Lecture on Nuclear Physics for Plasma Engineers

- Particle and Nuclide -

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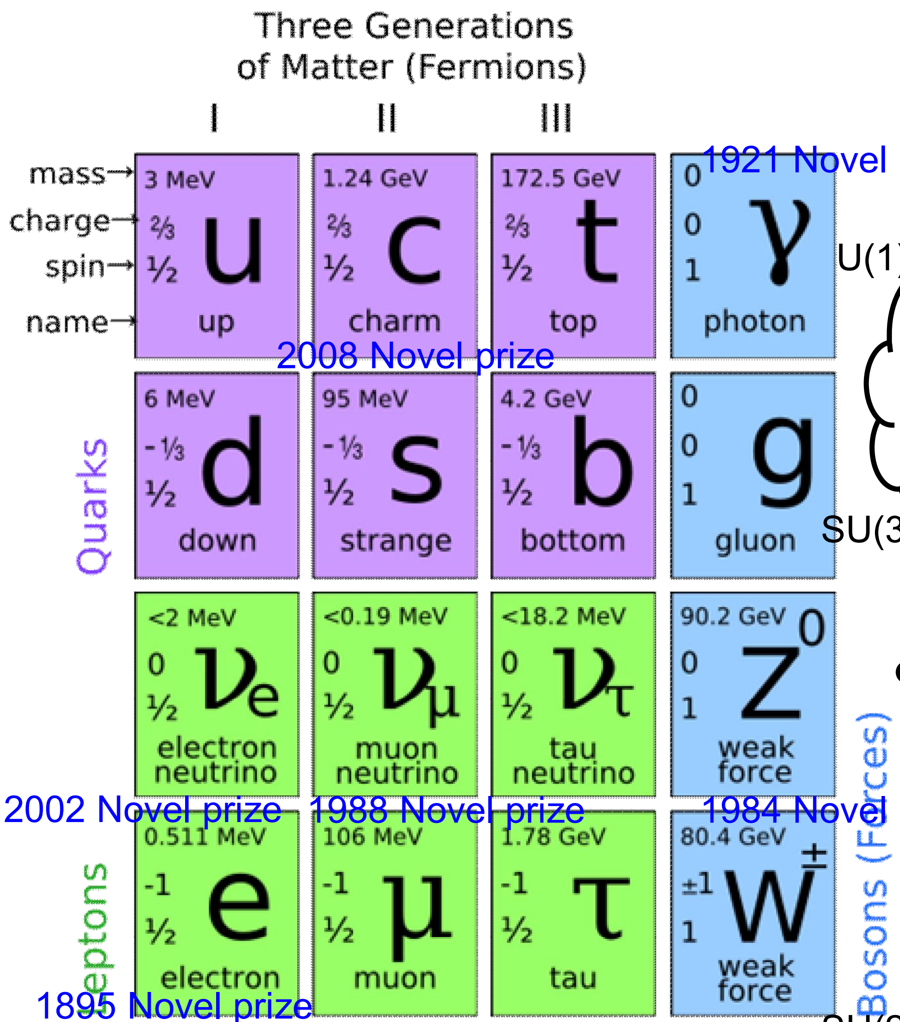
Standard Model



1921 Novel prize

2008 Novel prize

2002 Novel prize

1988 Novel prize

1984 Novel prize

1895 Novel prize

1936 e+

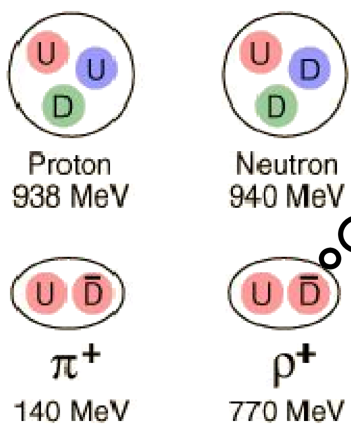
U(1)

SU(3)

SU(2)

anti neutrino has opposite lepton number

Mass of Nucleon



J=0 J=1

anti particle is same mass opposite charge

Color force don't decrease as distance increase

⇨Strong force is residual force

⇨Mass is effect due to color force

Quantum Chromo Dynamics

color force is similar to 3x3 EM potential

lattice QCD is promising

NEWS & VIEWS

PARTICLE PHYSICS

Mass by numbers

Frank Wilczek

A highly precise calculation of the masses of strongly interacting particles, based on fundamental theory, is testament to the age-old verity that physical reality embodies simple mathematical laws.

In a milestone paper, Dürr *et al.*[1] report a first-principles calculation of the masses of strongly interacting particles (hadrons, such as the proton), starting from the basic equations for their constituent particles (quarks and gluons), and including carefully documented estimates of all sources of error. Their results, published in *Science*, highlight a remarkable correspondence between the ideal mathematics of symmetry and the observed reality of the physical world.

Quantum chromodynamics (QCD), the theory of the so-called strong force or strong interaction, postulates elegant equations for

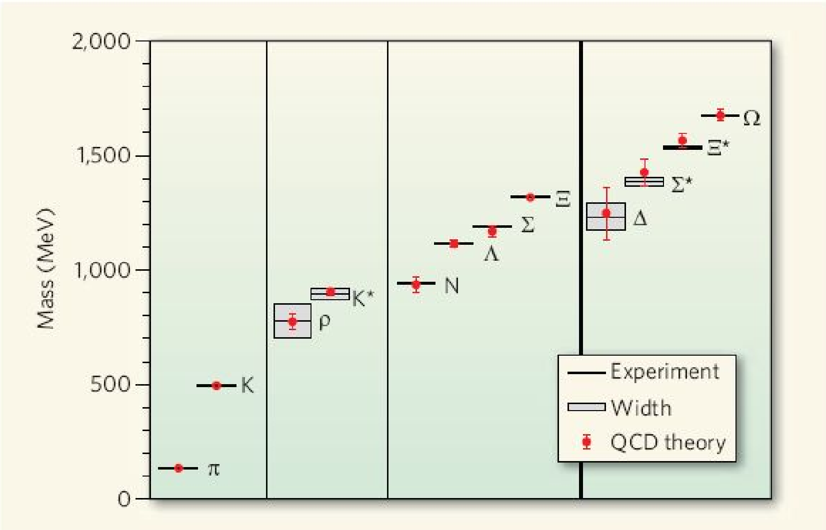


Figure 1 | Theory meets experiment. The masses of light hadrons (expressed in energy units; 1 MeV corresponds to 10^6 electronvolts)

quantum fluctuations, or 'virtual particles'. In the mathematical formulation, there is a master wavefunction for the quantum fields. The wavefunction is a superposition of different possible patterns of excitation in the fields, each occurring with some definite amplitude. The central problem involved in solving the equations of QCD, to predict the census of hadrons and their properties, is to compute this wavefunction: that is, to determine the numerical value of the amplitudes. Having constructed the wavefunction of 'empty space', we can inject different combinations of quarks and

Force between particle

❑ Yukawa potential

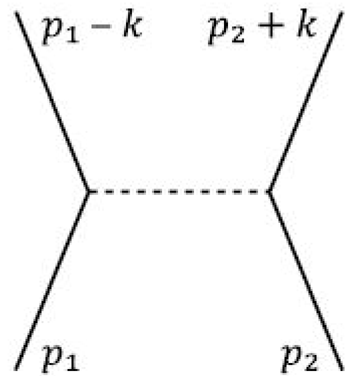
$$\left(\nabla^2 - \frac{1}{c^2}\frac{\partial^2}{\partial t^2} - \lambda^2\right) V(r) = 0$$

potential generated by decaying particle $\lambda c \Delta t$

$mc^2 \cdot r/c = \hbar$ or $mc = \lambda h$

mass given by uncertainty principle

1949 Novel prize



Force by exchanging scalar meson (pion)

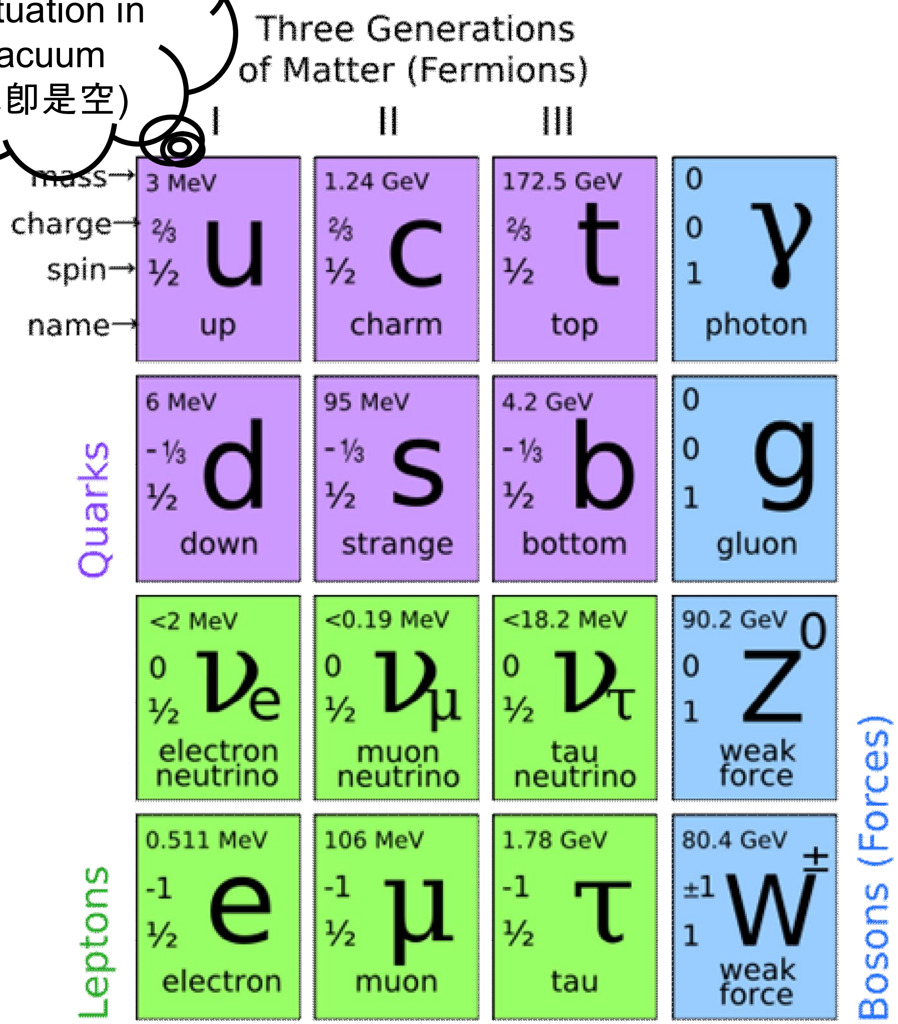
$$V(r) = -g^2 \frac{e^{-\lambda r}}{r} = \frac{1}{(2\pi)^3}\int e^{ikr}(-g^2)\frac{4\pi}{k^2+\lambda^2} d^3k$$

Force arises from
Exchange of Gauge Boson
between Fermions

Matter is composed of fermion

only one fermion of same quantum state can occupies the same place at given time

matter is fluctuation in vacuum (色即是空)



Fermion : Spin ½, ... (half integer)

-Pauli exclusion principle

-follows Fermi-Dirac statistics

$$n_i = \frac{g_i}{e^{(e_i - e_0)/kT} + 1}$$

Boltzman statistics

fill from low energy state

Boson : Spin 0, 1, ... (integer)

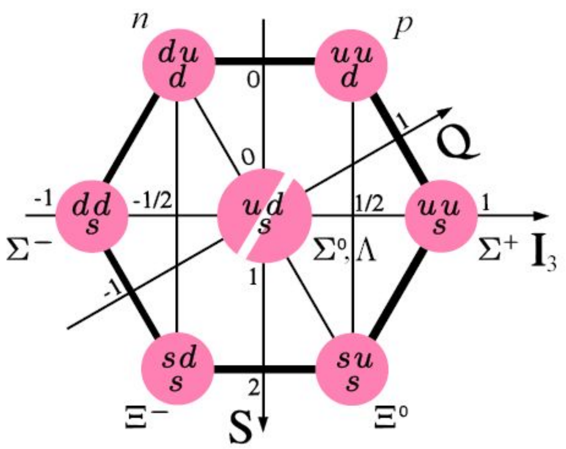
- force carrier
- follows Bose-Einstein statistics

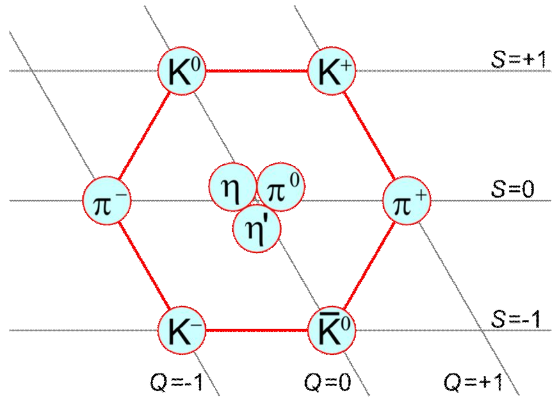
$$n_i = \frac{g_i}{e^{(e_i - e_0)/kT} - 1}$$

thermal disturbance

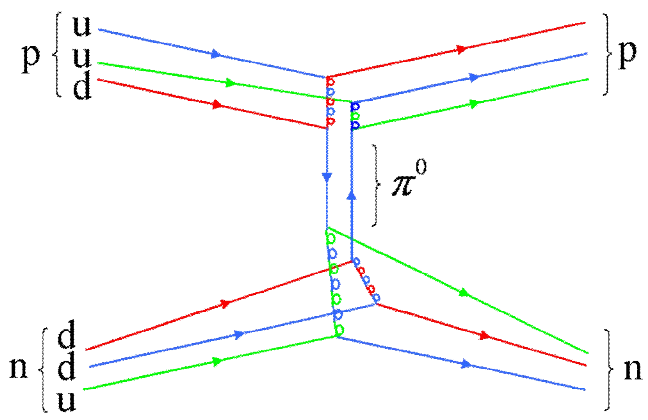
Hadron

- ❑ Meson is quark-antiquark pair
- ❑ Baryon is a 3 quarks system





Meson (Spin)

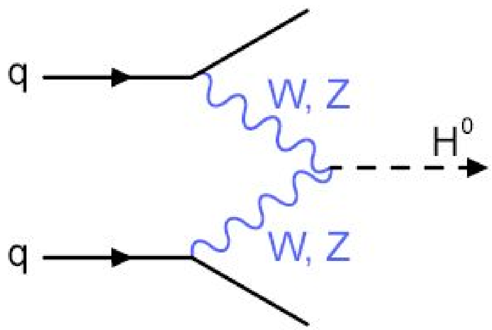


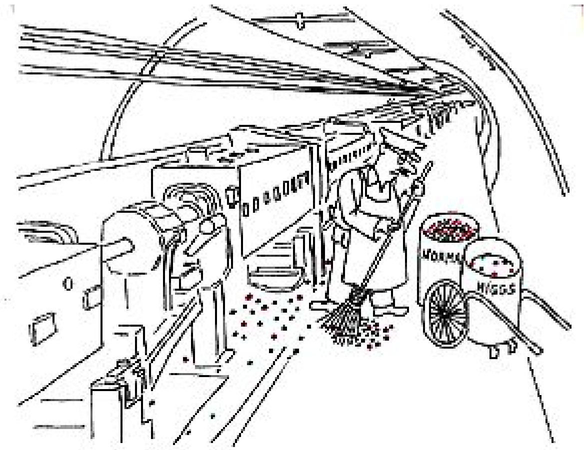
Nucleon Interaction

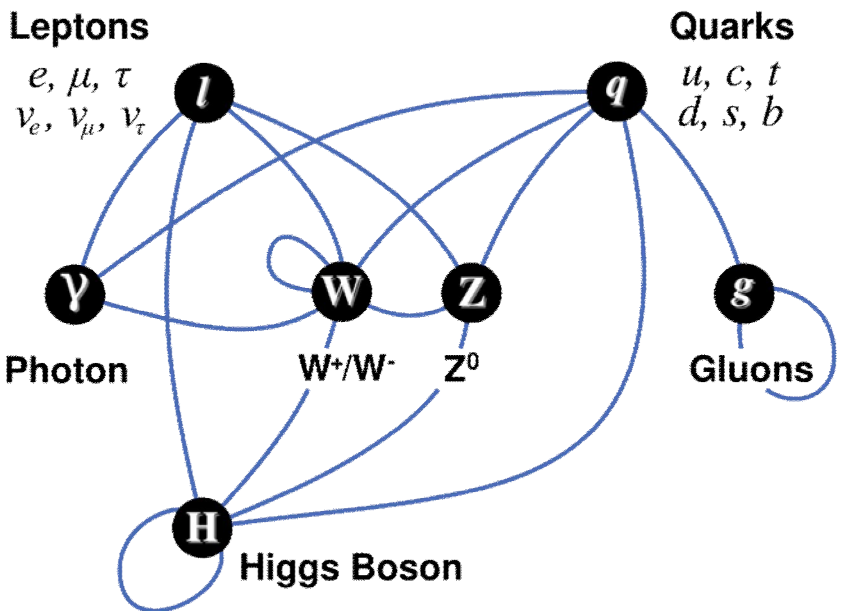
- ✓ We cannot observe Quarks due to Color force, but we observed Baryon and Meson.

Higgs boson

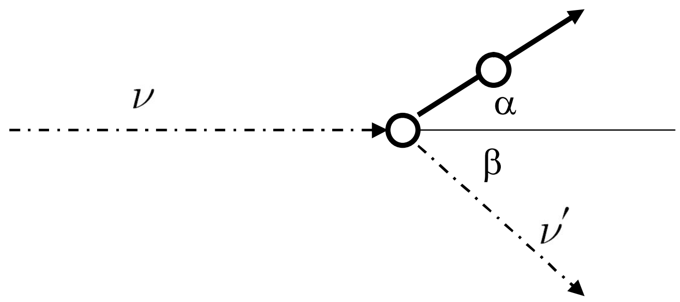
- Origin of mass ?
  - Stanard model is correct below 100 GeV.
  - Why W and Z have masses ?
  - Mass of H is 140 ~ 1,000 GeV ?
- Will CERN LHC find Higgs ?
  - 7 TeV is sufficient for finding Higgs.

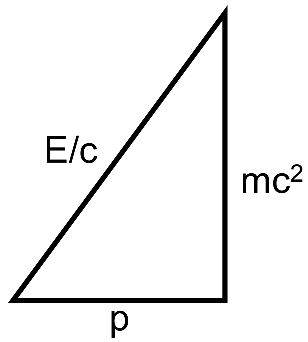






Compton scattering





Mass zero particle

$$p = E/c$$
$$E = h\nu$$

photon quanta

Energy Conservation

$$h\nu + mc^2 = h\nu' + \frac{mc^2}{\sqrt{1-u^2/c^2}}$$

Momentum Conservation

$$\frac{h\nu}{c} = \frac{h\nu'}{c} cos\beta + \frac{mu}{\sqrt{1-u^2/c^2}} cos\alpha$$

$$0 = -\frac{h\nu'}{c} sin\beta + \frac{mu}{\sqrt{1-u^2/c^2}} sin\alpha$$

$$m(\nu - \nu') = \frac{h}{c^2}(1-\cos\beta)\nu\nu'$$

$$\nu = \frac{c}{\lambda}$$

$$\lambda' - \lambda = \frac{2h}{mc} sin^2 \frac{\beta}{2}$$

$$\Delta\lambda_{\max} = \frac{h}{mc}$$

Compton wave length

$$\lambda_e = 2.4263102175(33) \times 10^{-12} \mathrm{m}$$

particle position cannot be determined below this limit !

before collision

after collision

Planck particle, Planck units

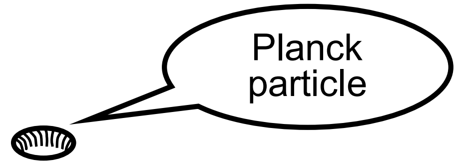
When Compton length is same as the Schwartzschild diameter

$$l_P = \frac{h}{m_P c} \propto 4\frac{\kappa m_P}{c^2}$$

$$g_{rr} = 1 + \frac{2\kappa m/c^2}{r - 2\kappa m/c^2}$$

Planck mass

$$m_P \equiv \sqrt{\frac{\hbar c}{\kappa}} \simeq 1.221 \times 10^{19} \mathrm{GeV}/c^2 = 2.176 \times 10^{-8} \mathrm{kg}$$



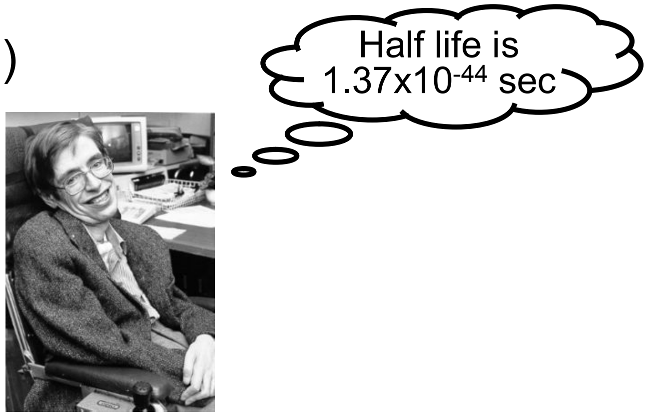
Planck length (size of Schwarzshild radius)

$$l_P = \sqrt{\frac{\hbar \kappa}{c^3}} \simeq 1.616 \times 10^{-35} m$$

10^{15} heavier than a proton
10^{-20} smaller than a proton

Planck time (light travelling time over Planck length)

$$t_P = \sqrt{\frac{\hbar \kappa}{c^5}} \simeq 5.391 \times 10^{-44} \mathrm{s}$$



Steven Hawking

! Higgs mass of 1000 GeV/c^2 is not enough for a small black hole.

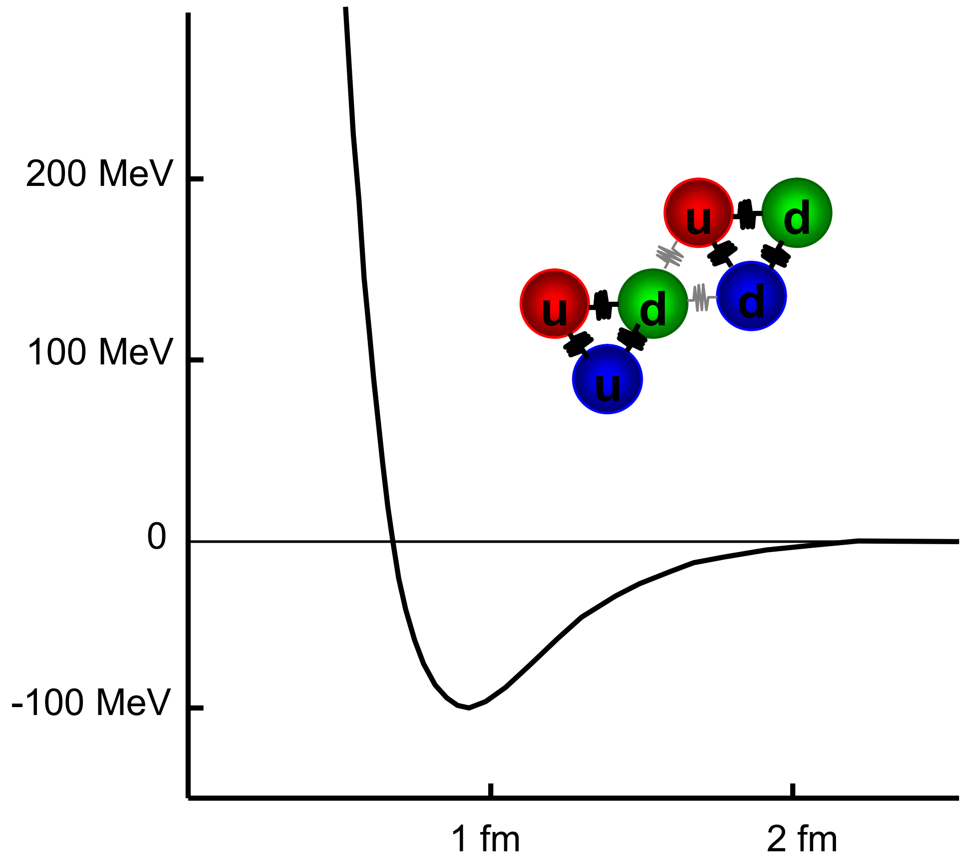
Nucleon (Proton and Neutron)

Source : http://pdg.lbl.gov/

	proton	neutron
Charge	+1	0
Spin/parity	½+	½+
Mass (u)	1.007276	1.008664
Mass (MeV)	938.272	939.565
charge r.(fm)	0.870(8)	j 0.34(5)
m. mom(μ_N)	2.792847	-1.913043
half life	> 2.1e+29 yrs	885.7(8) s

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

Age of universe
= 1.37e+10 yrs



nuclear force potential

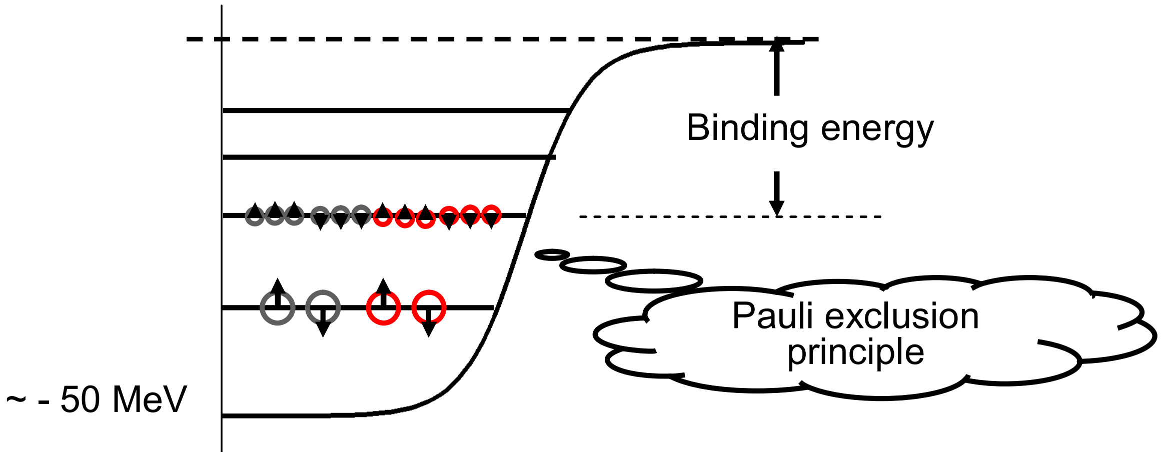
Atomic mass

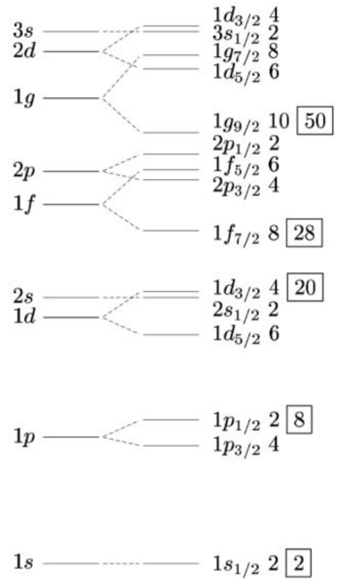
before 1961 amu was used
1u= 1/16 mass of 16O
1u = 1.0003179 amu(phys)
1u= 1.000043amu(chem)

- 1 u = 1/12 mass of 12C
  - 1.660538782(83)e-27 kg
  - 931.494027(23) MeV/c2

http://www.nndc.bnl.gov/amdc/

- Shell model





How to measure mass ?

- Cyclotron resonance

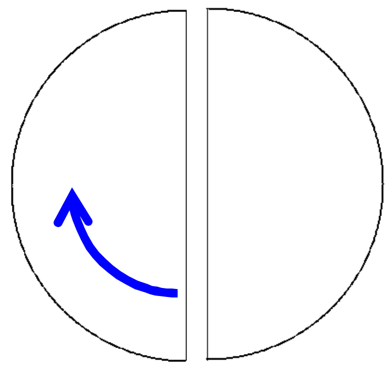
$$\mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$$

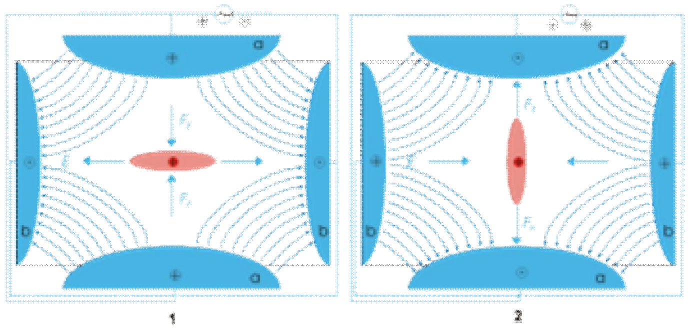
Lorentz force

$$\mathbf{F} = m\mathbf{a}$$

$$\omega_{ce} = \frac{qB}{\gamma m_0}$$

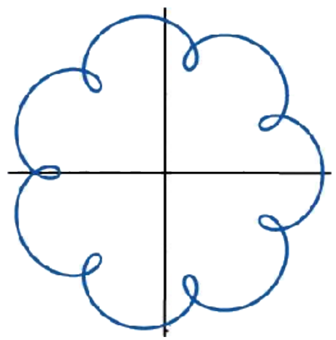
Relativistic correction





Paul Ion Trap (1989 Novel prize)

$\omega_+/\omega_- = 8$



Penning Trap

$$\frac{m_p}{m_e} = 1836.152\ 672\ 47(80)$$

Measured Atomic Mass

Masses of more than 1100 Nuclides were measured

Mass accuracy:

SMS $1.5 \cdot 10^{-7}$ up to $4 \cdot 10^{-8}$

IMS $\sim 5 \cdot 10^{-7}$

Results: ~ 350 new masses

In addition more than 300 improved mass values