Introduction to Modern Physics 2018/19 (SEF038)

Scale and Unit

Key words

- Scale and unit
- SI unit
- Joule and MeV

Scale

Physics deals with the very small to the very large. Let's go through a quick view of scales from the famous "Power of Ten" a movie (1977) directed by Charles and Ray Eames (1998 selected to USA National Film Regsitry, https://en.wikipedia.org/wiki/Powers_of_Ten_(film (https://en.wikipedia.org/wiki/Powers_of_Ten_(film))).

scale	name	symbol	
10^0			
10^1	*deca*	*da*	
10^2	*hecto*	*h*	
10^3	*kilo*	*k*	
10^6	*mega*	*M*	
10^8			$c = 299,792,458\ m/s \sim 3 \cdot 10^8\ m/s$
10^9	*giga*	*G*	*Radius of the Sun*
10^{11}			*Solar system*
10^{12}	*tera*	*T*	
10^{13}			*Pluto orbit* (1930) → *asteroid* (2006)
10^{15}	*peta*	*P*	
10^{16}			$1\ lyr = 0.946 \cdot 10^{16}\ m,\ 1pc = 3.26\ lyr$
10^{18}	*exa*	*E*	
10^{21}	*zetta*	*Z*	*Milky Way*
10^{24}	*yotta*	*Y*	*Limit of vision*
10^{26}			46 *Glyr = Cosmic Microwave Background*

Man, the universe is huge! Even tiny Milky Way is much larger than 1 light year! (sorry you have a really small chance to meet any Aliens). Notice, CMB is from distance 46 Glyr, which means light spend 46 billion years to arrie to the Earth. There is already something strange..., the age of the universe is 13.8 billon years? Let's move on to a smaller scale.

scale	*name*	*symbol*	
10^{0}			
10^{-1}	*deci*	d	
10^{-2}	*centi*	c	
10^{-3}	*milli*	m	
10^{-4}			*Human limit*
10^{-5}			*Human hair*
10^{-6}	*micro*	μ	
10^{-8}			*DNA*
10^{-9}	*nano*	n	*Molecularsizes*
10^{-10}	Ångström	Å	*Atom*
10^{-12}	*pico*	p	
10^{-14}			*Nucleus*
10^{-15}	*femto*	f	*Nucleon*
10^{-18}	*atto*	a	
10^{-21}	*zepto*	z	
10^{-24}	*yopto*	y	
10^{-35}			*Planck length*

The smallest we can reach is the inner structure of a nucleon, so 10^{-16} or so, but theory suggest space-time may be discrete at Planck scale (=size of "strings" of string theory?)

Unit

In our world, we use **SI unit** system (international system of units or "Système international d'unités"). SI unit is also called **MKSA system** because it includes metre (m), kilogram (kg), second (s), and ampare (A). All other units are derived from SI units. Science often uses other system as well. For example, physics for small world (including nuclear physics, particle physics, etc) often describes energy with **mega electron volt (MeV)** where $1\ MeV = 1.602 \cdot 10^{-13}\ J$ and $1\ MeV/c^2 = 1.782 \cdot 10^{-30}$kg. Alternatively, **CGS system** use centi-metre (cm), gram (g), and second (s) for the bases of units.

	Energy	*Momentum*	*Mass*
SI unit	$J\ (kg \cdot m^2/s^2)$	$kg \cdot m/s$	kg
Small world	$MeV\ (1.602 \cdot 10^{-13}\ J)$	MeV/c	MeV/c^2

SI units

5 of 7 SI units are defined by following way.

Table 1. Present SI base quantities, base units, and definitions		
Base quantity	**Base unit**	**Definition**
Time	second	The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom.
Length	meter	The meter is the length of the path traveled by light in vacuum during a time interval of 1/299 792 458 of a second.
Mass	kilogram	The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram.
Electric current	ampere	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 2×10^{-7} newton per meter of length.
Thermodynamic temperature	kelvin	The kelvin, unit of thermodynamic temperature, is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water.

However, from 2018, this SI unit will be changed a lot. The main purpose of this is to **remove kilogram**! Below is the list of new SI units. This shift will not affect our dayly lives.

Table 2. New SI base quantities, defining constants, and definitions		
Base quantity	**Defining constant**	**Definition**
Frequency	$\Delta\nu(^{133}\mathrm{Cs})_{\mathrm{hfs}}$	The unperturbed ground-state hyperfine splitting frequency of the cesium-133 atom $\Delta\nu(^{133}\mathrm{Cs})_{\mathrm{hfs}}$ is exactly 9 192 631 770 hertz.
Velocity	c	The speed of light in vacuum c is exactly 299 792 458 meter per second.
Action	h	The Planck constant h is exactly 6.626X $\times 10^{-34}$ joule second.
Electric charge	e	The elementary charge e is exactly 1.602X $\times 10^{-19}$ coulomb.
Heat capacity	k	The Boltzmann constant k is exactly 1.380X $\times 10^{-23}$ joule per kelvin.

Useful numbers

$h = 6.626 \times 10^{-34}\ J \cdot\ s$
$c = 2.998 \times 10^{8}\ m/s$
$e = 1.602 \times 10^{-19} C$
$N_A = 6.022 \times 10^{23}$
$k_B = 1.380 \times 10^{-23}\ J/K$
$\hbar \cdot c = 197\ MeV \cdot fm$
$G_N = 6.674 \times 10^{-11} N \cdot m^2/kg^2$
$1pc = 3.26\ lyr$