Elementary Particle Physics

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

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Contents

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 bellow:

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 $h = 6.62607015 \times 10^{-34} kg\ m^2 s^{-1}$
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 bellow:

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

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 possibles 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 there 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	$\overline{u}$	$1/2$	$-2/3$	$-1/3$	$-1/2$	$-1/2$					2.3
Down	d	$1/2$	$-1/3$	$1/3$	$-1/2$	$-1/2$					4.8
Anti-Down	$\overline{d}$	$1/2$	$1/3$	$-1/3$	$1/2$	$1/2$					4.8
Charm	c	$1/2$	$2/3$	$1/3$	$1/2$		1				1.275×10^3
Anti-Charm	$\overline{c}$	$1/2$	$-2/3$	$-1/3$	$-1/2$		-1				1.275×10^3
Strange	s	$1/2$	$-1/3$	$1/3$	$-1/2$			1			1.01×10^2
Anti-Strange	$\overline{s}$	$1/2$	$1/3$	$-1/3$	$1/2$			-1			1.01×10^2
Top	s	$1/2$	$2/3$	$1/3$	$1/2$				1		1.72×10^5
Anti-Top	$\overline{s}$	$1/2$	$-2/3$	$-1/3$	$-1/2$				-1		1.72×10^5
Bottom	s	$1/2$	$-1/3$	$1/3$	$-1/2$					1	4.19×10^3
Anti-Bottom	$\overline{s}$	$1/2$	$1/3$	$-1/3$	$1/2$					-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	$\overline{e}$	$1/2$	1	-1			$1/2$	5.10998×10^{-1}
Muon	μ	$1/2$	-1		1		$-1/2$	1.0565×10^2
Anti-Muon	$\overline{\mu}$	$1/2$	1		-1		$1/2$	1.0565×10^2
Tau	τ	$1/2$	-1			1	$-1/2$	1.776×10^3
Anti-Tau	$\overline{\tau}$	$1/2$	1			-1	$1/2$	1.776×10^3
Electron Neutrino	e	$1/2$		1			$-1/2$	< 0.0000022
Electron Anti-Neutrino	$\overline{e}$	$1/2$		-1			$1/2$	< 0.0000022
Muon Neutrino	ν_μ	$1/2$			1		$-1/2$	< 0.17
Muon Anti-Neutrino	$\overline{\nu} - \mu$	$1/2$			-1		$1/2$	< 0.17
Tau Neutrino	τ	$1/2$				1	$-1/2$	< 15.5
Tau Anti-Neutrino	$\overline{\tau}$	$1/2$				-1	$1/2$	< 15.5

S is spin ($\hbar$), Q is electric charge (e), L_e is lepton electron number, 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

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

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.