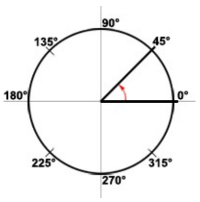
The intent of this paper is to present a basic understanding to the reader, and may not represent the current state of official definitions which might be somewhat more complex. Conversion factors to other measurement systems are not included. They are pretty straightforward to look up elsewhere. All commentary is the opinion of mypiezo. For this paper, the SI (metric) will be the system addressed.

Some of the standards and definition are for the most part absolute, but most are arbitrary… but globally accepted. As a diversionary example, the stars in the sky form constellations, and the regions of these constellations completely encompass and define the sky. Different cultures may assign different patterns. We agree on these arbitrary patterns so that these stars can be identified by many countries and cultures that adopt our definition of those constellations. However, the naming is quite arbitrary. It can be reasoned that it is more important to understanding what those stars are, how they got that way and what's in store for them... rather than what we call them.

In general, standard units of measure often get proportioned into a size that is directly relatable to humans. Call those standards of convenience. For example, as scientists considered a standard for length, it is likely they were looking for something greater than the width of a hand, but shorter than the height of an average person. A standard weight should be one that is relatively easy to carry around, as should be a standard for volume.

In antiquity different cultures had their own, often unique, standards of measure. As the world started to connect, it became important to develop standards understood and accepted by the global community.

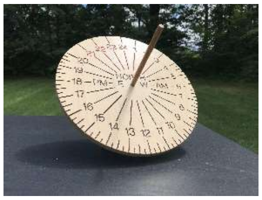
Angle – degrees



The circle is a fundamental building block of measurement. Circles are proportionally the exact same everywhere, in any country, during every era in history, at any altitude and at any temperature. The ancient Babylonians based their numbering system on the number 360, and were the ones to define that is circle is comprised of 360 equal wedges of pie, or 360°.

Time – second

We agree that there are 360 degrees in a circle, and 24 hours in a day. That means that one hour is equal to 360°/24 = 15° of observed transit of the sun across the sky. A sundial (an equatorial sundial) can be fashioned where the hours were laid out with this spacing of 15°. Water clocks were used thousands of years B.C., and likely calibrated to the hour. Eventually craftsmen created a sand hourglass that held just the right amount of sand to measure one hour (or whatever time increment they wished. These were much more consistent and portable than the water clocks. With these sandglasses, time could be measured without direct a shadow from the sun.



After mechanical timepieces were developed, the ability to measure fractions of an hour was enhanced. Minutes might have been able to be estimated from a finely crafted sundial, but the mechanical timepiece brought that ability indoors. Minutes were then able to be resolved into seconds.

In the 1970's, the quartz clock brought unprecedented accuracy and repeatability to the average person, at remarkably low cost. These quartz clocks were based on the piezoelectric principles of quartz crystals.

Eventually, measurement of the second was based on the vibrations of a cesium clock… proving to be extremely precise and consistent.

Distance – meter (m)

A standard for distance could have been based on a cubit… the distance from the elbow to the fingertip. Something close to one cubit would be a convenient unit of measure, a stick with a certain length that could be easily wielded. But whose cubit? If it was based on a king, then other kings might take issue with that. Scientists deferred to the constant nature of the Earth.

Our numbering system is based on factors of 10. So, determine the distance from the equator to the pole and keep dividing by 10 until a convenient length is reached. By convenient, we mean one that is a length of something we can easily carry around… not too large, and not to small.

Roby will take some survey equipment up a cliff next to a large body of water defining his horizon. He creates an arbitrary measurement length (because he doesn't know what a meter is yet) … let's say it is one Honda, based on the length of his car. With his surveying equipment, he can determine the height of the hill above sea level in units of Honda. On a calm day, he measured the angle from his plumb bob line to the horizon. It would have been an angle a little less than 90°. Maybe he makes many more measurements on different days and averages it all out. Roby calculates the Earth's radius and determines that the distance from the equator to the north pole is about 2,187,000 Hondas. If he divides this distance by 1 million, he arrives at a length of 2.187 Hondas, which is a pretty large distance and not too convenient. He divides again by a factor of 10 to get 0.2187 Hondas, about the length of his guitar. Had he divided again by 10, this would result in a distance about the width of his hand, which seems inconveniently small. So, the length of 0.2187 Hondas seems to be the standard length of convenience. Roby makes a measurement stick of this length.

At a different location on Earth, Jackie performs the same exercise using units of 'iPod' and makes her stick. Jackie calculates that the distance from the equator to the north pole is about 81 million iPods. She keeps dividing by factors of 10 until she reaches her standard length of 8.1 iPods. 81 iPods is too long to be convenient, and .81 iPods too short. Jackie determines that 8.1 iPods is a nice, convenient length. Jackie maker her standard stick of this length.

Roby and Jackie get together and find their sticks are the same length, although they were achieved using totally different units of measure. We call that length one meter.

Officially, diligent scientists measured this distance, taking into account the non-spherical nature of the Earth and agreed on the precise distance from the equator to the north pole. They kept dividing by powers of 10, and the convenient length of one meter resulted by dividing that large distance by 10 million. A standards lab likely fashioned the one-meter prototype rod as 'the' reference standard. Other institutions could solicit them to duplicate that length as precisely as possible for laboratories around the world. Those could be further replicated to common wooden meter stick. But the prototype standard remains the defining length for one meter.

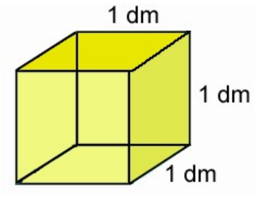
Realize that after establishment of the globally accepted meter, the distance from the equator to the pole would slightly change due to improved scientific capability… but the standard meter didn't change. It remained the prototype standard rod ever since it was crafted. Although we may say that the meter is 1/10,000,000th the distance from the equator to the north pole, it will not be exactly true. But the meter is based on that geologic measurement.

In time, scientists used the light waves of specific frequency to measure the actual length of the original prototype standard rod with unmatched precision. That experiment could be replicated around the world with those that had the equipment. Scientists could then precisely recreate the prototype meter without reference to the original physical prototype standard

In the atomic age, the definition became even more precise by relating one meter to the distance light travels in a vacuum.

Volume – liter (l)

If you make a cube with side dimensions of 1/10 meter (or dm, decimeter), you have one liter. If you have one liter of pretty much anything, it should be relatively easy to carry around. If the standard unit volume would have been one cubic meter, that would create an unwieldy volume. It seems that the standard was sized to create a volume of convenient size.



Mass – kilogram (kg)

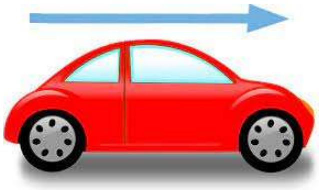
In ancient times, a grain of barleycorn was used as a mass standard. You could count out 1,000 grains of barleycorn and, using a balance, grind down a stone until it has the same mass. You'd now have a portable standard to use at the marketplace. That stone should be pretty close to the mass of someone else's stone representing 1,000 grains of wheat.

One liter of distilled water at 4°C basically has the mass of one kilogram. Water is the densest at about 4°. The mass of a pineapple is about one kilogram. One kilogram seems convenient… not too heavy, not too light.

In 1889 an updated standard, the International Prototype of the Kilogram (IPK) was created as a metal prototype, one designed with a certain material and shape to minimize oxidation and changes to its mass by the environment. A 90% platinum, 10% iridium material was chosen and machined into a right circular cylinder equal to a mass internationally agreed as the standard. This slug of metal was kept in nested vacuum jars. Several of these prototype standards were created, matched as precisely as possible and distributed to national standard laboratories around the world.

Then in 2019 the kilogram was more precisely defined in terms of the Planck Constant, the speed of light and the characteristic of cesium.

Velocity – meters/second (m/s)



Velocity is the rate change if distance. It is defined by units previously derived and uses distance (meter) and time (second). Speed is the amount of distance covered in one second. Recognize that speed is different from velocity. Technically, velocity also needs a directional component and is characterized as a vector. This is one set of terms that are commonly interchanged without too much grief. Saying "I am driving 60 km/hr" is a speed. Saying "I'm driving north at 60km/hr" is a velocity. Few people seem to nit-pick the difference.

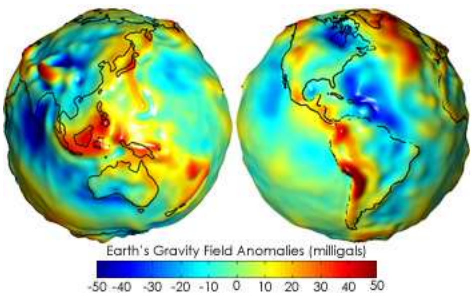
Velocity can be static, such as driving at a constant speed in the same direction. It can be dynamic and changing its amplitude or direction with time. The vector properties are apparent when considering acceleration (below). You can be driving at constant speed but in a turn, the change of velocity (caused by the change in direction) results in acceleration which will create lateral forces to the car and its contents.

Acceleration – meters/second^2 (m/s^2)

Acceleration occurs when velocity changes. Acceleration is the measure of how quickly velocity changes. It is velocity (meters/second) as it changes over time (per second). Sometimes this is referred to as meters/second per second which is the same thing as m/s^2. When driving in a car, the forces that make you lean during a turn, force your body back into the seat when speeding up or forcing your body to the front of the car when braking are due to your mass, and the acceleration of the car.

Acceleration – g

Most accelerometer manufacturers outside the USA specify sensitivity (signal output per unit acceleration) with acceleration units of m/s^2. It is suggested here that those units are the most practical. Most accelerometer manufacturers inside the USA specify sensitivity in terms of ‘g’, and maybe providing a parenthetical conversion to m/s^2. The g is assumed to mean the equivalent acceleration at the Earth’s surface due to the influence of gravity. It is also assumed to be equal to approximately 9.81 m/s^2. Confusion might arise when you consider that the value of g changes (slightly) over the surface of the Earth. This term is the net effect of the gravitational constant pulling objects toward the Earth’s center of mass, and the centrifugal force throwing it away from the Earth’s center of mass, due to rotation. This doesn’t make USA fabricated accelerometers any better or worse… it’s just another way we Yanks take pride in standing apart from conventions commonly accepted by the rest of the technical world. We still use, inches, pounds, Fahrenheit degrees, g’s and call the last letter of our alphabet ‘zee’.



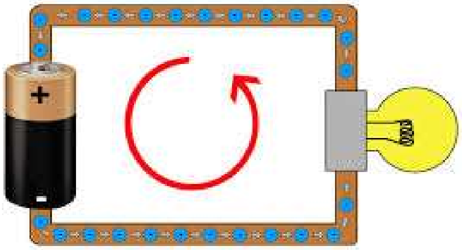
To keep the terms squared away, consider Newton’s law of universal gravitation.

Electric Potential – Volt

Consider a water analogy: The water level in a tank determines its ability to do work. It doesn’t mean it necessarily IS doing anything… it could be just sitting there. But when water is allowed to flow out of the tank, it can do work. The higher the water level, the more work it is capable of doing. The level of the water in a tank is analogous to electric potential. A household battery may have an electric potential of 1.5 Volts, whether it is working in a circuit or not.

Early manifestations of electric potential were experienced in the form of static electricity. In 1800, Alessandro Volta developed a method to generate electric potential with a device similar to a battery. In 1836 It was further developed into the Daniell cell that proved to be a stable, and greatly improved type of battery. Because of its consistency, it became widely used in telegraphy applications. Its electric potential was deemed to be the standard, and it was called a Volt.

Current – Ampere (A)



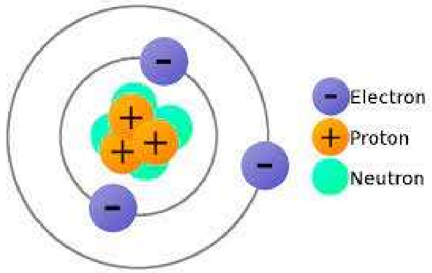
Think of the water analogy. An example of current is the amount of water that passes through a hose per second. Better yet, think of it as the quantity of water molecules that pass through a hose per second. That's a lot of molecules.

The origins of the Ampere unit is rooted not in the SI system, but in the CGS (centimeter-gram-second) system which was the standard at the time in 1881. It was the amount of current that generates a force of two dynes per centimeter of length between two wires one centimeter apart. The equivalent of current was later defined in the SI system as the amount of current that would deposit a fixed weight of silver per second from a solution of silver nitrate.

The standard for current is the Ampere, which is one Coulomb of charge passing through a wire in one second.

Once the elementary charge of the proton and electron were determined, the Ampere was later defined as one Coulomb worth of elementary charges moving past a point in one second.

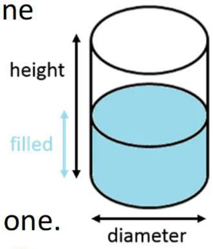
Charge – Coulomb (C)



A coulomb is a quantity of charge carried by a l???, called an elementary charge. It is a LOT of elementary charges, over 6 billion billion of them (6.24 x 10^{18}). In the water analogy, think of one charge as a molecule of water.

Capacitance – Farad

Start with a water analogy. Imagine a cylinder filled with water. This cylinder is one meter tall, and the base area is arbitrary. If the base area of the container is very small, then the container will not hold much water (has less capacity to store water). If the area is large, it will hold more water (has a greater capacity to store water). Consider discussing the amount of water in terms of water molecules, rather than volume. A larger vessel contains more water molecules than a smaller one. Assign an arbitrary number of water molecules to use as a standard. Let's say one billion water molecules just for the fun of it. Imagine a vessel that is one meter tall which has the ability to store one billion water molecules.



Now apply this water analogy to the electricity model. Let electric charge (Coulombs) replace the model of water molecules. Let volts replace the height of one meter. Imagine a body that has the capacity to store one Coulomb of charge that results in a potential difference of one volt.