โครงการอบรมอนุภาคฟิสิกส์มูลฐาน

ภาควิชาฟิสิกส์ คณะวิทยาศาสตร์ มศว

Modern Physics

ผศ.ดร.สุพจน์ มุศิริ

19 เมษายน 2560 10.45-12.00 น. ห้อง 19-401 มศว

Topics

- Contradiction between Classical mechanics and Electromagnetic theory
- Theory of Relativity
- Quantum mechanics
- Quantum field theory
- Standard model

Plato (pointing up to heavenly things) and Aristotle (gesturing down to Earth).
From Raphael, *The School of Athens*(1509)

Contradiction between Classical mechanics and Electromagnetic theory

- Classical Mechanics (1687)

Newton's Laws

1.Inertial frame of reference (no accelerated frame) (Galilean's transformation)

2. $$\sum_i \vec{F}_i = \frac{d\vec{P}_i}{dt}$$ Equation of motion

3. action = reaction

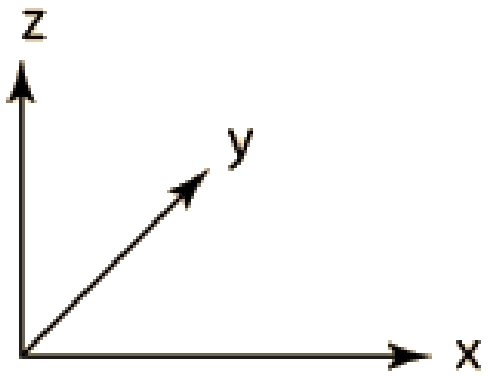
Galilean's transformation

- Physics is the same in all reference
- The equations of motion are the same in every frame

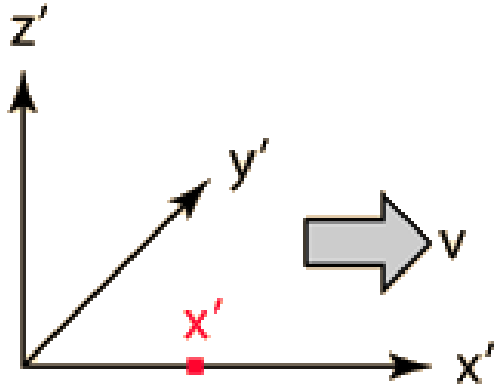
$$\vec{a} = 0$$

- The coordinates of reference have no acceleration.

Fixed frame



Moving frame



Galilean Transformation

$x' = x - vt$

$y' = y$

$z' = z$

$t' = t$

$$\sum_i \vec{F}_i = \frac{d\vec{P}_i}{dt} \qquad \sum_i \vec{F}'_i = \frac{d\vec{P}'_i}{dt'}$$

Equations of motion are the same form

http://hyperphysics.phy-astr.gsu.edu/hbase/Relativ/ltrans.html

Electrodynamics (electromagnetic Theory)

- Maxwell equations (in vacuum)(1862)

$$\nabla \cdot \vec{E} = \frac{\rho}{\epsilon_0}$$

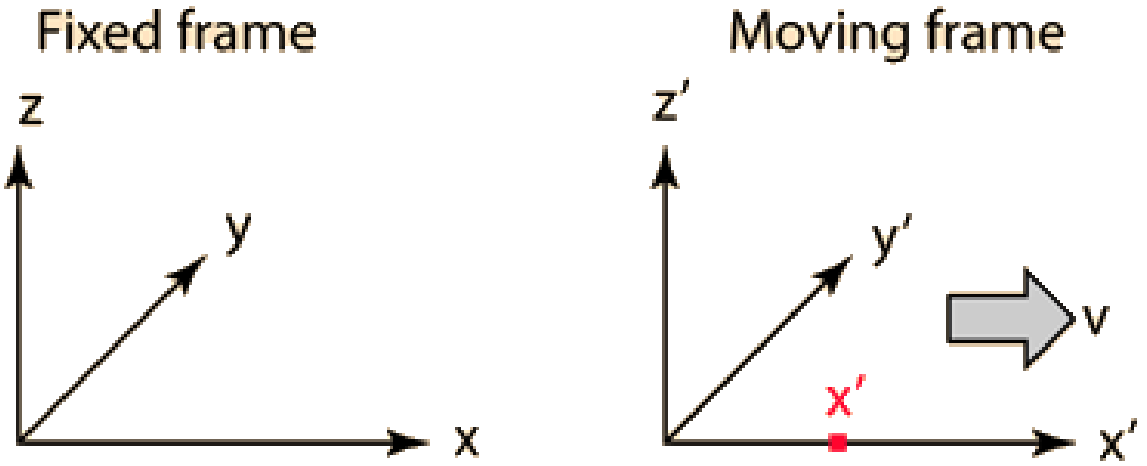
$$\nabla \cdot \vec{B} = 0$$

$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

$$\nabla \times \vec{B} = \mu_0 \vec{J} + \frac{1}{c^2}\frac{\partial \vec{E}}{\partial t}$$

- Lorentz Transformation

  Maxwell equations have the same from



$$x' = \frac{x - vt}{\sqrt{1 - \frac{v^2}{c^2}}}$$

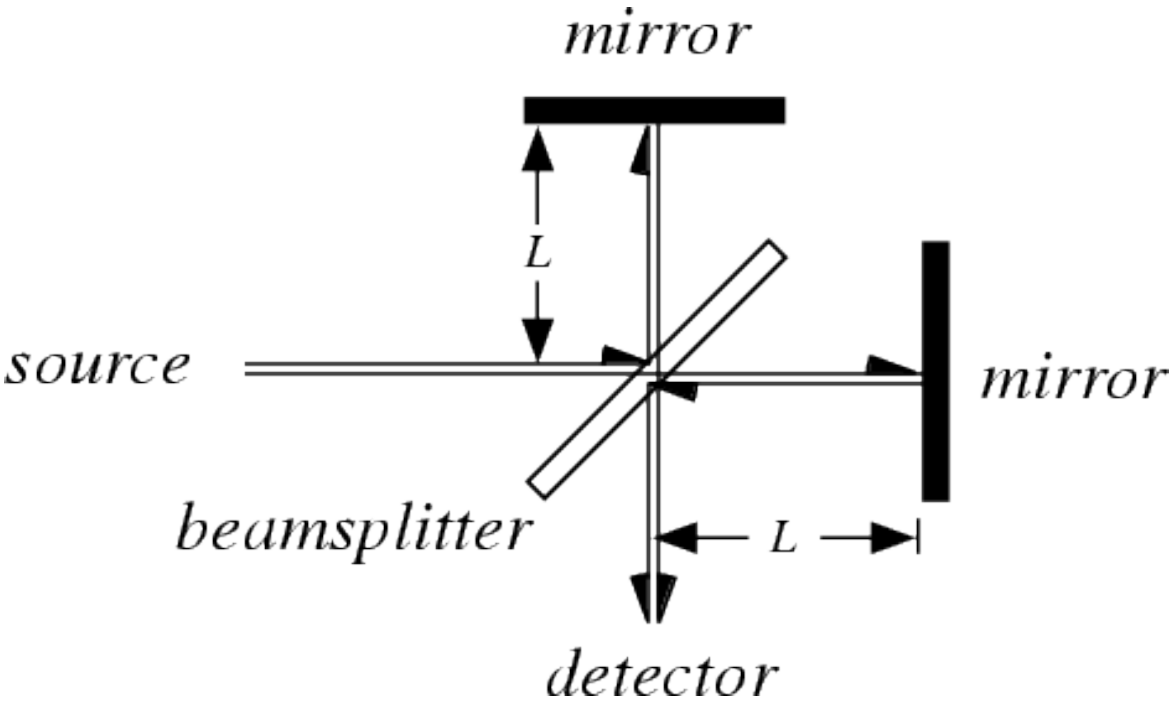
$$y' = y$$

$$z' = z$$

$$t' = \frac{t - \frac{vx}{c^2}}{\sqrt{1 - \frac{v^2}{c^2}}}$$

http://hyperphysics.phy-astr.gsu.edu/hbase/Relativ/ltrans.html

Michelson-Morley experiment



- No interference pattern detected (1988)

https://www.youtube.com/watch?v=8QUhgYaxWao

Special Relativity

- Einstein's postulates
- 1. All observers are in inertial frames
- 2.The speed of light is the same, regardless of the motion of light source and observer.

Special Relativity (1905)

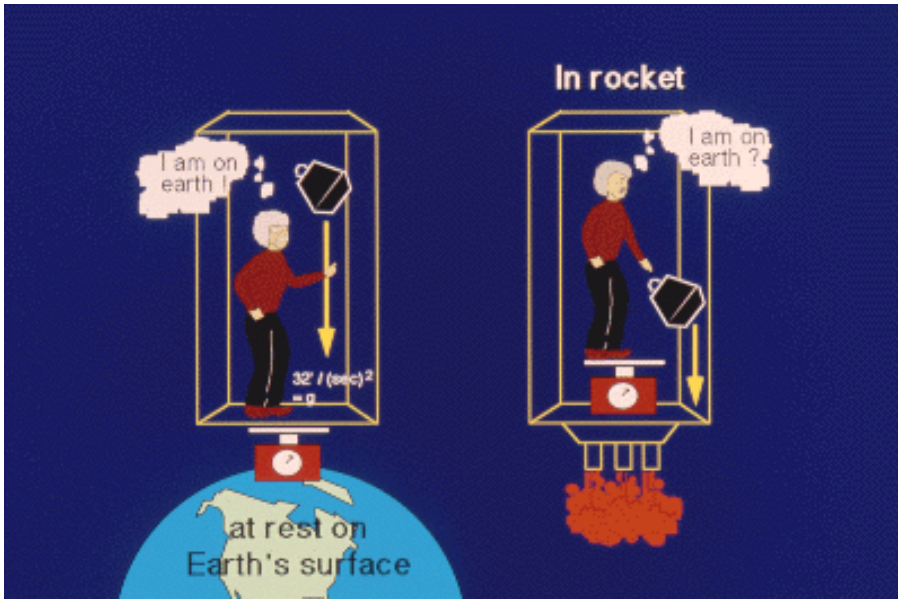
- Time is a component of a displacement vector in 4 dimensions

$$x^{\mu} = (ct, x, y, z)$$

- Time dilation , Space contraction, $E = mc^2$, equivalence of mass and energy,

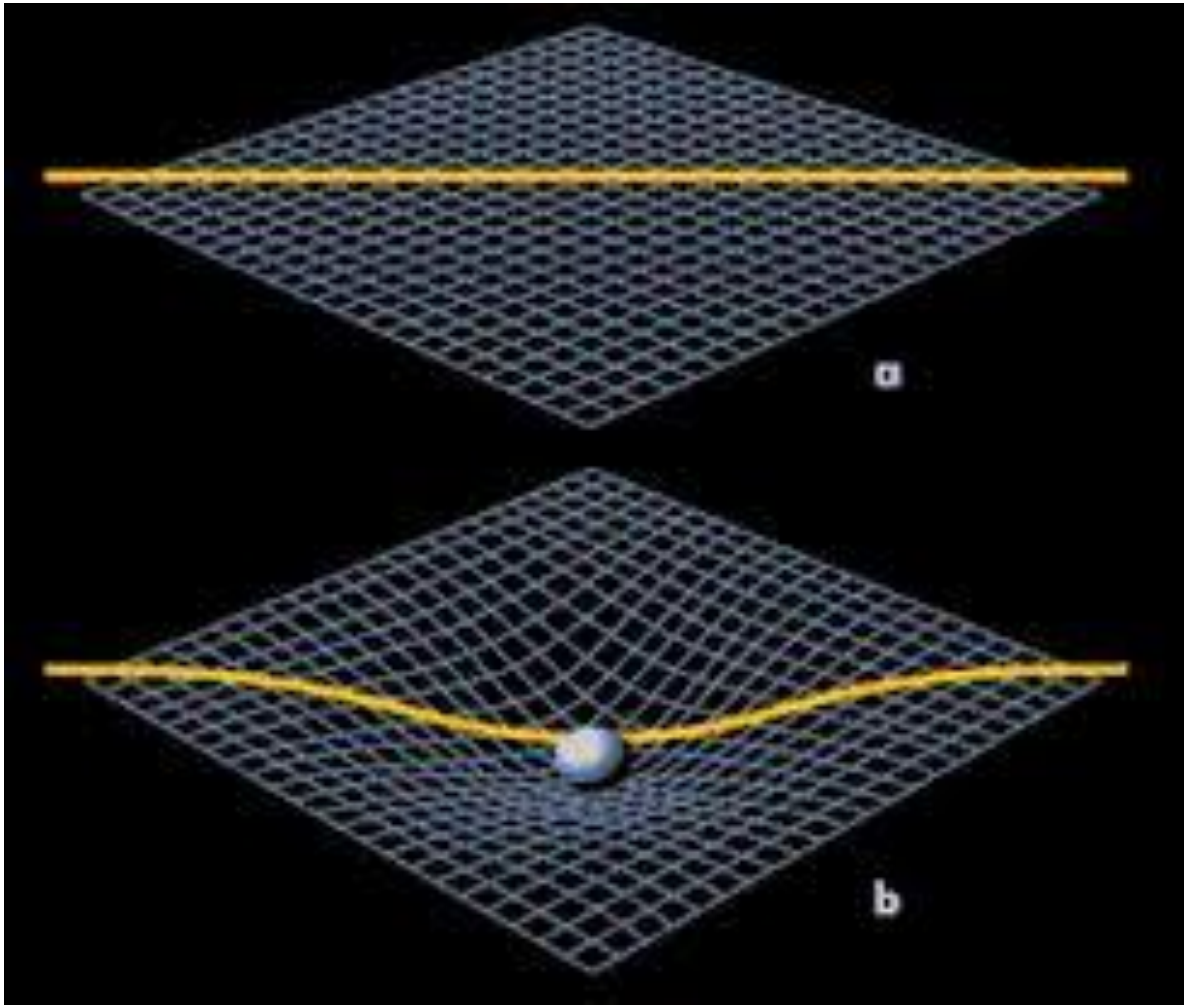
General Relativity (1915)

- Equivalence Principle
- Inertial mass = Gravitational mass



http://astro.physics.sc.edu/selfpacedunits/Unit57.html

Curved Spacetime



https://www.quora.com/What-is-gravity#!n=12

Einstein's equation

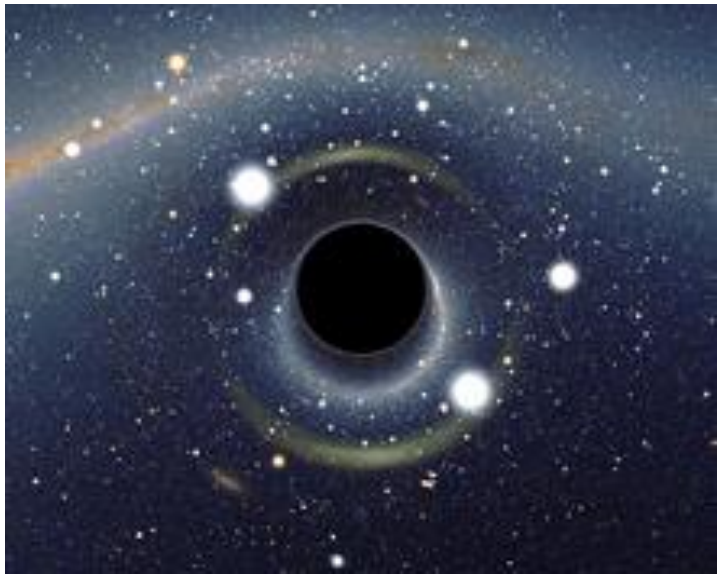
$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

- A simple solution is the Schwarzschild metric (1916)

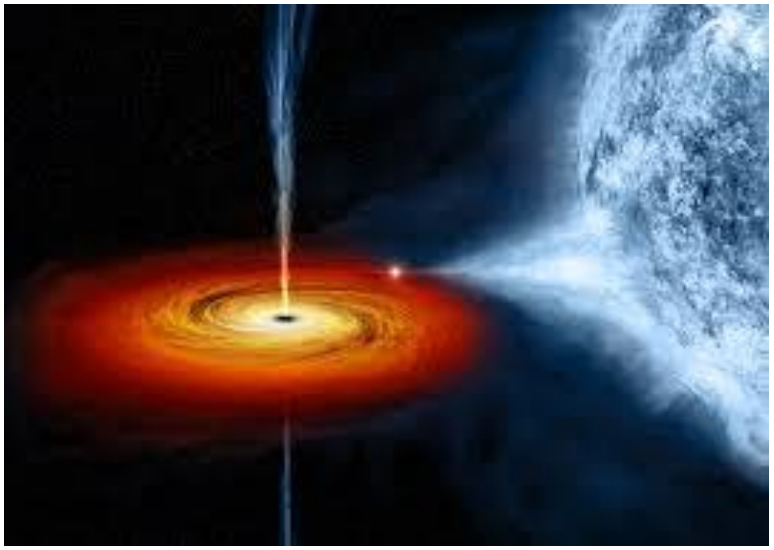
$$ds^2 = -(1 - r_H / r) dt^2 + (1 - r_H / r)^{-1} dr^2 + r^2 d\Omega^2$$

$$r_H = 2GM / c^2$$

Black Hole



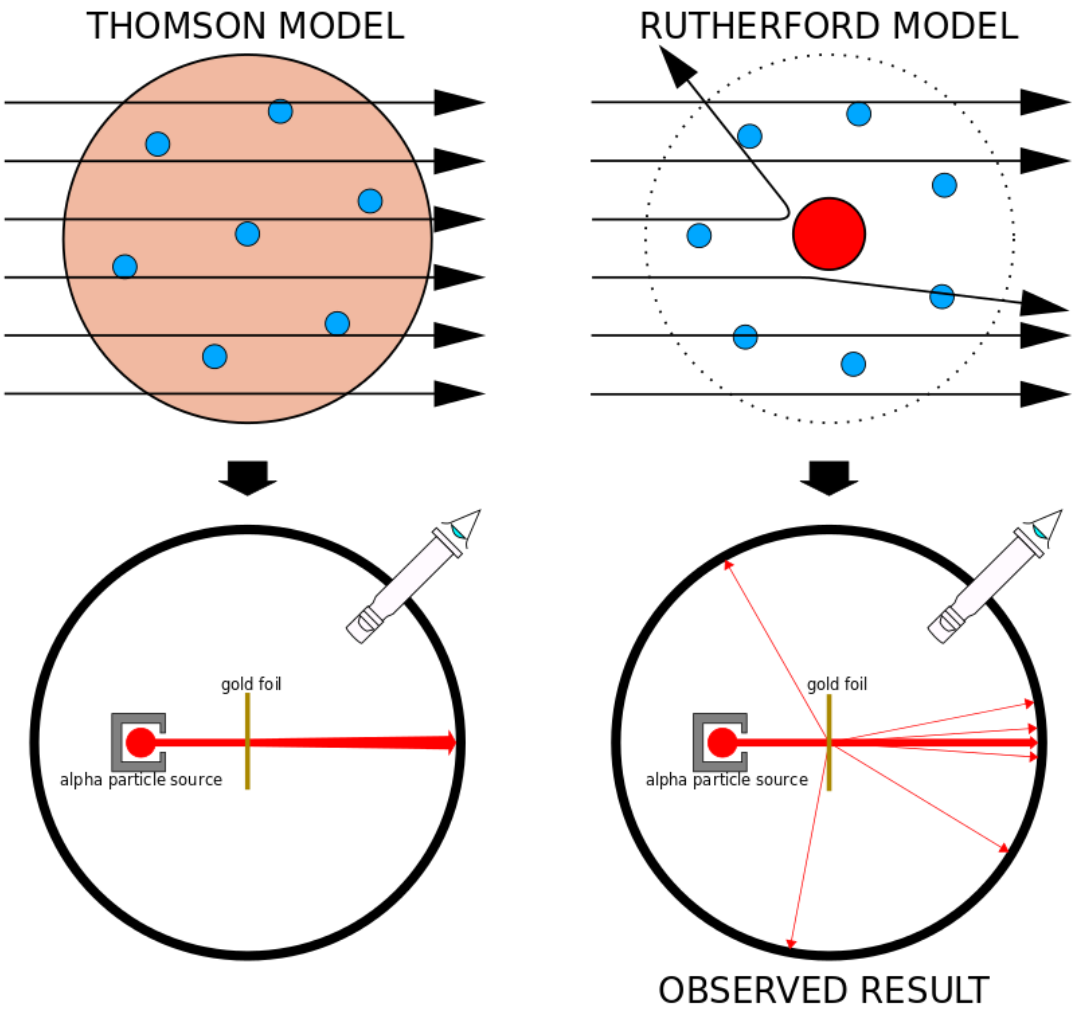
https://en.wikipedia.org/wiki/Black_hole#/media/File:BH_LMC.png



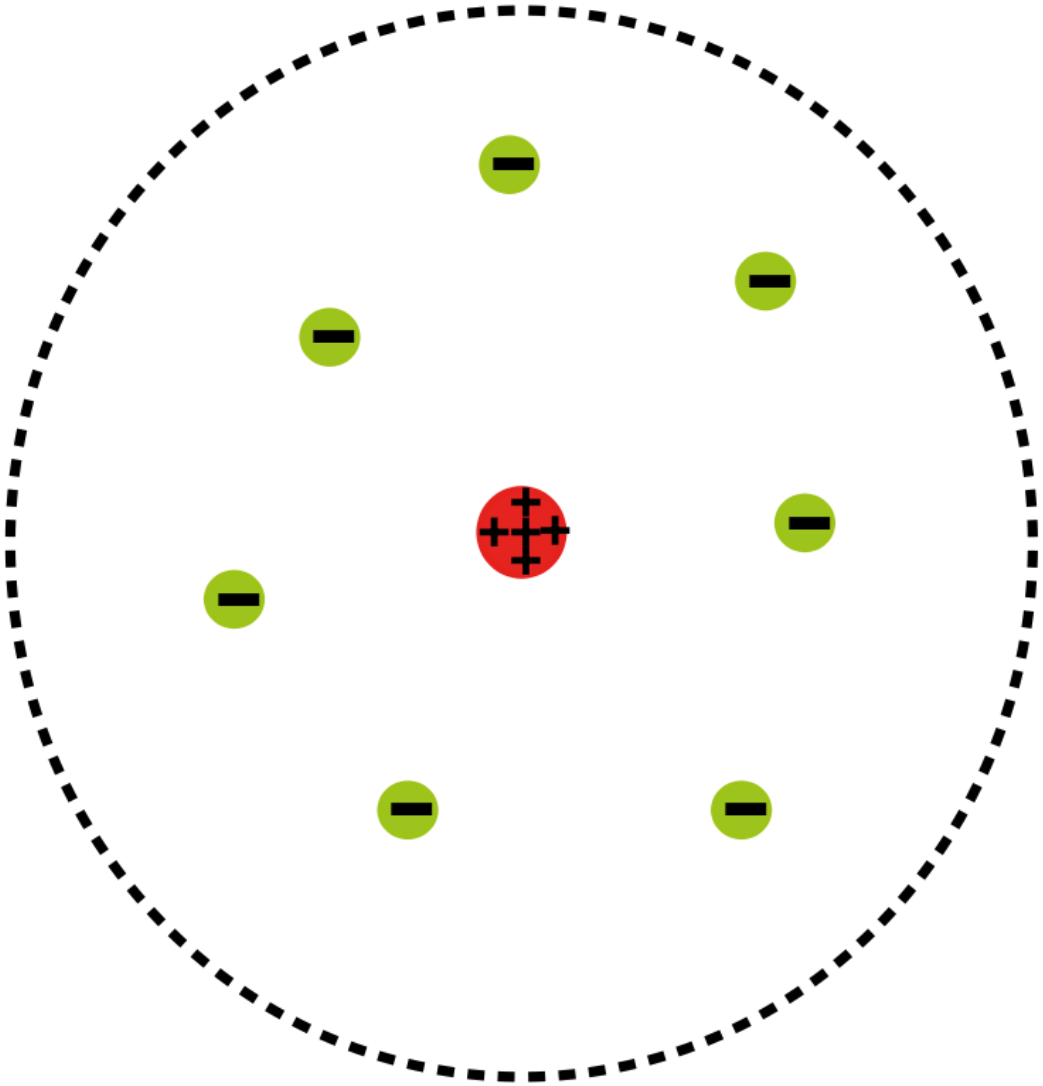
https://apod.nasa.gov/apod/ap131120.html

Problem with Black Holes

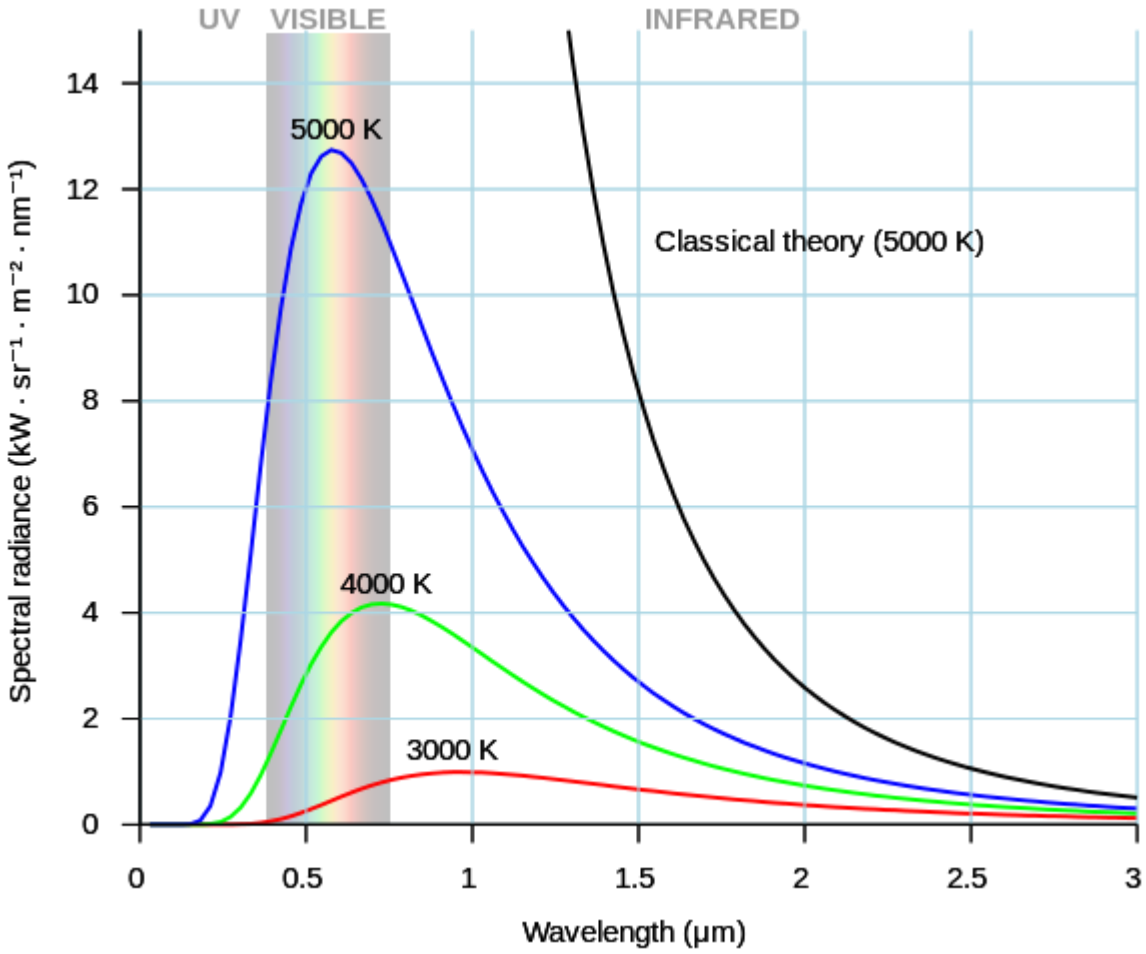
Rutherford Atom Model (1911)



https://en.wikipedia.org/wiki/Geiger%E2%80%93Marsden_experiment



Black Body Radiation (1900)



https://en.wikipedia.org/wiki/Black-body_radiation

Max Planck Postulate (1900)

$$E = nh\nu$$

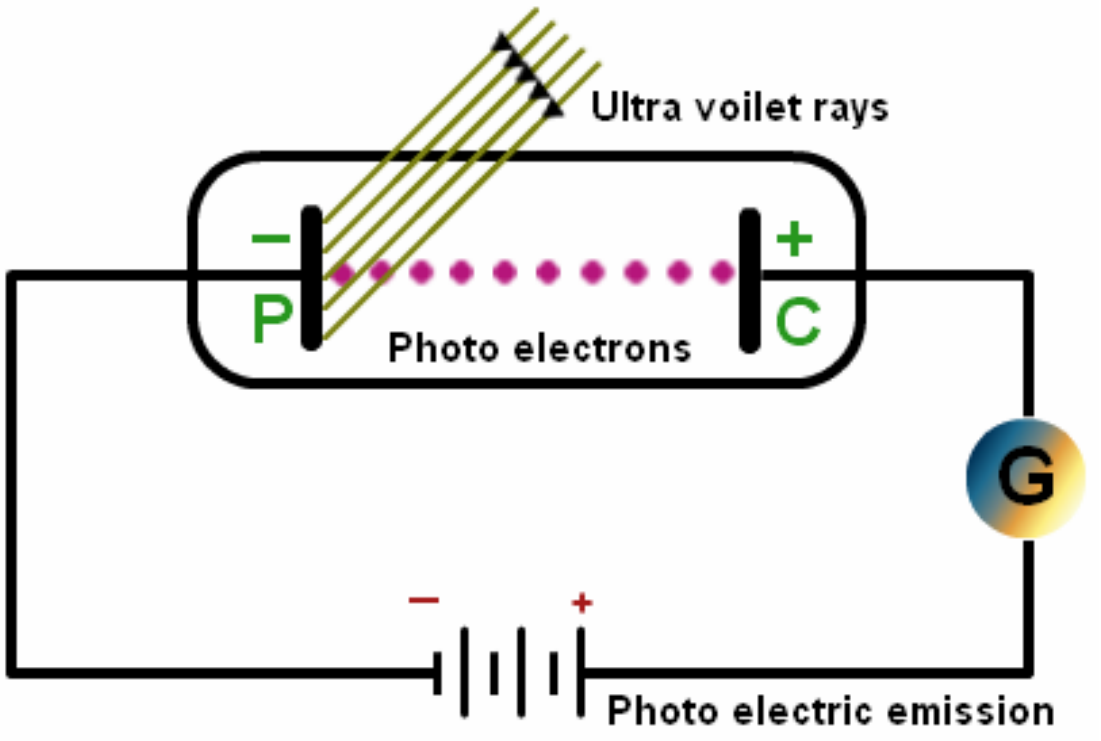
$h = 6.626 \times 10^{-34} J \cdot s$ = Planck constant,

$\nu =$ light frequency

$n = 1, 2, 3, \ldots$

discrete values of frequency

Photoelectric effect (1905)

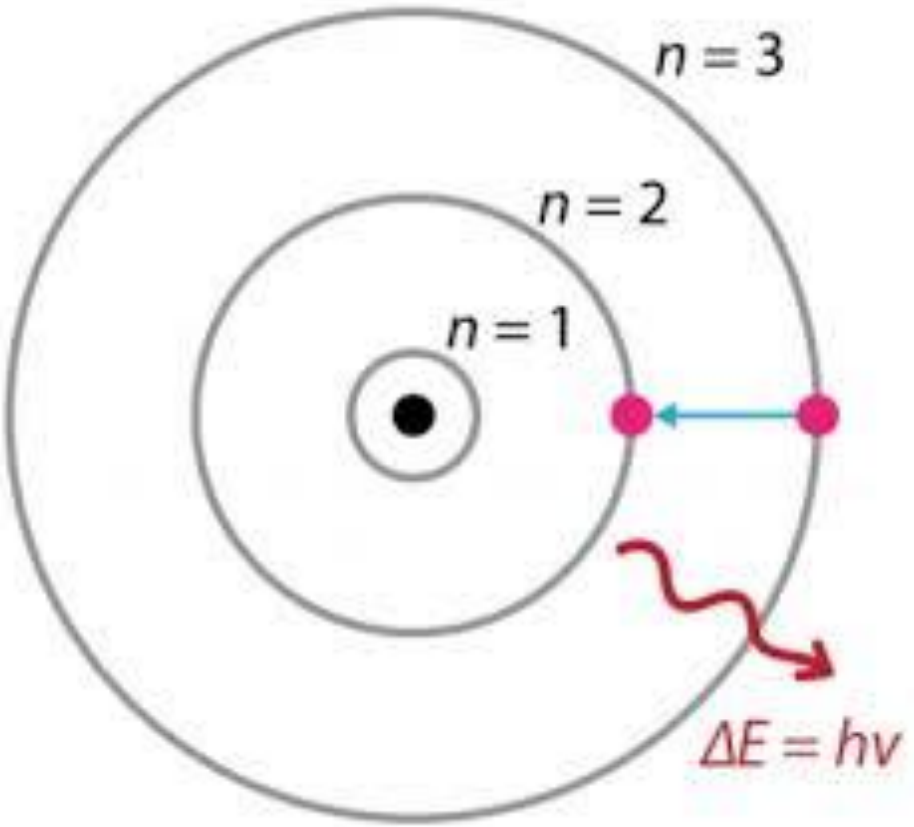


$$E = h\nu$$

proposed
by Einstein

http://physics.tutorvista.com/modern-physics/photoelectric-effect.html

Bohr Atom Model (1913)



Rydberg formula(1888) explained

Electrons have fixed orbits around the nucleus (not continuous orbits)

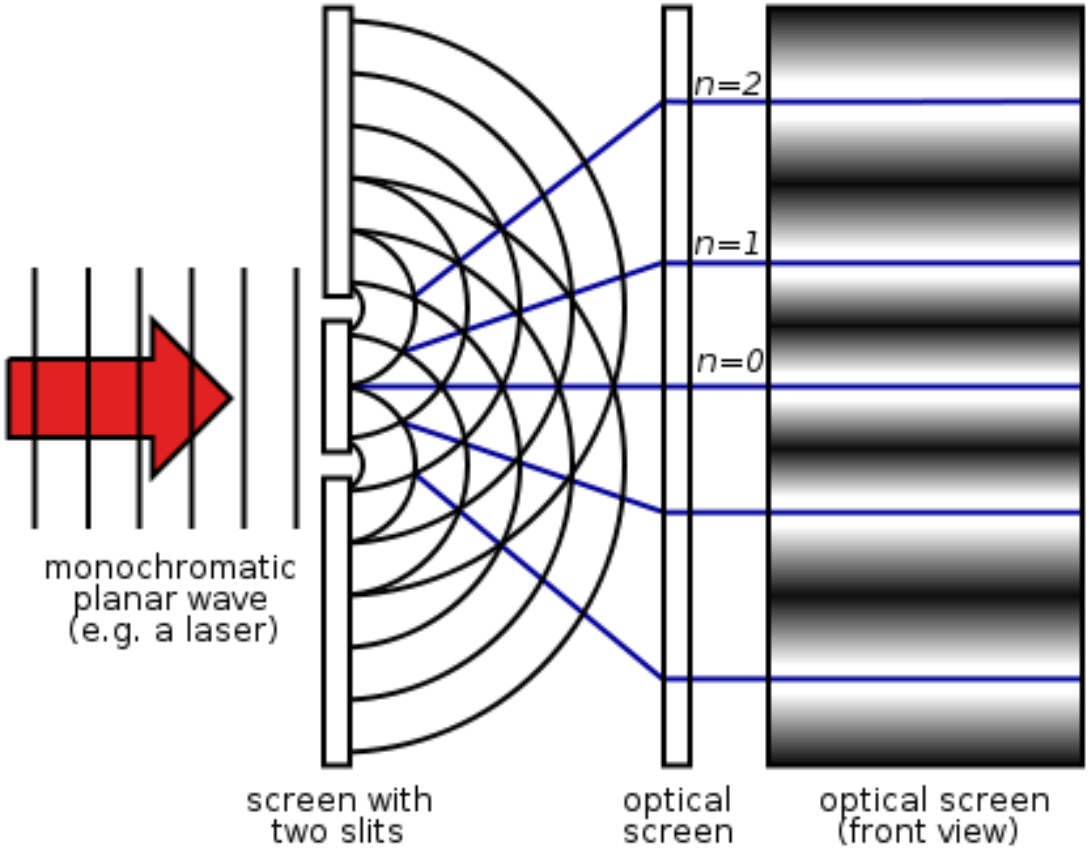
Wave-particle Duality (1923)

Louis de Broglie purposed

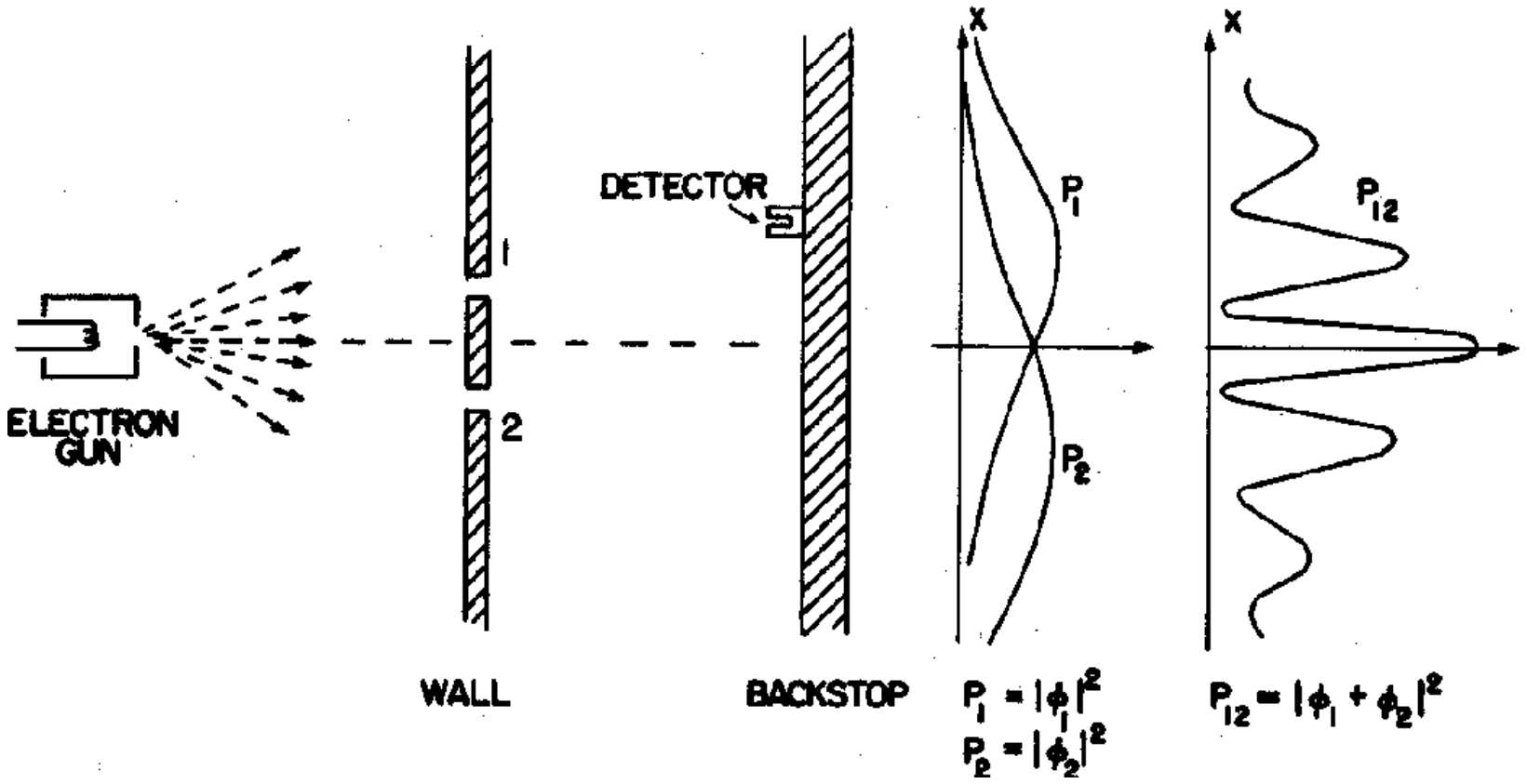
$$p = h / \lambda$$

p = momentum (of particles)

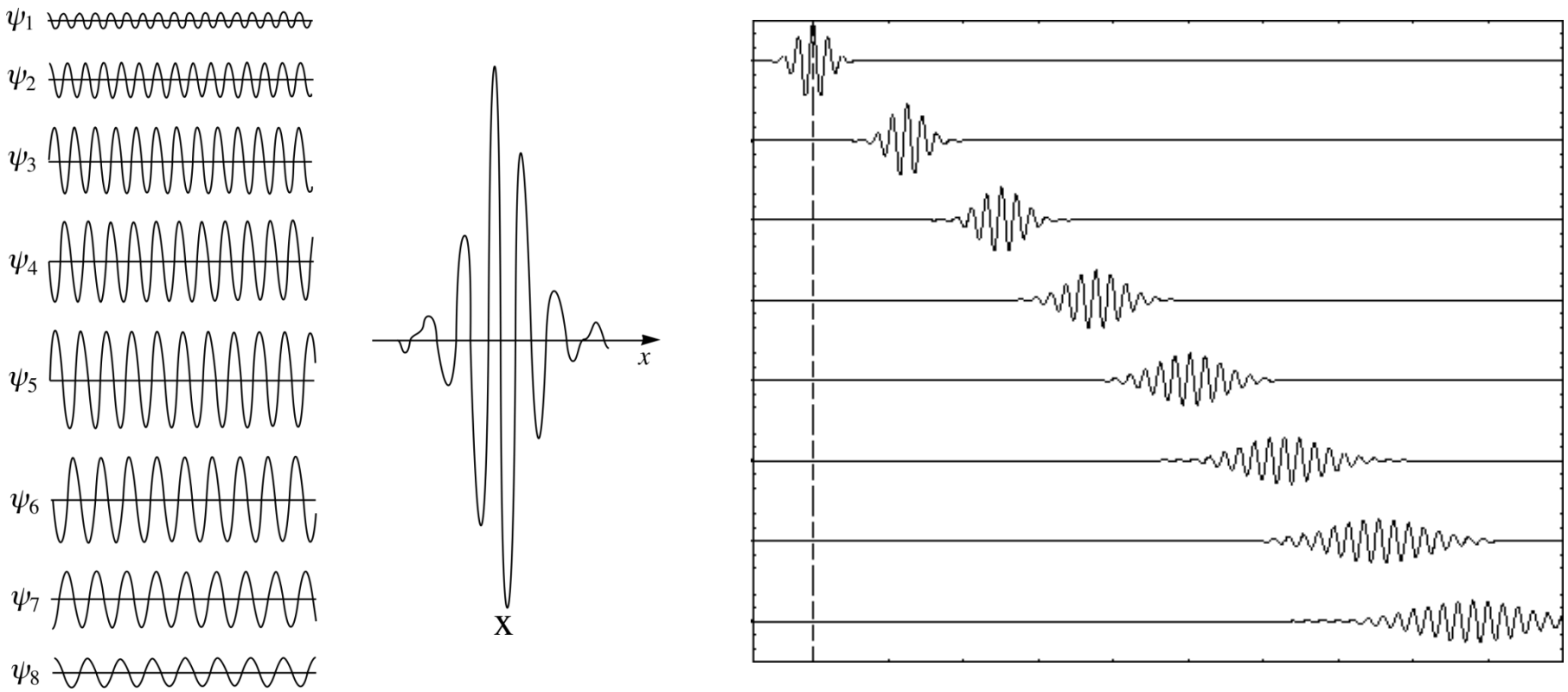
$\lambda =$ wave length

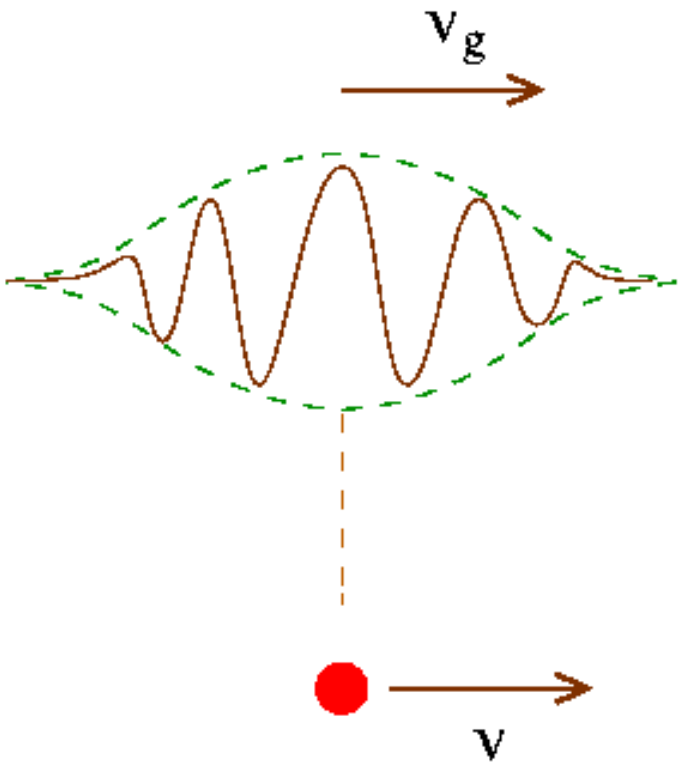


https://socratic.org/questions/what-are-some-examples-of-wave-particle-duality



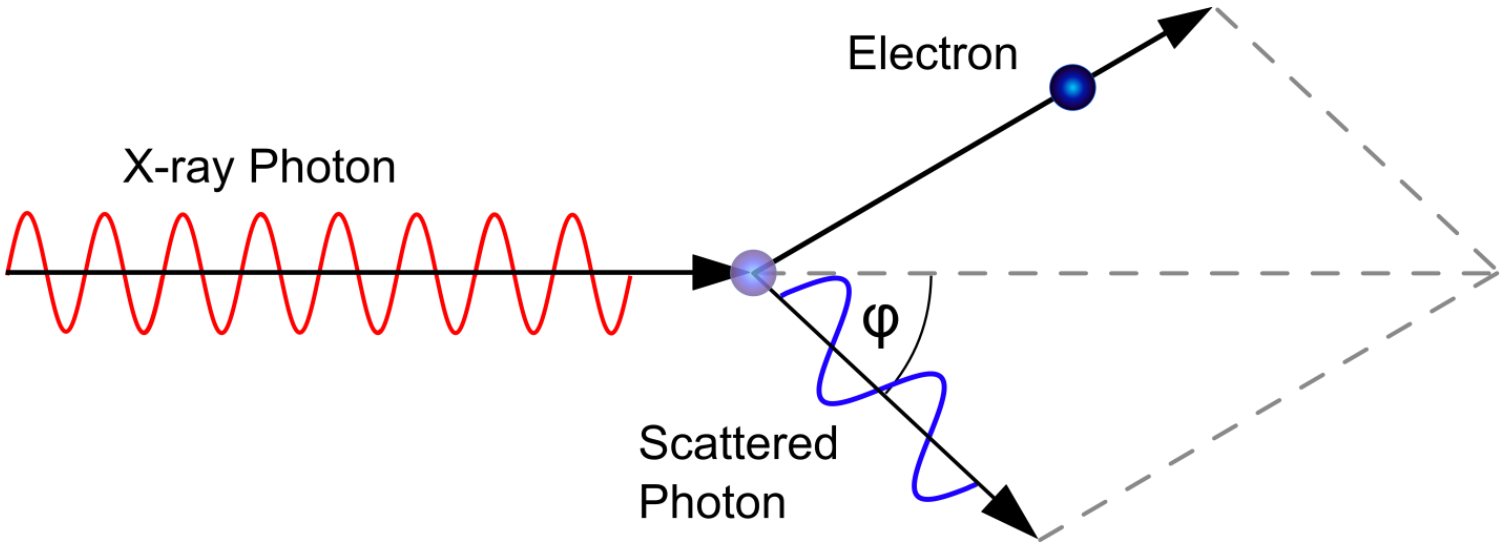
http://quantummechanics.ucsd.edu/ph130a/130_notes/node68.html


ψ1
ψ2
ψ3
ψ4
ψ5
ψ6
ψ7
ψ8
x
X



$$v = v_g$$

Compton Scattering (1923)



Momentum transfer from wave to particle

Bose-Einstein Statistics (1924)

Boson particles

- All particles are identical, indistinguishable.
- All particles can be in the same state

Pauli Exclusion Principle (1924)
Fermi-Dirac Statistics (1926)

Fermi particles

- All particles are identical, indistinguishable.
- No more one particle can be in the same state

Schrödinger wave equation

$$\left[-\frac{\hbar^2}{2m}\nabla^2 + V\right]\Psi = i\hbar\frac{d\Psi}{dt}$$

$\Psi(\vec{r},t) =$ wave packet

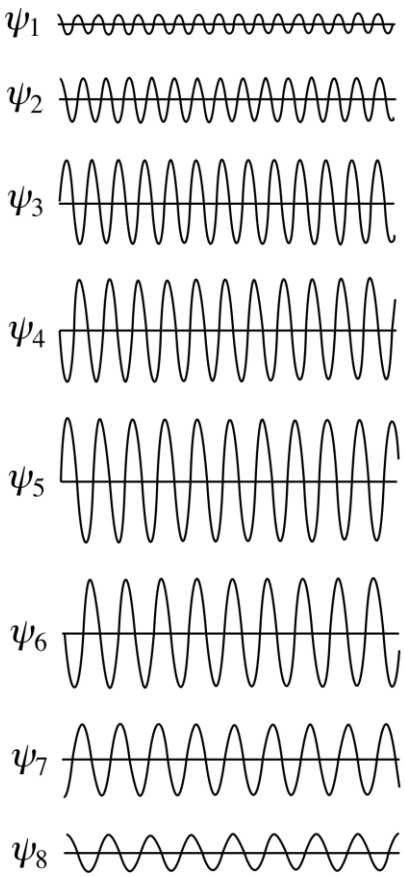
Matrix Mechanics (1925)

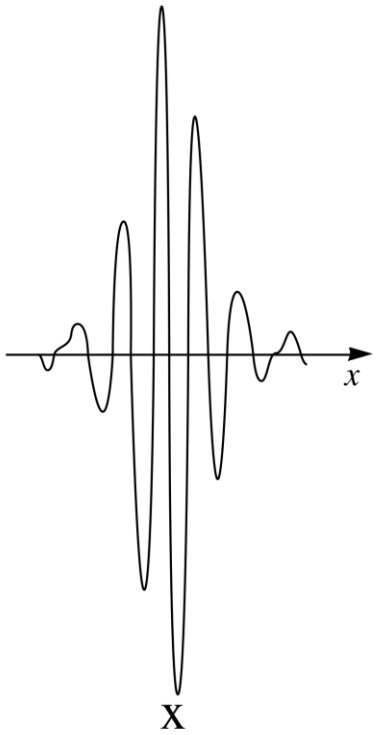
- Operator $\rightarrow$ Matrix representation
- [P , X] = -ih/2π, Quantization
- Observers are part of the systems

Klein-Gordon Equation (1926)

- Wave equation in relativistic 4-dimension for boson particles

Heisenberg Uncertainty Principle (1927)



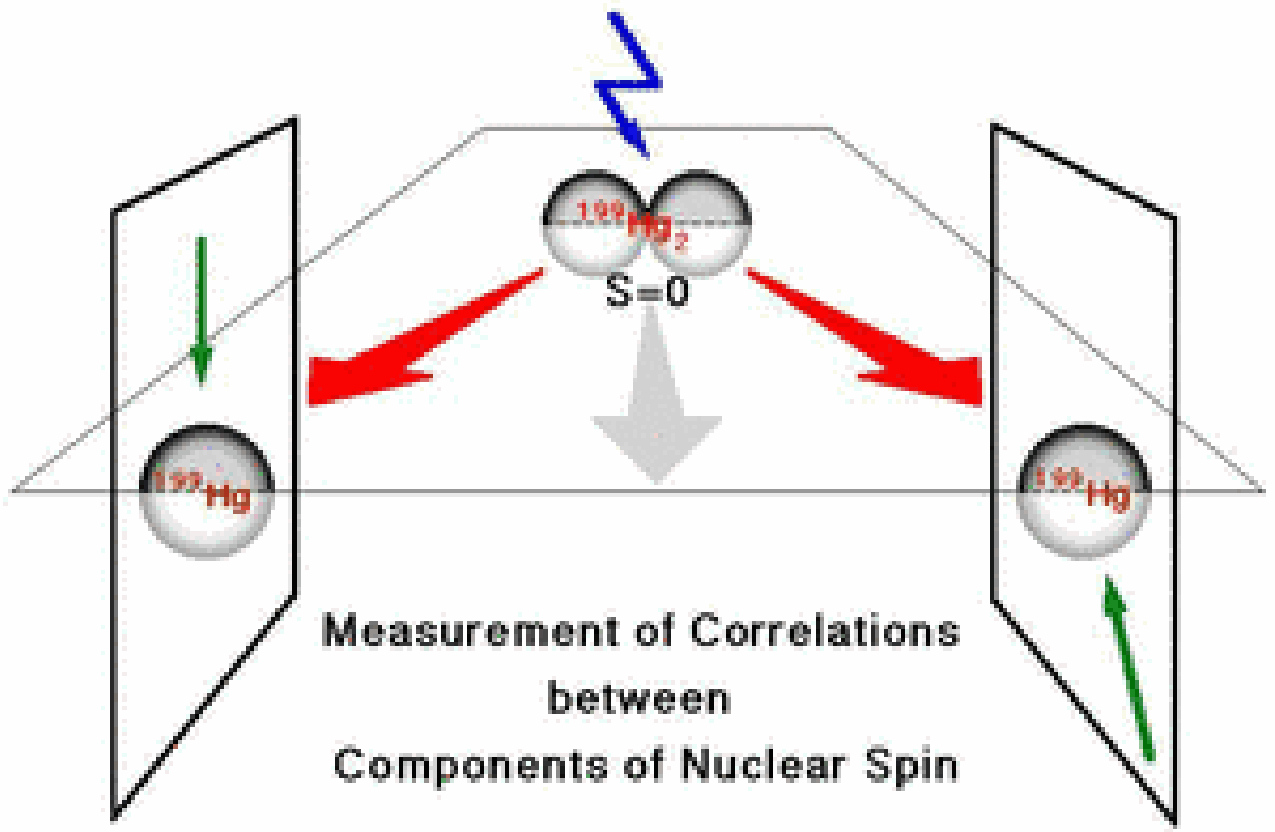


$$\Delta x \Delta p \geq \frac{\hbar}{2}$$

Dirac Equation (1927)

- Dirac studied the relativistic wave equation of electrons.
- The second quantization including the time component.
- (Called quantum electrodynamics, later called quantum field theory)

EPR Paradox (1935)

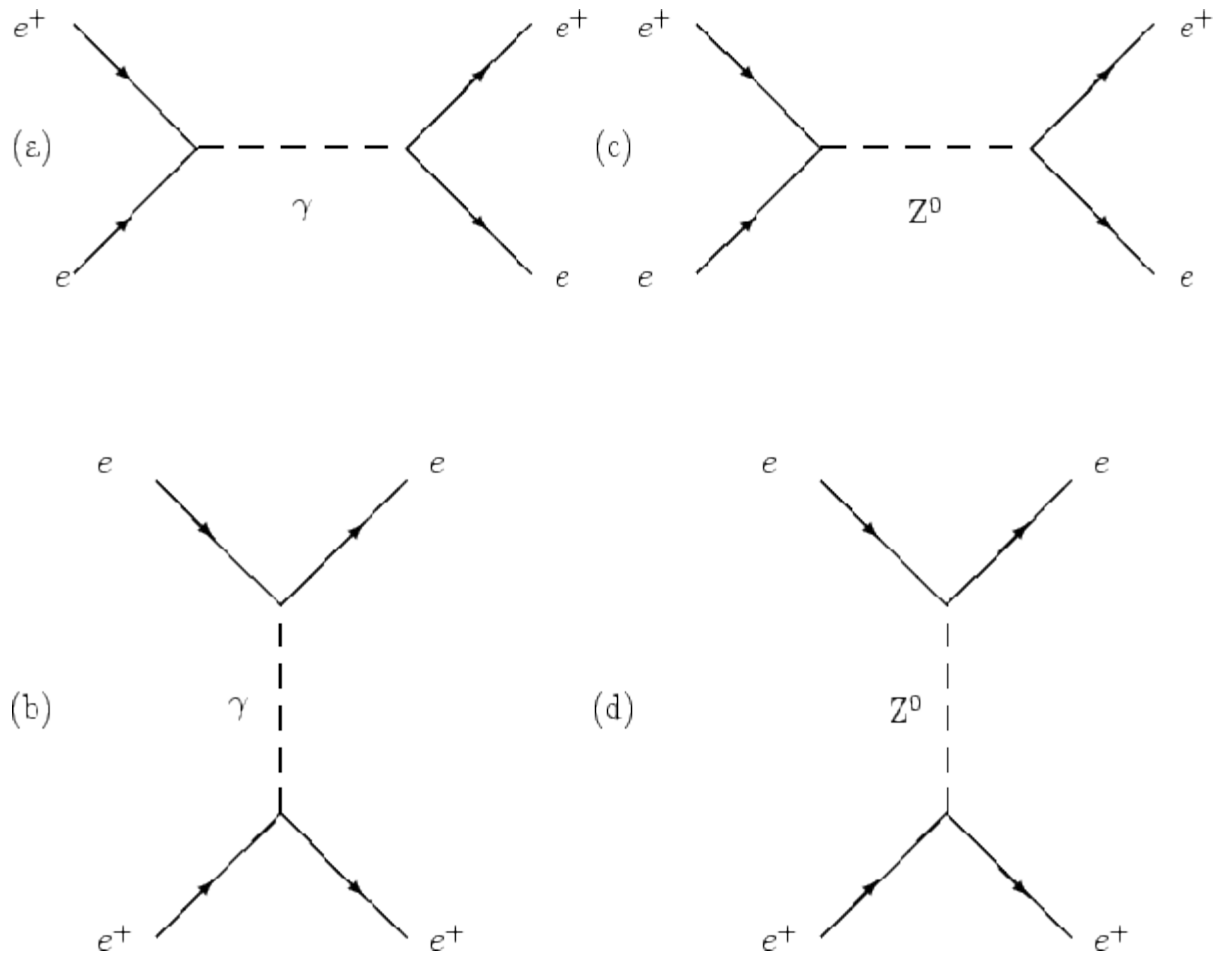


(Einstein, Boris Podolsky, Nathan Rosen)

iap.tu-darmstadt.de/lqo/research/epr/

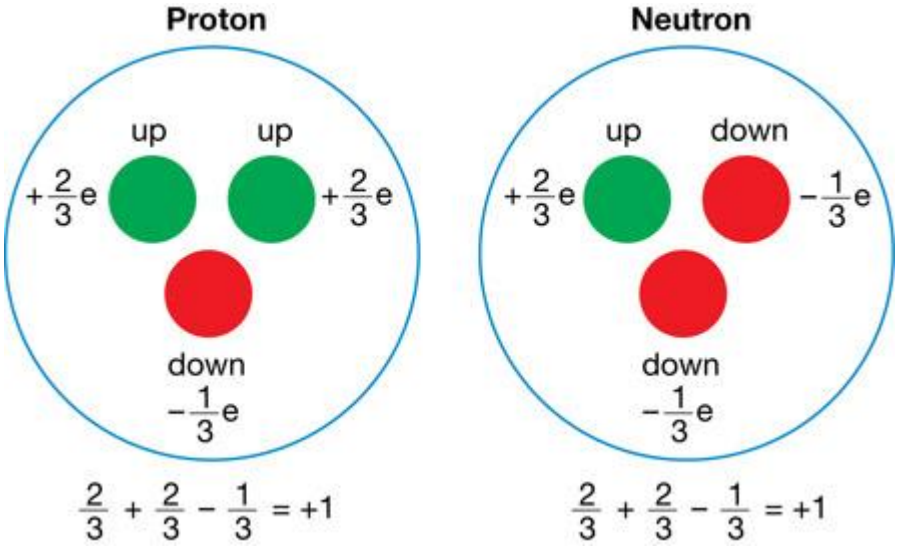
Quantum Electrodynamics (1949)

- Quantum path integral
- Feynman Diagrams
- Renormalization

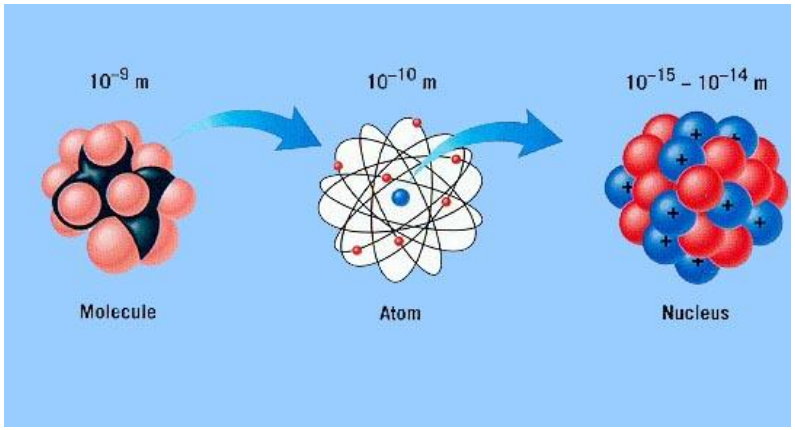

(a)
e^+
e^-
γ
e^+
e^-
(c)
e^+
e^-
Z^0
e^+
e^-
(b)
e^-
e^-
γ
e^+
e^+
(d)
e^-
e^-
Z^0
e^+
e^+

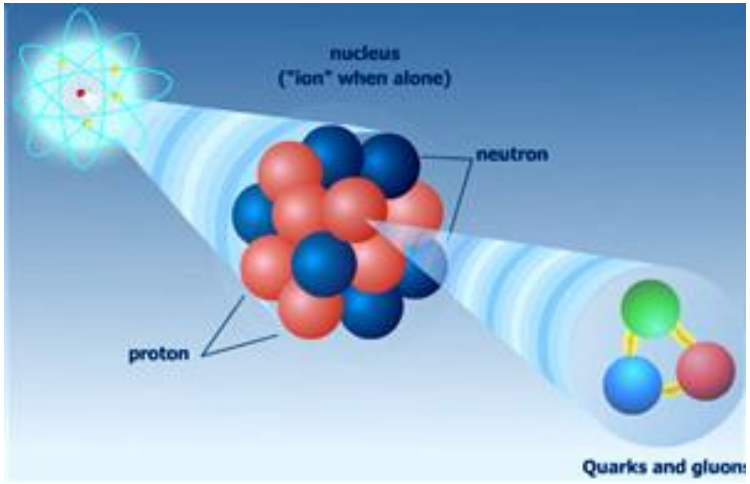
Quark Model (1964)

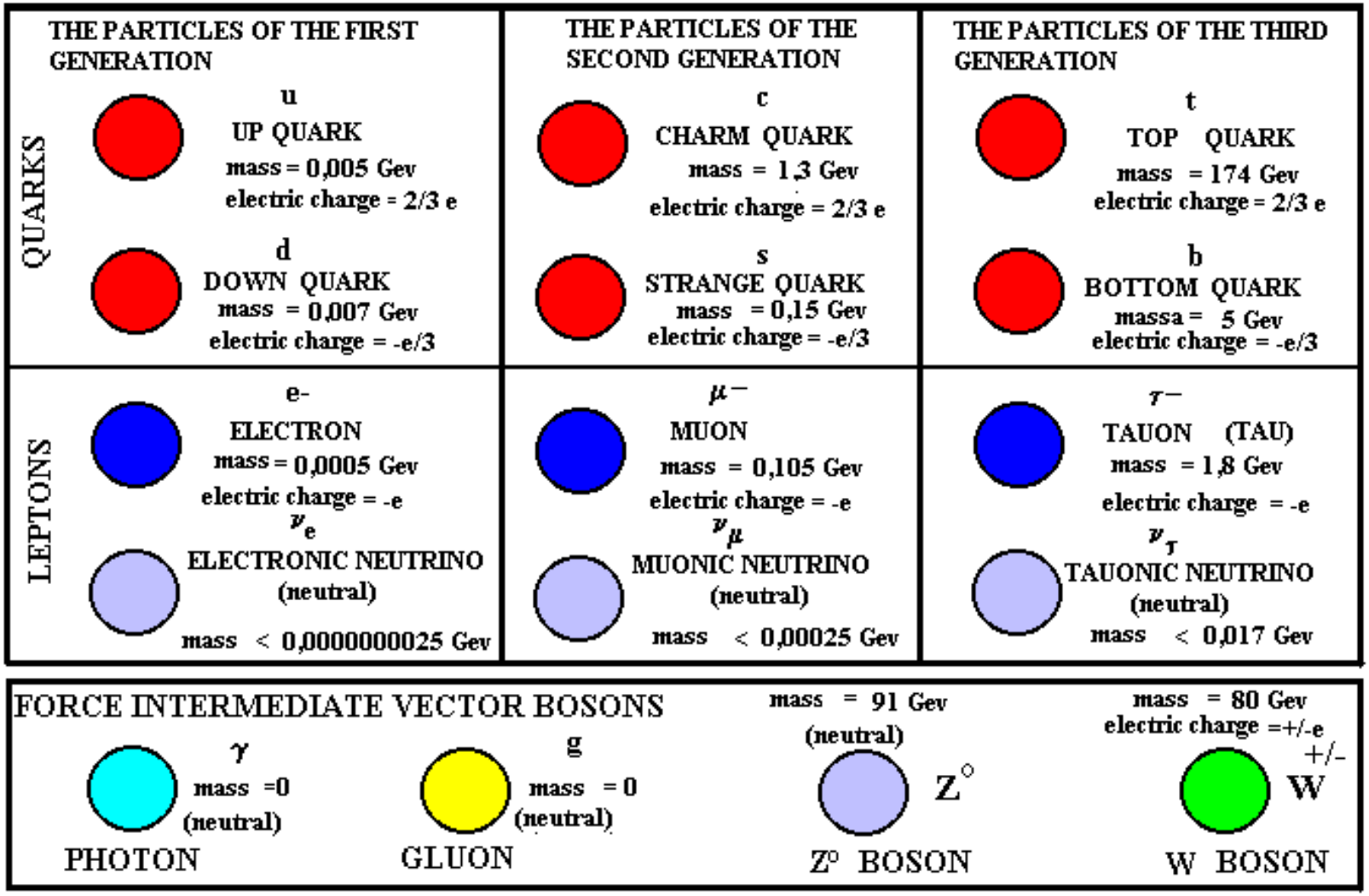
- Baryon number
- Strangeness
- Isospin of hardons



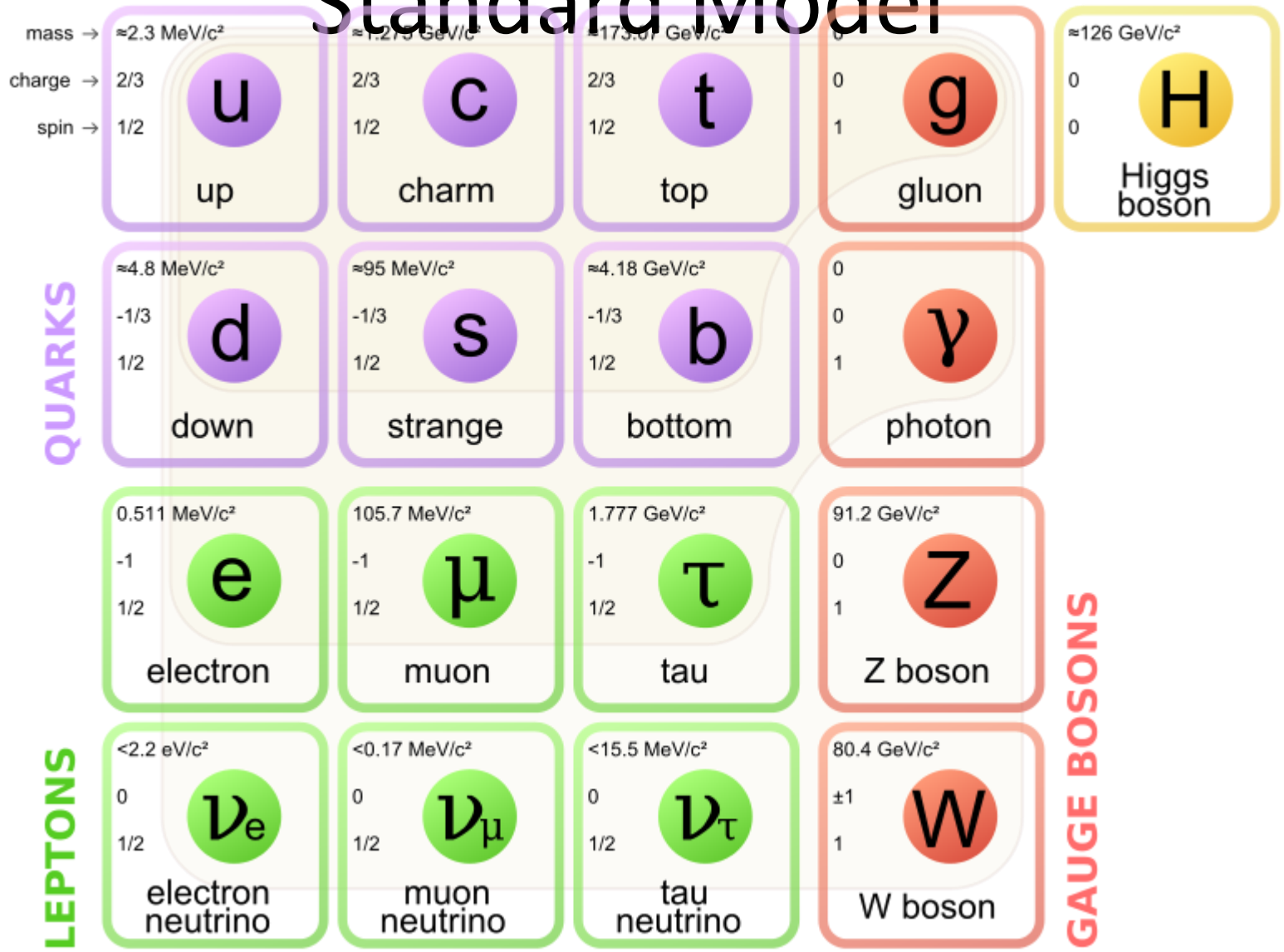
http://resource2.rockyview.ab.ca/physics30_BU/Unit_D/m8/p30_m8_l04_p3.html


10^{-9} m
10^{-10} m
$10^{-15} - 10^{-14}$ m
Molecule
Atom
Nucleus


nucleus
("ion" when alone)
neutron
proton
Quarks and gluon


THE PARTICLES OF THE FIRST GENERATION
THE PARTICLES OF THE SECOND GENERATION
THE PARTICLES OF THE THIRD GENERATION
QUARKS
u
UP QUARK
mass = 0,005 Gev
electric charge = 2/3 e
d
DOWN QUARK
mass = 0,007 Gev
electric charge = -e/3
c
CHARM QUARK
mass = 1,3 Gev
electric charge = 2/3 e
s
STRANGE QUARK
mass = 0,15 Gev
electric charge = -e/3
t
TOP QUARK
mass = 174 Gev
electric charge = 2/3 e
b
BOTTOM QUARK
massa = 5 Gev
electric charge = -e/3
LEPTONS
e-
ELECTRON
mass = 0,0005 Gev
electric charge = -e
ν_e
ELECTRONIC NEUTRINO
(neutral)
mass < 0,0000000025 Gev
μ^-
MUON
mass = 0,105 Gev
electric charge = -e
ν_μ
MUONIC NEUTRINO
(neutral)
mass < 0,00025 Gev
τ^-
TAUON (TAU)
mass = 1,8 Gev
electric charge = -e
ν_τ
TAUONIC NEUTRINO
(neutral)
mass < 0,017 Gev
FORCE INTERMEDIATE VECTOR BOSONS
γ
mass =0
(neutral)
PHOTON
g
mass = 0
(neutral)
GLUON
mass = 91 Gev
(neutral)
Z°
Z° BOSON
mass = 80 Gev
electric charge =+/-e
+/-
W
W BOSON

Standard Model



Standard Model of

FUNDAMENTAL PARTICLES AND INTERACTIONS

The Standard Model summarizes the current knowledge in Particle Physics. It is the quantum theory that includes the theory of strong interactions (quantum chromodynamics or QCD) and the unified theory of weak and electromagnetic interactions (electroweak). Gravity is included on this chart because it is one of the fundamental interactions even though not part of the "Standard Model."

FERMIONS

matter constituents
spin = 1/2, 3/2, 5/2, ...

Leptons spin = 1/2

Flavor	Mass GeV/c^2	Electric charge
ν_e electron neutrino	$<1\times10^{-8}$	0
e electron	0.000511	−1
ν_μ muon neutrino	<0.0002	0
μ muon	0.106	−1
ν_τ tau neutrino	<0.02	0
τ tau	1.7771	−1

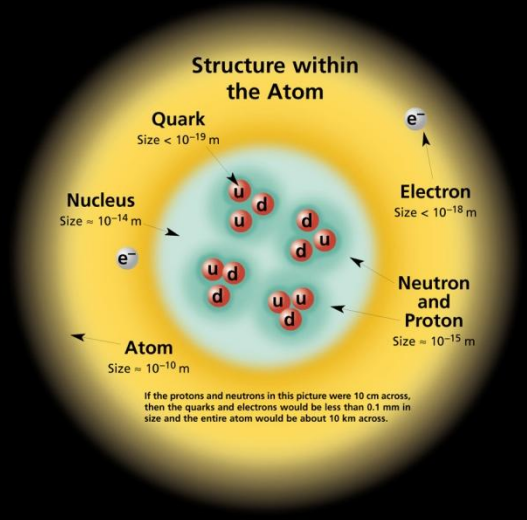
Quarks spin = 1/2

Flavor	Approx. Mass GeV/c^2	Electric charge
u up	0.003	2/3
d down	0.006	−1/3
c charm	1.3	2/3
s strange	0.1	−1/3
t top	175	2/3
b bottom	4.3	−1/3

Spin is the intrinsic angular momentum of particles. Spin is given in units of $\hbar$, which is the quantum unit of angular momentum, where $\hbar = h/2\pi = 6.58\times10^{-25}$ GeV s $= 1.05\times10^{-34}$ J s.

Electric charges are given in units of the proton's charge. In SI units the electric charge of the proton is 1.60×10^{-19} coulombs.

The **energy** unit of particle physics is the electronvolt (eV), the energy gained by one electron in crossing a potential difference of one volt. **Masses** are given in GeV/c^2 (remember $E = mc^2$), where 1 GeV = 10^9 eV = 1.60×10^{-10} joule. The mass of the proton is 0.938 GeV/c^2 = 1.67×10^{-27} kg.



BOSONS

force carriers
spin = 0, 1, 2, ...

Unified Electroweak spin = 1

Name	Mass GeV/c^2	Electric charge
γ photon	0	0
W^-	80.4	−1
W^+	80.4	+1
Z^0	91.187	0

Strong (color) spin = 1

Name	Mass GeV/c^2	Electric charge
g gluon	0	0

Color Charge
Each quark carries one of three types of "strong charge," also called "color charge." These charges have nothing to do with the colors of visible light. There are eight possible types of color charge for gluons. Just as electrically-charged particles interact by exchanging photons, in strong interactions color-charged particles interact by exchanging gluons. Leptons, photons, and ***W*** and ***Z*** bosons have no strong interactions and hence no color charge.

Quarks Confined in Mesons and Baryons
One cannot isolate quarks and gluons; they are confined in color-neutral particles called **hadrons**. This confinement (binding) results from multiple exchanges of gluons among the color-charged constituents. As color-charged particles (quarks and gluons) move apart, the energy in the color-force field between them increases. This energy eventually is converted into additional quark-antiquark pairs (see figure below). The quarks and antiquarks then combine into hadrons; these are the particles seen to emerge. Two types of hadrons have been observed in nature: **mesons** $q\bar{q}$ and **baryons** qqq.

Residual Strong Interaction
The strong binding of color-neutral protons and neutrons to form nuclei is due to residual strong interactions between their color-charged constituents. It is similar to the residual electrical interaction that binds electrically neutral atoms to form molecules. It can also be viewed as the exchange of mesons between the hadrons.

PROPERTIES OF THE INTERACTIONS

Property \ Interaction	Gravitational	Weak (Electroweak)	Electromagnetic (Electroweak)	Strong: Fundamental	Strong: Residual
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge	See Residual Strong Interaction Note
Particles experiencing:	All	Quarks, Leptons	Electrically charged	Quarks, Gluons	Hadrons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons	Mesons
Strength relative to electromag for two u quarks at: 10^{-18} m	10^{-41}	0.8	1	25	Not applicable to quarks
Strength relative to electromag for two u quarks at: 3×10^{-17} m	10^{-41}	10^{-4}	1	60	
for two protons in nucleus	10^{-36}	10^{-7}	1	Not applicable to hadrons	20

Baryons qqq and Antibaryons $\bar{q}\bar{q}\bar{q}$

Baryons are fermionic hadrons.
There are about 120 types of baryons.

Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
p	proton	uud	1	0.938	1/2
$\bar{p}$	anti-proton	$\bar{u}\bar{u}\bar{d}$	−1	0.938	1/2
n	neutron	udd	0	0.940	1/2
Λ	lambda	uds	0	1.116	1/2
Ω^-	omega	sss	−1	1.672	3/2

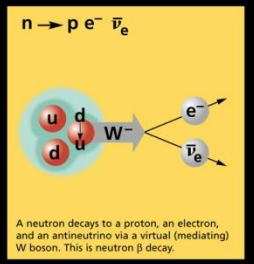
Mesons $q\bar{q}$

Mesons are bosonic hadrons.
There are about 140 types of mesons.

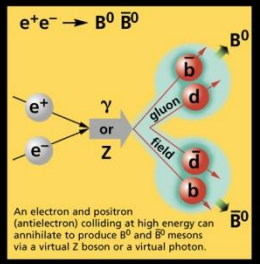
Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
π^+	pion	$u\bar{d}$	+1	0.140	0
K^-	kaon	$s\bar{u}$	−1	0.494	0
ρ^+	rho	$u\bar{d}$	+1	0.770	1
B^0	B-zero	$d\bar{b}$	0	5.279	0
η_c	eta-c	$c\bar{c}$	0	2 .980	0

Matter and Antimatter
For every particle type there is a corresponding antiparticle type, denoted by a bar over the particle symbol (unless + or − charge is shown). Particle and antiparticle have identical mass and spin but opposite charges. Some electrically neutral bosons (e.g., Z^0, γ, and $\eta_c = c\bar{c}$, but not $K^0 = d\bar{s}$) are their own antiparticles.

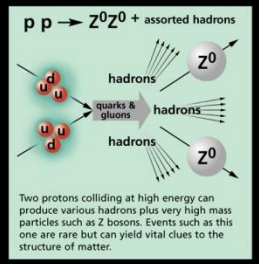
Figures
These diagrams are an artist's conception of physical processes. They are ***not*** exact and have ***no*** meaningful scale. Green shaded areas represent the cloud of gluons or the gluon field, and red lines the quark paths.



A neutron decays to a proton, an electron, and an antineutrino via a virtual (mediating) W boson. This is neutron β decay.



An electron and positron (antielectron) colliding at high energy can annihilate to produce B^0 and $\bar{B}^0$ mesons via a virtual Z boson or a virtual photon.



Two protons colliding at high energy can produce various hadrons plus very high mass particles such as Z bosons. Events such as this one are rare but can yield vital clues to the structure of matter.

The Particle Adventure
Visit the award-winning web feature *The Particle Adventure* at
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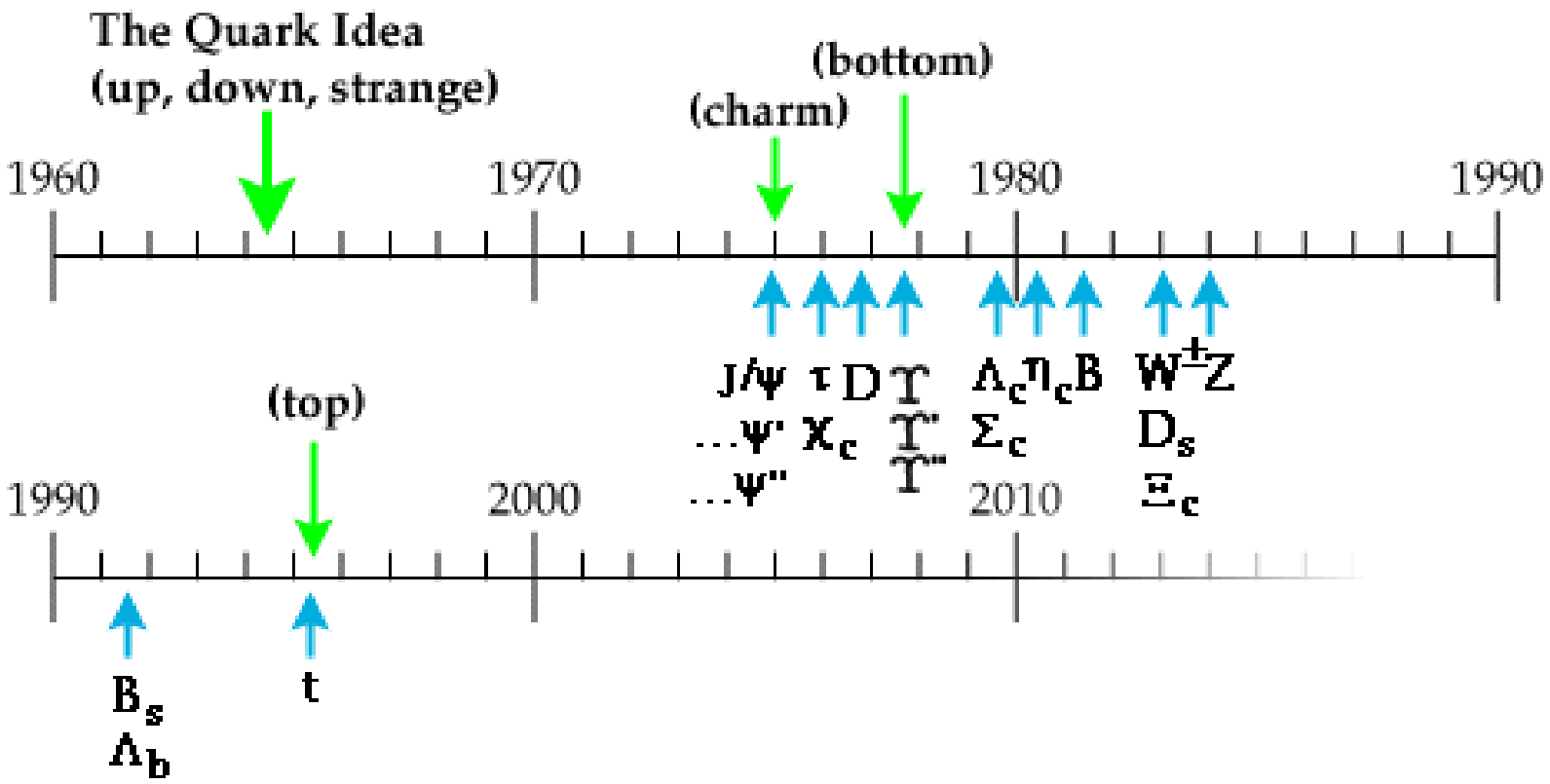

http://www.particleadventure.org/other/history/smt.html

Quantum - Gravity

- Big Bank
- Black Hole
- (Correspondence Conformal Field Theory/ Anti de Spacetime)