

4 Fundamental Forces

| Force | Relative Strength | Range |
|-----------------|-------------------|------------------------------|
| Strong | 1 | ≈ 1 fm |
| Electromagnetic | 10^{-2} | Infinite ($\propto 1/r^2$) |
| Weak | 10^{-6} | $\approx 10^{-3}$ fm |
| Gravitational | 10^{-43} | Infinite ($\propto 1/r^2$) |

Hadrons (Heavy particles)

| Particle | Particle symbol | Antiparticle symbol | Rest energy (MeV) | Lifetime (s) |
|----------------|------------------------|---------------------|-------------------|-----------------------|
| Baryons | Heavy particles | | | |
| Proton | p | p̄ | 938.3 | Stable |
| Neutron | n | n̄ | 939.6 | 900 |
| Lambda | Λ^0 | Λ^0 | 1116 | 2.6×10^{-10} |
| Sigma | Σ^+ | Σ^- | 1189 | 0.8×10^{-10} |
| | Σ^0 | Σ^0 | 1192 | 6×10^{-20} |
| | Σ^- | Σ^+ | 1197 | 1.6×10^{-10} |
| Omega | Ω^- | Ω^+ | 1672 | 0.8×10^{-10} |

Leptons (light particles)

| Particle | Particle symbol | Antiparticle symbol | Rest energy (MeV) | Lifetime (s) |
|----------|--------------------|---------------------|-------------------|----------------------|
| Electron | e^- or β^- | e^+ or β^+ | 0.511 | Stable |
| Muon | μ^- | μ^+ | 105.7 | 2.2×10^{-6} |
| Tau | τ^- | τ^+ | 1784 | 10^{-13} |

Fat electrons

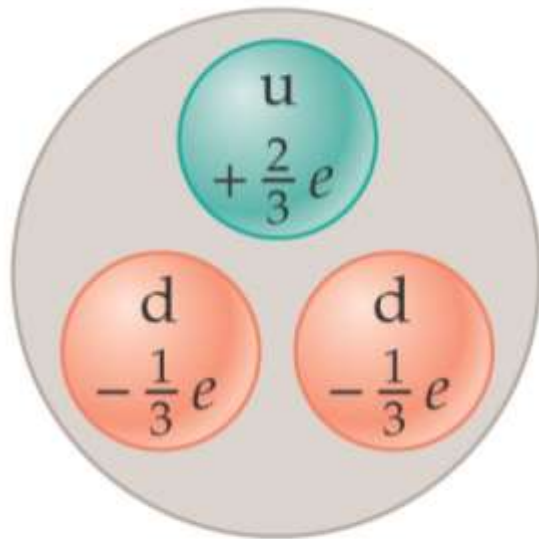
Neutrinos – involved in weak nuclear force

| Particle | Particle symbol | Antiparticle symbol | Rest energy (MeV) | Lifetime (s) |
|-------------------|-----------------|---------------------|-------------------------|--------------|
| Electron neutrino | ν_e | $\bar{\nu}_e$ | ≈ 0 but not 0!! | Stable |
| Muon neutrino | ν_μ | $\bar{\nu}_\mu$ | ≈ 0 but not 0!! | Stable |
| Tau neutrino | ν_τ | $\bar{\nu}_\tau$ | ≈ 0 but not 0!! | Stable |

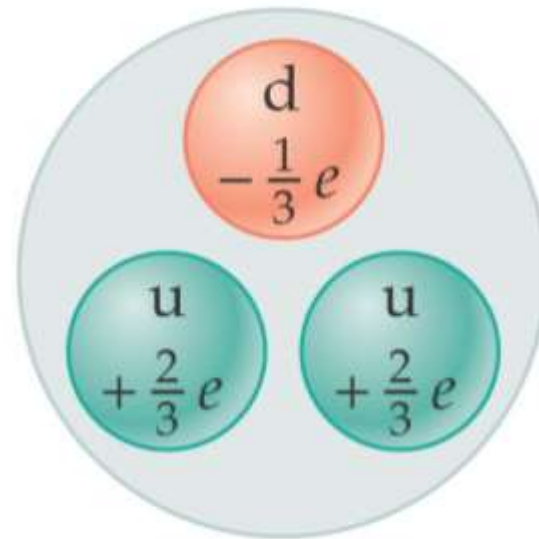
Quarks and Antiquarks

Valence quarks

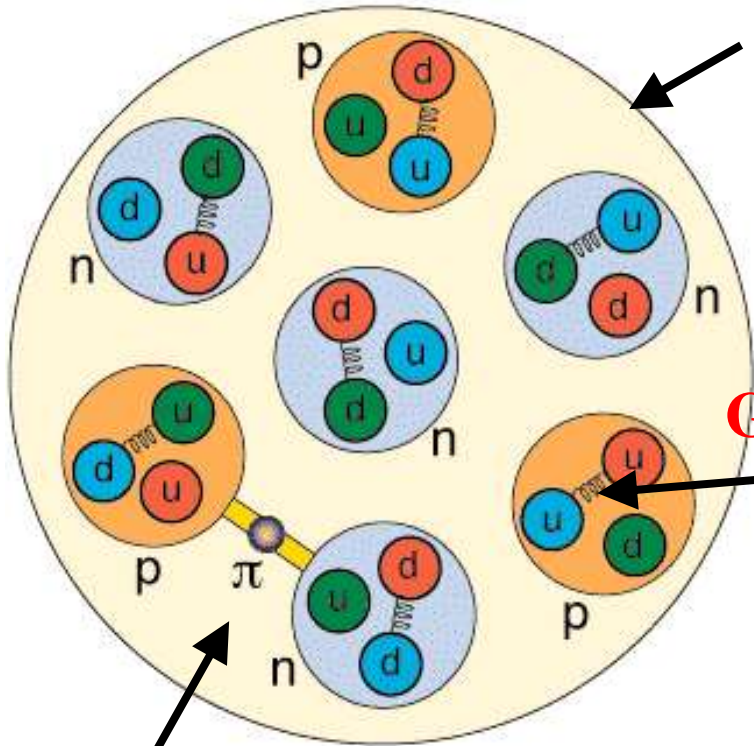
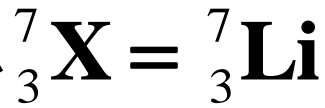
| Name | Rest energy (MeV) | Quarks | | Antiquarks | |
|---------|-------------------|--------|----------|------------|----------|
| | | Symbol | Charge | Symbol | Charge |
| Up | 360 | u | $+2/3 e$ | \bar{u} | $-2/3 e$ |
| Down | 360 | d | $-1/3 e$ | \bar{d} | $+1/3 e$ |
| Charmed | 1500 | c | $+2/3 e$ | \bar{c} | $-2/3 e$ |
| Strange | 360 | s | $-1/3 e$ | \bar{s} | $+1/3 e$ |
| Top | 173000 | t | $+2/3 e$ | \bar{t} | $-2/3 e$ |
| Bottom | 4180 | b | $-1/3 e$ | \bar{b} | $+1/3 e$ |



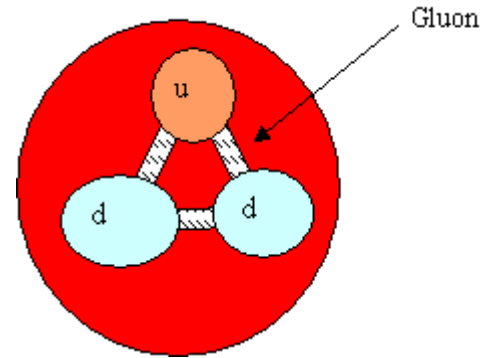
Neutron



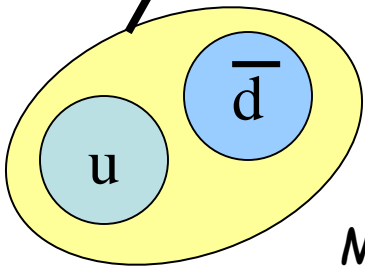
Proton



Gluons communicate force between quarks

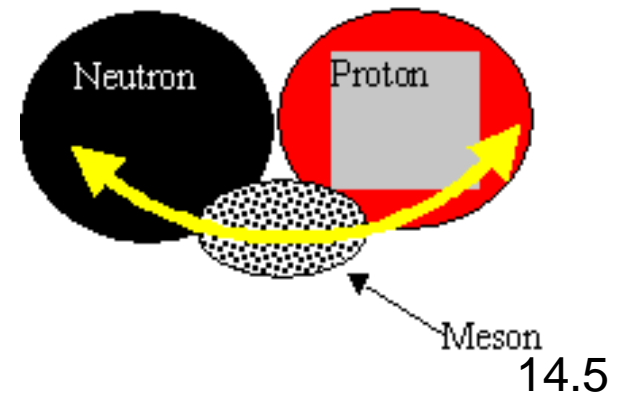


Mesons = **quark** / **anti-quark** “bound” together.
 communicates force between **p+** and **n**



$Q=+1$, and it's called a π^+

$M \sim 140 \text{ [MeV}/c^2]$
 Lifetime $\sim 2.6 \times 10^{-8} \text{ [s]}$



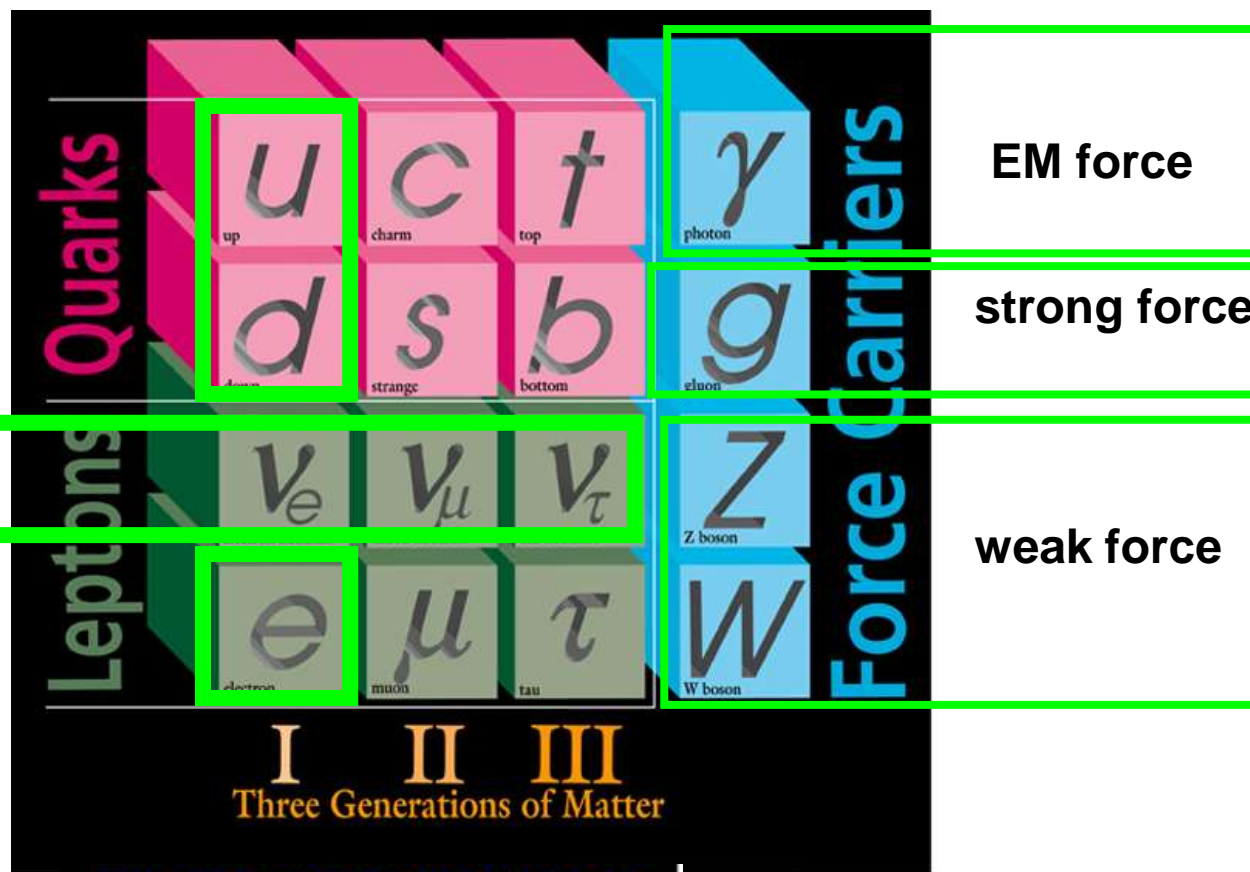
14.5

Quarks and **leptons** = most fundamental particles

Up & down quarks and **electrons** make up ordinary matter.

other quarks and leptons-produced in cosmic ray showers or high energy accelerators. (or early universe)

Lots neutrinos in Univ.



ELEMENTARY PARTICLES

