European commerce during the Roman Empire (circa 100 AD).

Isaac Newton (1642 – 1726) (ref [20]) published his fundamental treatise *Principia* in 1687. In it, he described Calculus with Force (**F**), mass (m), & the change in velocity ($\Delta \mathbf{v} / \Delta t$) or acceleration (**a**), ($\mathbf{F} = m\mathbf{a}$). Under his rigorous mathematical definitions, the weight (force) of a pound of feathers ($\mathbf{F}_{Moon} < \mathbf{F}_{Earth}$) would be less than a fifth (16%) on the Moon ($\mathbf{a}_{Moon} < \mathbf{a}_{Earth}$) (ref [21]). However, that same bag of feathers has the same mass ($m_{Feathers}$) anywhere in the Universe.

If an object with mass (m) is under acceleration (**a**), then by Newtonian definition, that object is experiencing a force (**F**). When the weight of an object stationary on Earth is being measured, equal but opposite forces oppose the Earth's force of gravity. If those constraining forces are removed, then measurable acceleration would occur (ref [3]).

In SI applications, mass (m) is measured in kilograms (kg); force (**F**) & weight are measured in Newtons (N); acceleration (**a**) is measured in meters per second per second. Acceleration (**a** – m/s^2) is defined as the time rate of change (derivative) of velocity (**v** – m/s). Once these labels are properly defined, other improvements could still be made. The acceleration of Earth's gravity is measured @ sea level of its mid-latitudes to yield $g = 9.8\ m/s^2$ ($32.17\ ft/s^2$) (ref [22]). Note that balance scales work quite well on any planet chosen. The reference weights have the same '"mass" with equivalently proportional changes in “weight” as the pound of feathers being weighed on an alien planet.

Until 2018, a platinum-iridium reference weight for all reference weights weighed the “exact” 1 kilogram. It was kept outside Paris, France in a tripled-locked vault & termed ”Le Grand K” (the Big K). This artifact was the last fundamental prototype to be used in measurement definitions. By international decree in 2018, a kilogram was finally derived from our knowledge & measurement of the 6 SI Fundamental Constants (ref [2]).

Length: The measurement of length is wrapped up in how far it is to the next town, how many acres of land one owns, or how much water to add in a cooking recipe: length, area, volume. Cubits were one of the 1st measurements handed down from the ancients (ref [23]). Steven Spielberg knew how to accurately portray Indiana Jones' Ark of the Covenant (ref [24]), because its measurements are given in the Bible in Exodus 25:10-22 (ref [25]). When the Israelites were exiting Egypt in biblical times, a cubit measured about 20 inches (50 cm) in length.

The yard was “the length of King Henry I of England's outstretched arm.” A mile was derived from “*mille passus* in Latin, or 1,000 paces” where a pace was a left step-right step count. “The inch was conceived as the length of 3 barleycorns laid end to end.” (ref [23])

Around 1792, a platinum bar was decreed a length of one meter, with meter (m) the fundamental unit of length. Then, by definition, area has fundamental units of square meters (m^2); volume has fundamental units of cubic meters (m^3). In 1875, the Treaty of the Meter established that bar as the principal rod of length. During the 20th century, great technological strides were made in measuring length per wavelengths of EM radiation. An inch could be measured to an accuracy of 1 part in a million. Finally, the meter was defined by the standard light frequency & speed of light constants of 2018 (ref [23]).

Time: The passage of time has been kept by the rotation & orbit of the Earth long before humankind appeared on its stage. As the thread of knowledge has passed through the Sumerians, Egyptians, Greeks & Romans, these civilizations have all shaped how modern civilization segments time, from the 12-month calendar to the 24-

hour clock to 60 minutes & 60 seconds (ref [26]). Used in Egypt & Babylon in 1500 BC, the sun dial is humankind's 1st clock & is very accurate in determining high noon in adequate sunlight (ref [27]). Heed warnings when determining the Sun's location in the sky (refs [28] & [29]).

Warning: Never look @ the Sun directly. Damage can occur to one's vision "in as little as a few seconds."

As Britain explored the world with sailing ships in the 17th century onward, they required an accurate way to measure longitude while crossing oceanic expanses. A ship's latitude (a horizontal circle on the globe) was more easily derived from a specific elevation of Polaris (the North Star) from the ship's horizon. A ship's longitude (a vertical circle on the globe) had to be calculated by keeping an accurate clock while traveling. The time of high noon was recorded as opposed to high noon back home & longitude was determined (ref [30]). The 1st administrators of this charting were established by the British. Therefore, 0° Longitude runs through Greenwich, England. Solar high noon in Universal Time (UT) or Greenwich Mean Time (GMT) occurs in Greenwich, England.

With typical British flare, the photo to the right shows the old Royal Observatory in Greenwich, England (1851 – 1953) that determined astronomical data to establish 0° Longitude (ref [31]). The "Airy Transit Circle" (telescope) on this line in the museum was deemed "the centre of time and space". If a modern atomic clock gives time in a UT or GMT zone, it's most accurate on this yellow line. A more modern observatory has since been built elsewhere in England on the *Prime Meridian*.

The 2018 declaration of fundamental constants uses the Cesium-133 isotope (^{133}Cs) in an atomic clock apparatus to measure emitted EM frequency. The ^{133}Cs atom is illuminated with microwave radiation & emits a specified frequency (ν_{Cs}) of radiation whose wavelengths can be counted. These waves travel @ a constant light speed in a vacuum; then an invariant passage of time can be measured. "Today, commercially available cesium clocks keep time to within 1/3,000,000 of a second per year." (ref [26])

Temperature: This unit of measure is entirely manifest in the device that measures it, a thermometer. Hero of Alexandria (10 – 70 AD) noticed air in an air / water tube contracted / expanded in volume with the weather (ref [5]). In the Renaissance, Galileo Galilei (1564 – 1642) (ref [32]) investigated the thermoscope, an air / water filled tube & its measure of hotness & coldness (ref [3]). In 1617, Giuseppe Biancani (1566 – 1624) added a numerical scale to a thermoscope in a publication & is thus credited with the invention of "thermometer measuring temperature". (ref [5])

In 1714, Daniel G. Fahrenheit (1686 – 1736) (ref [33]), used a sealed glass tube filled with mercury & a scale to produce a thermometer that could be repeatably made & accurately record a temperature measurement. The invention of this device defined the scale & method of measurement. In this scale, a water / salt solution was @ 0°; 30° was @ the melting of ice; 90° was @ roughly the human body temperature. The 300-year-old thermometer to the right made by Fahrenheit is one of a remaining 3 known to exist (ref [34]). This thermometer is scaled from 0°F to 132°F.

By the 20th century, an absolute temperature scale had been developed with an Absolute Zero as a lower temperature limit, in part, due to work of William Thomson, 1st Baron Kelvin (1824 – 1907) (ref [35]). During his life, Thomson achieved celebrity status as a scientist & engineer earning wealth, fame & titles. He was fundamental in establishing the 1st & 2nd Laws of Thermodynamics, proposing an Absolute Zero on a Thermodynamic Temperature scale, improved the maritime compass & helped engineer the 1st trans-Atlantic telegraph cable. He was knighted in 1866 & ennobled to the British House of Lords in 1892. Thomson spent his 53-year career @ the University of Glasgow in Scotland; "Kelvin" refers to a river that flows near the University of Glasgow.

In 1967, the Kelvin (K) temperature scale was defined as "the fraction 1/273.16 of the thermodynamic temperature of the triple point of water." (ref [36]) The Absolute Zero extrapolation point of the 3rd Law of Thermodynamics provided the 2nd point of reference for the Kelvin scale. The "triple point of water" is a state of temperature & pressure whereby water, steam & ice can co-exist without change. Even then, the isotope composition (ratio of stable proton:neutron occurrences in the nucleus) of water has to be specified & a better description was required (ref [37]). Finally, the Kelvin was defined from the Boltzmann & other constants in 2018 (ref [36]).

BTW, Lord Kelvin was ***not*** correct 100% of the time (ref [3]). To address the gradual process of evolution, Thomson gave an age of the Earth @ 20M to 400M years (siData.pdf) in 1862. Thomson's calculations started with a molten Earth cooling to its present state. However, he did ***not*** consider nuclear decay of radioactive material within Earth that helps modify its age to about 4 billion years (4G years). To his credit, the energy of nuclear forces was little known @ the time of Lord Kelvin's analyses (ref [38]).

Electric Current: Gravity is the weakest force in the universe. The EM force is orders of magnitude stronger (ref [3]). Consider a pole vaulter (ref [39]) propelling her body over the crossbar. After the vaulter clears the bar, she falls toward the mat below, attracted by the Earth's mass estimated @ 6 septillion kilograms (6×10^{24} kg) @ a weight of 6.6 sextillion tons (6.6×10^{21} tons) (siData.pdf, ref [40]).

However, the vaulter's trajectory halts abruptly when molecular bonds of the mat exert an opposite EM force negating Gravity's force. We live in a 3D space, but are confined to a 2D plane … the interface of the Earth's gravitational & terrestrial EM forces. Importantly, the unit electrical charge of a negative electron (-e) or positive proton (+e) is fundamental in quantifying the EM forces that oppose Earth's Gravitational force.

Up until 2019, the amount of electric charge was expressed as the quantity of electrons moving past a point in a measured time interval (ref [41]). An Ampere (A) of electric current (shortened to Amp) was defined per Ampère's Law, discovered by André Ampère (1775 – 1836) (ref [42]):

> An Ampere is the constant electric current flowing between 2 infinite straight parallel wires a meter apart producing a force between them of 0.2 micro-Newtons per meter (μN/m) of wire. (siData.pdf, ref [41])

The electric current assesses the negative moving charges, the proton:electron mass ratio where the positively charged proton (ref [43]) is 1836 times more massive than the electron (ref [44]). In electric current, the conducting wire remains statically neutral. The very light & mobile electrons move among a lattice of almost static protons bound in atomic nuclei (ref [3]). A magnetic field occurs because of the perceived length contraction in moving electron density due to Special Relativity (SR) effects from a stationary observer (ref [45]).

James Clerk Maxwell (1831 – 1879), the originator of Maxwell's Equations (ref [46]) tipped his hat to Ampère as the "Newton of Electricity" (ref [42]). From the observation that a compass needle orients itself circumferentially around a conductor of constant current, Ampère developed his namesake law. Monsieur Ampère was a Frenchman, so his name is pronounced "am-PEER" (ref [47]).

In 2019, fundamental constants defined the EM forces for measurement, then the basic unit charge of the electron (-e) became the fundamental unit of measure. The Coulomb is the macroscopic measure of unit charge where an electron has a charge amount of about 160×10^{-21} Coulombs or 160 sixtillionth of a Coulomb (siData.pdf). Its reciprocal gives electron count per Coulomb. Then ($1/160\times10^{-21} = 6.25\times10^{18}$) or about 6.25 quintillion electrons are in a Coulomb (siData.pdf).

BTW, about the only natural & significant effect of terrestrial charge inequity apparent to the ancients was lightning. This effect is caused by wind blowing over terrestrial features & ripping away outer-shell electrons, those most loosely-bound to their atomic nuclei. These outer negative electrons are shielded from the full positive attraction of nucleus protons by inner-shell more stable electrons having smaller orbital radii. On Earth's EM / Gravity interface, we exploit this low level of binding energy inherent in outer-shell electrons to the extreme. Much of our technology & engineering involves the manipulation of loosely-bound electrons. Indeed, our Gee-Whiz Technology answers the basic question: “What can technology accomplish by controlling indistinguishable outer-shell electrons?”

Societal energy is directed toward pulling countless electrons from atomic nuclei, forcing this energy through power lines to operate our modern appliances, like electronic computers. Often these machines number-crunch vast amounts of vector algebra to construct virtual imaging in video games. Elsewhere, Carbon atoms are extracted from crude oil within the Earth where they laid buried across epochs. Their covalent bonds are then re-engineered for our relentless use of Plastics as in the construction of single-use soda bottles. These indestructible bottles provide effortless convenience to memorialize a person’s jog through a park for hundreds of years (ref [48]). This is how we entertain ourselves in “modern society”. **YOLO!**

Substance Amount: A building block of nature, the atom, is so small that individual atoms are difficult to isolate & measure. A consistent pure macroscopic sample of many atoms of an element is needed to measure & study. From 1971 onward, the mole was defined as the number of Carbon-12 (^{12}C) atoms contained in 12 grams of pure ^{12}C (ref [7]). The 12 here denotes Carbon isotope or the mass number (A) of nucleons (protons & neutrons) in the ^{12}C nucleus. The number of atoms in that 12 gram sample sets the Avogadro Constant (N_A). The atomic & molecular weights of all other elements & chemical products are expressed through the Avogadro Constant (N_A) as the macroscopic count of those elements or molecules. The value (N_A) is named after Amedeo Avogadro (1776 – 1856) (ref [7]). From 1811 onward, he formulated the idea that different gases @ the same volume, temperature & pressure have the same count of molecules. The Avogadro Constant is a count of molecules (siData.pdf) set @:

$$N_A = 6.02214076\times10^{23} \;\; (1/mol)$$

All C atoms have 6 protons (p^+), termed (Z) the atomic number. A neutral $_6C$ atom also has 6 electrons (e^-). The protons & neutrons resided in a very dense nucleus. Positive charges repel & (N) neutrons (n^0 with zero charge) are included to make a stable atom (ref [3]). Three isotopes of $_6C$ appear in nature (ref [49]).

Stable Carbon ($_6C$) Isotopes

mass number	p^+ (Z)	e^- (Z)	n^0 (N)	natural occurrence
^{12}C	6	6	6	99%
^{13}C	6	6	7	1%
^{14}C	6	6	8	trace

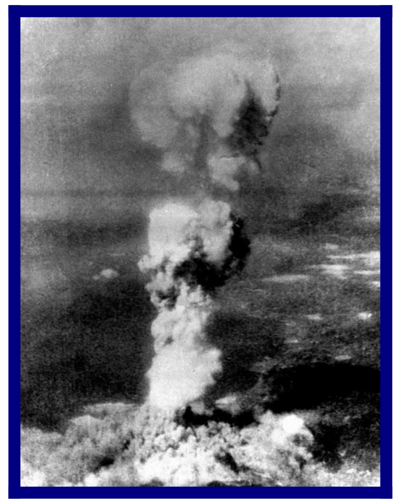
The $_6C$ element has an atomic weight of 12.011 gm/mol (ref [50]) reflecting ^{12}C & ^{13}C occurrences. Molecular or atomic weights of other atomic / molecular units are always expressed as an Avogadro Constant (N_A) count of whatever molecule is being measured. For example, “cause a half-mole of oxygen molecules (O_2) to react with a mole of hydrogen molecules (H_2),” resulting in a mole (about 18 grams) of water (H_2O)

(ref [51]).

Uranium ($_{92}U$) has 92 protons & 92 electrons with an atomic weight 238.028 gm/mol (ref [50]). Its most common isotope is Uranium-238 (^{238}U). From basic math, 238 minus 92 equals 146 neutrons doing their best to bind all of those 92 positive & repulsive protons in the dense nucleus. Even then, ^{238}U is not stable, but with a half-life (ref [3]) of about 4G years (the estimated age of the Earth) (ref [50]).

> “At the range of 10^{-15} m (1 femtometer, slightly more than the radius of a nucleon), the strong force is approximately 100 times as strong as electromagnetism, 106 times as strong as the weak interaction, and 1038 times as strong as gravitation.” (siData.pdf, ref [52])

In 2019, a more rigorous derivation of Avogadro Constant was proposed, that has an exact evaluation (siData.pdf, ref [51]).



BTW, the $_{92}U$ used in the “Little Boy” atomic bomb dropped over Hiroshima, Japan in 1945 (refs [53] & [54]) was composed of ^{235}U (ref [50]), a half-life of about 0.7 billion years. No $_{92}U$ isotope is stable. Remember, when a ^{235}U nucleus decays in a bomb detonation (ref [3]), it showers surrounding ^{235}U nuclei with the fragmented atomic nuclei, lone protons & neutrons, along with high-energy radiation ($E = \Delta m c^2$). Nucleons such as protons & neutrons lose significant mass (Δm) when not bound in atomic nuclei. The charged protons are immediately repelled, but zero charged neutrons readily collide with surrounding ^{235}U nuclei.

Many of these nuclei with added neutrons are unstable. They rapidly decay emitting more neutrons & more ($\Delta m c^2$) energy. Leo Szilard (1898 – 1964) (ref [55]) was 1st to envision this “nuclear chain reaction” in 1933 foreseeing a great explosive bomb. In 1939, just before World War II, he contacted Albert Einstein (1879 – 1955) (ref [56]) & others to promote the making of an Allied atomic bomb.

Useful Derived Units – Table

Joseph Henry
1797 – 1878

The following defined units have not been identified as fundamental units of nature. These units are derived from the previous cited 6 SI Base Units. Their existence is dependent on the Science & Engineering of the period finding a need for them in society. These units are named after early scientists in the field to which they contributed concepts & applications.

The derived units are based on scientific advances mostly in the 19th & 20th centuries; therefore, all of the scientists honored & listed here are European with one exception. The henry measures the inductance of the circuit element known as an inductor.

Joseph Henry (refs [57] & [58] & [59]), was an American Scientist. He did most of his pioneering work as a Math & Physics Professor @ the Albany Academy, an independent college-preparatory day school in New York's capital city. This school educated only male children of means from 3 years of age through the 12th grade.

Useful Derived Units

quantity	units	abr	alternate units		definition	scientist	span (yr)
space							
* length	meter	m	m		$\text{Length} \equiv \int dx$	–	–
area	Hectare	ha	10k m^2		$\text{Area} \equiv \iint d^2x$	–	–
volume	liter	L	0.001 m^3		$\text{Volume} \equiv \iiint d^3x$	–	–
mechanics							
* time	second	s	s		t	–	–
* mass	kilogram	kg	kg		m	–	–
force	Newton	N	kg▪m/s^2		$\mathbf{F} \equiv dp/dt = ma$	Isaac Newton	1642 – 1726
energy	Joule	J	W▪s	N▪m	$\Delta E_P = -[W \equiv \int(\mathbf{F} \cdot d\ell)]$	James P Joule	1818 – 1889
power	Watt	W	J/s	N▪m/s	$P \equiv dE/dt$	James Watt	1736 – 1819
* absolute	Kelvin	K	K		T_0	Lord Kelvin	1824 – 1907
common	Celsius	°C	K		$T_C \equiv T_0 - 273.15$ K	Anders Celsius	1701 – 1744
electromagnetism							
* current	Ampere	A	C/s		$I = dQ/dt$	André M Ampère	1775 – 1836
charge	Coulomb	C	A▪s		$Q = \Sigma(I \cdot \Delta t)$	CA de Coulomb	1736 – 1806
potential	Volt	V	J/C	N/A▪m/s	$V = (\mathbf{F}/Q) \cdot \mathbf{\Delta x}$	AGAA Volta	1745 – 1827
resistance	Ohm	Ω	V/A	N/A²▪m/s	$R \equiv V/I$	Georg S Ohm	1789 – 1854
alternating current parameters							
frequency	Hertz	Hz	1/s		$\nu = c/\lambda$	Heinrich R Hertz	1857 – 1894
flux	Weber	Wb	V▪s	N▪m/A	$\Phi_B \equiv \iint(\mathbf{B} \cdot \hat{\mathbf{n}}_a)d^2x$	Wilhelm E Weber	1804 – 1891
flux density	Tesla	T	V▪s/m^2	N/A/m	$\varphi_B = \Phi_B/\text{Area}$	Nikola Tesla	1856 – 1943
capacitance	Farad	F	s/Ω	A²/N▪s²/m	$C \equiv Q/V$	Michael Faraday	1791 – 1867
inductance	Henry	H	s▪Ω	N/A²▪m	$L \equiv \Phi_B/I$	Joseph Henry	1797 – 1878
chemistry							
* amount	Mole	mol		–	$n \equiv N / N_A$	A Avogadro	1776 – 1856
pressure	Pascal	Pa	N/m^2		$p = (\mathbf{F} \cdot \hat{\mathbf{n}}_a)/\text{Area}$	Blaise Pascal	1623 – 1662
catalyst	katal	kat	mol/s		$X \xrightarrow{catalyst} Y$	–	–
radioactivity							
activity	Becquerel	Bq	1/s		A = # decay/s	AH Becquerel	1852 – 1908
ionized dose	Gray	Gy	J/kg	N▪m/kg	D = ions/mass	Louis H Gray	1905 – 1965
equal dose	Sievert	Sv	J/kg	N▪m/kg	$H = Q_{ICRP} \cdot D_{Gray}$	Rolf M Sievert	1896 – 1966

* SI Base Unit — Wikipedia.org

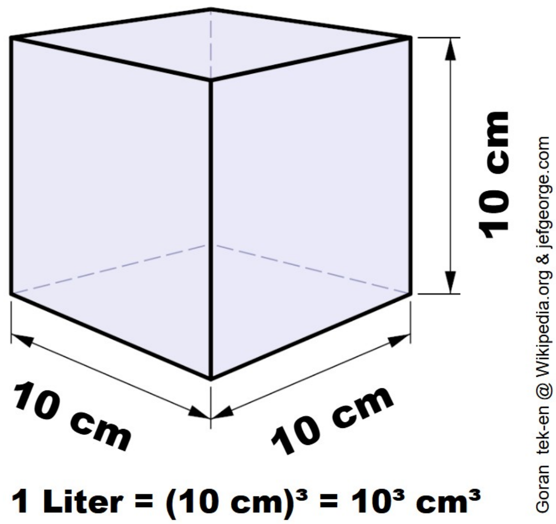
List of Useful Derived Units. The above table gives a partial list of derived units of measure all based on the 6 previously listed SI Base Units (ref [60]). Any combination of the 6 SI Base Units can be judged useful in societal applications. Likewise, any combination can take on a label that honors a scientist in the field. For units of measure that society is so familiar with, i.e. Watts, Amps, Volts, Hertz & Celsius, the following data gives a brief synopsis of the scientists behind the units & links to pursue further information. As stated previously, the only human-biased measure, the optical Lumen &

its supporting units of measure, are not included in the list.

An Academic Challenge! We need more representation of minorities & women in the nomenclature of derived units from the SI Base Units. The scientists listed herein, were where the technical information was, made the effort to learn it, then had the drive to improve scientific knowledge for humankind. Some luck is involved, but minorities & women must do the same! Advocate for equal childhood schooling & demand the same technical information that other academic professionals have access to.

Useful Derived Units – Mechanics & Thermodynamics

Area / Volume. Once the SI fundamental unit of length (meter) was defined, area (square meters) & volume (cubic meters) were also defined. Then for land area, 1 Hectare is 10,000 m². For medicine, 1 cc (cubic centimeter) = 1 mL (milliliter) = 0.001 L (Liters) (siData.pdf, refs [61] & [62]).



1 Liter = (10 cm)³ = 10³ cm³
1 Liter = 1000 cm³ = 1000 cc

Force is defined as a body with mass (*m*) under acceleration (**a**) or a Newton. If an object is stationary due to opposing forces, remove these constraining forces & the resultant acceleration would define a single force. This unit of measure is named after its definer, Isaac Newton (1642 – 1726) with (**F** = m**a**). Through his invention of Calculus, Newton (ref [20]) discovered the mechanics of the Universe.

BTW, considering the 4 known forces of Nature (ref [63]), the Sun heats the Earth by combining Hydrogen nuclei ($_1H$) to produce Helium ($_2He$), via the ***Strong Force***; terrestrial volcanoes erupt molten rock heated in part by nuclei decay of the Earth's internal Uranium ($_{92}U$) via the ***Weak Force***. However, we assume terrestrial atomic nuclei remain constant & go to great lengths in finding / exploiting existing deposits of almost all elements we use, extracting them from the Earth's crust (ref [3]). Then, modern society manipulates outer-shell electrons through chemical & electrical processes to generate the technology that improves our lives. This all takes place on the interface between the two macroscopic dominant forces, ***Electromagnetism*** & ***Gravity*** on the surface of our "Spaceship Earth".

Work or loss in potential **Energy** is defined as traversed distance times a parallel force or a Joule ($W = \mathbf{F} \cdot \Delta\mathbf{x}$). When a rock slides down a hill, the vertical displacement of ($\Delta\mathbf{x}$) is parallel to the gravitational force ($\mathbf{F}_g$). The dot product is positive ($\mathbf{F} \cdot \Delta\mathbf{x}$) & the gravitational force ($\mathbf{F}_g$) performs positive work (W). However, the rock loses potential energy (ΔE_P), hence the negative sign ($\Delta E_P = -(\mathbf{F} \cdot \Delta\mathbf{x})$) (ref [64]).

This unit of measure was named after James Prescott Joule (1818 – 1889) (ref [65]), a brewer by trade & hobby Physicists on the side. A consummate businessman, Joule set out to determine which was more cost-efficient, burning coal in a steam engine or supplying Zinc ($_{30}Zn$) in a battery for the newly invented electric motor. Through additional experiments, Joule helped formulate the Conservation of Energy, the 1st Law of Thermodynamics. Mister Joule was English & his name sounds like "JOOL" (ref [66]).

Power is defined as energy expended per unit time or a Watt ($P \equiv dE/dt$). This unit of measure was named after James Watt (1736 – 1819) (ref [67]), inventor of an improved steam engine. Early steam engines of the time were primarily used to remove water from mines. Watt added a separate condenser to the steam engines so that the piston & cylinder did not have to be heated & cooled, repeatedly. Internal combustion engines with a water-cooled radiator under the hood can thank James Watt. That radiator addresses the low efficiencies & large amounts of heat that must be dissipated to get one down the road. The Industrial Revolution could not have happened without Watt's improvement & he died a wealthy man.

Local Temperature: The Celsius temperature scale is derived from the more encompassing Thermodynamic Kelvin (K) scale that always has positive values. Celsius is chosen with a zero reference defined for convenience as the freezing point of water @ about 273.15 K. In 1742, Anders Celsius (1701 – 1744) (ref [68]) proposed a scale with 0° at the boiling point & 100° at the freezing point of water, the opposite of the scale today. More importantly, Celsius showed that the melting point of ice is little affected by atmospheric pressure; however, the boiling point of water does vary with atmospheric pressure. A standard atmospheric pressure @ sea level should be chosen for the water boiling point calibration for 0° Celsius mark.

BTW, a year after Celsius' death, Carl Linnaeus (1707 – 1778) (ref [69]), "father of taxonomy" & genus-species nomenclature in biology, reversed the Celsius scale with 0° as the freezing point of water. Linnaeus was a very traveled biologist collecting botanical specimens to identify every where he went. Naturally in Sweden, he needed a thermometer within his greenhouse to monitor his specimens (ref [70])!

Useful Derived Units – Electromagnetism EM Color

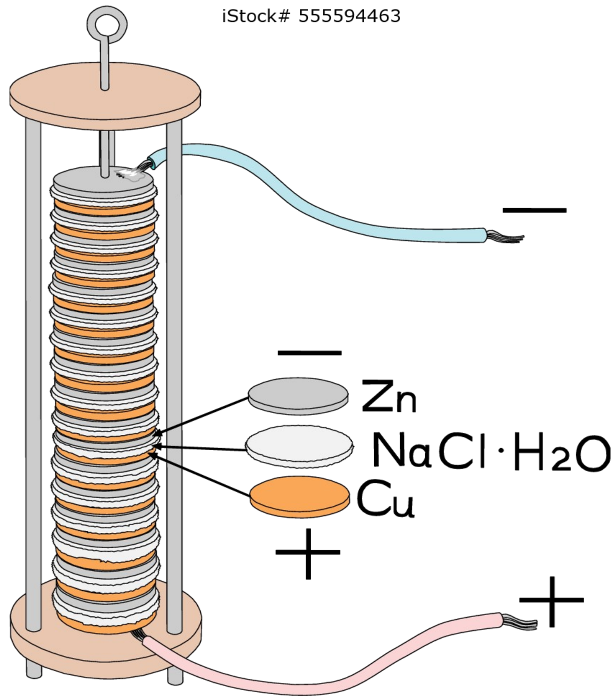
Electrical Charge represents a set number of positively charged protons (+e) or negatively charged electrons (-e). A Coulomb is measured @ 6.241509×10^{18} or about 6.2 quintillion elemental charges. This unit is named after Charles-Augustin de Coulomb (1736 – 1806) (ref [6]). Coulomb was an Experimental Physicist in today's parlance. In 1785, he determined that:

> The "force between two oppositely charged spheres is proportional to the product of the quantities of charge on the spheres and is inversely proportional to the square of the distance between the spheres." (ref [6])

Coulomb correctly assumed forces between static electric charges were similar to the gravitational forces between bodies of mass as stated by Isaac Newton (1687) (ref [71]).

$|\mathbf{F}_{Newton}| = [G][m_1 m_2]/(\mathbf{r_{12}} \bullet \mathbf{r_{12}}) \Rightarrow |\mathbf{F}_{Coulomb}| = [1/4\pi\varepsilon_0][q_1 q_2]/(\mathbf{r_{12}} \bullet \mathbf{r_{12}})$

Unlike attractive gravitational forces, electrostatic forces are both attractive & repulsive (ref [3]). Monsieur Coulomb was a Frenchman, so his name is pronounced "COO-lam" (ref [72]);

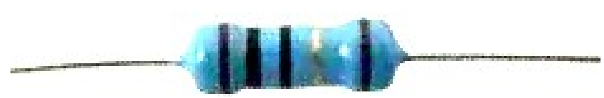


Electrical Potential is defined as energy per unit charge (Joules/Coulomb) or Volts (V). When force is applied to individual electrons, pulling them from their once bound atomic nuclei, an attractive Coulomb force opposes the motion & the recoverable energy is measured as applied force times distance. As each unit charge count of electrons is displaced from their atomic nuclei, Volts is the recoverable energy (Joules) stored in the unit charge (Coulombs) of electrons.

The unit of measure Volt (V) is named after Alessandro Volta (1745 – 1827) (ref [73]). Around 1799, Volta invented the battery or electrochemical voltaic pile (ref [74]) whereby a crude battery would supply an electric current due to chemical reactions (shown above ref [75]). With this invention, study of electricity & electric currents became accessible to many.

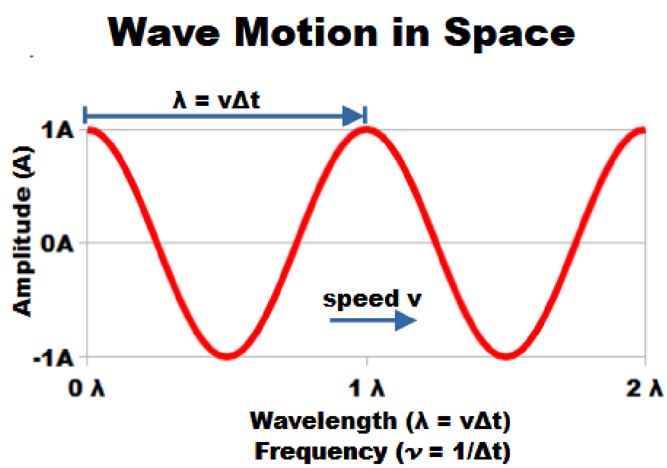
Here, Copper ($_{29}Cu = [_{18}Ar]\ 3d^{10}\ 4s^1$) & Zinc ($_{30}Zn = [_{18}Ar]\ 3d^{10}\ 4s^2$) (ref [76]) are placed in a brine ($NaCl \bullet H_2O$) solution. A single $_{30}Zn$ atom gives up its two ($4s^2$) loosely bound electrons to two hydrogen (H^+) ions forming a diatomic hydrogen (H_2) molecule. Both the NaCl ions & $_{29}Cu$ act as catalysts.

BTW, the electric eel species *Electrophorus voltai* is named after Alessandro Volta (ref [73]).



Electrical Resistivity Due to the 2nd Law of Thermodynamics, some heat loss occurs in current flow (I) through conductors @ room temperature, typically Copper ($_{29}Cu$) wire. Current degradation is measured in ohms (Ω) & named after Georg Ohms (1789 – 1854) (ref [77]). Unlike superconductors @ frigid temperatures, electrical current @ room temperature is less than 100% efficiency ($V = I \bullet R$). This inefficiency is manifest in heat generated by the moving electrons. The above image (ref [78]) shows a typical circuit resistor rated @ 47 Ω (Ohms) for which the color coded bands on the resistor reflect.

Frequency is given as Hertz (Hz) or cycles per second (1/s). Hertz measures the wavelength (λ) of a spatial wave moving with velocity (v). Then, (v = $\lambda \nu$). For EM radiation waves that traverse a vacuum, (v = c) where (c) is the speed of light in a vacuum. This frequently used unit of measures is named after Heinrich Rudolf Hertz (1857 – 1894) (ref [79]) who proved what Maxwell's Equations predicted in 1862 (ref [46]). In 1887, Hertz definitively proved that EM radiation has a frequency (ν) attached to its propagation (ref [80]). In technical literature, frequency is typically denoted by an italicized Greek lower-case "nu" (ν).



Electrical Capacitance measures the ability of a capacitor to store electrons & their electrical energy. A capacitor is formed by putting a dielectric insulator between two plates of conducting material. A voltage difference is applied across the insulator to store the electrons.

> "One farad can be described as the capacitance which stores a one-coulomb charge across a potential difference of one volt." (ref [81])

Farad is named after Michael Faraday (1791 – 1867) (ref [82]). Having little early formal education (ref [83]), Faraday established the concept of force fields & lines of force around a charge distribution. Faraday devised the concept of the magnetic flux created by wire coils. He invented the forerunner of the electric motor.

Capacitance (C) is measured in farads (F) & indicates a capacitor's ability to store charges (Q) for an applied voltage (V). A change in voltage (ΔV) across a capacitor produces a current (I) from the capacitor based on its capacitance (C) & stored charges (Q). A typical circuit capacitor to the right (ref [84]) is rated @ 10 μF (micro-Farads, siData.pdf).

BTW, Michael Faraday is a little known "Great in Physics History". Margret Thatcher (1925 – 2013) (ref [85]) as a United Kingdom (UK) Prime Minister (PM) (1979 – 1990) broke two glass ceilings. The "iron lady" was the 1st female PM & 1st PM with a Science degree. She had an Oxford degree in Chemistry emphasizing X-Ray crystallography. As PM, Thatcher had Faraday's bust placed in 10 Downing Street. In a speech she stated, "The value of his work must be higher than the capitalisation of all the shares on the Stock Exchange!"

Another fan, Albert Einstein (1879 – 1955) (ref [56]) "kept a picture of Faraday on his study wall, alongside … Arthur Schopenhauer and James Clerk Maxwell." (ref [82])

James Maxwell's contributions are outlined in ref [46]. Arthur Schopenhauer (1788 – 1860) (ref [86]) was a German philosopher, having atheistic views & Indian beliefs of *Maya* where the world is an illusion ... not as it seems.

History reports Michael Faraday "had a nervous breakdown" in 1839. Mental health was less well-defined back then. Neither did the gossip press of the day have the prying-eyes of modern times. "For five years he was unable to concentrate his mental faculties on the problems of electricity and magnetism." (ref [87]) However, in perspective, we should still be grateful of the Scientific Knowledge Faraday contributed despite the tribulations of his life.

Magnetic Flux measures the magnetic field flowing across a surface whose variation in time (t) can produce a voltage change across a conductor loop.

> "A change in flux of one weber per second will induce an electromotive force of one volt." (ref [88])

The magnetic flux (Φ_B) is used to evaluate Faraday's Law of Induction (Maxwell's 3rd Law) & is measured in Webers (Wb) or Volt•seconds (V•s).

Magnetic flux measures performance of a typical transformer (ref [89]) to change power line voltage in delivering electric power. The unit Weber is named after Wilhelm Eduard Weber (1804 – 1891) (ref [90]). In 1855, Weber showed through experiment that the proportionality constants of static charge density (ρ) & electric **E**-field or current density (**J**) & magnetic **B**-field are linked through the speed of light (c). Indeed, we can thank Weber for choosing the letter "c" as the speed of light in a vacuum, a universal constant.

Magnetic Flux (Φ_B) & Transformers EM Color		
$\oint(\mathbf{E} \cdot d\ell) = -d/dt \iint(\mathbf{B} \cdot \hat{\mathbf{n}}_s)\, ds$	(Volts)	Maxwell's 3rd Equation (ref [46])
$\Phi_B \equiv \iint(\mathbf{B} \cdot \hat{\mathbf{n}}_s)\, ds$	(Weber)	Definition of Magnetic Flux (Φ_B) over surface (s) @ **B**-field, s-normal ($\mathbf{B} \cdot \hat{\mathbf{n}}_s$) dot product within wire loop (ℓ)
$V = n_c \oint(\mathbf{E} \cdot d\ell)$	(Volts)	Determination of voltage change (V) around closed loop (ℓ) of coil with loop count (n_c)
$V = -n_c\, d\Phi_B / dt$	(Volts)	Lenz's Law

In the metric system with MKSA (meter / kilogram / second / amp) units, the electric permittivity constant (ε_0) relates static charge density (ρ) & electric potential ($\Phi(\mathbf{x})$). The magnetic permeability constant (μ_0) relates current density (**J**) & magnetic potential ($\mathbf{A}(\mathbf{x})$) (ref [91]). These potentials evaluate the energy per charge required to assemble the charges & currents from far away to the present configuration.

$$\Phi(\mathbf{x}) \equiv [1 / (4\pi\varepsilon_0)] \times \iiint [\rho(\mathbf{x}')/|\mathbf{x}-\mathbf{x}'|]\, d^3x' \quad \text{(Volts)}$$

$\mathbf{A}(\mathbf{x}) \equiv [\, \mu_0 / (4\pi) \,] \times \iiint [\, \mathbf{J}(\mathbf{x}')/|\mathbf{x}-\mathbf{x}'| \,] d^3x'$ (Volts)

The following equation holds (siData.pdf) for EM constants:

$\varepsilon_0 \, \mu_0 = 1/c^2$

This experimental conclusion helped James Maxwell formulate his namesake equations presented in 1862 (ref [46]).

Magnetic Flux Density (φ_B) is the magnetic flux (Φ_B) divided by the integral area (A_s).

$\varphi_B(t) = \Phi_B(t) / A_s = \iint (\mathbf{B} \bullet \hat{\mathbf{n}}_s) ds \,/\, \iint ds$ with $A_s = \iint ds$

This measurement is assigned the unit of Tesla (T) with derived units of Weber/meter² (Wb/m²). Both Nikola Tesla (1856 – 1943) (ref [92]) & George Westinghouse (1846 – 1914) (ref [93]) contributed to the design of electric power distribution (ref [94]). In 1896, Westinghouse Electric implemented the transmission of alternating current (AC) electrical power (refs [95] & [96]) for 26 miles (42 km) from Niagara Falls to Buffalo, New York. Both the Weber (Wb) & Tesla (T) were formulated to support the application of transformers in transporting electrical power over long distances economically.

Inductance: This is another unit of measure that supports the use of conducting coils in producing a magnetic flux.

> "If a current of 1 ampere flowing through a coil produces flux linkage of 1 weber turn, that coil has a self inductance of 1 henry." (ref [97]).

An inductor is a principal macroscopic circuit element identified by inductance (L) measured in henries (H)

$L \equiv \Phi_B / I \;\Rightarrow\; \Phi_B = L \bullet I \;\Rightarrow\; d\Phi_B/dt = L \bullet (dI/dt)$

(Lenz's Law) $V = -d\Phi_B/dt \;\Rightarrow\; V = -L\,(dI/dt)$

An inductor normally consists of a Copper wire wound around a ferrous material & associated with a voltage difference between two wires. The torodial inductor to the right (ref [98]) has a rating of 1 mH (milli-Henry , siData.pdf).

The unit of inductance is named after Joseph Henry (1797 – 1878) (ref [57]), the only American to be honored by MKSA (meter / kilogram / second / amp) derived units. As is the case throughout Science, Henry duplicated research of others @ about the same time period. Henry discovered self-inductance while in Albany, New York (1832). Self-inductance is the ability of an electrical current to oppose changes in the current flow. The previous year in Westminster, England (1831), Michael Faraday had discovered the same phenomena termed Faraday's Law of Induction.

BTW, Henry was appointed the first Secretary of the Smithsonian Institution (the national museum of the US) in the nation's capital (1846 – 1878). With that position, he was exposed to other areas of Science. During the US Civil War (1861 – 1865), his interest in hot-air manned balloons motivated the formation of the Union Army Balloon Corps of the Army of the Potomac. Henry met a young Alexander Bell (1847 – 1922) (refs [99] & [100]) in 1875 who sought advice from Henry about his speech-to-electricity device. Henry noted Bell had "the germ of a great invention". (ref [57])

Unfortunately, Henry had some bigoted beliefs of the time. The famous orator & former slave Frederick Douglas was scheduled for a Smithsonian event in 1862. Henry blocked his speech explaining: “I would not let the lecture of the coloured man be given in the rooms of the Smithsonian.” (ref [101])

Useful Derived Units – Chemistry & Radioactivity

Pressure is given as force per unit area or a Newton per square meter or a Pascal ($p = \langle \mathbf{F} \cdot \hat{\mathbf{n}}_a \rangle / Area$). This unit of measure was named after Blaise Pascal (1623 – 1662) (ref [102]) who helped develop the concept of air pressure using a barometer. A barometer measures atmospheric pressure which changes due to elevation & weather conditions. If a tube is filled with liquid Mercury ($_{80}Hg$ – a metal, liquid @ room temperature), a temporary seal is placed on end of the tube, the tube is turned upside down & the temporary sealed end placed in a basin of $_{80}Hg$ with seal removed. Voila! A Hg barometer is made (ref [103]). Warning information of $_{80}Hg$ is from refs [104] & [29].

Warning: Liquid Mercury should only be used by trained professionals. Mercury toxicity includes damage to the kidney, nervous system & pregnancy complications.

If the tube with $_{80}Hg$ is longer than about 30 inches (76 cm), an empty space will appear @ its top. Aristotle (384 – 322 BC) (ref [105]) had conjectured: “Nature abhors a vacuum!” Renaissance thinkers reasoned that Aristotle was wrong … a vacuum was present @ the top of the tube. The column of $_{80}Hg$ is supported by the air pressure exerting force on the basin of $_{80}Hg$. In fact, the empty space is a partial vacuum filled with $_{80}Hg$ vapor. The image to the right (ref [106]) shows the “quicksilver” $_{80}Hg$ liquid below the transparent partial vacuum in a Hg barometer.

BTW, $_{80}Hg$ is very heavy, about 13 times heavier than water (H_2O). Then, an H_2O barometer would have to be [(13×30 inches)▪(1 foot / 12 inches) = 33 feet] about 3 stories high. A partial vacuum would appear @ the top of a barometer tube of H_2O above about 33 feet (10 meters) in height. By 1640, water siphoning & well extraction experience had determined that a column of water would “break” above about 3 stories of height. In 1644, Evangelista Torricelli (1608 – 1647) (ref [107]), correctly interpreted this phenomena & wrote:

> "We live submerged at the bottom of an ocean of the element air, which by unquestioned experiments is known to have weight." (ref [108])

Pascal further showed air pressure supports liquids of different weights with correspondingly different heights. As elevation above sea level increases, the column of $_{80}$Hg supported in a barometer & hence the air pressure @ height decreases (ref [102]).

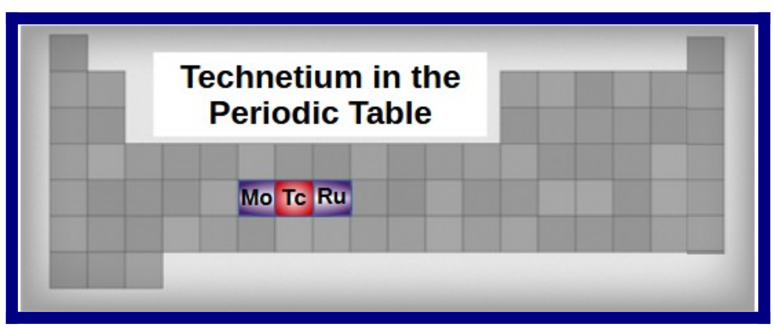
Catalyst Activity: The newest SI derived unit devised around 1991, the katal (kat) measures the effectiveness of enzyme catalysts in chemical reactions (ref [109]). The name is derived from the same ancient Greek word as "catalyst" & means "dissolution".

Radioactivity: Units of measure which define decay & radiation of radioactive material are relatively new additions to SI derived units. These units have been added primarily to define healthy limits of exposure from radioactive phenomena on humans.

In 1789, Uranium was isolated as an element from pitchblende by chemist Martin Klaproth (1743 – 1817) (ref [110]). Klaproth named his element after the newly discovered planet Uranus (1781). As Uranium ($_{92}$U) was further isolated & purified, hindsight reveals the effects of $_{92}$U radioactivity on the researchers. Notable scientists involved in radioactivity research had their lives cut short!

A Becquerel (Bq) is an SI derived unit defined as the nuclear decay of one atom per second. The unit is named after Antoine Becquerel (1852 – 1908) (ref [111]). He discovered the radioactivity of $_{92}$U by studying emitted high-energy electrons termed β-rays. Antoine Becquerel (died @ age 55) was awarded the 1903 Nobel prized in Physics along with Marie (died @ age 66) & Pierre Curie (died @ age 46) for their research on Radioactivity (ref [112]).

Two additional derived SI units for radioactivity are an absorbed radioactive dose Gray (Gy) & Sievert (Sv). The Gray measures the amount of radioactive energy absorbed by a unit mass of living human tissue (J/kg). This SI derived unit is named after Louis Harold Gray (died @ age 59) (ref [113]) who researched damage of neutrons on human tissue. The Sievert measures radioactive dosage similar to a Gray. This unit is name after Rolf Sievert (died @ age 70) (ref [114]) who studied human health effects from ionizing radiation.



BTW, Nuclear Physics is bizarre also! When Dmitri Mendeleev (1834 – 1907) (ref [115]) proposed the Periodic Table (ref [50]) in its correct form in 1869, a noticeable element gap appeared between Molybdenum ($_{42}$Mo) & Ruthenium ($_{44}$Ru). Elements surrounding this gap in the Periodic Table all have isotopes with stable atomic nuclei.

The missing element was finally discovered on spare parts of one of the 1st particle accelerators in 1937 & given the name Technetium ($_{43}Tc$) (refs [116] & [117]). This name means "artificial" in Greek. This element has several unstable isotopes that have all been produced artificially. The half-lives of these isotopes range from about 4 days (^{96}Tc) to 4M years (^{97}Tc), much shorter than the estimated 4G years of the Earth (siData.pdf).

Conclusion

Let's be objective!

When one makes a ***subjective*** judgment, one is using his / her feelings & opinions. An ***objective*** judgment is by definition the opposite of ***subjective***, being devoid of personal feelings & opinions (ref [118]). One way to force objectivity is to require well-defined numerical measurements to make decisions from. Then, the question becomes, "What can be numerically measured to base a decision on?" This article delineates in a brief but direct fashion the 6 SI Base Units & many useful derived SI Units that have been devised to develop much of the technology we have today.

For self-protection in our *litigious* society, a "profession" may promote subjective (non-numerical) data in its decision-making & documentation. The SI Base Units of measure listed here mandate that numerical measurements be made rigorously & accurately. Over time, objective measurements force a better, more successful "profession" that improves through learning from mistakes & better collection of data.

Remember this data point (ref [119])! A subjective & ***incorrect*** Earth-centered "astrology" languished for over 1400 years based on *Almagest* (c 150 AD) by Ptolemy. *On the Revolutions of the Celestial Spheres* (1543) by Copernicus provided a ***corrected*** Sun-centered "astronomy" & Galileo introduced telescopic measurements in 1609. These advances culminated in Neil Armstrong stepping on the Moon in 1969. From horse & buggy to spaceship, pursuit of knowledge progressed with *Godspeed* across just 360 years.

References

[1] Hartford, Tim, BBC, The World's 1st Accountants used Cuneiform, 2017.
[2] National Institute of Standards & Technology (NIST), Kilogram – Introduction, 2023.
[3] Hewitt, Paul G, *Conceptual Physics*, 12th Ed, Pearson Press, 2014.
[4] National Institute of Standards & Technology (NIST), Metric SI Units, 2023.
[5] Wikipedia.org, Thermometer, 2023.
[6] Wikipedia.org, Charles-Augustin de Coulomb, 2023.
[7] Wikipedia.org, Avogadro Constant, 2023.
[8] National Institute of Standards & Technology (NIST), Candela – Introduction, 2023.
[9] Kiriakos, Carolyn, SUNYsb.org, Photometry & Light Sources.
[10] Wikipedia.org, Benjamin Franklin, 2023.

[11] Wikipedia.org, Thomas Jefferson, 2023.
[12] David, I Heart Britain, Understanding British Money, 2020.
[13] Naughtin, Pat, HomeOfBob.com, Metric System History, 2019.
[14] Wikipedia.org, French Revolution, 2023.
[15] Wikipedia.org, International System of Units, 2023.
[16] OSHA Technical Manual: Section X, Chapter 1, Metric System Conversion, 1983.
[17] Wikipedia.org, Bangladesh, 2023.
[18] Wikipedia.org, Liberia, 2023.
[19] Wikipedia.org, Weighing Scales, 2023.
[20] Wikipedia.org, Isaac Newton, 2023.
[21] Space Math, NASA.gov, Your Weight on Different Planets, 2023.
[22] Math Is Fun: Gravity Value, 2022.
[23] National Institute of Standards & Technology (NIST), Meter – Introduction, 2023.
[24] Indiana Jones, Fandom, Ark of the Covenant, 2023.
[25] Napier, Chad, Christianity.com, Meaning of the Ark of the Covenant, 2019.
[26] National Institute of Standards & Technology (NIST), Second – Introduction, 2023.
[27] Wikipedia.org, Sundial, 2023.
[28] Cafasso, Jacquelyn, et al, Healthline, Don't Stare @ the Sun!, 2018.
[29] Members, Institute of Physics, London, UK, 2023.
[30] Pentecost, Kate, Australian National Maritime Museum, Where Are You?, 2023.
[31] Wikipedia.org, Royal Observatory, 2023.
[32] Wikipedia.org, Galileo Galilei, 2023.
[33] Wikipedia.org, Daniel Fahrenheit, 2023.
[34] Hanlon, Mike, NewAtlas, Original Fahrenheit Thermometer at Auction, 2022.
[35] Wikipedia.org, William Thomson, Lord Kelvin, 2023.
[36] National Institute of Standards & Technology (NIST), Kelvin – Introduction, 2023.
[37] National Institute of Standards & Technology (NIST), Kelvin – Realization, 2023.
[38] Wikipedia.org, Age of Earth, 2023.
[39] Women's Track & Field, GA Tech, Pole Vaulters Gallery, 2023.
[40] Sharp, Tim, Space.com, How big is Earth?, 2021.
[41] National Institute of Standards & Technology (NIST), Ampere – Introduction, 2023.
[42] Wikipedia.org, André-Marie Ampère, 2023.
[43] Wikipedia.org, Sub-Atomic Hadron: Proton, 2023.
[44] Wikipedia.org, Sub-Atomic Lepton: Electron, 2023.
[45] French, AP, PhD, *Special Relativity*, 1st Ed, MIT Physics, WW Norton & Co, 1968.
[46] George, Everett, *Idea Contributions*. Maxwell's Equations Demystified, 2023.
[47] Miquel, Julien, YouTube.com, Pronounce Ampère, 2019.
[48] Hughes, Mariah, Forge Recycling, Decomposition Times, 2022.
[49] Khan Academy, Atomic Number, Atomic Mass & Isotopes, 2023.
[50] PubChem, National Institutes of Health, Periodic Table of Elements, 2023.
[51] National Institute of Standards & Technology (NIST), Mole – Introduction, 2023.
[52] Wikipedia.org, Strong Interaction, 2023.
[53] Wikipedia.org, Los Alamos Laboratory, 2023.

[54] Rosen, RJ, The Atlantic, Rare Photo of the Mushroom Cloud Over Hiroshima, 2013.
[55] Wikipedia.org, Leo Szilard, 2023.
[56] Wikipedia.org, Albert Einstein, 2023.
[57] Wikipedia.org, Joseph Henry, 2023.
[58] Joseph, Kathy, KathyLovesPhysics.com, Joseph Henry Biography, 2018.
[59] National Portriat Galley, SI.edu, Joseph Henry, 2023.
[60] Physics, Vedantu.com, SI Units List, 2023.
[61] UnitConverters.ardnet, Express Version, 2023.
[62] McKenna, H, Wikipedia.org, Liter, 2023.
[63] Universe, NASA.gov, the Four Fundamental Forces.
[64] Halliday, David, et al, *Principles of Physics*, 11th Ed, Wiley, 2020.
[65] Wikipedia.org, James Prescott Joule, 2023.
[66] Pronunciation Guide, YouTube.com, Pronounce Joule, 2023.
[67] Wikipedia.org, James Watt, 2023.
[68] Wikipedia.org, Anders Celsius, 2023.
[69] Wikipedia.org, Carl Linnaeus, 2023.
[70] Tietz, Tabea, SciHi.org, Anders Celsius & his Temperature Scale, 2020.
[71] Electrical 4 U, Coulomb's Force Law, 2020.
[72] Pronunciation Guide, YouTube.com, Pronounce Coulomb, 2023.
[73] Wikipedia.org, Alessandro Volta, 2023.
[74] Joseph, Kathy, KathyLovesPhysics.com, Etymology of the Name "Battery", 2020.
[75] ShutterStock.com, Voltaic Pile, #555594463, 2023.
[76] Gray, Theodore, et al, Wolfram Research, Periodic Table, 2023.
[77] Wikipedia.org, Georg Ohm, 2023.
[78] Amazon.com, Metal Film Fixed Resistors (47Ω), #B0B4D7PJF4, 2024.
[79] Wikipedi.org, Henrich Hertz, 2023.
[80] Joseph, Kathy, KathyLovesPhysics.com, Heinrich Hertz Biography, 2018.
[81] Wikipedia.org, Farad (unit), 2023.
[82] Wikipedia.org, Michael Faraday, 2023.
[83] Joseph, Kathy, KathyLovesPhysics.com, Michael Faraday Biography, 2017.
[84] Amazon.com, 400V/10uF Aluminum Electrolytic Capacitor, #B0CPFVQW9J, 2024.
[85] Wikipedia.org, Margret Thatcher, 2023.
[86] Wikipedia.org, Arthurm Schopenhauer, 2023.
[87] Encyclopedia.org, Physics Biographies, Michael Faraday, 2018.
[88] Wikipedia.org, Weber (unit), 2023.
[89] IndiaMart.com, VPI Transformer #16036359888, 2023.
[90] Wikipedia.org, Wilhelm Eduard Weber, 2023.
[91] George, Everett, *Idea Contributions,* SR Elucidates Maxwell's Equations, 2024.
[92] Wikipedia.org, Nikola Tesla, 2023.
[93] Wikipedia.org, George Westinghouse, 2023.
[94] Joseph, Kathy, KathyLovesPhysics.com, Tesla: Fact vs Fiction, 2023.
[95] Dunlap, OE, Western Electric, Electric Power: Niagara Falls to Buffalo, 1896.
[96] Joseph, Kathy, KathyLovesPhysics.com, History of Transformers, 2023.

[97] Wikipedia.org, Henry (unit), 2023.
[98] Amazon.com, Bourns/JW Miller Toroidal Inductor (1 mH), #B00DJS8Q0G, 2024.
[99] Wikipedia.org, Alexander Graham Bell, 2023.
[100] Joseph, Kathy, KathyLovesPhysics.com, History of the Telephone, 2018.
[101] Grummitt, Julia, Princeton & Slavery, Joseph Henry & Sam Parker, 2023.
[102] Wikipedia.org, Blaise Pascal, 2023.
[103] Wikipedia.org, Barometer, 2023.
[104] OSHA.gov, Safety & Health Topics, Mercury: Overview, 2023.
[105] Wikipedia.org, Aristotle, 2023.
[106] iStock.com, image #507082970-84543039, 2023.
[107] Wikipedia.org, Evangelista Torricelli, 2023.
[108] West, JB, PubMed @ NIH.gov, Torricelli & the Ocean of Air, 2013.
[109] Wikipedia.org, Katal (unit), 2023.
[110] Wikipedia.org, Martin Klaproth, 2023.
[111] Wikipedia.org, Henri Becquerel, 2023.
[112] Joseph, Kathy, KathyLovesPhysics.com, History of Radioactivity, 2020.
[113] Wikipedia.org, Louise Harold Gray, 2023.
[114] Wikipedia.org, Rolf Sievert, 2023.
[115] Wikipedia.org, Dmitri Mendeleev, 2013.
[116] Wiipedia.org, Technetium, 2023.
[117] Scerri, Eric, Nature Articles, Tales of Technetium, 2009.
[118] Dictionary,com, Definition: objective (adj.), 2023.
[119] George, Everett, *Idea Contributions,* Calculus Elucidates Kepler's Laws, 2024.

Note: Please donate $50/year if you find Wikipedia useful!!!

Everett George 16 March 2025