Largely rewritten 2013

P 2260 Nuclear + Particle Physics

[What is world made of?]

What are the most fundamental elementary particles?

[Answer depends on when you ask question

Ancient greeks: earth, water, air, fire

Democritus: atoms + the void

19th c'y: ~100 distinct chemical elements
atoms = uncuttable

20th c'y: subatomic particles

Known particles c. 1935

e^- JJ Thomson 1897 (cathode rays)
p Rutherford 1911
γ Planck / Einstein / Compton named by Gilbert in 1926
n Chadwick 1932 [before that it was thought that nucleus was made of p + e^-]
e^+ Anderson 1932 (antiparticle of e^-) [explain about Dirac eqn]

A tidy picture and one that most ppl still believe
But shortly thereafter floodgates opened + by 1960's
there were 100's more.
By ~1975, the standard model of particle physics
was in place

oratory exercise, Monday, 8.30-10.30, Thursday, 1.30-3.30, Friday, 1.30-3.30. PROFESSORS LITTLE AND BARTLETT, AND DR. JEPPESEN

An introductory course covering the whole field of General Physics, and providing sufficient practice in laboratory technique to meet the elementary requirements of the other natural sciences and medicine.

Elective for Freshmen, Sophomores, Juniors, and Seniors.

3. *Mechanics.* First semester: Tuesday, Thursday, Saturday, 10.30. PROFESSOR BARTLETT

An introductory course in mechanics, dealing with the application of Newton's laws of motion to problems in the statics and dynamics of the particle and rigid body. It is designed to furnish the student with the theoretical background necessary for work in engineering or the physical sciences.

Prerequisites, Physics 1-2, and Mathematics 1, 2.

4. *Modern Physics.* Second semester: Tuesday, Thursday, Saturday, 10.30. PROFESSOR BARTLETT

An elementary survey of the development of physics in the twentieth century, with particular emphasis upon recent advances in the theory of atomic structure. It is designed primarily to acquaint the student of physics and chemistry with the evidence for the existence of the electron, proton, neutron, positron, and photon, and with our present ideas of the manner in which these fundamental particles interact to form atoms and molecules.

Prerequisite, Physics 1-2.

5. *Laboratory Physics.* First semester: Tuesday, Thursday, 8.30; Laboratory hours to be arranged, on Monday and Tuesday.

6. *Continuation of Course 5.* Second semester: at the same hours. [In 1936-1937, Course 6 is combined with Course 5 and given in the first semester.] PROFESSOR LITTLE

Standard physical measurements are made in the fields of mechanics, sound, heat, electricity and magnetism, optics, and modern physics.

Prerequisites, Physics 1-2, and Mathematics 1, 2.

7-8 *Special Laboratory or Theoretical Studies.* Whole year: three hours a week to be arranged, or an equivalent in laboratory work. PROFESSORS LITTLE AND BARTLETT

This course offers to students having requisite training the

Standard model of particle physics (c. 1975)

Elementary particles of "matter" / antiparticles

6 leptons

ν_e	ν_μ	ν_τ
e^-	μ^-	τ^-

antiparticles

$\bar{\nu}_e$	$\bar{\nu}_\mu$	$\bar{\nu}_\tau$
e^+	μ^+	τ^+

[same mass, opposite charge]

[antiparticles are the less abundant ones]

[why matter/antimatter asymmetry?]

6 quarks

u	c	t
d	s	b

$\bar{u}$	$\bar{c}$	$\bar{t}$
$\bar{d}$	$\bar{s}$	$\bar{b}$

[but quarks are never observed in isolation]

"quark confinement" due to the strong nuclear (color) force

Composites of quarks (hadrons)

baryons qqq e.g. $p = uud$, $n = udd$

antibaryons $\bar{q}\bar{q}\bar{q}$

mesons $q\bar{q}$ e.g. $\pi^+ = u\bar{d}$

[why not qq, or $q\bar{q}\bar{q}$?]

Size of hadrons $\sim 10^{-15}$ m = 1 femtometer = 1 fm = 1 fermi [Enrico Fermi]

[All pcls known before 1935 and all stable matter belongs to 1st generation.

Why does nature repeat itself?]

IN3

discuss the

elementary vs composite?

elementary ~~= point like~~ ⇒ no substructure i.e. point-like

depends on how much resolution you have

atoms as elementary

Rutherford + Thomson

electrons and nucleus elementary → it looked like pt charges → a charge distribution appears as a point outside due to Gauss's law

later after observing radioactivity eg $\alpha+ = +p$ → ~~need more energy to probe closer~~

electrons protons + neutrons

~~deep inelastic scattering~~

~~protons~~

quarks + leptons

Could ~~current elementary ptl~~ qks + leptons be composites? Yes but no evidence

to probe a scale of a chgd ptl need high energy projectile to overcome Coulomb barrier

even if not chgd, ~~need~~ Heisenberg says eg $\lambda \sim \frac{h}{p}$

→ high energy physics

so small λ, lg p, lg E

[why do composites form? force b/w pcls. Atom ← EM
Hadrons ← strong force

IN 4

Forces/interactions (described by quantum field theory = QM + SR)   Force-mediating particles

Electromagnetism (QED [1940's])   photon γ

long-range: $V = \frac{ke^2}{r}$

↳ because photon is massless

[[talk about strengths later]]

Weak nuclear (GWS [1968]) W^+, W^-, Z^0

$V \sim \frac{1}{r} e^{-\frac{r}{r_0}}$

Short range:

↳ because W, Z are massive

range $r_0 = \frac{\hbar}{M_W c}$

[[do/estimate later]]

Strong nuclear (QCD [1973])   8 gluons (massless)

Short range ~ 1 fm

↳ because of color shielding (neutrality) [similar for neutral atoms]

gravity (quantum gravity [?])   graviton

long range

↳ because graviton is massless

Symmetry-breaking sector

Higgs boson(s) [disc. 2012]

Beyond the standard model

massive neutrinos

dark matter

multiplex Higgs

more forces (grand unified theory)

supersymmetric partners

magnetic monopoles

quantum gravity?

superstrings? membranes?

old intro

QFT: All ptcls are quanta of a quantized field

Standard model of particle physics (~1975) is a QFT that describes 3 of the 4 forces.

QED [Schwinger, Feynman, Tomonaga] 1940's Nobel 1965

weak nuclear

} electroweak theory SU(2) × U(1) [Glashow Weinberg Salam] 1968 Nobel 1979

QCD (strong nuclear) SU(3) [Gross, Wilczek, Politzer] 1973 Nobel 2004 [NB: always 3! Nobel rules]

very successful at describing most data

• ~~[illegible]~~

• massive neutrinos

Is it the final answer? No.

⓪ neutrino mass.

① not unified: grand unified theories (GUTs) unite all three (e.g. SU(5), SO(10)) (but no evidence yet)

② supersymmetry (no evidence yet)

③ doesn't include gravity: TOE (string theory)

	slow	fast	massive
large	CM	SR	GR
small	nonrel QM	QFT	?

add this column