

Elementary Particle Physics
from the context of the courses
PHY 493: Elementary Particle Physics

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0.1 The SI System

In physics it's often important to have precisely defined units for the purposes of making very accurate measurements or simply having a coherent unit system. It's possible to derive all necessary units from five measurements of **length, mass, time, current, and temperature**. The standard SI units for these properties are listed below:

Type	Unit	Definition
Length	Meter(m)	Length of distance light in a vacuum travels in $\frac{1}{299792458}$ seconds
Mass	Kilogram(kg)	Defined by fixing the Planck's constant $h = 6.62607015 \times 10^{-34} kg \cdot m^2 s^{-1}$
Time	Second(s)	Defined by fixing the ground-state hyperfine transition frequency of the caesium-133 atom, to be $9192631770 s^{-1}$
Current	Ampere(A)	Defined by fixing the charge of an electron as $1.602176634 \times 10^{-19} A \cdot s$
Temperature	Kelvin(K)	Defined by fixing the value of the Boltzmann constant k to $1.380649 \times 10^{-23} kg \cdot m^2 s^{-2} K^{-1}$

Common prefixes are listed below:

Prefix	Symbol	Definition
mega	M	10^6
kilo	k	10^3
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}

Additionally, the following are defined constants:

Symbol	Definition
\hbar	$\hbar = \frac{h}{2\pi} \approx 1.0546 \times 10^{-34} kg \cdot m^2 s^{-1}$

Chapter 1

Fundamental Particles

1.1 Fermions and Bosons

Definition 1.1.1. A **fermion** is a particle with half integer spin.

Definition 1.1.2. The **color** of a particle is a quantum number that can be in 7 possible states: colorless, red, green, blue, anti-red, anti-green, and anti-blue.

Definition 1.1.3. A **quark** is a fermion with color charge and an **anti-quark** is a fermion with anti color charge.

Table 1.1.4. Quarks and Anti-Quarks Table of quarks and anti-quarks and their corresponding properties.

Name	Sym.	S	Q	B_a	T_3	I_3	C	S	T	B_o	Mass (MeV/c ²)
Up	u	1/2	2/3	1/3	1/2	1/2					2.3
Anti-Up	\bar{u}	1/2	-2/3	-1/3	-1/2	-1/2					2.3
Down	d	1/2	-1/3	1/3	-1/2	-1/2					4.8
Anti-Down	\bar{d}	1/2	1/3	-1/3	1/2	1/2					4.8
Charm	c	1/2	2/3	1/3	1/2		1				1.275×10^3
Anti-Charm	\bar{c}	1/2	-2/3	-1/3	-1/2		-1				1.275×10^3
Strange	s	1/2	1/3	1/3	-1/2			1			1.01×10^2
Anti-Strange	\bar{s}	1/2	-1/3	-1/3	1/2			-1			1.01×10^2
Top	t	1/2	2/3	1/3	1/2				1		1.72×10^5
Anti-Top	\bar{t}	1/2	-2/3	-1/3	-1/2				-1		1.72×10^5
Bottom	b	1/2	-1/3	1/3	-1/2					1	4.19×10^3
Anti-Bottom	\bar{b}	1/2	1/3	-1/3	1/2					-1	4.19×10^3

S is spin (\hbar), Q is electric charge (e), B_a is baryon number, I_3 is strong isospin, T_3 is weak isospin, C is charmness, S is strangeness, T is topness, B_o is bottomness.

Definition 1.1.5. a **lepton** or an **anti-lepton** is a fermion with no color charge.

Table 1.1.6. Leptons and Anti-Leptons Table of leptons and anti-leptons and their corresponding properties.

Name	Sym.	S	Q	L_e	L_μ	L_τ	T_3	Mass (MeV/c ²)
Electron	e	1/2	-1	1			-1/2	5.10998×10^{-1}
Anti-Electron	\bar{e}	1/2	1	-1			1/2	5.10998×10^{-1}
Muon	μ	1/2	-1		1		-1/2	1.0565×10^2
Anti-Muon	$\bar{\mu}$	1/2	1		-1		1/2	1.0565×10^2
Tau	τ	1/2	-1			1	-1/2	1.776×10^3
Anti-Tau	$\bar{\tau}$	1/2	1			-1	1/2	1.776×10^3
Electron Neutrino	ν_e	1/2		1			-1/2	< 0.0000022
Electron Anti-Neutrino	$\bar{\nu}_e$	1/2		-1			1/2	< 0.0000022
Muon Neutrino	ν_μ	1/2			1		-1/2	< 0.17
Muon Anti-Neutrino	$\bar{\nu}_\mu$	1/2			-1		1/2	< 0.17
Tau Neutrino	ν_τ	1/2				1	-1/2	< 15.5
Tau Anti-Neutrino	$\bar{\nu}_\tau$	1/2				-1	1/2	< 15.5

S is spin (\hbar), Q is electric charge (e), L_e is lepton electron number, L_μ is lepton muon number, L_τ is lepton tau number, and T_3 is weak isospin.

Definition 1.1.7. A **Boson** is a particle with integer spin.

Table 1.1.8. Bosons Table of bosons and their corresponding properties.

Name	Sym.	S	Q	T_3
Photon	γ	1		or 1
Positive Weak	W^+	1	1	1
Neutral Weak	Z^0	1		or 1
Negative Weak	W^-	1	-1	-1
Gluon	g	1		
Higgs	H^0			

S is spin (\hbar), Q is electric charge (e), and T_3 is weak isospin.

1.2 Feynman Diagrams

Definition 1.2.1. A **feynmann diagram** is a pictorial representation of and interaction between particles.

1.3 Rutherford Scattering

Definition 1.3.1. The **Rutherford scattering experiment** was an early experiment that demonstrated the approximate size of the nucleus. The scattering of electrons off a charged nucleus can be approximated with

$$N = \frac{N_i n L Z^2 k^2 e^4}{4r^2 E^2 \sin^4(\theta/2)} \quad (1.3.1)$$

where N is the rate of detected α particles, N_i is the rate of incoming α particles, n is atoms per unit volume, L is thickness of the target, Z is the atomic number, r is the distance from the target, E is the kinetic energy, and θ is the scattering angle.