The story of base units in brief

There are myriad units for measuring all sorts of quantities and magnitudes. For example, length can be measured in yards, inches, versts and numerous other units. The basic units of time, however, have been essentially the same for everyone all throughout history. The world is united in thinking in days, months and years, subdivided into hours, minutes and seconds.

Time

The second, selected as the base unit of time, is derived from the length of the ideal tropical day. The day is subdivided into twenty-four hours, in each hour there are sixty minutes, and every minute consists of sixty seconds. It exactly equals the length of one 86,400th of an ideal tropical day of an ideal tropical year. Of course, in reality there is no such thing as an ideal second.

Greater accuracy of measurement methods requires precise definitions of base units. The second has therefore been redefined as the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium-133 atom (^{133}Cs). That constitutes a big change. This number of periods was selected so that the new definition of the unit would be as close as possible to the old one.

Having an exact number as the base unit of time leads to certain problems when dealing with time in reality. Occasionally, a leap second has to be added to the year because there is a difference precise time does not exactly correspond to observed solar time, because the rotation of the Earth is changes over time. The International Earth Rotation and Reference Systems Service (IERS) is a service organization doing exactly that.

Length

The metre, which is the base unit of length, is a product of human thinking accustomed to the decimal number system. It was originally defined as the ten millionth fraction of a quarter of the terrestrial meridian, embodied as a metal etalon with two scratch marks. So, the metre is derived from the size of the Earth even though its metal etalon is not same as the value which defines it. The etalon nevertheless served its purpose well for more than one hundred years. Progress in physics then necessitated a more precise definition of the metre, and this was devised using the wavelength of orange light emitted by a krypton discharge tube. As has happened with the second, the metre has been redefined as 1,650,763.73 wavelengths of such light. The aim was to redefine the metre as closely as possible to the old metal etalon.

The year 1983 brought about yet another big change, this time to the definition of the metre. Since then it has been reckoned as the distance travelled by light in exactly 1/299,792,458 s. The velocity of light, 299,792,458 ± 0.5 m/s, is a greatly popular constant. In a vacuum it is always the same for any object regardless of its speed, as postulated by the theory of relativity. For the purpose of defining the metre, the range of accuracy (± 0.5 m/s) is omitted, so the precision of the definition of the metre comes from the accuracy of the measurement process. We need to measure one second and after that to measure the length of one meter.

One metre is the distance travelled by light in vacuo for exactly $\frac{1}{299792458}$ of a second. The relationship between length and time can therefore be expressed by the equation s (length) = c (speed of light) · t (time).

Mass

As in the case of the metre, the base unit of mass, the kilogram, has a metal etalon made of an alloy of platinum and iridium, even though mass stems from length in three spatial dimensions. One tenth of a metre is a decimetre, and one cubic decimetre of water under normal conditions weighs one kilogramme. Analogically, the gram equals the mass of one cubic centimetre of water.

The metal etalon of the kilogram was made more than 200 years ago. As to why this primary standard had been the same for such a long time is beyond the scope of this article. Today, the base unit for weight, the kilogram, is defined in the same spirit as the second and the metre, by invoking the Planck constant, which is exactly equal to the number $6{,}626{,}070{,}15 \times 10^{-34}$ J/s.

Two fundamental pieces of information about our universe, the speed of light and the Planck constant are derived, like all other physical constants, from old base units and are defined with a certain accuracy.

Mass can be derived from the Planck constant. Expressed using base units, the joule (J) is the same as $kg \cdot m^2/s^2$. One J/s therefore translates to 1 $kg \cdot m^2/s$. The definition of the second and the metre therefore allows us to realize the definition of the kilogram using a special Kibble (watt) balance.

Conclusion

is the purpose of this chapter if it doesn’t bring anything new? It is to summarize where base units come from and how they are related to each other. The second, the metre and other base units are useful approximations for describing our universe. What we measure are mere ratios between measured values and base units. The fundamental question is how to measure the dimensions of spacetime with utmost precision if every part of the universe is constantly changing, and not only due to the thermal motion of atoms and molecules, but also quantum vacuum fluctuations.