5- PHYSICS AFTER 1900
5.2. THE QUANTUM MECHANICS

❒ Introduction:

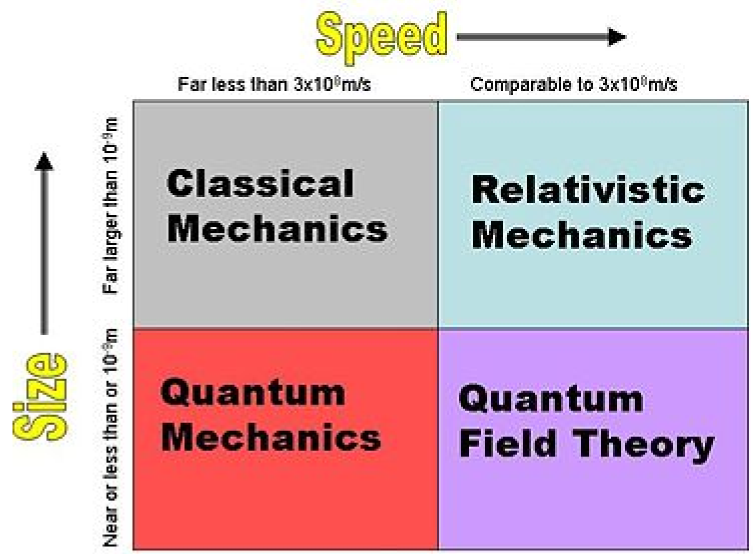
Quantum mechanics is a fundamental branch of physics that replaces *classical mechanics* and *classical electromagnetism* at the **atomic** and **subatomic** levels.

Objects in our universe range from Quarks ~ 10^{-18} m to Planets ~ 10^{7} m.

➲ **CLASSICAL MECHANICS:** works very well for ordinary objects around us:
- Masses range from the smallest object you can see ~10^{-4} m to Planets ~ 10^{7} m.
- velocities ~ 100 m/s (fastest rockets ~ 10^{4} m/s)

➲ **RELATIVITY:** (*the Special*) is important for objects moving very fast (near c = 10^{8} m/s) and (*the General*) is for very massive bodies (Strong effects of gravity).

➲ **QUANTUM MECHANICS:** essential to understand the behavior of very small units from which matter is made such as: Atoms ~ 10^{-10}, Nuclei ~ 10^{-14} m and Quarks ~ 10^{-18} m.



❒ The Origin of the Quantum Theory

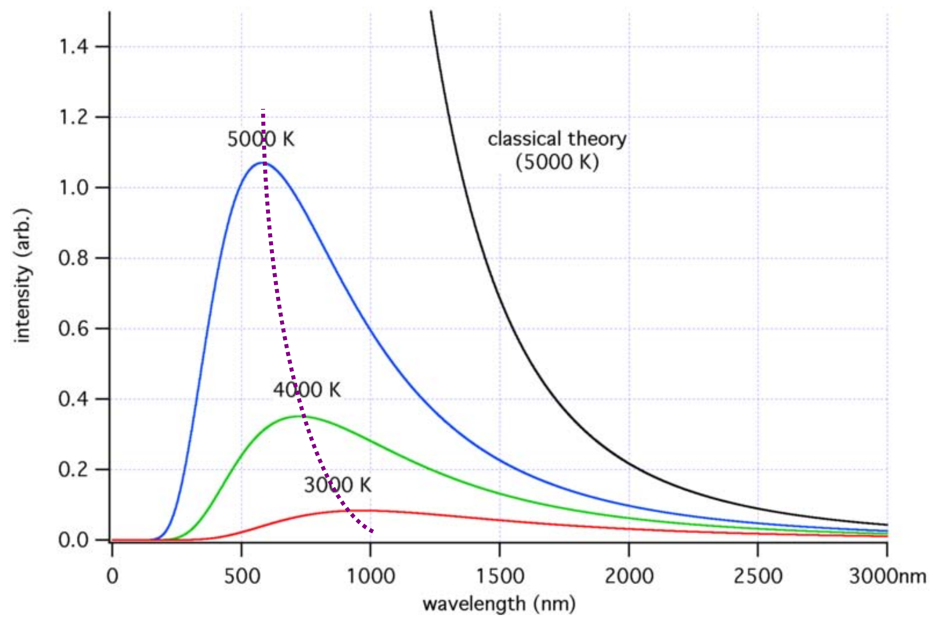
Quantum mechanics was initially developed to explain **two important** physics that could not be explained by classical mechanics or by classi electromagnetism.

- One of these puzzles was the study of the *black body radiation*.
- The other problem that led to quantum mechanics was related to the atom, especially explanation for *the electron's* staying in its *orbital*.

1- BLACKBODY RADIATION

❍ The true beginnings of the quantum theory lie in a strange place: ***the frequency spectrum emitted by a solid when it is heated*** (“**blackbody**” ***radiation***).

❍ The frequency spectrum was well determined by experimental measurements. It was a continuous spectrum with a shape that depended only on the temperature. ***As the temperature decreases, the peak of the black body radiation curve moves to lower intensities and longer wavelengths***.



- When the ***wave picture*** of light was applied to this problem, however, it failed - it predicted that the intensity, ***I*** , for a given temperature should behave as

$$I \propto \frac{1}{\lambda^4}$$

which agrees with the experimental data for *long wavelengths* but diverges for *short wavelengths.*

- In **1900 Max Planck** made a brave assumption in order to describe the data. He proposed that the molecules of a body cannot have arbitrary continues energies but instead they have *discrete* (***quantized***) *values of energies*.

- Hence, ***light is emitted in packets or quanta of energy.*** The magnitude of these energies is given by the formula;

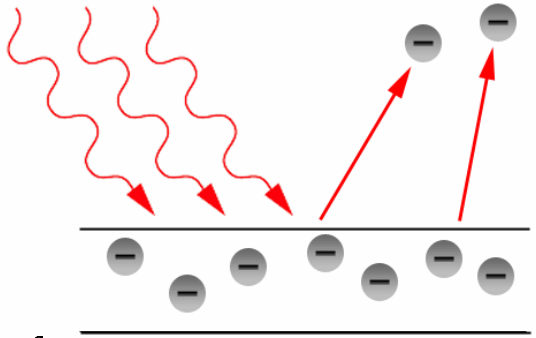
$$E = h\nu$$

where ν is the frequency of the light and h is **Planck's constant (h = 6.63 × 10^{-34} J.s).** ***With this quanta picture, Planck was successfully able to explain the blackbody radiation curves, both at long and at short wavelengths***.

2- PHOTOELECTRIC EFFECT:

❍ If a metallic surface is exposed to electromagnetic radiation that is above a **"specific" *frequency***, the photons are absorbed and ***electric current*** is produced.

❍ In **1905** the photoelectric effect was explained mathematically by **Albert Einstein**, who extended the work on **quanta** developed by **Planck**. By assuming that light actually ***consisted*** of discrete energy packets **"light quanta"** (later called "***photons***").



❍ Einstein wrote an equation for the photoelectric effect that fit experiments. In this equation Einstein stated that ***no electrons** are emitted for radiation with a frequency below that of the **threshold**,* as the electrons are unable to gain sufficient energy to overcome the material's electrostatic barrier (or; the material's **work function** ϕ). Hence;

$$h\upsilon = \phi + E_{K\,max}$$

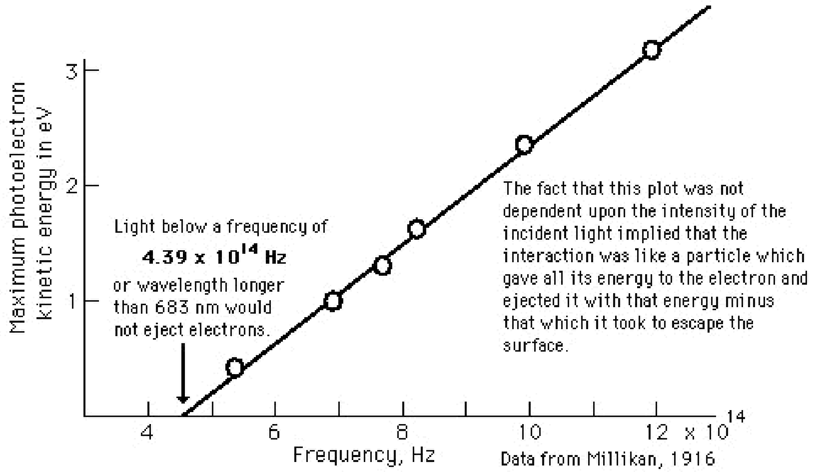
Where;

- ***h*** is **Planck's constant**,
- ν is the frequency of the incident photon,
- ϕ is the **work function**, the minimum energy required to remove a delocalized electron from the surface of any given metal. Note: $\phi = h\nu_0$ *where* ν_0 is the **threshold frequency** for the photoelectric effect to occur.

$$E_{k_{max}} = \frac{1}{2} m v_m^2$$ is the maximum kinetic energy of ejected electrons,

This equation explained why the energy of the photoelectrons was dependent only on the frequency of the incident light and not on its intensity.

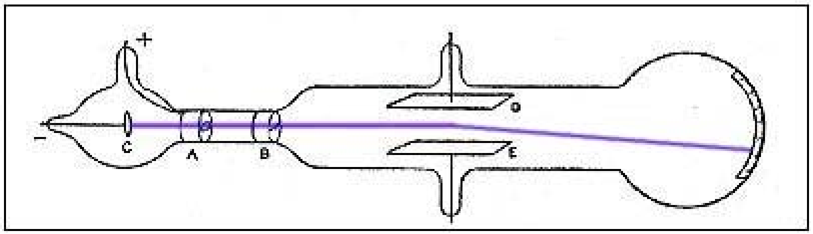
- It was known that the energy of the photoelectrons increased with increasing frequency of incident light, but the manner of the increase was not **experimentally** determined to be **linear** until **1915** when the American experimental physicist **Robert Millikan** showed that Einstein was correct.

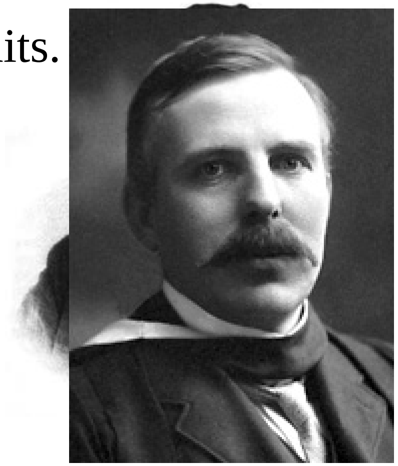


- In **1921**, Einstein was awarded the Nobel Prize in Physics, "*for his services to Theoretical Physics, and especially for his discovery of the law of the photoelectric effect*".

3- BOHR ATOM:

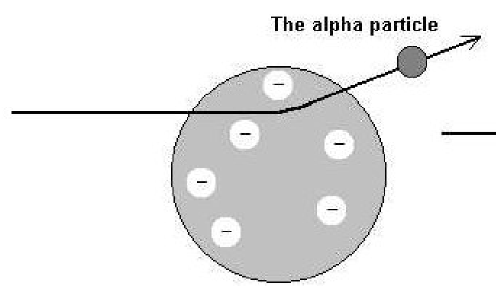
- In **1897**, the British scientist **J.J Thomson**, through his work on *cathode rays*, discovered the ***electron*** and its subatomic nature (i.e. its lightness compared with the mass of atoms).
This discovery destroyed the concept of atoms as being indivisible units.





- Thomson believed that the electrons were distributed evenly throughout the atom, balanced by the presence of a uniform sea of positive charge (plum-cake model).

- In **1909**, the **gold foil experiment** of the British scientist **Ernest Rutherford** suggested that the positive charge of an atom and most of its mass was concentrated in a ***nucleus*** at the center of the atom, with the ***electrons*** orbiting it like a tiny solar system.



Thomson's model of atom

But that simple analogy predicted that electrons would crash, within **~ 10^{-8} s**, into the nucleus of the atom.

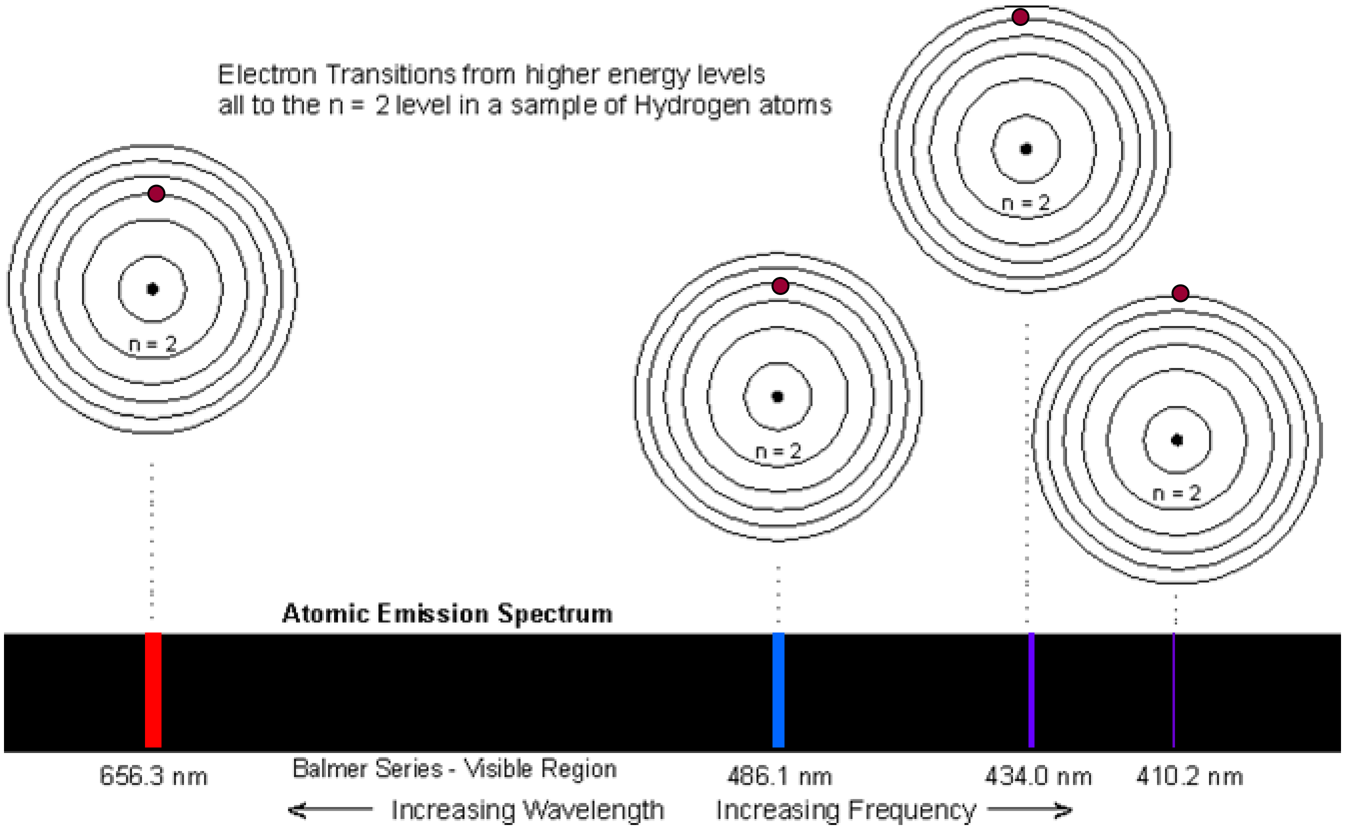
The great question of the early 20th century was:

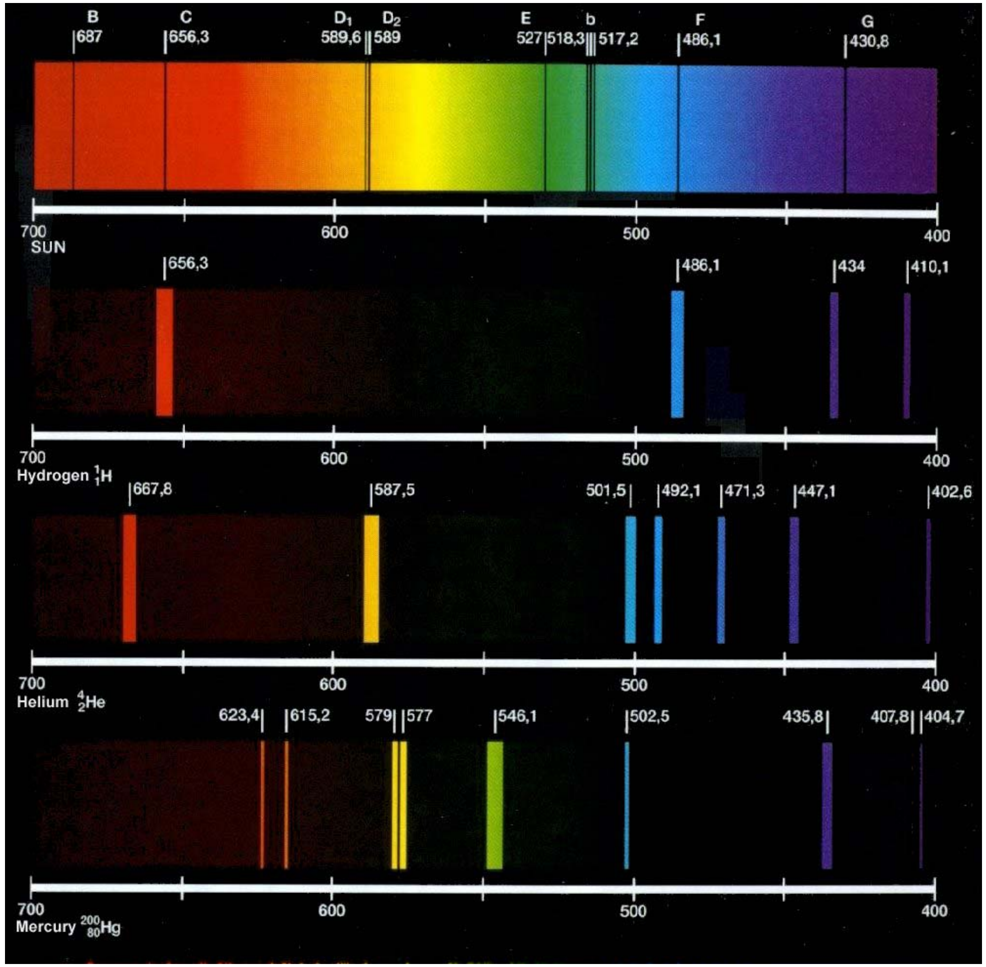
"**Why do electrons normally maintain a stable orbit around the nucleus ?**"

❑ BOHR MODEL OF THE ATOM

❍ In **1913**, the Danish physicist **Niels Bohr** removed this significant problem by applying the idea of *discrete (non-continuous) quanta* to the orbits of electrons. This account became known as the **Bohr model of the atom** in which he stated:

- Electrons can only inhabit certain orbits around the atom. These orbits could be derived by looking at the ***spectral lines*** produced by atoms.


Electron Transitions from higher energy levels
all to the n = 2 level in a sample of Hydrogen atoms
n = 2
n = 2
n = 2
n = 2
Atomic Emission Spectrum
656.3 nm
Balmer Series - Visible Region
486.1 nm
434.0 nm
410.2 nm
Increasing Wavelength
Increasing Frequency


B
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E
527
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500
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SUN
656,3
486,1
434
410,1
700
600
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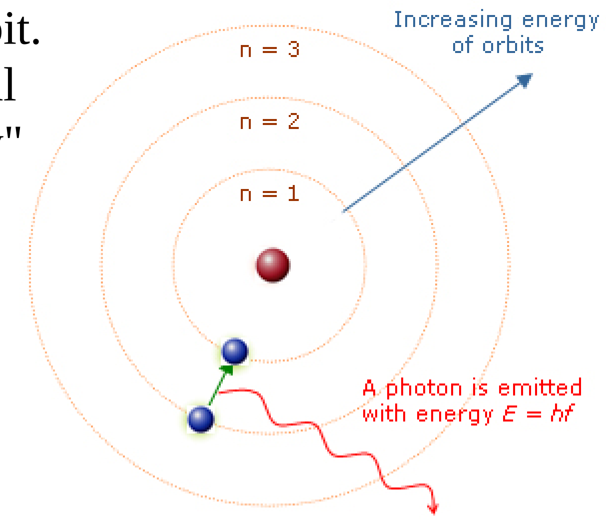
400
Hydrogen ¹₁H
667,8
587,5
501,5
492,1
471,3
447,1
402,6
700
600
500
400
Helium ⁴₂He
623,4
615,2
579
577
546,1
502,5
435,8
407,8
404,7
700
600
500
400
Mercury ²⁰⁰₈₀Hg

- An electron in the lowest orbital has an **angular momentum** equal to ***h*/2π**, where *h* is ***Planck's constant***. Each orbit after the initial orbit must provide for an electron's angular momentum being an **integer multiple** of that lowest value.

- Electrons in atoms are similar to planets in a solar orbit. However, Planck's constant is taken to be a fundamental quantity that determines the spacing of those "planetary" orbits

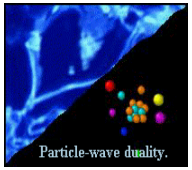


- When an electron changed orbits it did not move in a continuous trajectory from one orbit around the nucleus to another. Instead, it suddenly disappeared from its original orbit and reappeared in another orbit.

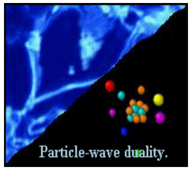
- Key to Bohr's theory was the fact that the electron could only "*jump*" and "*fall*" to precise energy levels, thus emitting a limited spectrum of light.

- This work earned Bohr the **1922** Nobel Prize for Physics.

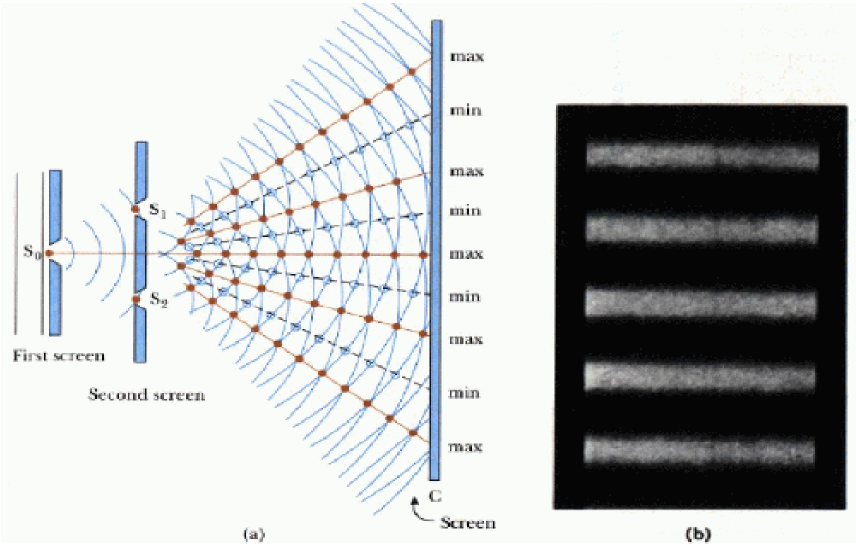
❒ particle-Wave duality:

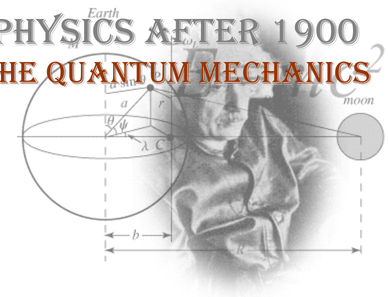


➲ In 1660's there were two theories of light; ***wave theory*** proposed by **Christiaan Huygens** in **1678** and ***corpuscular theory*** introduced by **Newton** in **1675**. Because of Newton's great reputation, his theory which states that light consisted of small particles or **"corpuscle"** went essentially unchallenged for over a century.



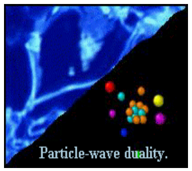
➲ In **1801**, **Thomas Young** provided an evidence for **Huygens'** theories with his famous **double-slit Experiments**.



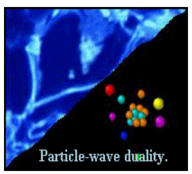


Young passed a beam of light through two parallel slits in an opaque screen, a characteristic interference pattern is observed, very similar to the pattern resulting from the interference of water waves. This led Young to deduce that;

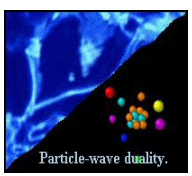
light was composed of waves.



➲ In **1864**, **Maxwell** explained light as the propagation of ***electromagnetic waves***. Maxwell equations made ***Huygens' view*** widely accepted.



➲ In **1905**, **Einstein** provided an explanation of the ***photoelectric effect***, which could not be explained by the **wave theory** of light. He did explain the phenomenon by postulating that light can be exist on a form of *quanta* of light energy "**photon**".



DE BROGLIE'S HYPOTHESIS;

Louis-Victor Raymond, 7th duc de Broglie (1892-1987), was a French physicist. His **1924** doctoral thesis, (***Research on Quantum Theory***), introduced his theory of **electron waves**.

Based on the work of **Einstein** and **Planck**, he introduced what we called today the ***de Broglie hypothesis*** which stating that ***any moving particle or object had an associated wave.***

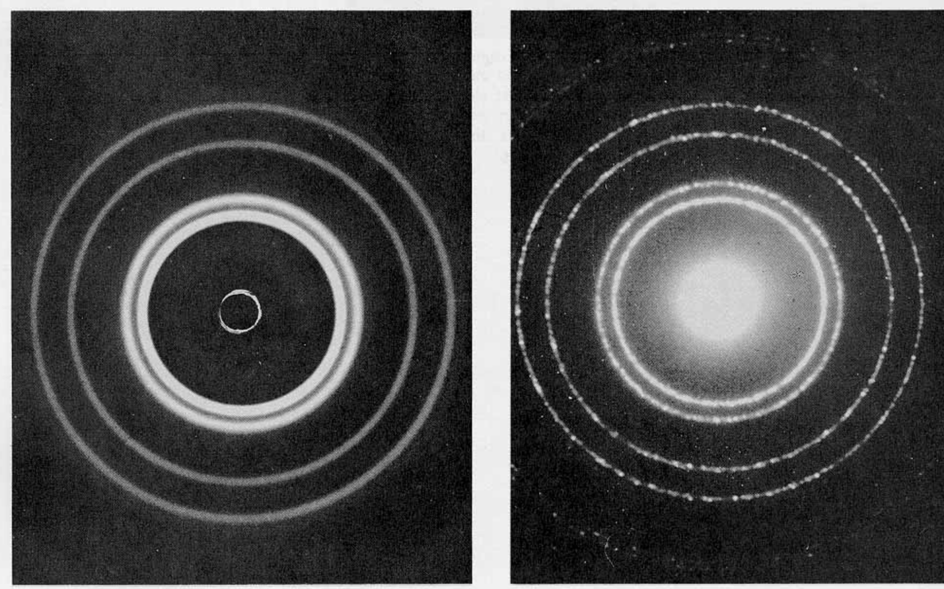
He related the wavelength, λ and momentum, p *through the relation:*

$$\lambda = \frac{h}{p}$$

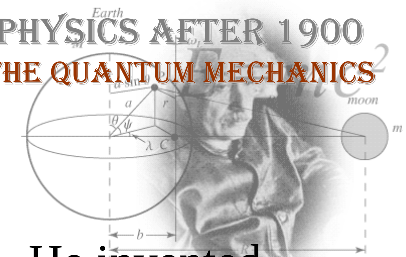
This is a generalization of ***Einstein's equation*** above since the momentum of a photon is given by $p = E / c$ where c is the speed of light in vacuum, and $\lambda = c / \nu$.

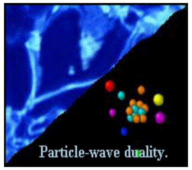
De Broglie's formula was confirmed three years later for **electrons** with the observation of ***electron diffraction***.

De Broglie was awarded the Nobel Prize in **1929** for his hypothesis.



The diffraction pattern on the left was made by a beam of x rays passing through thin aluminum foil. The diffraction pattern on the right was made by a beam of electrons passing through the same foil.





THE UNCERTAINTY PRINCIPLE:

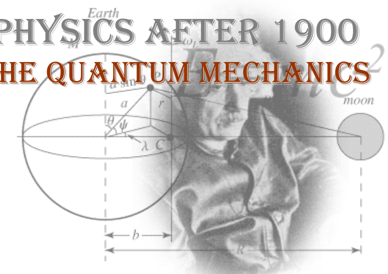
Werner Heisenberg (1901-1976) was a student of **Niels Bohr** . He invented ***matrix mechanics***, the first formalization of quantum mechanics, with the help of **Max Born** and **Pascual Jordan**.

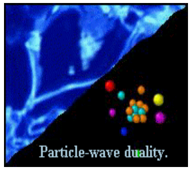
His ***uncertainty principle***, developed in **1927** provides a quantitative relationship between the uncertainties of the precise measurements of the particle's momentum ***p*** and position ***x***. It was formulated such that;

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

This requires that the product of the uncertainties in position and momentum is **equal to or greater than** about **10^{-35}** joule-seconds. Therefore, **the product of the uncertainties only becomes significant for small regimes**. Thus, the uncertainty principle governs the observable nature of atoms and subatomic particles while its effect on measurements in the macroscopic world is negligible and can be usually ignored.

He received the Nobel Prize in physics in **1932** for the creation of quantum mechanics.



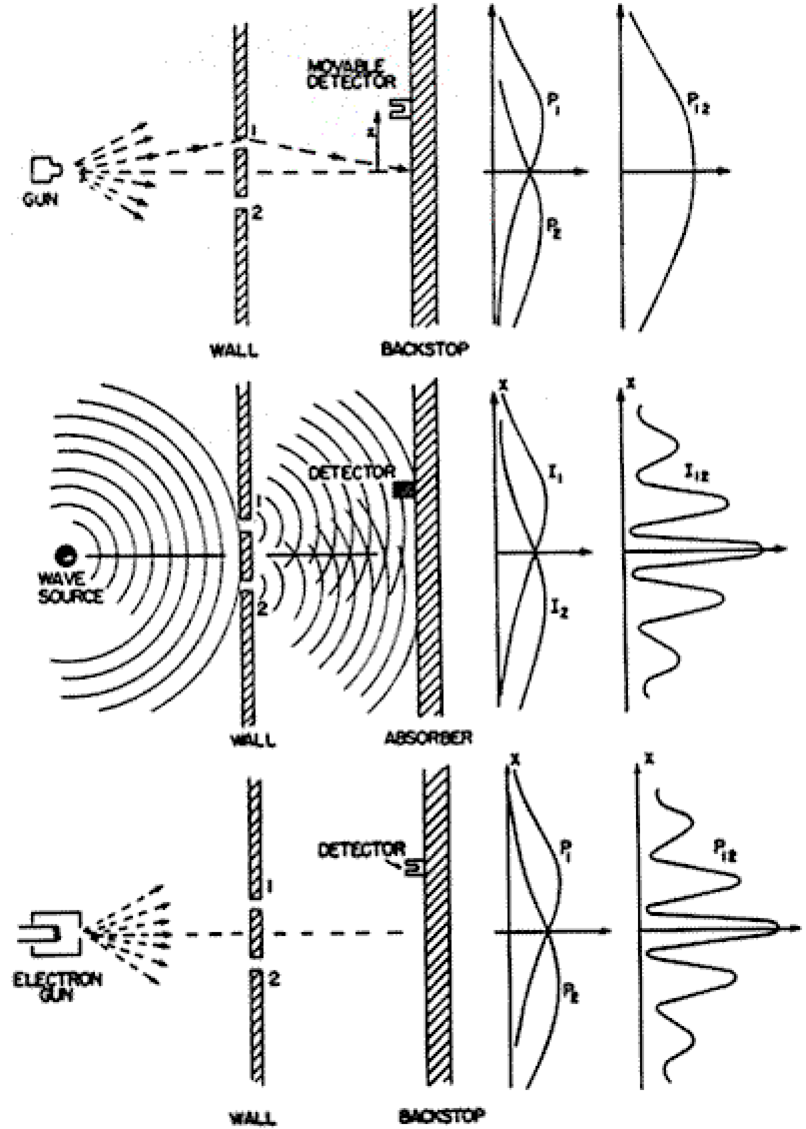


COMPLEMENTARITY PRINCIPLE;

The *principle of complementarity* was first proposed by **Niels Bohr** in **1928**. It was stated that:

> ***a single quantum mechanical entity can either behave as a particle or as wave, but never simultaneously as both; that a stronger appearance of the particle nature leads to a weaker appearance of the wave nature and vice versa***.

For example, an experiment that illustrates the particle properties of light will not show any of the wave properties of light.
This principle also implies that only certain kinds of information can be gained in a particular experiment. Some other information that are equally important cannot be measured simultaneously and they are lost.


MOVABLE DETECTOR
GUN
1
2
x
WALL
BACKSTOP
P1
P2
P12
DETECTOR
WAVE SOURCE
WALL
ABSORBER
x
I1
I2
I12
DETECTOR
ELECTRON GUN
WALL
BACKSTOP
P1
P2
P12

❐ Mathematical formulation

1- OLD APPROACH (BOHR MODEL) :

Combining the energy of the ***classical electron orbit*** with the ***quantization of angular momentum***, Bohr approach, yields expressions for the electron orbit radii and energies:

$$\frac{mv^2}{2} = \frac{(mvr)^2}{2mr^2} = \frac{n^2h^2}{8\pi^2 mr^2} = \frac{Ze^2}{8\pi\varepsilon_0 r}$$

kinetic energy of electron; expressed in terms of angular momentum; use quantization of angular momentum; set equal to total energy of classical orbit.

This is for hydrogenic atoms; the use of the atomic number Z is appropriate only if there is only one electron.

Substitution for ***r*** gives the *Bohr energies and radii*:

$$E = -\frac{Z^2 me^4}{8n^2h^2\varepsilon_0^2} = -\frac{13.6\,Z^2}{n^2}\ \text{eV} \qquad r = \frac{n^2h^2\varepsilon_0}{Z\pi me^2} = \frac{n^2 a_0}{Z}$$

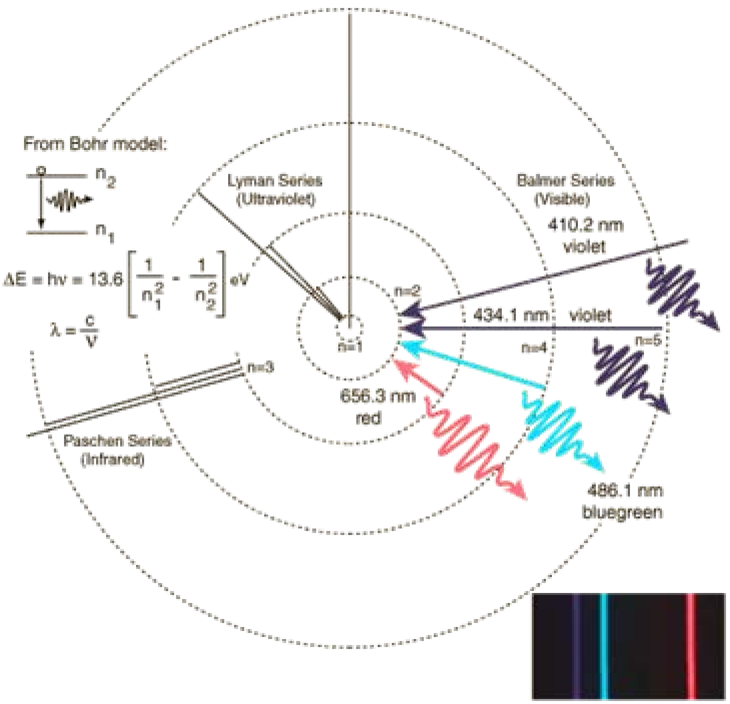
$a_0 = 0.529$ Å = Bohr radius

Failure of Bohr Model:

Some of the model shortcomings are:

1- It fails to provide any understanding of why certain spectral lines are brighter than others. There is no mechanism for the calculation of ***transition probabilities***.

2- The Bohr model treats the electron as if it were a tiny planet, with definite radius and momentum. This is in direct violation of the ***uncertainty principle*** which dictates that position and momentum cannot be simultaneously determined.



Howevere, *Bohr model* is accurate only for one-electron systems such as the **hydrogen atom** or **singly-ionized helium**.

2- NEW QUANTUM MECHANICS:

Erwin Schrödinger
(1887 - 1961)

Schrödinger was an Austrian physicist. In **1925** he proposed his ***famous equation*** (now bearing his name) that describes the ***space (&time) - dependence*** of quantum mechanical systems.

In quantum mechanics, the particle can be represented as a **wave**, of arbitrary shape and extending over all of space, called a ***wavefunction***.

The ***position*** and ***momentum*** of the particle are observables. If one performs a position measurement on such a ***wavefunction***, this is called an ***eigenstate of position***. If the particle is in an ***eigenstate*** of position then its momentum is completely unknown and **vise versa**.

Schrödinger's equation is an equation for ***the wave associated to an electron in an atom*** according to **de Broglie**, and explained energy quantization by the differential operators that had a discrete spectrum.

The time independent **Schrödinger** equation for **1D** is of the form:

$$\frac{-\hbar^2}{2m}\frac{d^2\Psi(x)}{dx^2}+U(x)\Psi(x)=E\Psi(x)$$

where **Ψ(*x*)** is the *wavefunction*, ***U(x)*** is the potential energy and ***E*** represents the system energy.

Schrödinger equation is of central importance to the theory of quantum mechanics, playing a role analogous to Newton's second law in classical mechanics.

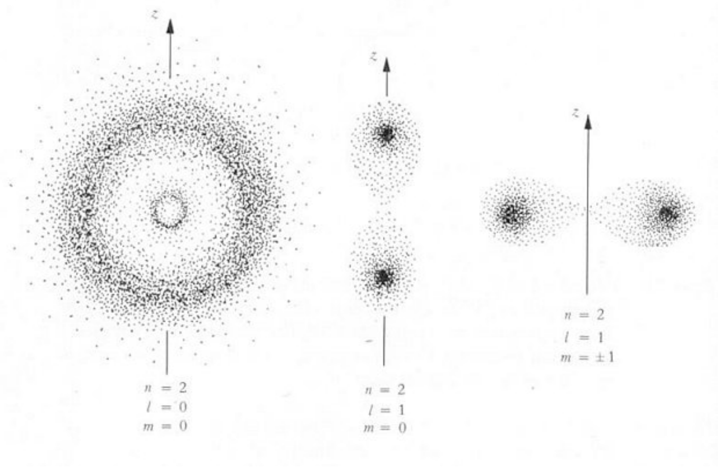
Max Born
(1882-1970)

Born was a German mathematician and physicist. He was the first to explain the ***squared amplitude of the wave function*** (ψ^2) ***as the probability density of the object position.***

According to Born view, nothing will be detected most of the time, but only when this thing is observed.

The concept of the electron as a point particle moving in well-defined path around the nucleus is replaced by clouds that describe the probable locations of the electron in different states.

Although, this interpretation was published in 1926, he was awarded the **Nobel Prize in Physics** in 1954, some three decades later.



Wolfgang Pauli
(1900-1958)

In **1925** a new quantum principle was formulated by the Austrian physicist **Wolfgang Pauli**; it was ***the exclusion principle*****.**
This principle is significant, because it explains why matter occupies space exclusively for itself and does not allow other material objects to pass through it, while at the same time allowing light and radiation to pass.

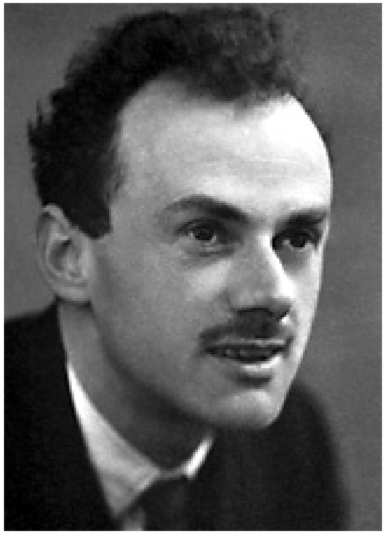
Pauli exclusion principle is now stated as,
"***No two electrons in an atom can have the same set of four quantum numbers***."

That is, if $n, l,$ and m_l are the same, m_s must be different such that the electrons have opposite spins.
The exclusion principle subsequently has been modified to include a whole class of particles of which the electron is only one member.

Subatomic particles fall into two classes:

FERMIONS: particles that obey *Pauli exclusion principle*, such as electrons , protons and neutrons.

BOSONS: particles that Don't obey *Pauli exclusion principle*, such as photon and phonons.



Paul Dirac (1902-1984)

In **1930**, Heisenberg's matrix mechanics and Schrödinger's wave mechanics were unified into a single mathematical formalism known as "***transformation theory***". This theory was proposed by the British theoretical physicist **Paul Dirac**.

This theory was published in a book called "*Principles of Quantum Mechanics"* which quickly became one of the standard textbooks on the subject and is still used today. The book also introduced the ***bra-ket notation*** and the ***delta function***, which are now universally used

Dirac and **Schrödinger** shared the Nobel Prize in Physics **1933** "for the discovery of new productive forms of atomic theory".

John von Neumann (1903-1957)

The first complete mathematical formulation of this approach is generally credited to John von Neumann's **1932** book "*Mathematical Foundations of Quantum Mechanics*".

5- PHYSICS AFTER 1900

5.3. ELEMENTARY PARTICLES PHYSICS

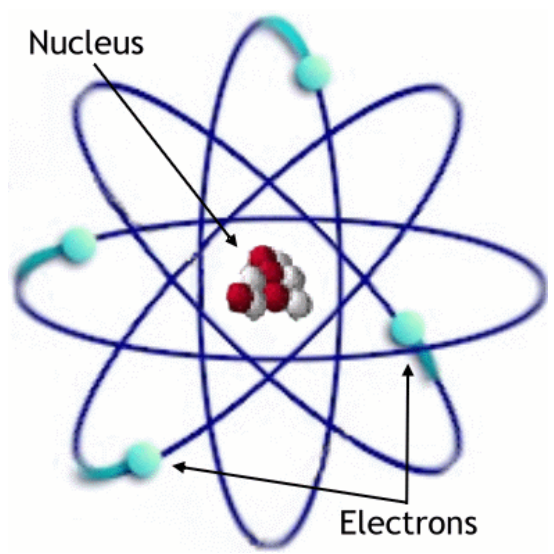
❑ Introduction:

Particle physics is the study of the structure and properties of the elementary particles and their interactions.

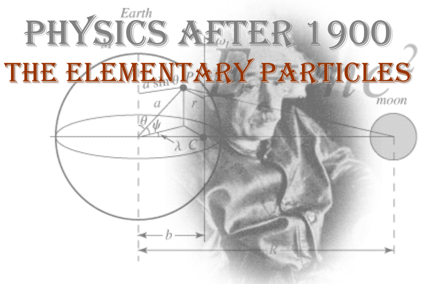
❑ What is the fundamental particle?

➲ Before the *gold foil experiment* of **Rutherford** (in 1909), people thought that **atom** was fundamental. This experiment helped scientists to determine that atoms have a tiny but dense, positive *nucleus* and a cloud of negative *electrons* (e^-). Because nucleus appeared small, solid, and dense, scientists originally thought that the **nucleus** was fundamental.

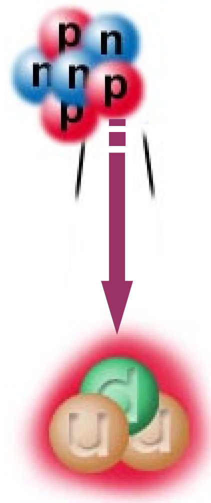
➲ Later, they discovered that it was made of **protons** (p^+), which are positively charged, and **neutrons** (n), which have no charge.



But, are protons and neutrons fundamental?

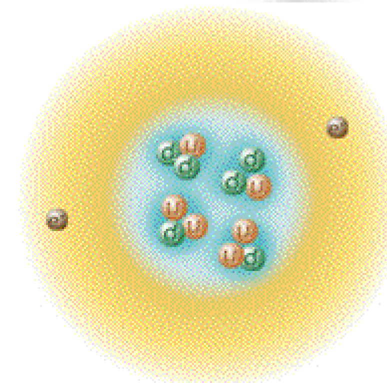


➲ In 1970s, Physicists have discovered that protons and neutrons are composed of even smaller particles called **quarks**. Quarks are like points in geometry. They're not made up of anything else.

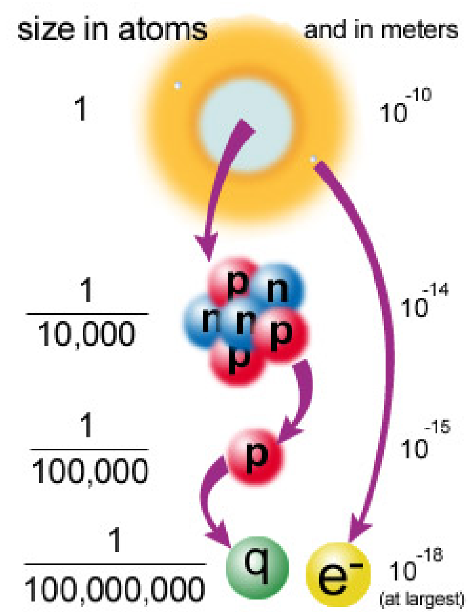


➲ Thus, the modern model of the atom is that;

Electrons are in constant motion around the nucleus, protons and neutrons jiggle within the nucleus, and quarks jiggle within the protons and neutrons.



While an atom is tiny, the nucleus is ten thousand times smaller than the atom and the quarks and electrons are at least ten thousand times smaller than that. We don't know exactly how small quarks and electrons are; but they are definitely **smaller than 10^{-18} meters**.

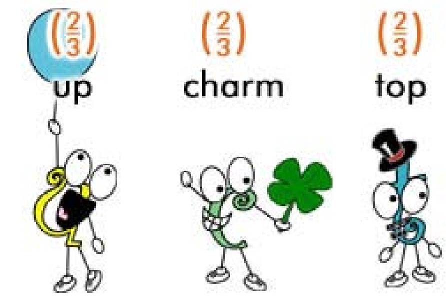


❒ What is a Quark?

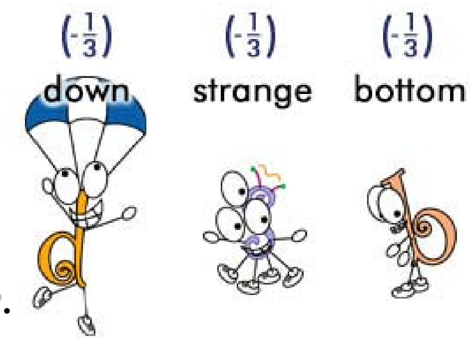
➲ Quarks *are one of the* ***two basic*** *components of* matter (the other are ***leptons***).

➲ In **1964**, **Murray Gell-Mann** and **George Zweig** suggested that hundreds of the particles known at the time could be explained as combinations of just three fundamental particles. Gell-Mann chose the name "**quarks**," for these particles.

➲ In order to make their calculations work, the quarks had to be assigned ***fractional electrical charges*** of **2/3** and **-1/3**. So initially these quarks were regarded as mathematical fiction. Experiments have since convinced physicists that not only do quarks exist, but there are **six types** of them.



➲ physicists usually talk about them in terms of three pairs: **up/down, charm/strange,** and **top/bottom.** For each of these quarks, there is a corresponding **antiquark**.



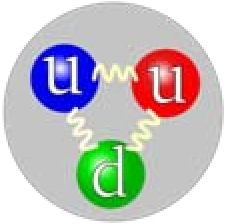
➲ Quarks also carry another type of charge called ***color charge***.

➲ The two lightest are called **up** and **down** , while the **top** quark, discovered last in **1995**, is the most massive quark

❒ HADRONS:

➲ Quarks only exist in groups with other quarks and are never found alone. ***Combined particles made of quarks*** are called ***Hadrons.***

➲ There are two classes of hadrons **BARYON** (made of three quarks (qqq)) and **MESON** (contain one quark (q) and one antiquark).



➲ Although individual quarks have fractional electrical charges, they combine such that **hadrons** ***have a net integer electric charge***.

➲ Another property of **hadrons** ***is that they have no net color charge,*** even though the quarks themselves carry color charge. For example; three quarks can exist together: one quark is "**red**", another "**blue**", and another "**green**". These three colored quarks together form a **color neutral baryon.** Or a quark may pair up to an antiquark: the quark has a color and the antiquark has the corresponding anticolor. The color and anticolor cancel out, forming a **color neutral meson.**

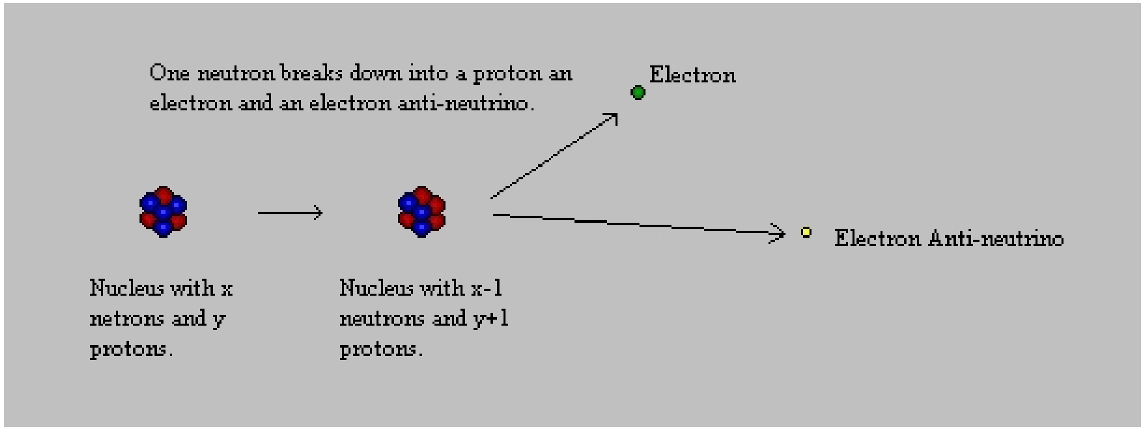
❐ LEPTONS

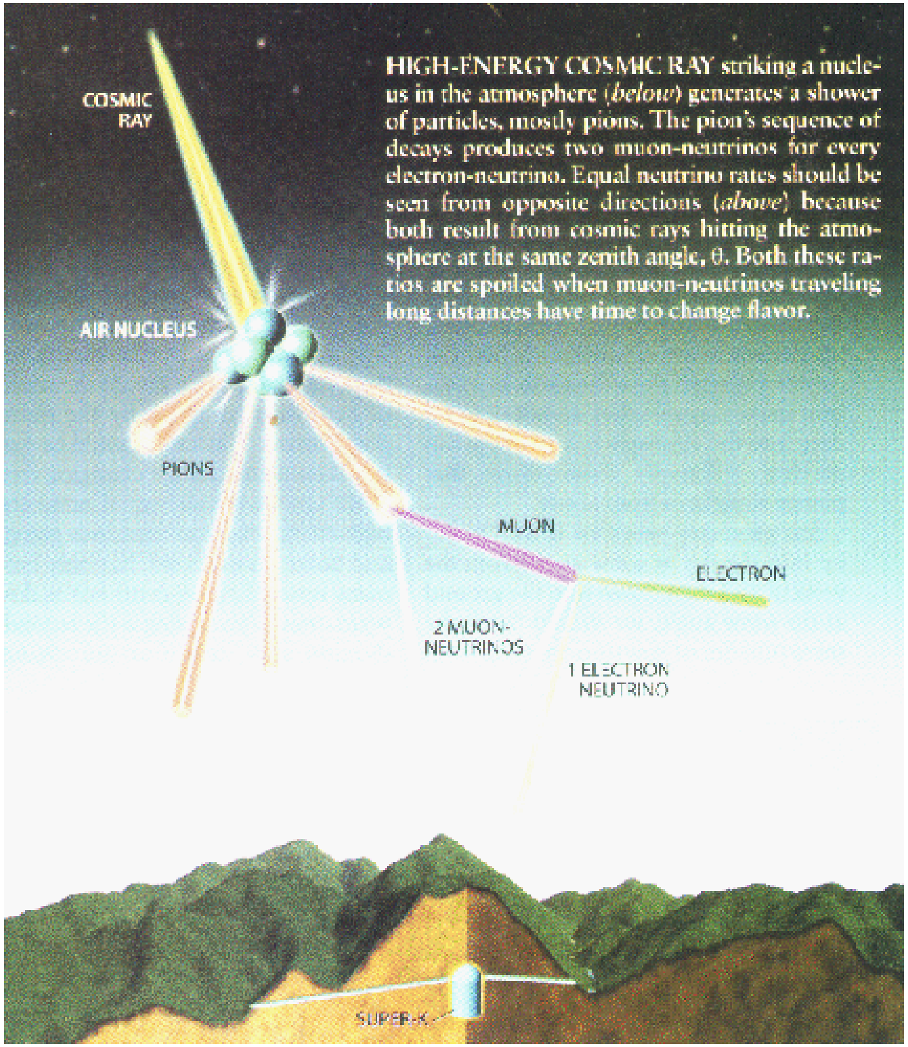
➲ The other type of matter particles are the ***leptons***. There are **six leptons**, three of which have electrical charge and three do not. They appear to be point-like particles without internal structure.

➲ The best known lepton is the ***electron*** (e). The other ***two charged leptons*** are the ***muon*** (μ) and the ***tau*** (τ), which are charged like electrons but have a lot more mass.

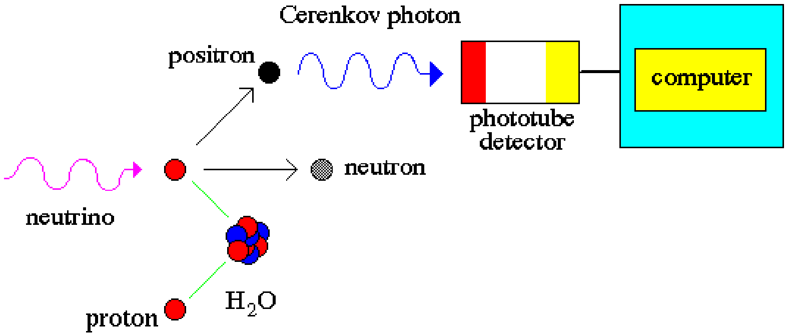
➲ The other leptons are the three types of ***neutrinos*** (ν). They have ***no electrical charge, very little mass***, and they are very hard to find.

➲ The need for the existence of neutrinos arises during the study of Beta decay, to verify the energy and momentum conservation laws.





➲ Since neutrinos have no electrical or strong charge they almost never interact with any other particles. Most neutrinos pass right through the earth without ever interacting with a single atom of it.



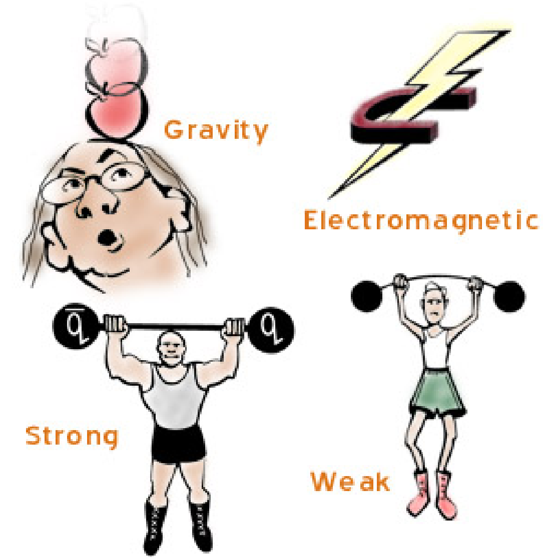
➲ Neutrinos are extremely difficult to be detected, and that what make them sometimes classified as a kind of the ***dark matter***.

❒ The Four Fundamental Interactions

Q- If the world is made of ***quarks and leptons***, **WHAT HOLDS IT TOGETHER?**

A- the universe exists because ***its fundamental particles interact with each other***.

➲ There are four fundamental interactions between particles, and **all forces in the world can be credited to these four interactions!**

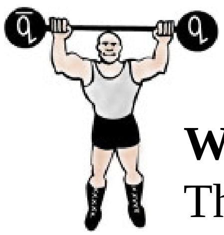


➲ These interactions are due to an exchange of a different type of particles known as ***force carrier particles.***

ELECTROMAGNETIC FORCE

This force causes like-charged things to repel and oppositely-charged things to attract.

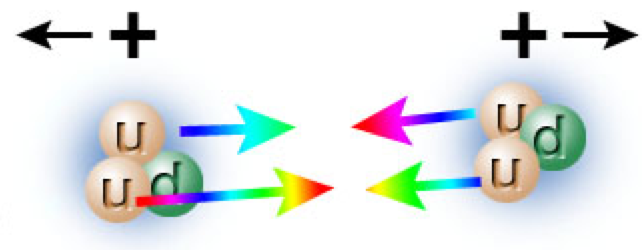
The carrier particle of the electromagnetic force is the **photon** (γ). Photons have zero mass, and always travel in a vacuum at the "**speed of light**", c.
The electromagnetic force is what allows atoms to bond and form molecules, and create the matter around us.



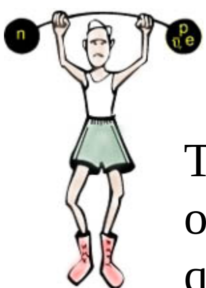
STRONG FORCE

What binds the nucleus together?

The gravitational force is too weak to overpower the electromagnetic force. So there must be another form of force that is very strong. This is what we call today **the strong force**.



The strong force holds quarks together to form hadrons, and its carrier particles are called **gluons** because they so tightly "glue" quarks together.

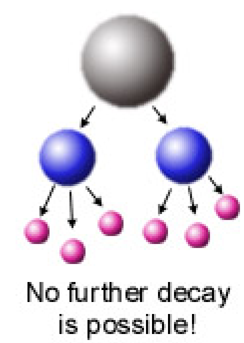


WEAK FORCE

There are six kinds of quarks and six kinds of leptons. But all the stable matter of the universe appears to be made of just the **two least-massive quarks** (up quark and down quark), **the least-massive charged lepton** (the electron, and its neutrino).

Weak interactions are responsible for the decay of massive quarks and leptons into lighter quarks and leptons.

The carrier particles of the weak interactions are the **W+, W-,** and the **Z** particles. The **W's** are electrically charged and the **Z** is neutral.

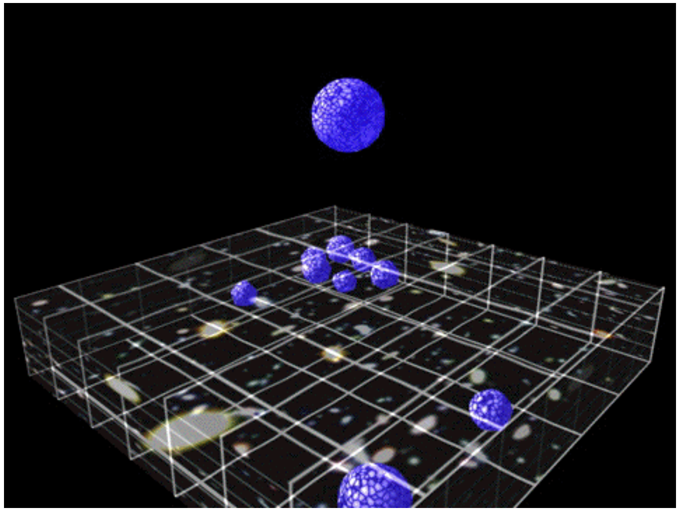


GRAVITY

Gravity is strange. It is clearly one of the fundamental interactions, but *the Standard Model* cannot satisfactorily explain it.

In addition, the gravity force carrier particle (the **graviton**) has not been found. Such a particle, however, is predicted to exist and may someday be found.

Which fundamental interaction is responsible for:



FRICTION ?

Friction is caused by ***electromagnetic interactions*** between the atoms of the two materials.

NUCLEAR BONDING ?

Nuclear bonding is caused by ***strong interactions*** between the various parts of the nucleus.

PLANETARY ORBITS ?

The planets orbit because of ***the gravity*** that attracts them to the sun

THE STANDARD MODEL

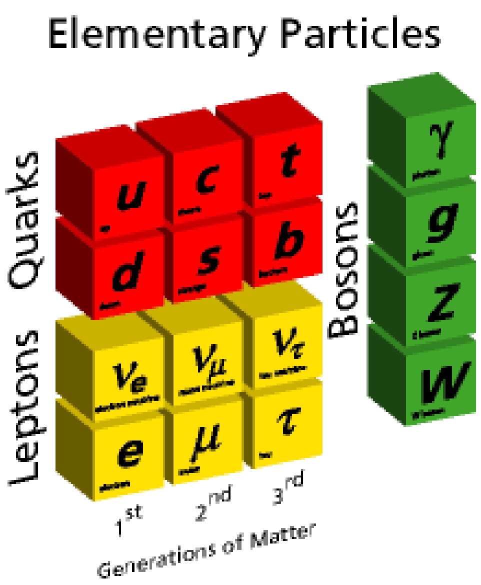
❒ Introduction:

➲ In **1970s**, high energy physicists have arrived at a picture of the microscopic physical universe, called "**The Standard Model**" (**SM**) ***which is consistent with both quantum mechanics and special relativity.***

➲ This model **unifies** the *nuclear, electromagnetic, and weak forces* on one hand; on the other hand, it **specifies** the fundamental building blocks of the universe.

In other words, (SM) is a theory that explains what fundamental particles are and how they do interact.

➲ It gathers the hundreds of particles and their complex interactions with ***two general categories***: ***Fermions*** (the matter constituents) and ***Boson*** (the force carrier particles).



1- FERMIONS:

Fermions are particles which possess ***half-integer*** spin and obey the ***Pauli Exclusion Principle***. Fermions are the building blocks of the entire world and they are divided into two main groups: ***quarks*** and ***leptons***;

Quarks:

There are six different quarks which are usually grouped, as in Table (2.1), into three pairs because of their mass and charge proprieties: up / down, charm / strange and top/ bottom. Quarks are observed to exist only in combinations known as **HADRONS**.

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

Hadrons that consist of combination of three quarks called ***Baryons***, while hadrons consist of combination of 1 quark and 1 antiquark 2 known as ***Mesons***.

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

Leptons:

On the other hand, there are six leptons, **three** ***with a charge and mass***: electron (e), muon (μ), and tau (τ), and **three** associated ***neutrinos*** which are ***neutral and have very little mass*** .

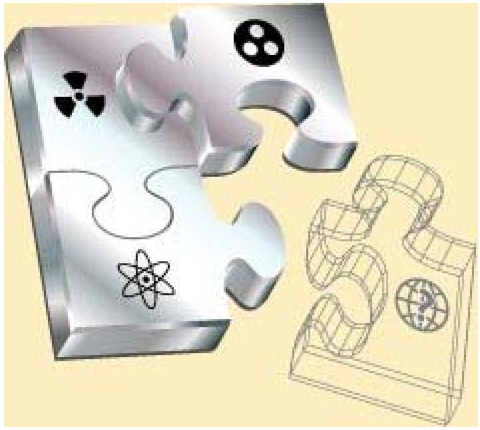
Leptons spin = 1/2			
Flavor		Mass GeV/c^2	Electric charge
ν_e	electron neutrino	$<1\times10^{-8}$	0
e	electron	0.000511	–1
ν_μ	muon neutrino	<0.0002	0
μ	muon	0.106	–1
ν_τ	tau neutrino	<0.02	0
τ	tau	1.7771	–1

2- BOSONS:

Forces are transformed between particles by **bosons**, which carry discrete amounts of energy from one particle to another. Each force has its own characteristic bosons. Bosons possess **integer spin** and **do not obey** the ***Pauli Exclusion Principle*****.**

➲ The Standard Model has united electromagnetic interactions and weak interactions into one unified interaction called **electroweak** .

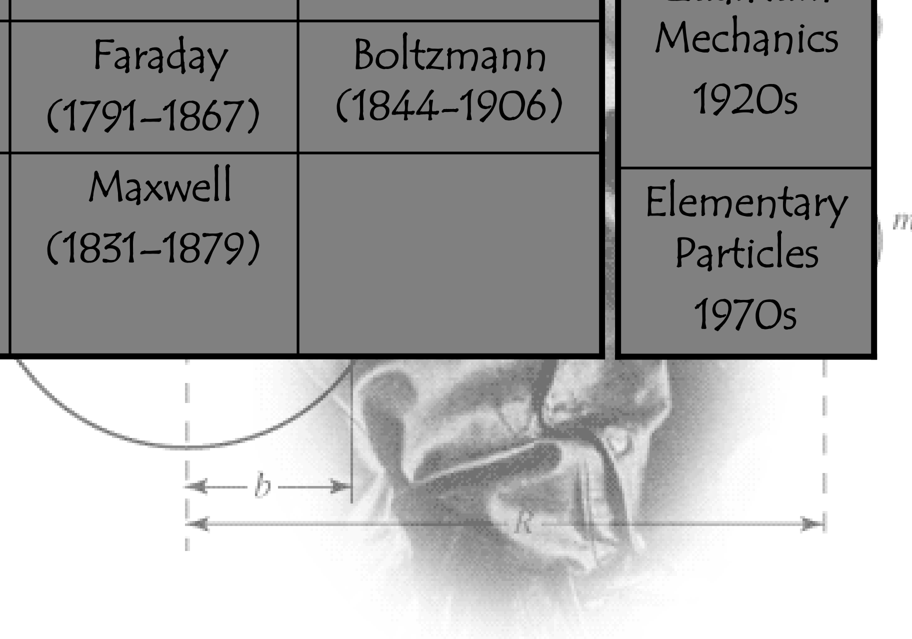
➲ The standard model does not include the effects of the fourth force of the nature, ***gravity***. Since these effects are tiny under high-energy physics situations, and can be neglected in describing the experiments.

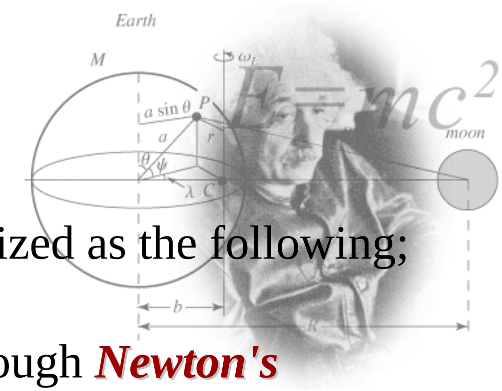


THE PROGRESS OF PHYSICS

Classical Period 500 BC	Middle Ages 400 AD	Renaissance Ages 1300	Classical Physics 1700 -1900 EM	Thermo
Aristotle 300 BC	Al-Fazari (735-806)	Copernicus (1473-1543)	Franklin (1706–1790)	Carnot (1796-1832)
Ptolomy 200 AD	Al-khwarizmi (850-926)	Kepler (1571-1630)	Coulomb (1736–1806)	Kelvin (1824-1907)
	Ibn Sina, (965-1039)	Galileo (1564-1642)	Faraday (1791–1867)	Boltzmann (1844-1906)
	Ibn Al-Haitham (980-1037)	Newton (1642-1727)	Maxwell (1831–1879)	

Modern Physics > 1900
Relativity 1905
Quantum Mechanics 1920s
Elementary Particles 1970s





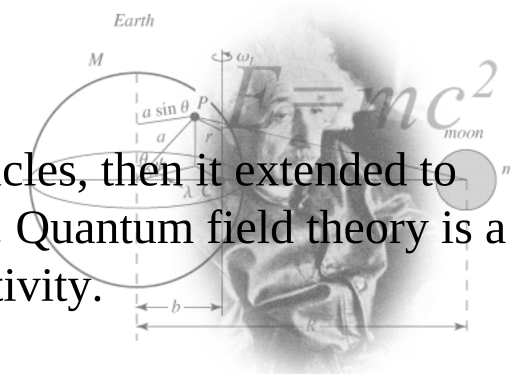
THE PROGRESS OF PHYSICS through centuries can be summarized as the following;

- Newtonian mechanics and ***Kepler's*** law were unified through ***Newton's*** famous ***theory of gravity***.

- Then, ***Maxwell*** unified electricity and magnetism in his ***theory of electromagnetism***.

- One century latter, ***Einstein*** introduced his two famous theories of relativity; ***special relativity*** ***which somehow gathered between classical mechanics and electromagnetism, and*** ***general relativity*** which redefined gravity according to the relativistic concept of space-time.

- Meanwhile, a group of physicists introduced ***quantum mechanics.*** With its birth two new forces were discovered; **the weak force** that describes the interactions in beta decay and neutrino, and **the strong force** that describes the nuclear interactions.



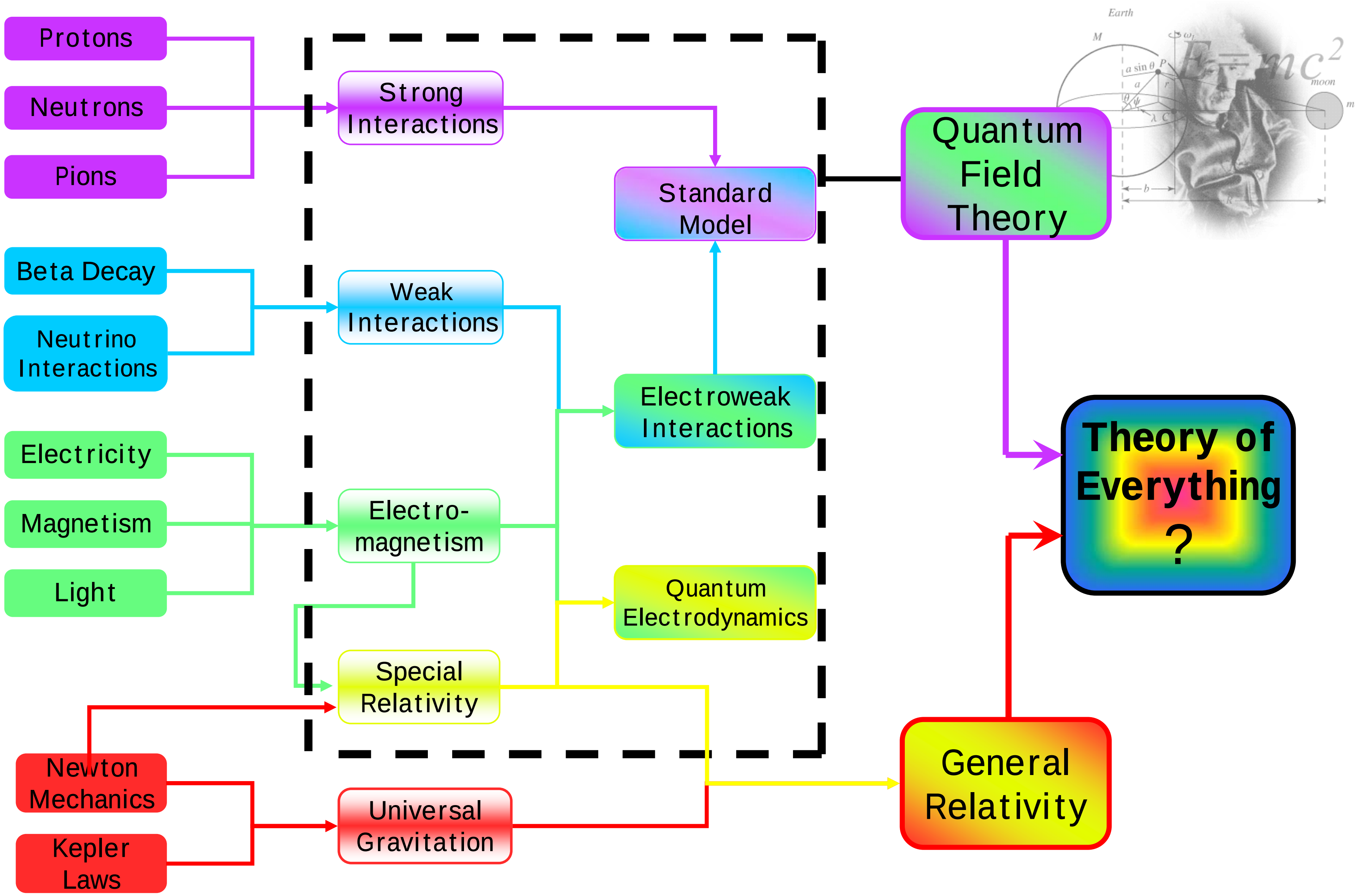
- Quantum mechanics was at first applicable only on particles, then it extended to include **fields** in what was named ***quantum field theory***. Quantum field theory is a theory that unifies quantum mechanics with special relativity.

- Afterwards a famous model, known as ***the standard model,*** was formed to give a complete picture about the three quantum interactions.

- The unification of the three quantum forces kept us with an inquiry about the forth fundamental force; gravity. Where does it fit in all of this? The answer to this question was the motivation for scientists to start their search of ***the final theory*** that could fulfill Einstein's dream.

  Such theory will explain all physical phenomena in the universe; from its birth to its end, containing all bodies from the smallest subatomic particle to the vastness of the cosmos.

- Therefore, many theories were proposed to achieve this goal. But the most promising ones were ***string theory*** and ***loop quantum gravity***.
  At the moment there is no direct experimental test for any of these two theories. Nevertheless, supporters of each theory have a strong feeling that the evidence is coming soon.



Protons
Neutrons
Pions
Strong Interactions
Standard Model
Quantum Field Theory
Beta Decay
Neutrino Interactions
Weak Interactions
Electroweak Interactions
Electricity
Magnetism
Light
Electro-magnetism
Quantum Electrodynamics
Theory of Everything ?
Special Relativity
Newton Mechanics
Kepler Laws
Universal Gravitation
General Relativity
Earth
moon
E=mc^2