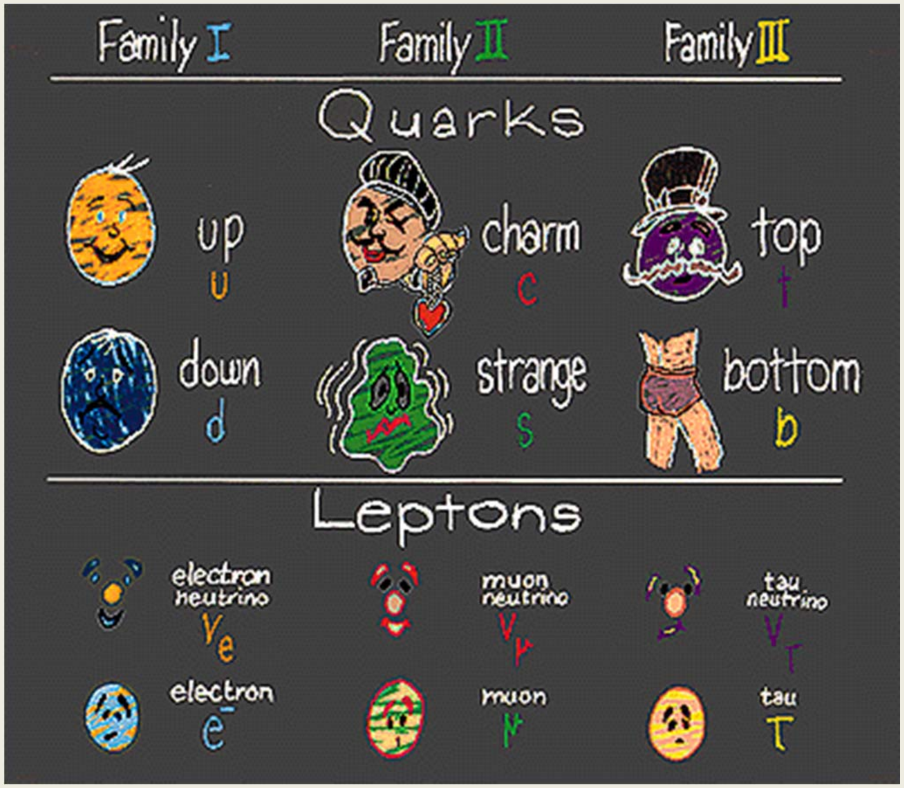


Quarknet
Syracuse Summer Institute
Particle Physics
Standard Model Introduction

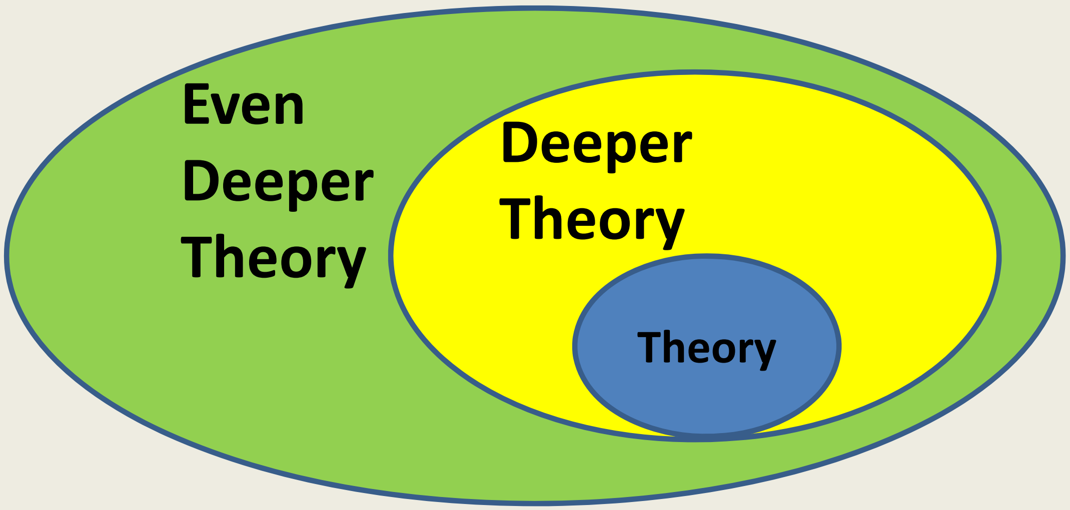
Lecture 2

Topics for Lecture 2

- Introduction to Standard Model
- Electromagnetic & Strong Interactions

Prelude

- **Definition of Theory:** a coherent group of tested general propositions, commonly regarded as correct, that can be used as principles of explanation and prediction for a class of phenomena.
- **Important to add & recall:** Theory is something that is falsifiable, but not provable.
- Theories we teach about have proven to be predictive, and therefore we believe them… but they are still falsifiable.



When do you know that you've reached the "ultimate" theory…

The Theory of Everything!
?

The Standard Model - Particles

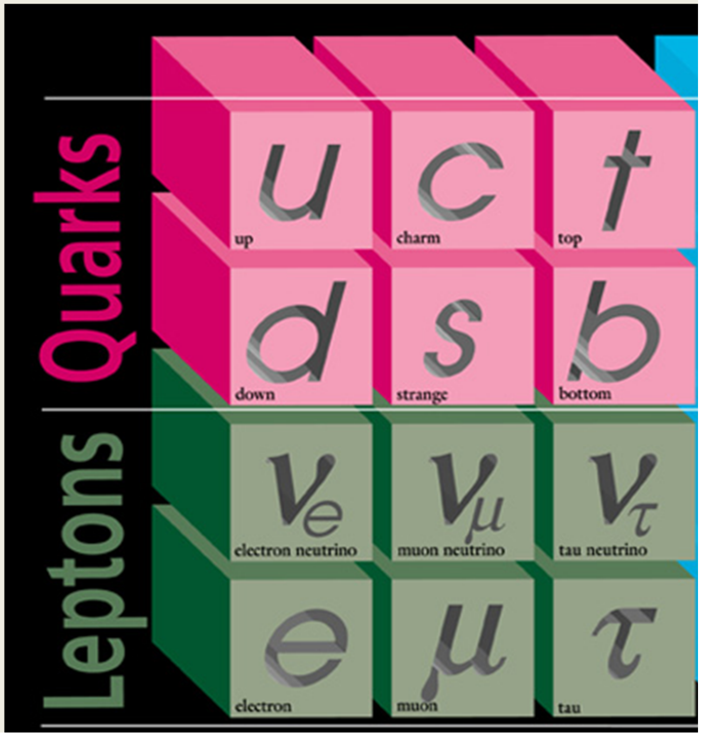
- Aim of research into matter is to come up with the **most fundamental description of particles and forces**.

- 100+ years have lead us to a fairly economical picture.

- All fundamental particles to date are found to be fermions (spin 1/2) of type:
  - **Quarks** (q=+2/3[u,c,t] or -1/3[d,s,b])
  - **Leptons** (q=0 or -1)

- Antiparticles have opposite charge and same mass as these particles.

I II III

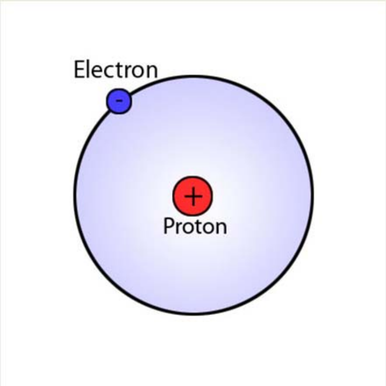


The Standard Model - Forces

- Particles interact via forces.
- What is force?
  - Yeah, OK, a push or a pull …
  - F = -dp/dt, **an exchange of momentum**.
- The modern view of forces is that they result from an **interaction between two particles**
  - Not surprising, even Newton's 3rd Law tells us that!
- In the modern view, the "interaction" is produced by the exchange of a "force carrier".
  - Each force has one (or more) carriers that mediate the interaction in question.
  - The **photon** is the **mediator** of the **electromagnetic interaction**.

The Hydrogen atom

- You all know that the principal energy levels of the H-atom is given by the simple formula:



E_n = -13.6 eV / n^2

- But where does the **13.6 eV** come from?
- From quantum physics, you can show that:

$$13.6\ eV = \frac{m_e}{2}\left(\frac{e^2}{\hbar}\right)^2 = \frac{m_e c^2}{2}\left(\frac{e^2}{\hbar c}\right)^2 = \frac{1}{2}\alpha_{em}^2 (m_e c^2)$$

- The quantity α_{em} is called the **EM coupling constant**.
- It's value is ~1/137, and gives the **strength of the coupling between a charge q=±e and a photon**.
    - What would α_{em} be the coupling between a γ and a up-quark?

What is charge anyway?

- What is electric charge?
  - I really don't know, do you?
- <u>**Best answer I have**</u>: It is an **intrinsic property** that allows certain particles to interact via the EM force, i.e. **interact with photons**.

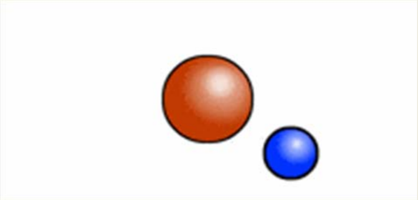
  → No charge → no play with Dr. photon !
- The **strength of the interaction** will depend on the charge (larger charge → larger force)

- What is mass? What is spin?

Coupling constants

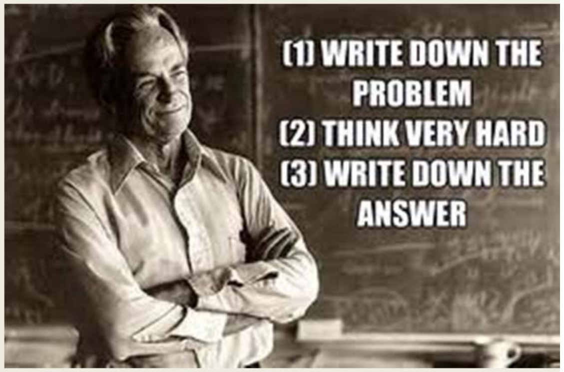
- In the H atom, the electron is bound due to the continual exchange of photons between the electron and the proton.

- The strength of that interaction is directly proportional to the EM coupling constant, α_{em}!



- In general, all force carriers will "couple to" particles with some "strength".
  - The particle in question must have the "right charge" (more on this as we go)
  - The larger the coupling constant, the large the energy level splittings, larger probability of interaction occurring, etc.

The EM force



- The quantum description of EM interactions of charged particles is called **QED (Quantum ElectroDynamics)**. Richard Feynman was a pioneer in developing QED.

- Thanks to him (and others), we can draw diagrams of interactions, apply well known "Feynman rules" to them, and calculate the rate or probability of some process.
  - So called "Feynman diagrams"
  - We won't calculate anything, but they are a **very useful** visual aid …

Back to forces

- Why does a nucleus with many (repelling) protons stay together?
  - The protons are so close, the repulsive EM force must be ginormous!
  - From Newtonian physics, you know there MUST be a STRONGER force that's holding them all together!

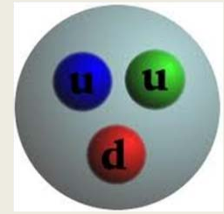
- The **STRONG FORCE**

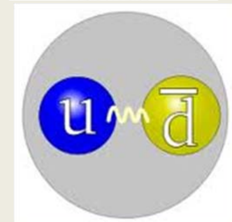
Strong Force

- The strongest of the four forces
  - responsible for holding the nucleus together.
  - Modeled after QED, due its spectacular success.
- It is called **QCD** (**Q**uantum**C**hromo**D**ynamics)
  - QCD is really a theory of the interactions of quarks
  - The binding between protons and neutrons is a residual effect of the QCD interactions.
  - Ex: Hydrogen, van der Waal, covalent, ionic, etc bonds in chemistry are NOT fundamental forces. They're all residual effects of the EM force!
- **QCD** has some similar features to QED
  - A force carrier (gluon, also massless)
  - It couples to some intrinsic property of quarks (color charge)
- **Big difference**: range limited to ~nuclear sizes (∞ range for EM force)

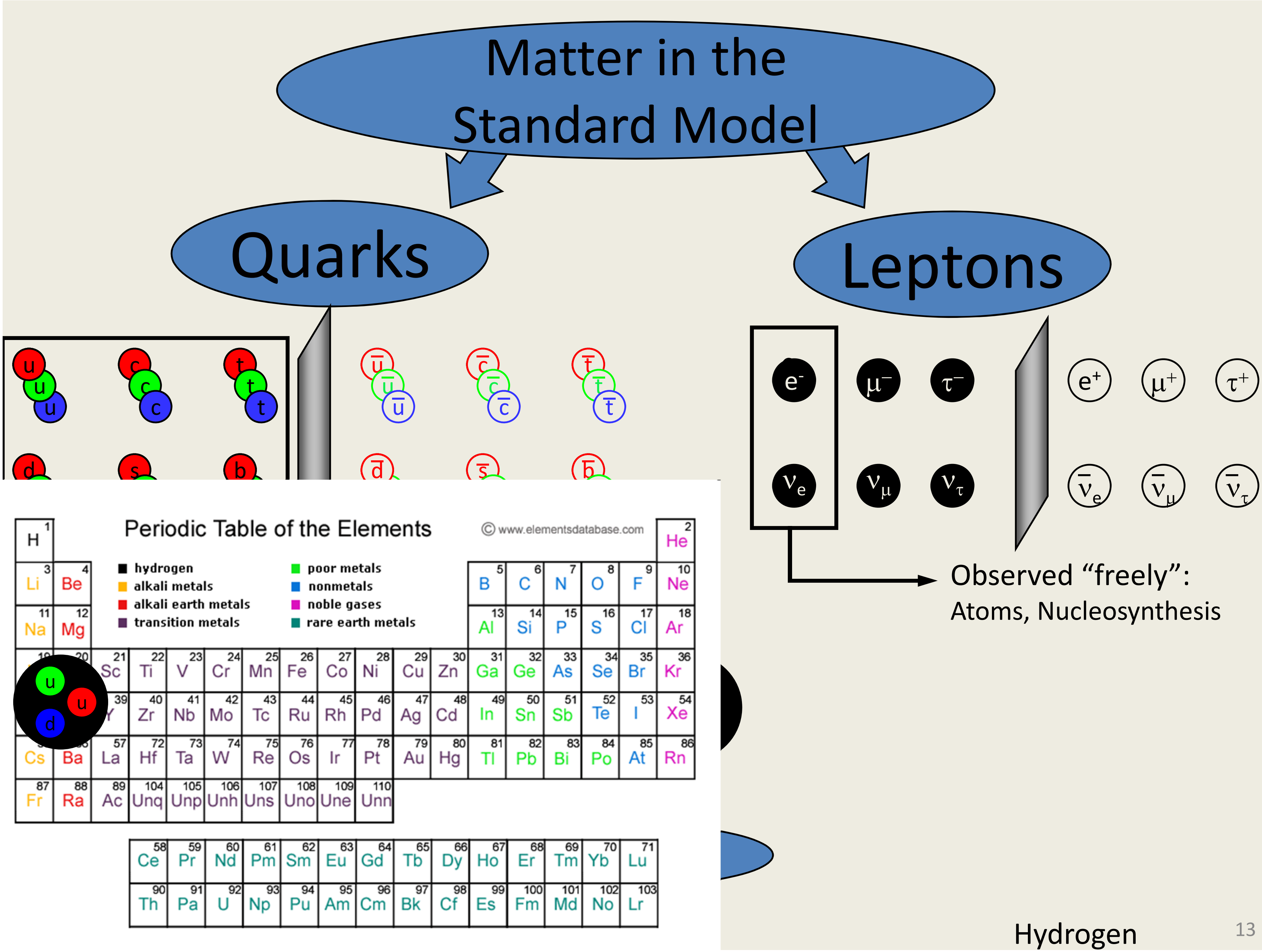
Hadrons

- We find in nature that quarks are bound up in two possible ways:
  - Baryons: 3 quarks stuck together
    proton = (uud) , neutron = (udd)
  - Mesons: quark + antiquark bound together
    pions: $\pi^+ = (u\bar{d})$, $\pi^- = (\bar{u}d)$, $\pi^0 = (1/\sqrt{2})(u\bar{u}+d\bar{d})$





- Recall, in electromagnetism, it is the <u>electric charge</u> that "allows" them to interact via the EM force (photons)
- **Quarks carry color charge, and it is <u>this property</u>** (not electric charge) **that allows them to interact via the strong force (gluons)**
  - But instead of (+,-), quarks have <u>3 possible values</u> of this attribute.
  - For historical reasons, they're labeled **RED**, **GREEN** & **BLUE**.



Matter in the Standard Model
Quarks
Leptons
u u u
c c c
t t t
d
s
b
ū ū ū
c̄ c̄ c̄
t̄ t̄ t̄
d̄
s̄
b̄
e^-
μ^-
τ^-
ν_e
ν_μ
ν_τ
e^+
μ^+
τ^+
$\bar{\nu}_e$
$\bar{\nu}_\mu$
$\bar{\nu}_\tau$
Observed "freely":
Atoms, Nucleosynthesis
Periodic Table of the Elements
© www.elementsdatabase.com
hydrogen
alkali metals
alkali earth metals
transition metals
poor metals
nonmetals
noble gases
rare earth metals
u u d
Hydrogen