Phyx 320
Modern Physics

May 3, 2021

Suggested Reading: Introduction to Elementary Particles, Griffiths

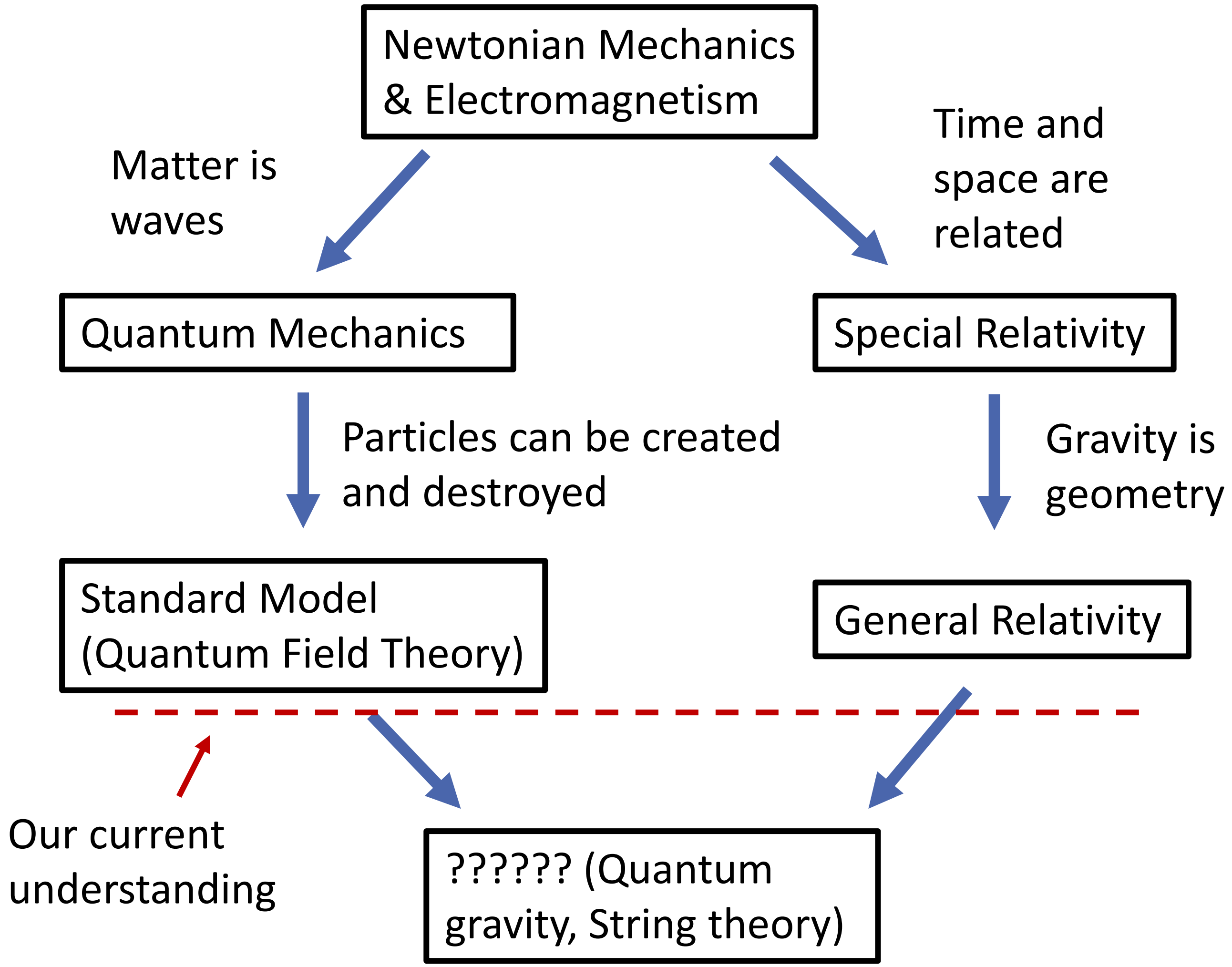
Homework #12 Due Tuesday

Modern Physics

The development of special relativity and quantum mechanics led us to our current understand of the physics

We currently have two separate theories:

- General Relativity (gravity) – space-time is bent by matter; gravity is just objects falling along straight lines in curved geometry
- Standard Model (everything else) – a particle is just an excitation of a quantum field that permeates all of space; particles interact by exchanging other particles



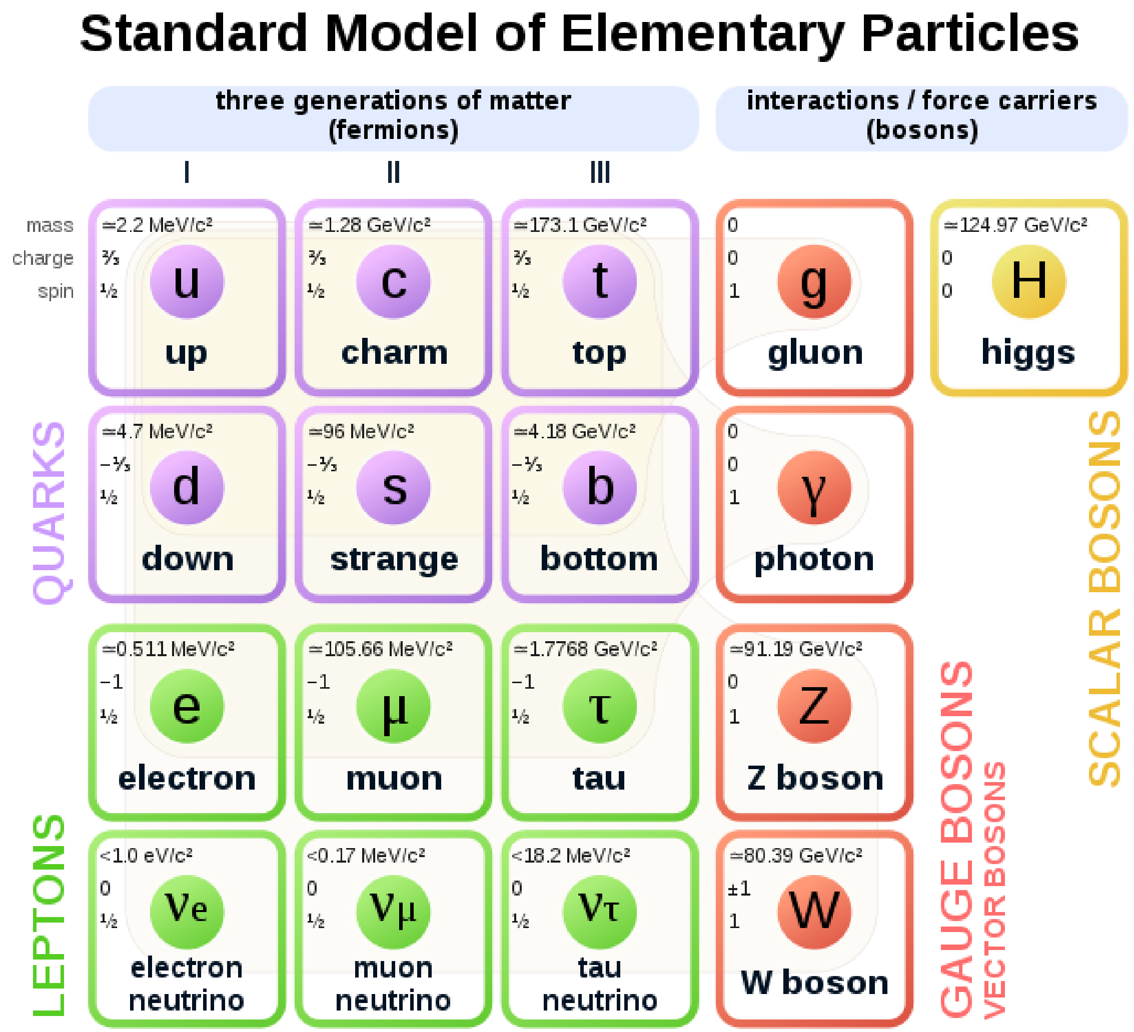
Fundamental Particles

We have two types of fundamental particles

- Fermions – spin 1/2, all matter is made of collections of fermions, follow Pauli exclusion principle
- Bosons – spin 1, forces are mediated by bosons, multiple can occupy same state

Three generations of matter, each generation is more massive than the last

Every charged particle has a corresponding antiparticle of opposite charge



Symmetries

Emmy Noether showed that every conserved quantity corresponds to a symmetry of physics

For an interaction between particles a variety of quantum numbers are usually conserved

- Electric charge (Q)
- Lepton number (L)
- Baryon number (B)
- Color charge

We also have the classically conserved quantities:

- Energy
- Momentum
- Angular momentum

$$n \rightarrow p + e^- + \bar{\nu}_e$$

Initial:

$Q = 0$

$L = 0$

$B = 1$ (n)

Final:

$Q = +1$ (p) $+ -1$ (e) $= 0$

$L = +1$ (e) $+ -1$ ($\bar{\nu}_e$) $= 0$

$B = 1$ (p)

Interactions

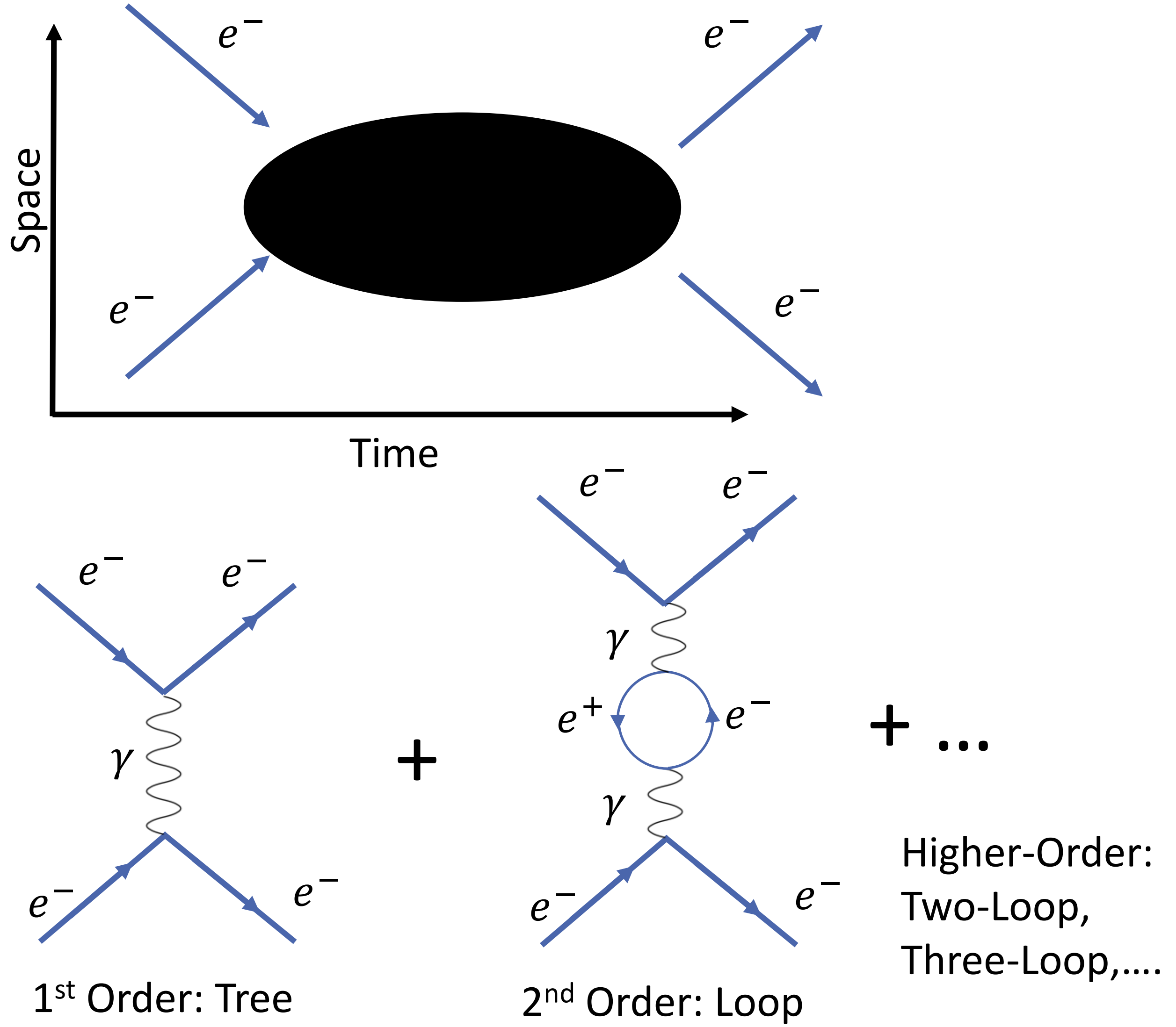
Interactions between particles are described by Feynman diagrams

Feynman diagrams are representations of approximations of integrals

Number of vertices = ½ order of approximation

Anti-particle are written as arrows moving backward in time

Only three particles can join together in a vertex



Interactions

Any interaction that can happen, will happen

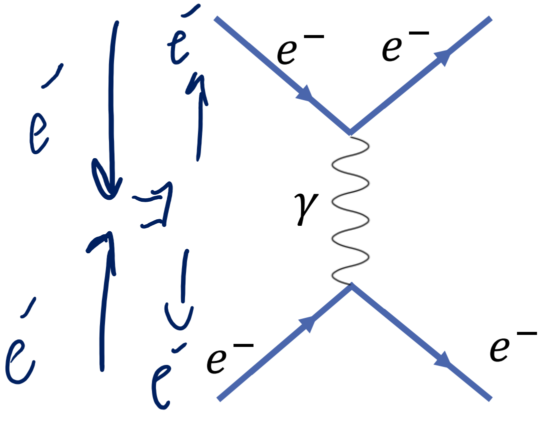
Feynman diagrams are valid no matter which way they're written

Particles with only internal connections are called virtual particles

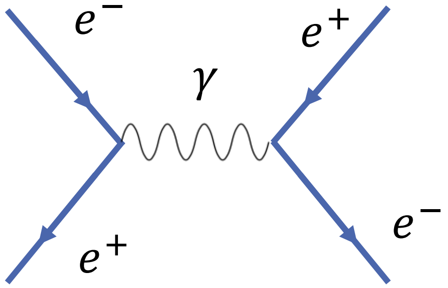
Virtual particles can not be directly detected and are limited by the uncertainty principle $\Delta E \Delta t \geq \hbar/2$

Virtual particles can have different masses than real particles but must conserve energy and momentum

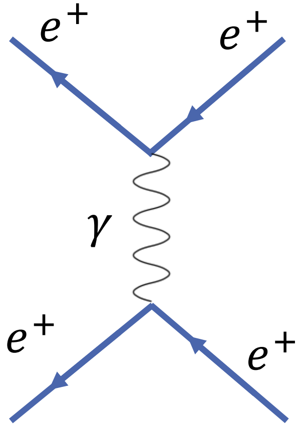
Electron-Electron Scattering



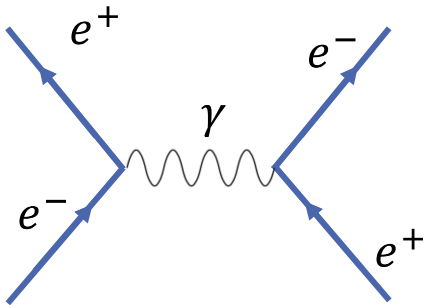
Electron-Positron Annihilation



Positron-Positron Scattering



Electron-Positron Annihilation

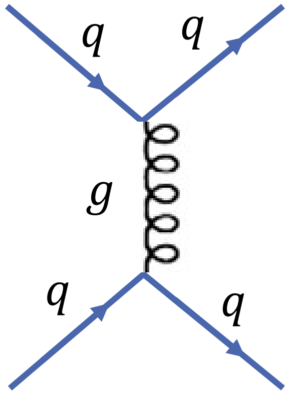


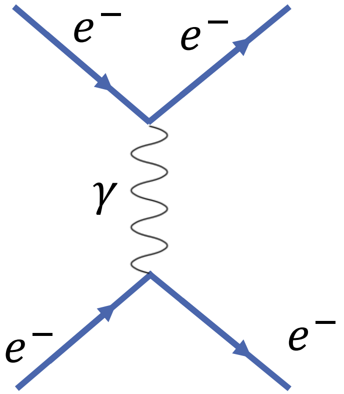
Forces

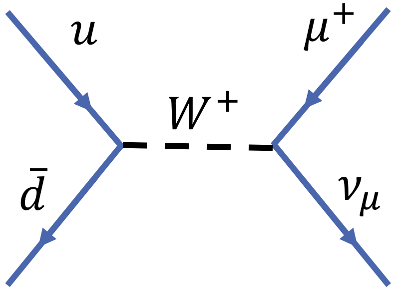
Forces are mediated through exchange of spin-1 bosons

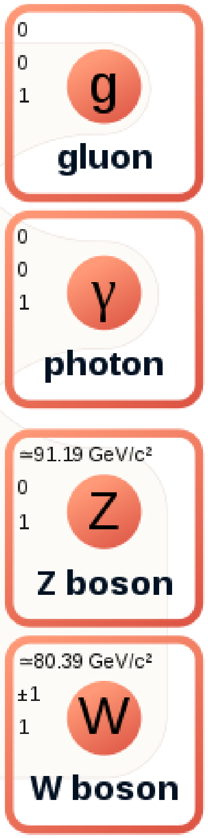
- Strong force – gluons, particles must have color (quarks)
- Electromagnetic – photons, particles must have electric charge
- Weak – Z, $W^{+/-}$ bosons, all particles

If we find evidence for a quantum description of gravity, then gravity would be the exchange of gravitons









Leptons

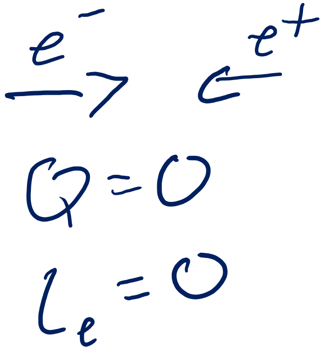
Two types of leptons

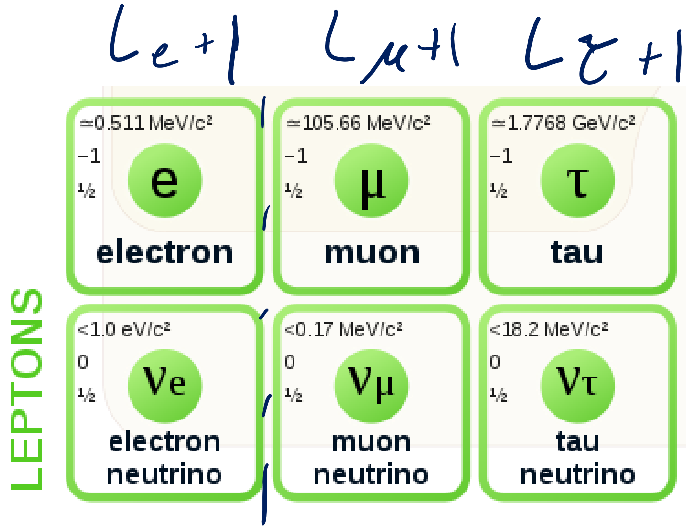
- Charged – $Q = \pm 1$, electron, muon, tau
- Neutral – electron neutrino, muon neutrino, tau neutrino

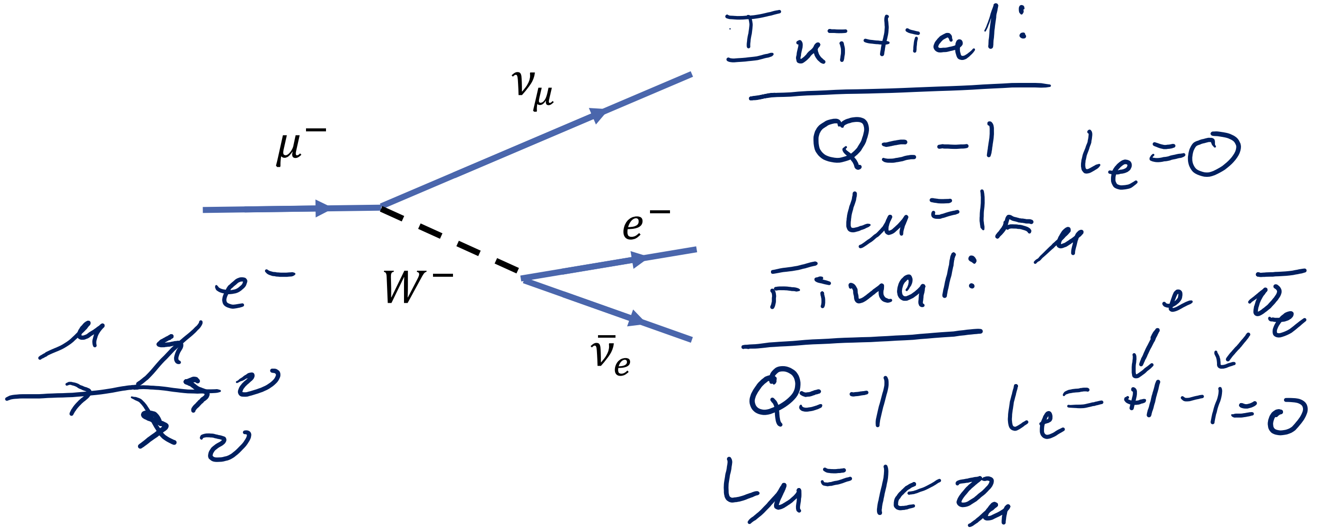
Lepton flavor number is conserved in most interactions (lepton: $L = +1$, antilepton: $L = -1$)

For example, a muon can decay into an electron but also must emit a muon neutrino and an electron antineutrino

More on neutrinos next lecture







Quark

$Q = +\frac{2}{3} + \frac{2}{3} - \frac{1}{3} = +1$

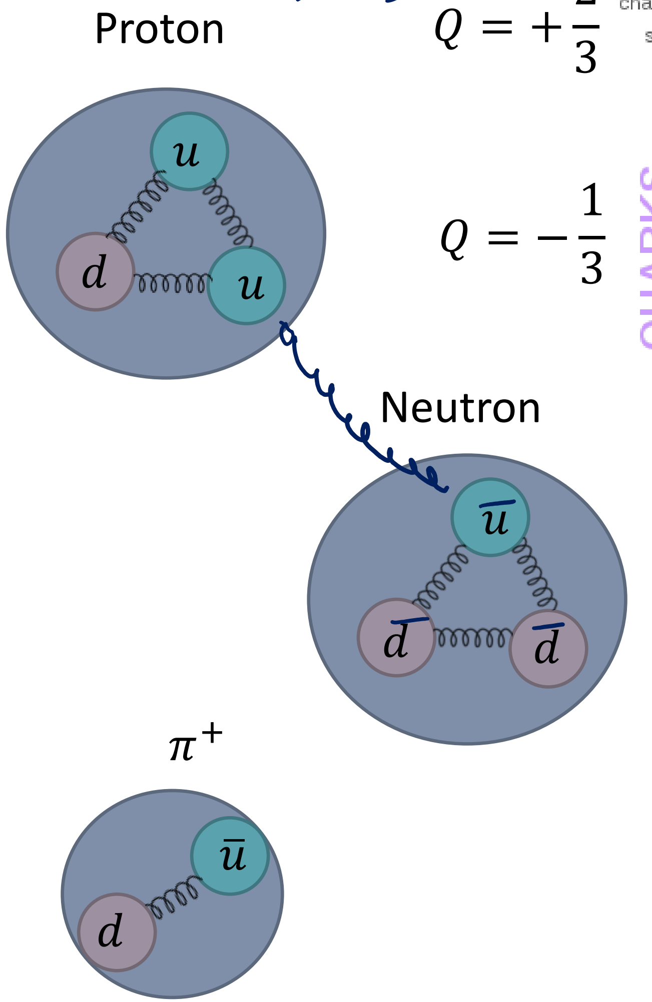
Quarks can be found in two different types of particles held together by strong force

- Baryons $(\mathrm{B} = \pm 1)$ – 3 quarks or antiquarks, protons (uud), neutrons (udd), anti-proton $(\bar{u}\bar{u}\bar{d})$
- Mesons $(\mathrm{B} = 0)$ – a quark-antiquark pair, pion $(\pi^+ : \bar{u}d)$

Each quark has a color (red, green, blue) and a gluon has a color and anti-color

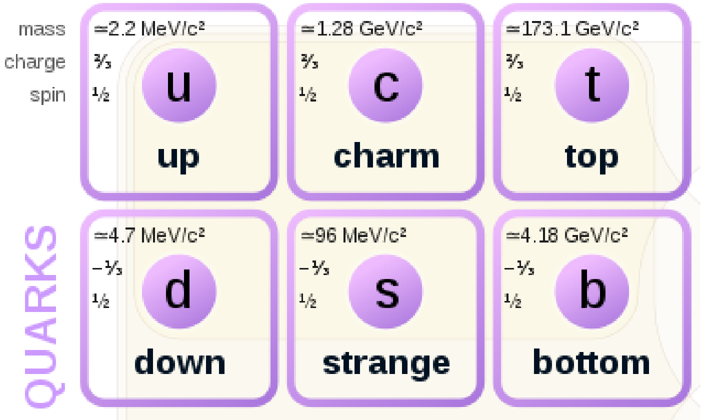
Every particle must be colorless (red+ green + blue or red + anti-red)

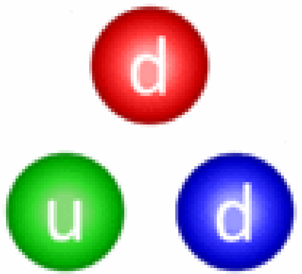
Color is constantly changing to maintain colorless



$Q = +\frac{2}{3}$

$Q = -\frac{1}{3}$





Homework Questions

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