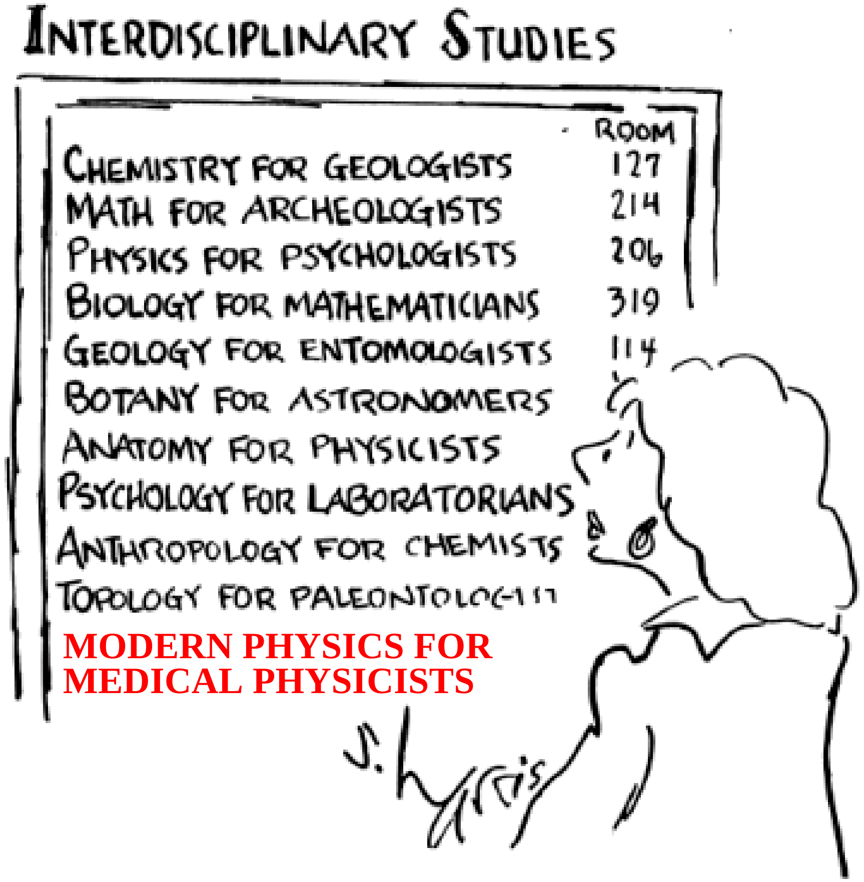
Purpose of these lectures



The Menu

- particle physics
  - elementary particles
  - fundamental interactions
- quantum mechanics
  - concepts
  - mathematical formulation
- atomic physics
  - H atom
  - many-electron atoms
- nuclear physics
  - properties of the nucleus
  - nuclear decays

What is the world made of?

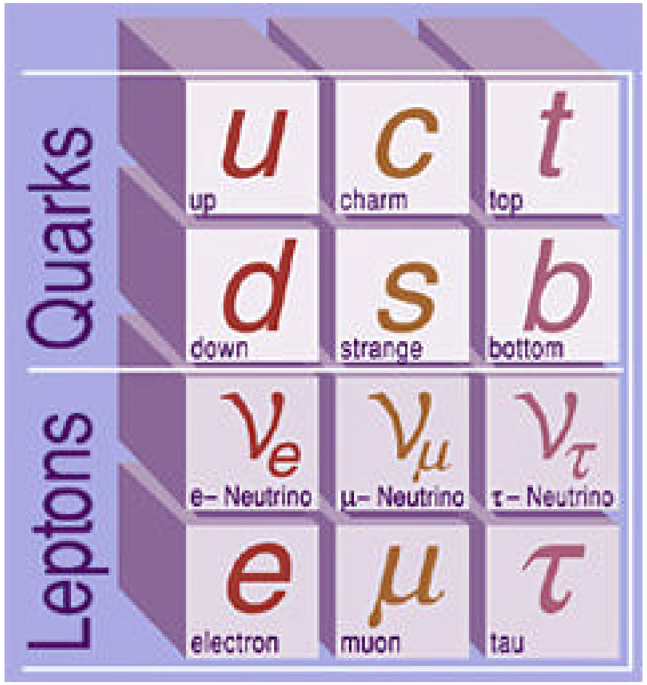
Let's find the smallest blocks of matter
and see how it all works!

Elementary Particles

... which are they?

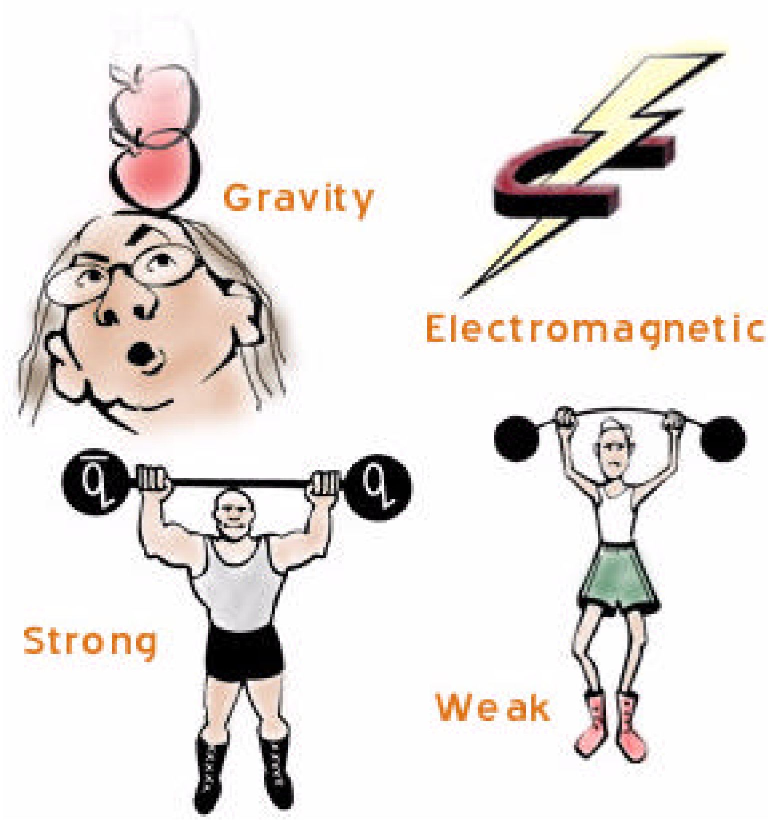
...they have:

- no structure (definition)
- mass
- electric charge
- other types of ‘charges’
- quantum numbers:
  - baryon number, B
  - lepton number, L (3)
  - spin, S
- antiparticles



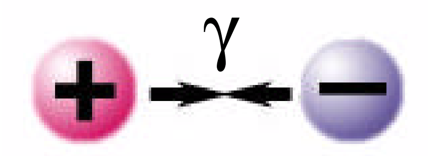
antiparticles: $\bar{u}$, $\bar{\nu}$, e^+

Fundamental Interactions



The mediators

The interactions occurs by the exchange of *mediators*:

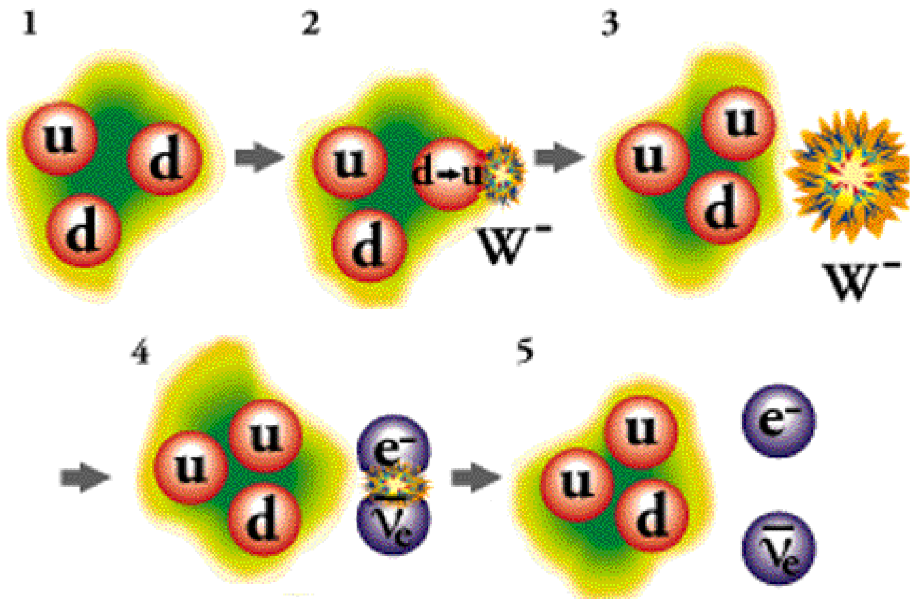
e/m force: 

strong force: 

- *strong*: gluons, g (8)
- *e/m*: photon, γ
- *weak*: Z, W^+, W^-
- *gravity*: graviton

A weak interaction

$$n \to p + e^- + \bar{\nu}_e \text{ means } d \to u + W^- \text{ and } W^- \to e^- + \bar{\nu}_e$$

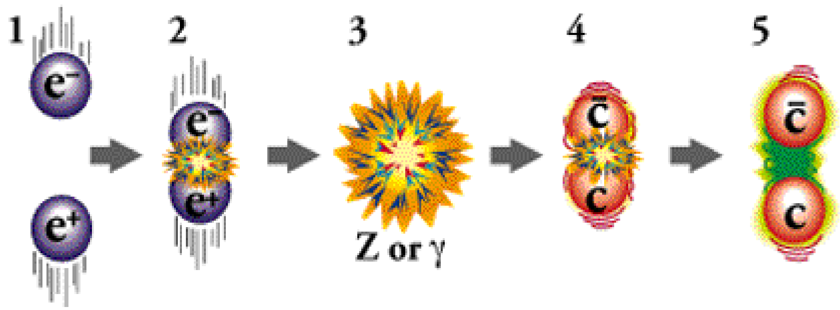


Weak or electromagnetic?

$$e^{+} + e^{-} \rightarrow \gamma^{*} \rightarrow c + \bar{c}$$

or

$$e^{+} + e^{-} \rightarrow Z \rightarrow c + \bar{c}$$

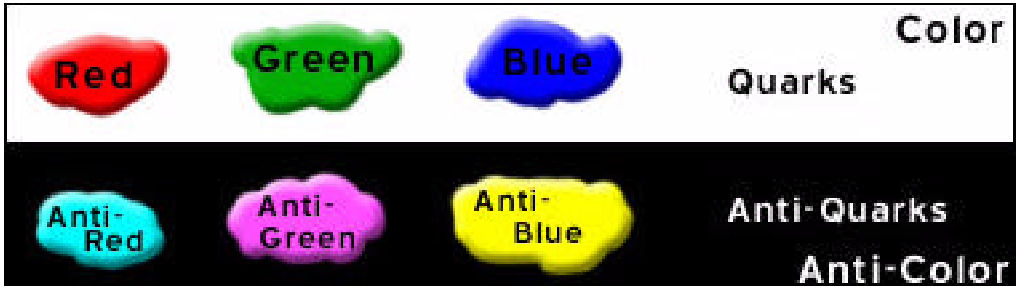


Fundamental interactions: properties

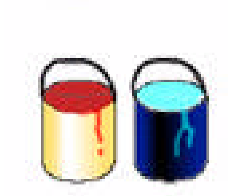
interaction	relative strength	time	range	participating particles
strong	1	10^{-23} s	10^{-15} m	quarks (gluons)
e/m	0.01	10^{-20} s	infinite	electrically charged (γ)
weak	0.00001	10^{-8} s	10^{-18} m	all (Z^0,W^+,W^-)

The strong ‘charge’

Quarks have *colour*, antiquarks have *anticolour*



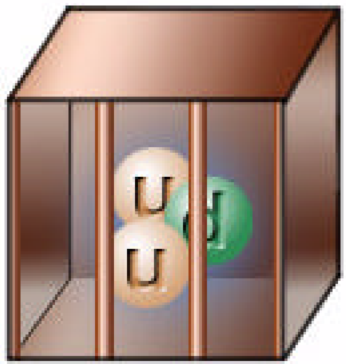
Gluons have *colour* and *anticolour*



Gluons can interact with *each other!*

Quarks are not free particles

Only colourless (‘white’) objects can be free: *confinement*



White *hadrons*: *baryons* (q q q) and *mesons* ($q\,\bar{q}$)

proton: $p = uud$,

neutron: $n = udd$

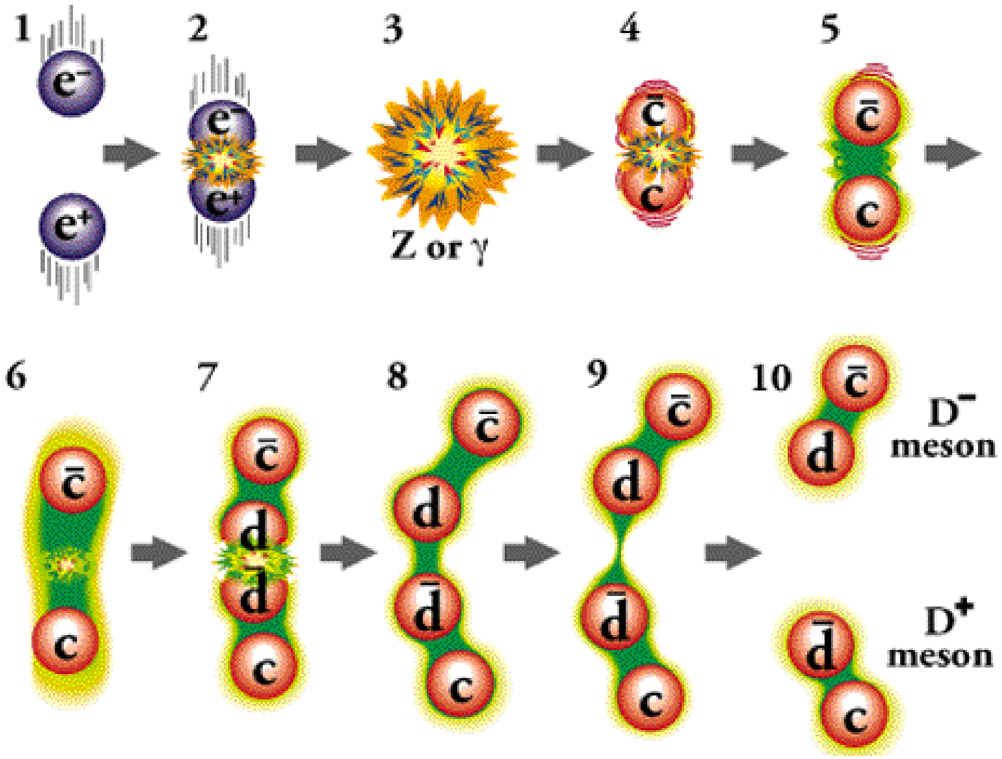
positive pion: $\pi^{+} = u\,\bar{d}$

antiproton: $\bar{p} = \bar{u}\,\bar{u}\,\bar{d}$

antineutron: $\bar{n} = \bar{u}\,\bar{d}\,\bar{d}$

negative pion: $\pi^{-} = \bar{u}\,d$

What happens if we pull two quarks apart?



hadronization

Quantum Numbers

Quarks:
B = 1/3, L = 0, S = 1/2,
Q=2/3 (up) or -1/3 (down)

Leptons:
B = 0, L = 1, S = 1/2,
Q = -1 or 0 (neutrinos)

Antiparticles: opposite quantum numbers (but same spin)

Conservation laws

	strong	E/M	weak
energy	☺	☺	☺
momentum	☺	☺	☺
electric charge	☺	☺	☺
spin	☺	☺	☺
Baryon #	☺	☺	☺
Lepton #	☺	☺	☺
Parity	☺	☺	☹

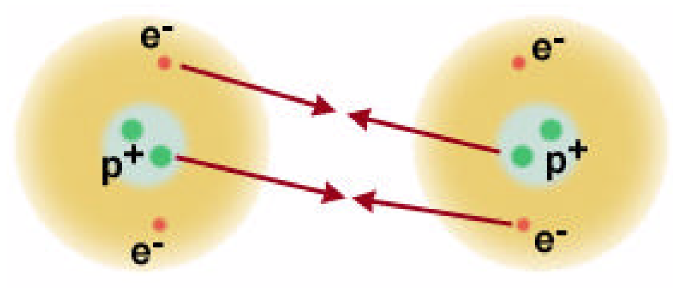
The muon decay

$$\mu \to e^- + \bar{\nu}_e + \nu_\mu$$

electron lepton number, L_e:	$0 = 1 + (-1) + 0$
muon lepton number, L_μ:	$1 = 0 + 0 + 1$
tau lepton number, L_τ:	$0 = 0 + 0 + 0$

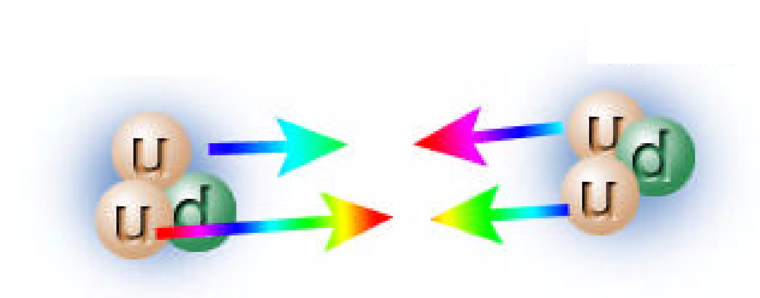
The residual effects of the forces

...which acts between elementary particles, but we see this:



residual
e/m force

...and this:



residual
strong force

<u>How does the microcosm ‘move’?</u>

In classical mechanics, we have:

- observables: p, v, x, ...
- parameter: t
- Newton’s law: F=ma
- equation of motion: x(t)

The observables take continuous values

Is it so in the microcosm?

Wave-Particle Duality

- radiation is made of quanta: waves behave like particles

one quantum of radiation has energy:

$$E = hf$$

h = Planck's constant = 6.6 10^{-34} J s

f = frequency of the radiation

- electrons show interference: particles behave like waves

the wave-length of a particle is:

$$\lambda = h/p$$

p = momentum of the particle