Introduction to Elementary Particle Physics

Néda Sadooghi

Department of Physics
Sharif University of Technology
Tehran - Iran

Elementary Particle Physics

Lecture 1: Bahman 13, 1397

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Info

- Books
- Just for fun (Veltman's book)
- Exams and Homeworks
- Your grade (2+8+10 points +1 bonus point)
- Term papers (on a voluntary basis)
- Course Homepage:
  http://sharif.edu/˜sadooghi/4-Courses.html

Lecture 1: Introduction

- **Our goals:**
  - Identifying elementary particles
  - Understanding their properties
  - Learning how they interact
- **Two avenues toward these goals:**
  - Conducting experiments
  - Theoretical predictions (Model building etc)

Sources for Experimental Information:

- **Scattering events**, in which we fire one particle to another and record e.g. the angle of deflection
- **Decays**, in which a particle spontaneously disintegrates and we examine the debris
- **Bound states**, in which two or more particles stick together, and we study the properties of the composite object

Our Tools:

- **Experimental**
  - **Particle accelerators (Our eyes)**: In particle accelerators, beams of subatomic particles are boosted to nearly the speed of light and then brought into collision with either a stationary target or another beam of accelerated particles coming from head-on $\rightarrow$ **Creation of matter**
  - **Detectors (Our brains)**: Devices that surround the collision point to capture enough information about the particles produced to deduce **their properties**

Lecture 1: Introduction

(Indistinguishable Elementary) Particle Properties:

- Their (electric) charge
- Their mass
- Their spin
- Their lifetime

Lecture 1: Introduction

Our Tools:

- **Theoretical**

  - **Quantum Mechanics**; Here, the physical system is described by its state. A physical process, such as scattering or decay, consists of a transition from one state to another. But in quantum mechanics the outcome is not uniquely determined by the initial conditions (we can only calculate the **probabilities**).
    Example: $\pi^- \rightarrow \mu^- + \nu_\mu$ but sometimes $\pi^- \rightarrow e^- + \nu_e$
    Moreover: $\lambda = \frac{\hbar}{|\mathbf{p}|}$

  - **Relativistic Mechanics**; Only energy and momentum are conserved (mass is not conserved). Thus the decay $\Delta \rightarrow \pi + p$ is acceptable, even though the Δ weights more than the sum of p and π. Such a process would not be possible in classical mechanics (because of mass conservation). Moreover, relativity allows for particles or zero (rest) mass.

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Quantum Field Theory

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Quantum Mechanics + **Relativistic Mechanics**

$$[x_i, p_j] = i\delta_{ij} \qquad \longrightarrow \qquad [\Phi_i(\mathbf{x}, t), \pi_j(\mathbf{y}, t)] = i\delta_{ij}\delta^3(\mathbf{x} - \mathbf{y}) \qquad \text{(ETC)}$$

$$(\hbar = c = 1)$$

Force	Strength	Theory	Mediator
Strong nuclear	1	Q-Chromodynamics	Gluon
Electromagnetism	10^{-2}	Q-Electrodynamics	Photon
Weak nuclear	10^{-6}	Flavordynamics	W and Z
Gravity	10^{-40}	Geometrodynamics	Graviton

Standard Model of Particle Physics

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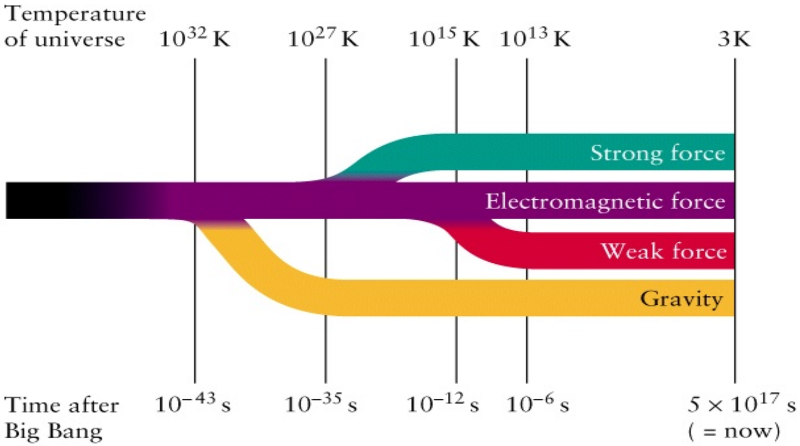
BIG BANG Cosmology

10^4K $\sim$ 1 eV



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Chemical Element:

Definition: An element is a substance that cannot be decomposed further into simpler substances by ordinary chemical means

Group → / ↓ Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba		72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra		104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo

Lanthanides	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
Actinides	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

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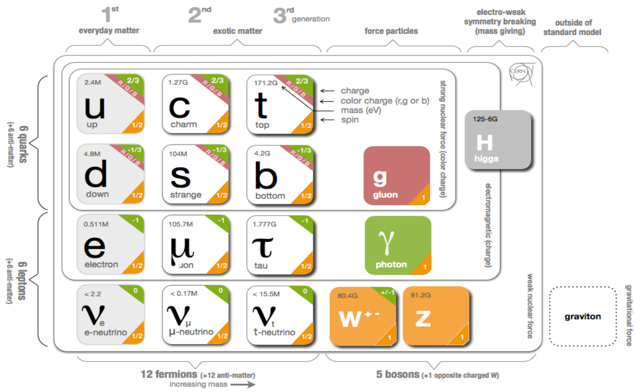
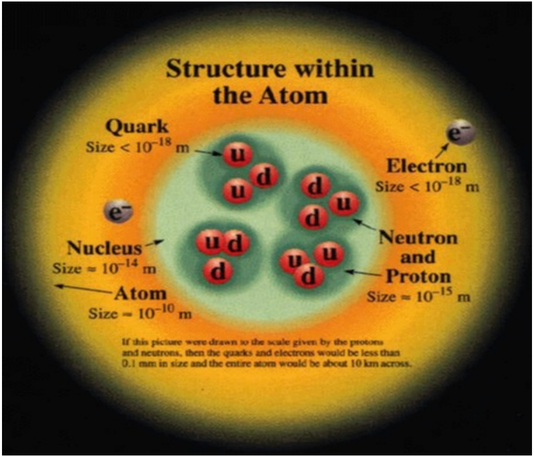
Elementary Particle:

Definition: A particle is considered to be elementary only if there is no evidence that it is made up of smaller constituents



Length Scales and Units



Length Scales and Units

Scale in m		Scale in 10^{-18} m
10^{-10} m	**Atom**	$100,000,000$
10^{-14} m	**Nucleus**	$10,000$
10^{-15} m	**Proton**	1000
$\leq 10^{-18}$ m	**Quark**	≤ 1

Length Scales and Units

	Scale in	m
Systems of planets (distance Earth-Sun)	10^{11}	m
Stars: Sun's radius	10^{9}	m
Planets, Earth's radius	10^{7}	m
Rocks, humans, $\cdots$	1	m
Grains of sands	10^{-3}	m
Viruses	10^{-7}	m
Simple molecules	10^{-9}	m
Atoms	10^{-10}	m

Length Scales and Units

Quantity	High energy Unit	Value in SI units
Length	1 fm	10^{-15} m
Energy	1 GeV=10^9 eV	1.602×10^{-10} J
Mass	1 GeV/c^2	1.780×10^{-27} kg
$\hbar = \frac{h}{2\pi}$	6.577×10^{-25} GeVs	1.054×10^{-34} Js
c	2.998×10^{23} fms^{-1}	2.998×10^{8} ms^{-1}
$\hbar c$	0.197 GeV fm	3.159×10^{-26} Jm

Length Scales and Units ($c = 1$)

Mass	Mc^2/c^2	$\to 1$ GeV
Length	$\hbar c/Mc^2$	$\to 1\ \mathrm{GeV}^{-1} = 0.197$ fm
Time	$\hbar c/Mc^3$	$\to 1\ \mathrm{GeV}^{-1} = 6.57 \times 10^{-25}$ s

Lecture 1: Introduction

Force	Strength	Range	Mediator
Strong	1	10^{-15} m (Nucleus size)	Gluon
EM	10^{-2}	Infinite	Photon
Weak	10^{-6}	10^{-18} m (Nucleon size)	$W^{\pm}$ and Z^0
Gravity	10^{-40}	Infinite	Graviton