There is another form of temptation even more fraught with danger. This is the disease of curiosity. . . . It is this which drives us on to try to discover the secrets of nature, those secrets which are beyond our understanding, which can avail us nothing, and which men should not wish to learn. . . . In this immense forest, full of pitfalls and perils, I have drawn myself back, and pulled myself away from these thorns. In the midst of all these things which float unceasingly around me in my everyday life, I am never surprised at any of them, and never captivated by my genuine desire to study them. . . . I no longer dream of the stars.

ST. AUGUSTINE
Confessions

AD 397-398 1st western autobiography

TRIUMF

CANADA'S NATIONAL LABORATORY FOR PARTICLE AND NUCLEAR PHYSICS

Owned and operated as a joint venture by a consortium of Canadian universities via a contribution through the National Research Council Canada

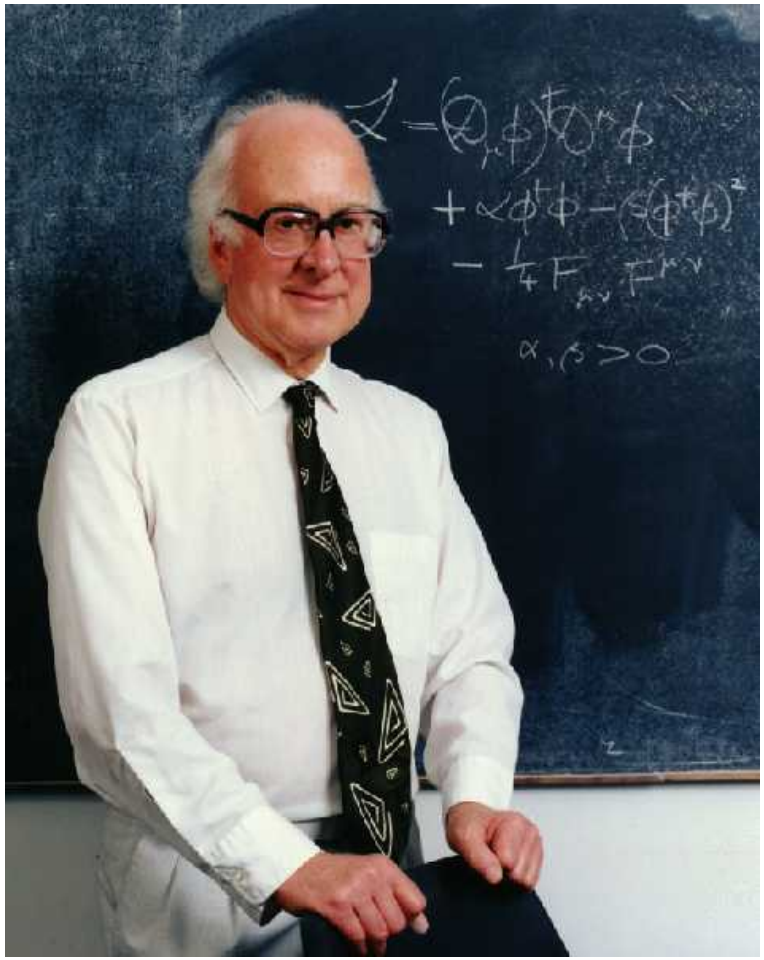
Higgs

12 Jan 2008

LABORATOIRE NATIONAL CANADIEN POUR LA RECHERCHE EN PHYSIQUE NUCLÉAIRE ET EN PHYSIQUE DES PARTICULES

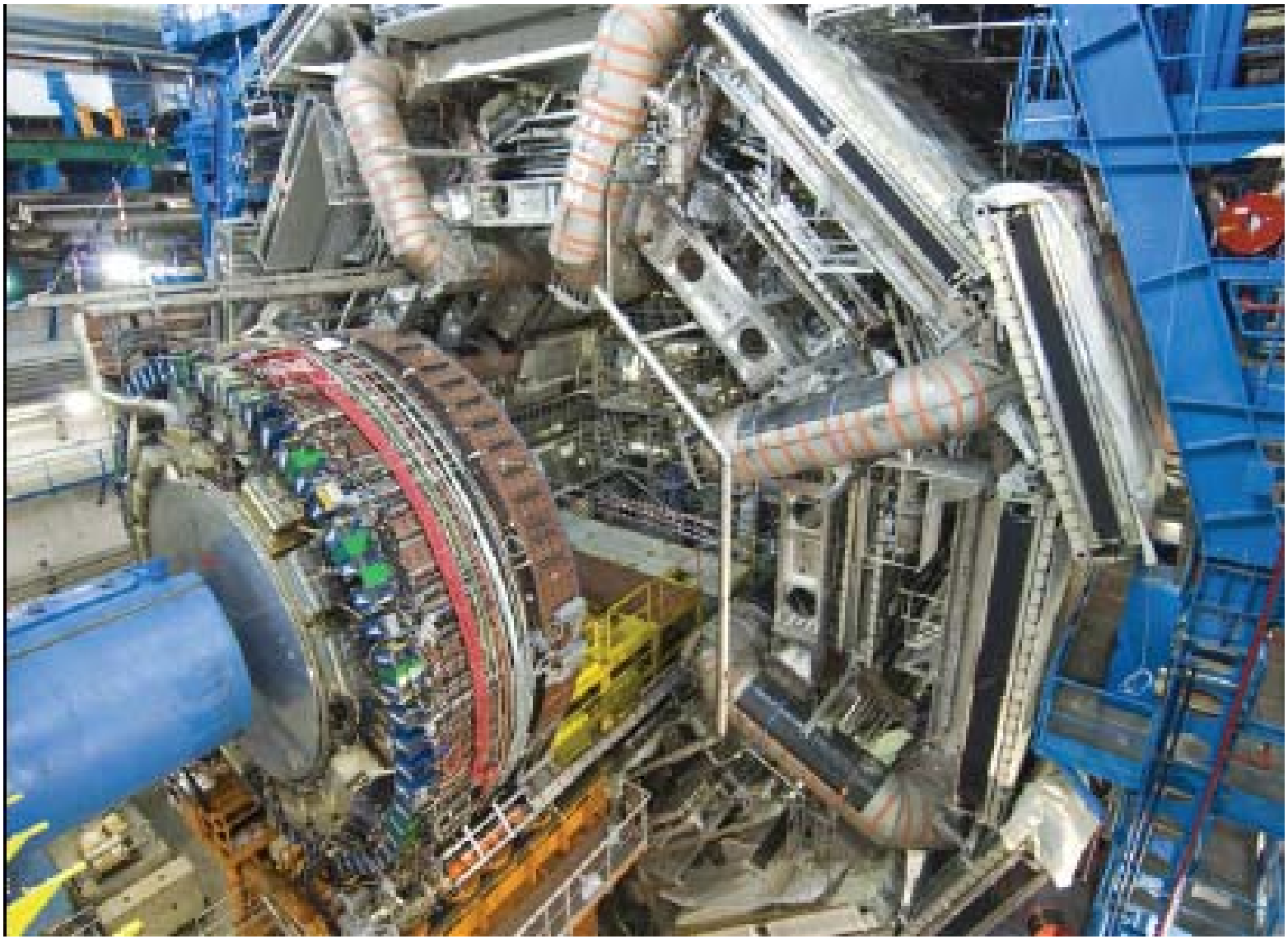
Propriété d'un consortium d'universités canadiennes, géré en co-entreprise à partir d'une contribution administrée par le Conseil national de recherches Canada

Peter Higgs



Waiting 44 years for particle physicists to discover his Boson

The Wait is Almost Over

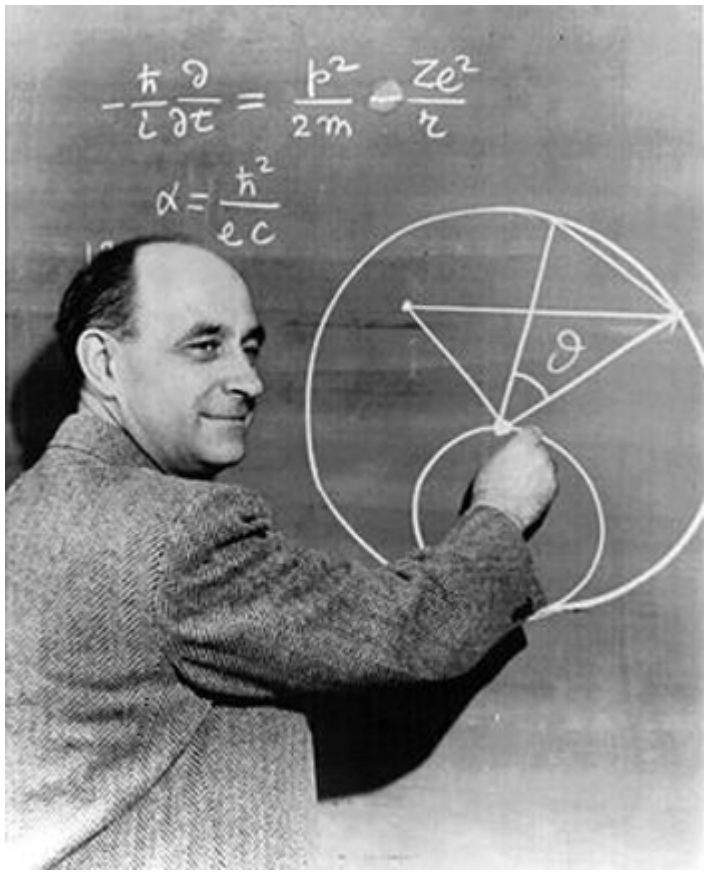


Bose-Einstein Statistics

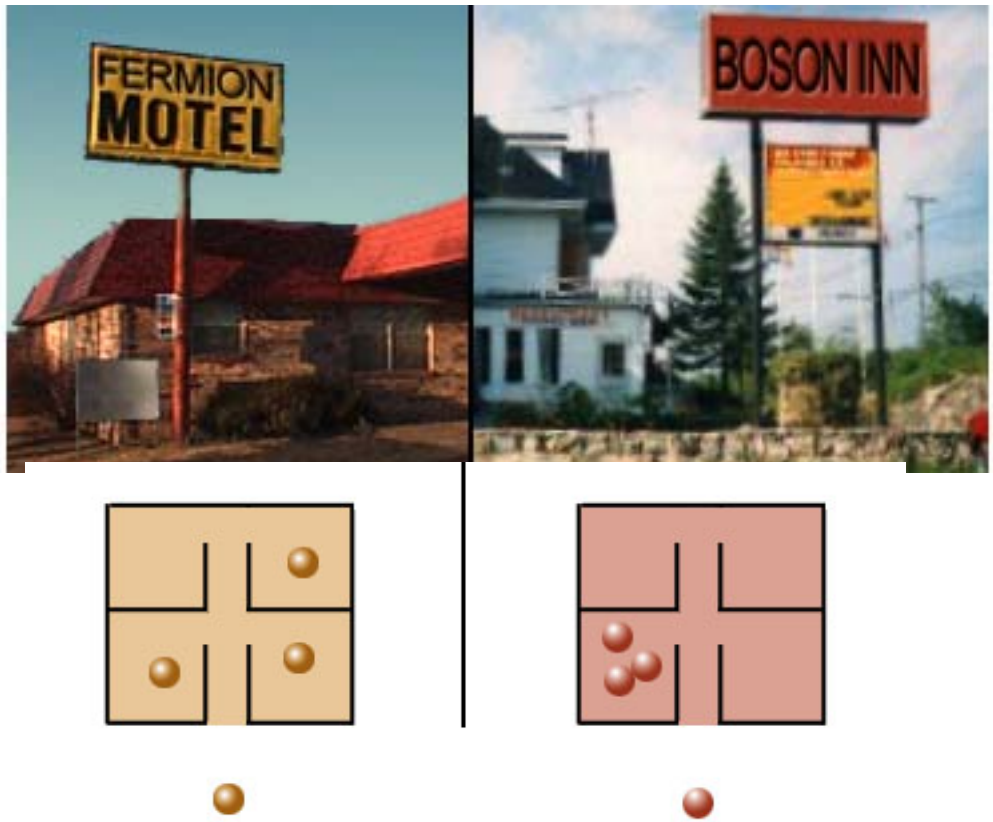
Bose

Einstein

Fermi and Dirac



Fermions and Bosons



Higgs checks in the Boson Inn

The Essence

Higgs field breaks the electroweak symmetry

Early universe

Particles and fields

Forces

Force carriers

Spontaneous symmetry breaking

Long History

- Even earlier but lets start with Greeks
- Greeks invented word atom-not divisible
- Aristotle says everything composed of earth, water, air, fire, ether
- Reductionist thinking still here today
- John Dalton (father of chemistry) used idea of atoms (1766-1844).
- Thomson, Rutherford, Chadwick discovered electron, proton, neutron

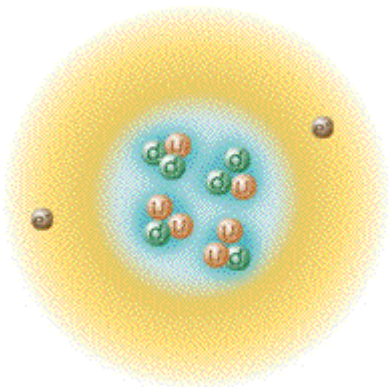
Some More Work Needed

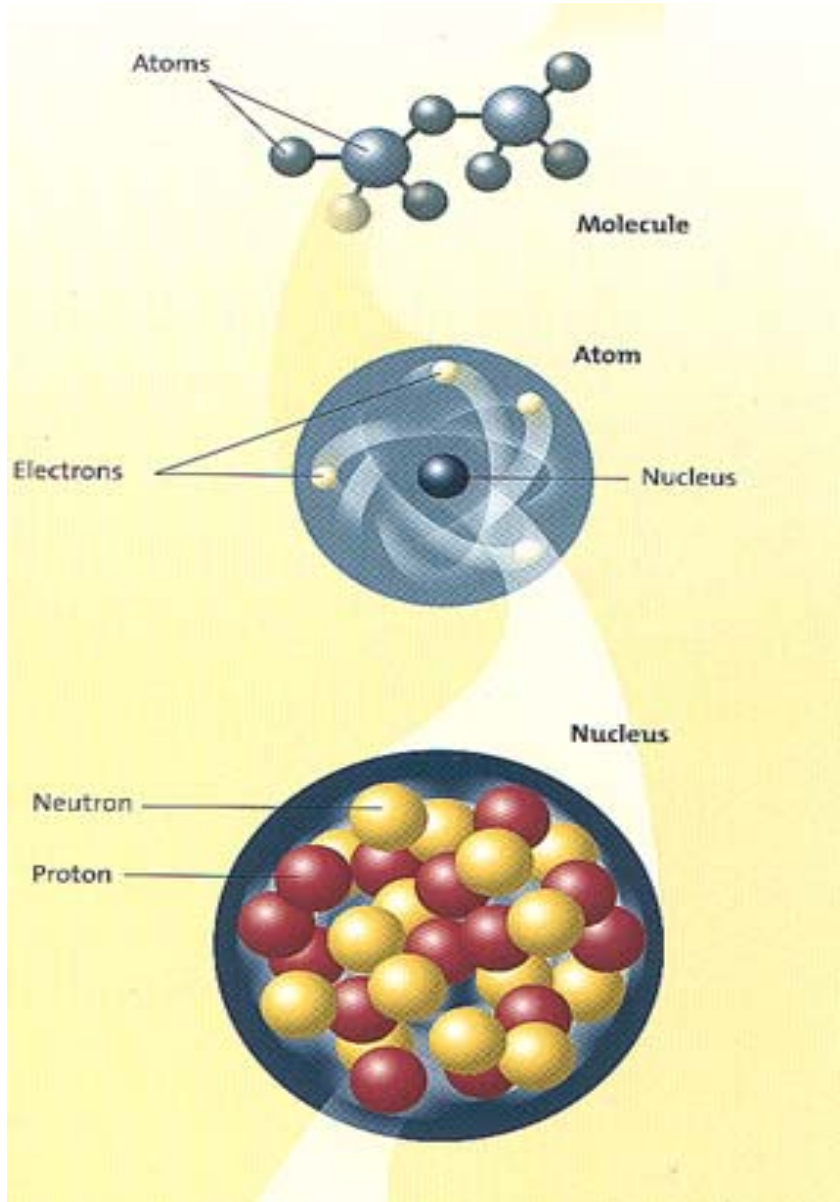
Important to look for deviations from your model

Develop a model and get data to look for deviations is a way to make progress in science

Composition of Atom

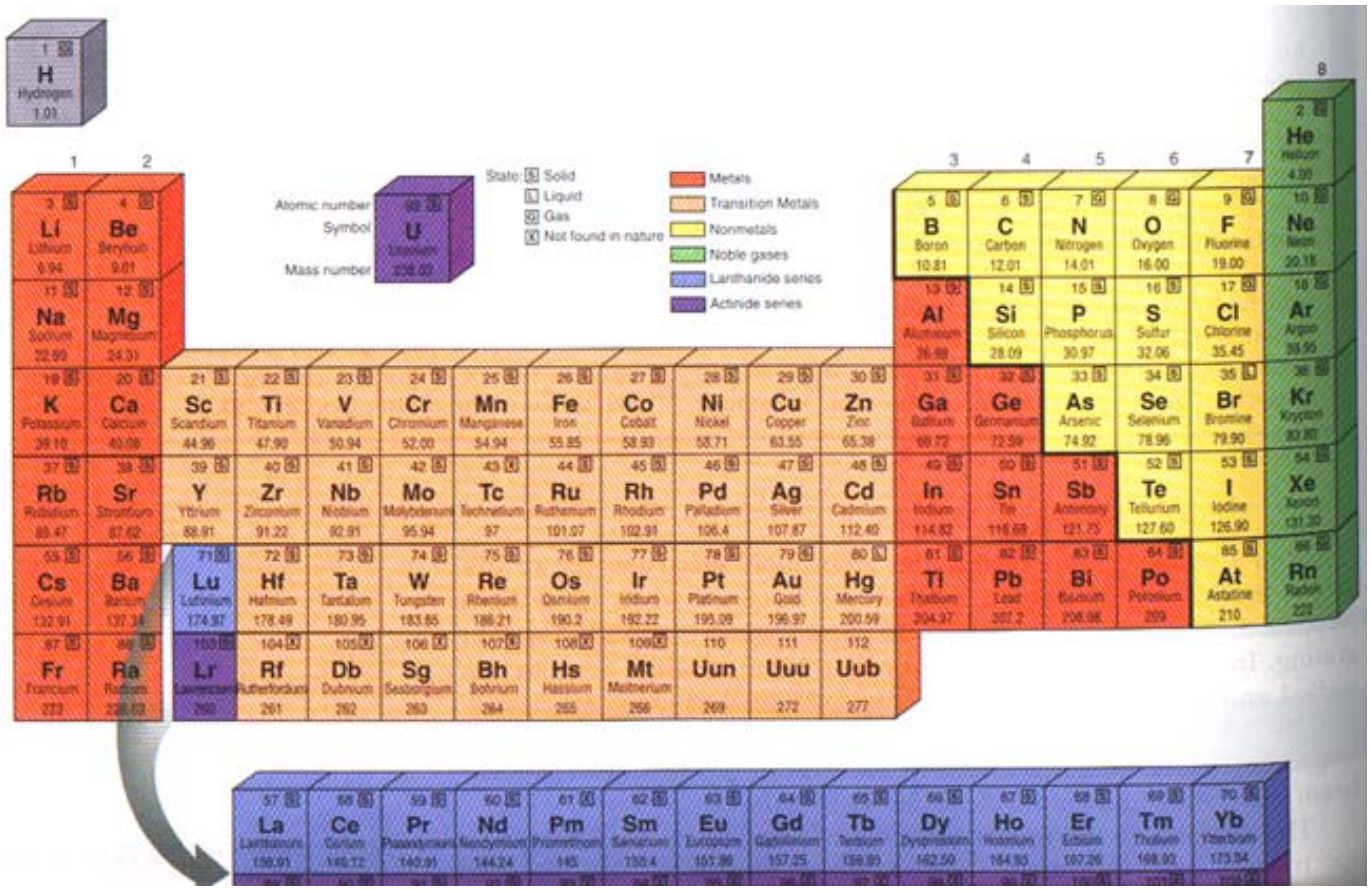
Each element is an atom
made up of a central nucleus and shells of electrons
The number of the element corresponds to the number of electrons in the outer shell
Inside the nucleus there are an equal number of protons
And there are also many neutrons
Are electrons, protons and neutrons the new “elements”??



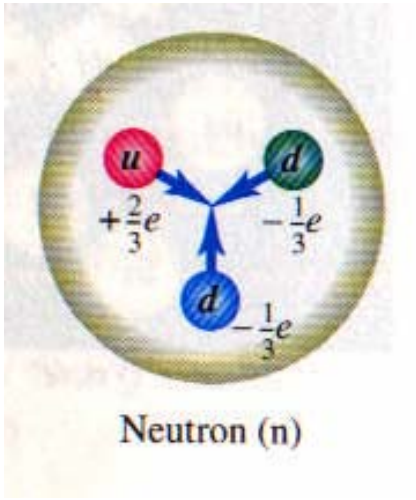


Periodic Table

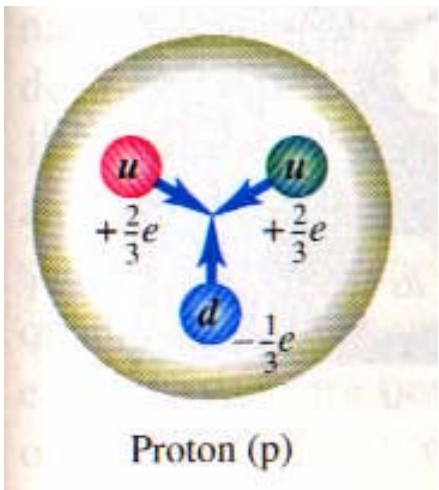
- The Periodic Table brought <u>order</u> among the elements
- Why is it called periodic?? Because the patterns repeat
- Why do the patterns repeat?
- Yes, there is order, But is this really simple or elegant?
- Why are there so many elements? > 100
- Because there is an underlying structure; The underlying order is simpler



Proton is Not Elementary Mr. Watson



Neutron (n)



Proton (p)

Electron, Proton, Photon

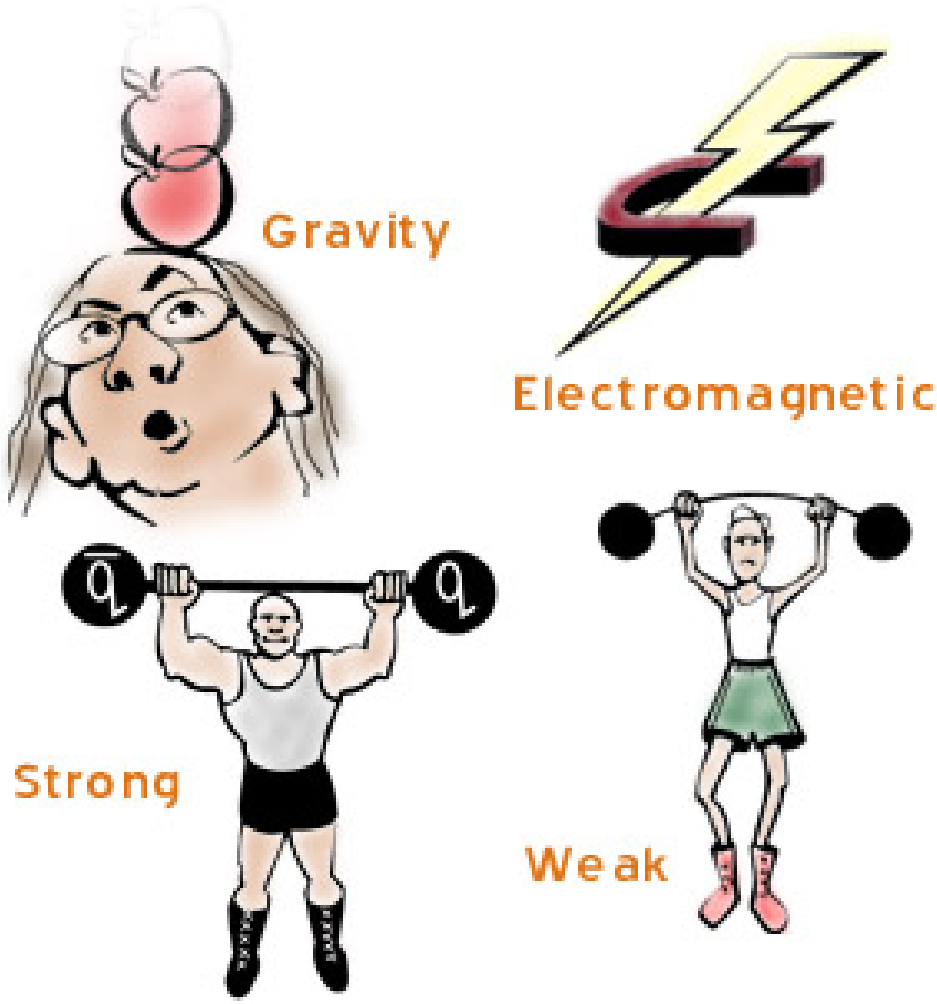
- J.J. Thomson discovered electron in 1897 and thus showed atoms are “tomos” or divisible & measured electric charge =(-1) and electron e/m
- Rutherford measured size of proton, charge = (+1) and proton mass
- Einstein’s photoelectric effect was quantization of EM radiation E=hf (photons)
- Atoms can emit (create) photons and absorb (destroy) photons
- Photons have zero rest mass and zero charge

Introduction to Particle Physics

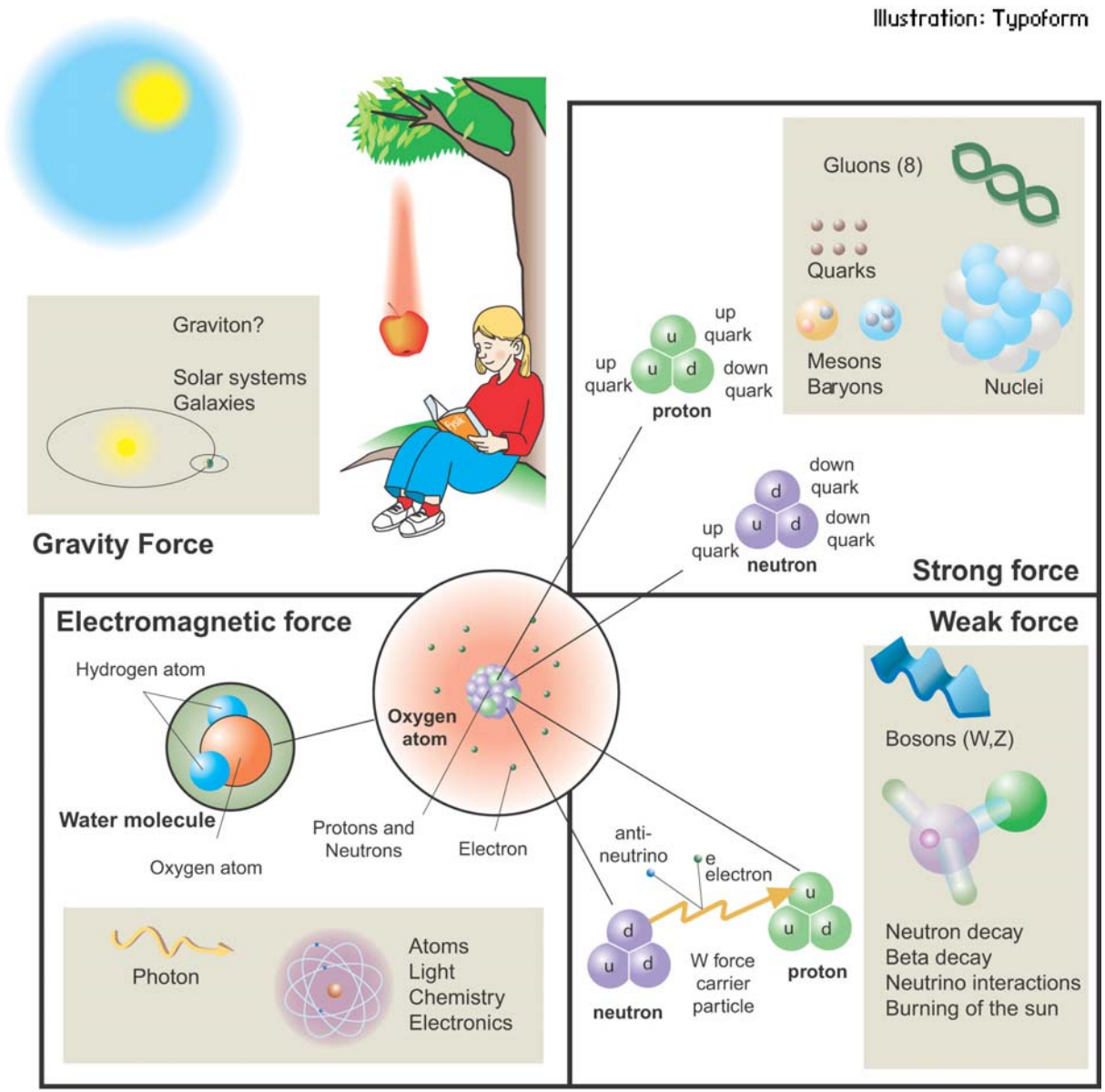
- Fundamental particles are not permanent entities
- Particle are created and destroyed
- Particles & interactions = subject of particle physics
- Classified into several categories based on conservation laws and symmetries
- Recent connection between shortest distance scale physics and early universe or cosmology
- Particle physics is based upon well developed mathematical description—quantum field theory
- Experimentally based science

Four Fundamental Forces In Nature

Why are they so different?



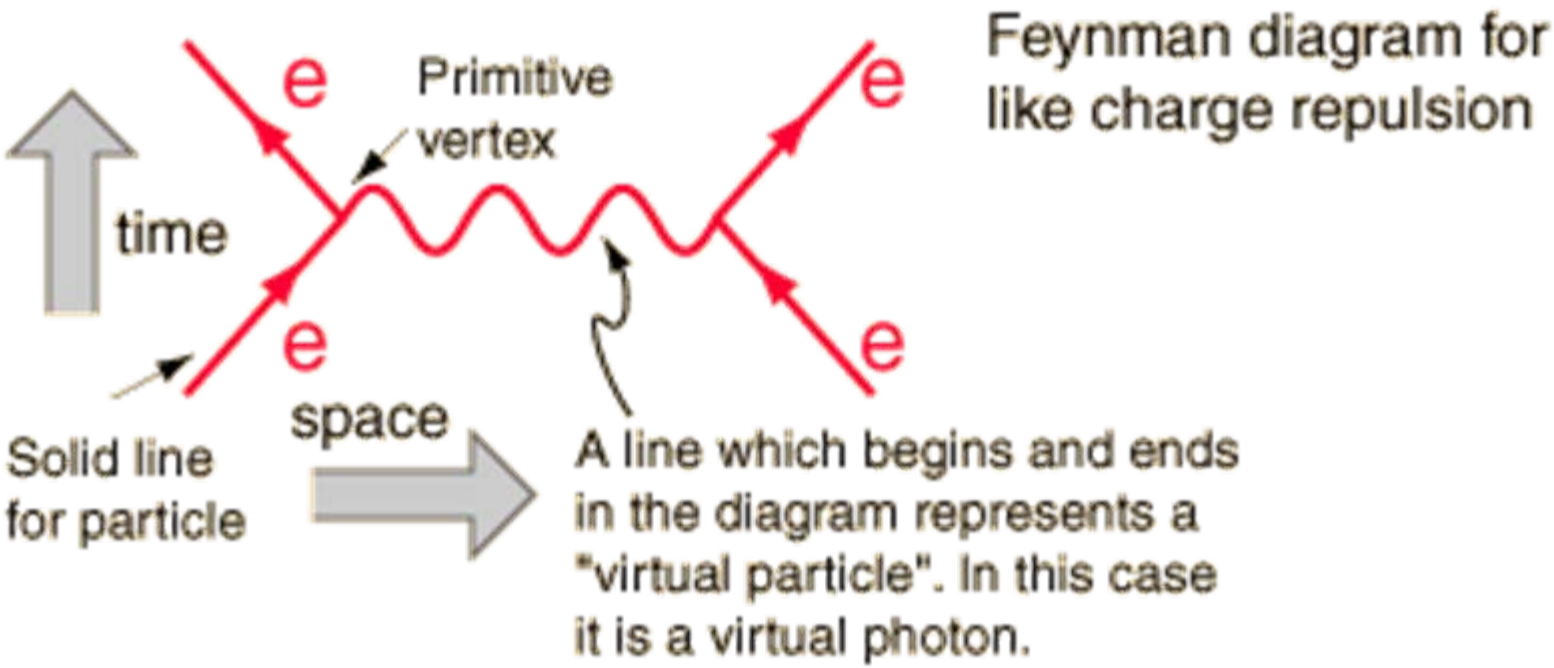
The Four Forces In Nature



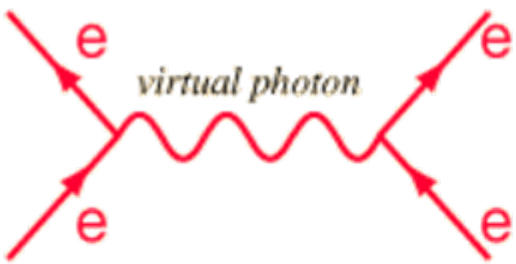
Particles as Force Mediators

- Classical picture for repulsion is exchanging two heavy balls between two people on ice skates
- Attraction would be trying to grab the ball out of the other persons hands
- Real description needs quantum mechanics and development of a potential
- Two electrons repel one another by exchanging a photon
- Impulse of photon can have either sign in QFT
- Electromagnetic interaction mediated by photons
- A photon that exists for a period of time like this is called a virtual photon.

Feynman Graph

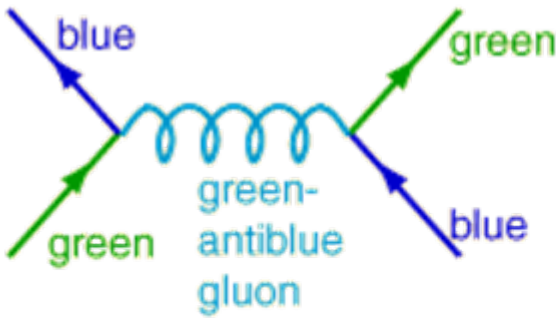


Feynman Graphs

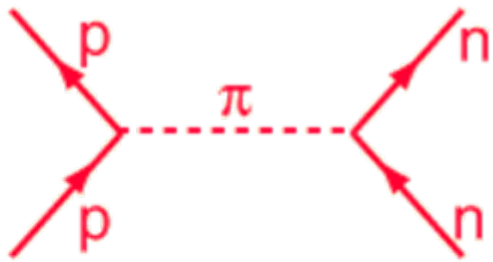


Electromagnetic

Weak



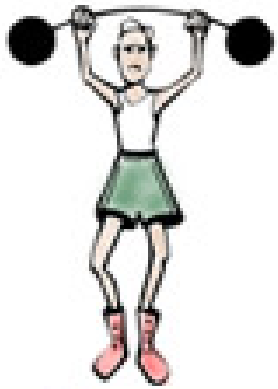
between quarks



between nucleons

Strong Interaction

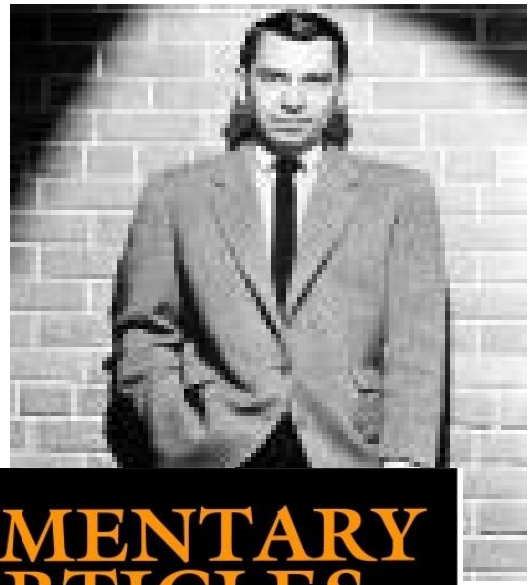
Force Summary



	Gravity	Weak (Electroweak)	Electromagnetic	Strong
Carried By	Graviton (not yet observed)	W^+ W^- Z^0	Photon	Gluon
Acts on	All	Quarks and Leptons	Quarks and Charged Leptons and W^+ W^-	Quarks and Gluons

Standard Model combines electroweak and strong

"All we need are the facts, ma'am."



Particle physics asks:

What is the universe made of and how does it work?

Universe is made of matter particles held together with force carriers:

Matter Fields:

3 generations of quarks and leptons

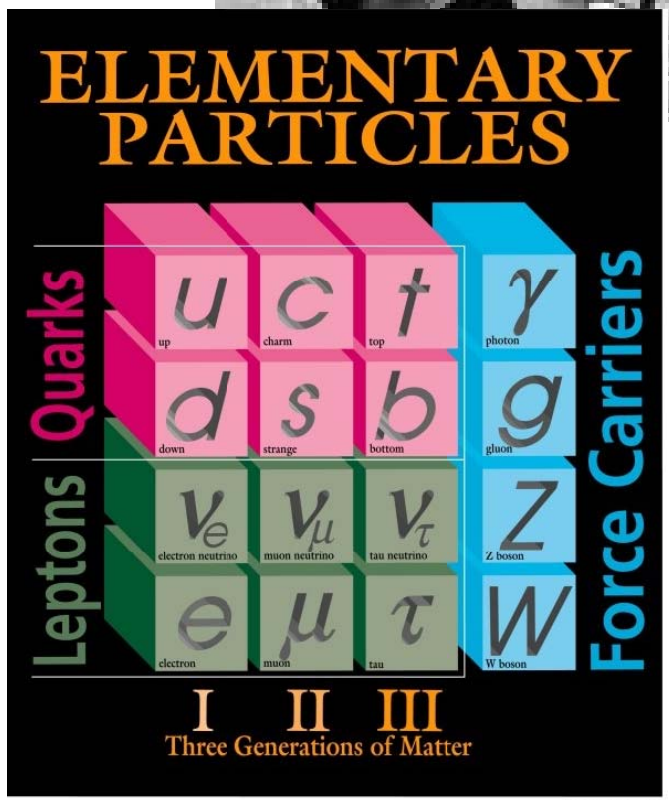
Force Carriers:

12 fundamental gauge fields

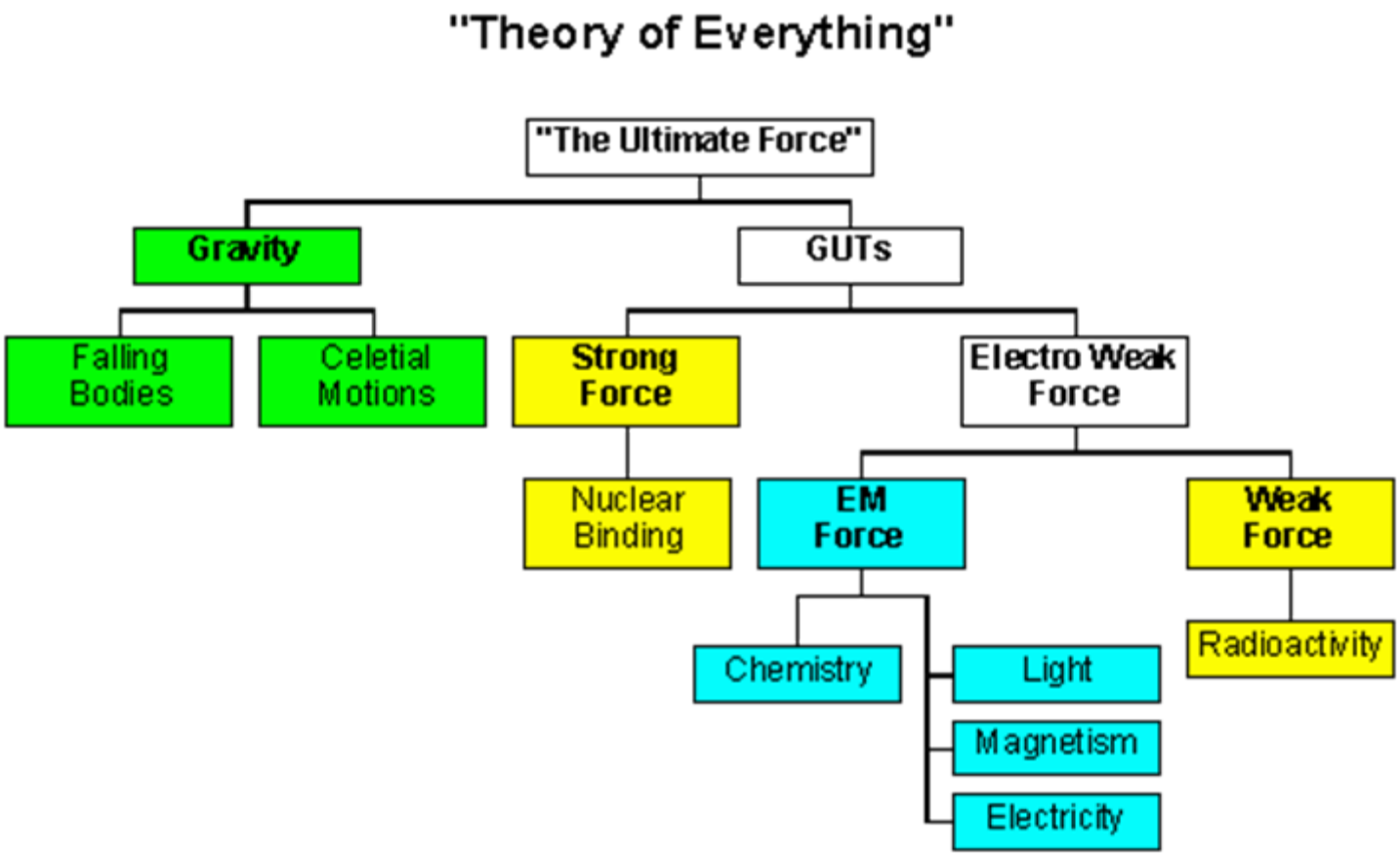
8 gluons, W^+, W^-, Z, photon

(3 gauge couplings, g_1,g_2,g_3)

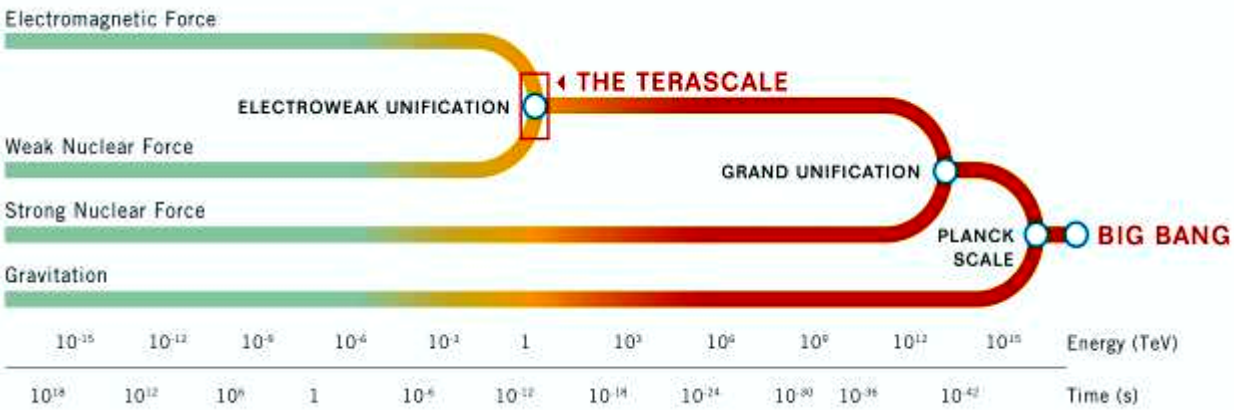
Plus much more we do not know!



High Temperature All Forces Same



Unification of All Four Forces



We believe that there was just one force after the Big Bang

As the universe cooled down that single force split into the four we know today: gravity, electromagnetism, the strong and weak nuclear forces

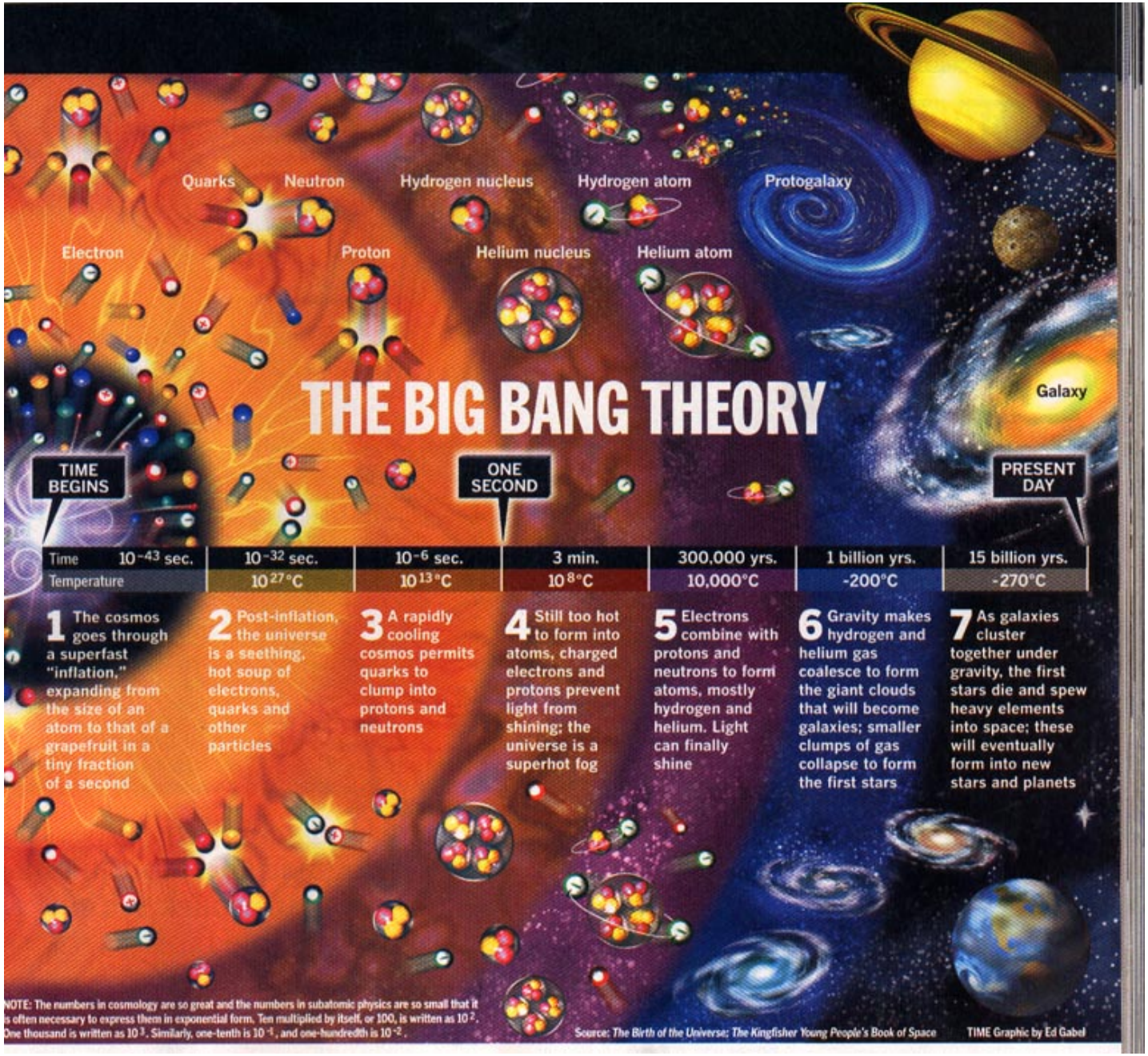
Similar mathematical laws describe three of the forces but not gravity

At the TeV scale electromagnetism and weak forces unified

Strong interaction thought to be unified at GUT scale

Gravity unifies at Planck Scale

Hubble Deep Field (10 day exposure)
(12 billion years ago)



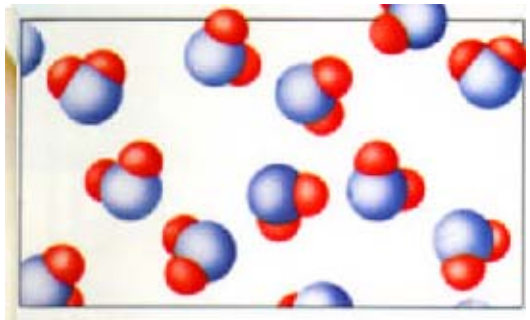
The Physicists' View

Symmetry in Art

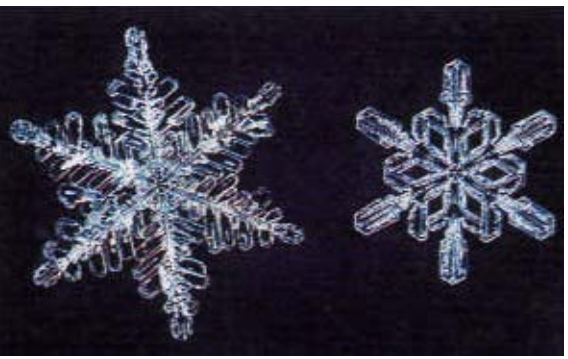
M. C. Escher

What is Spontaneous Symmetry Breaking? from Steam to Snow

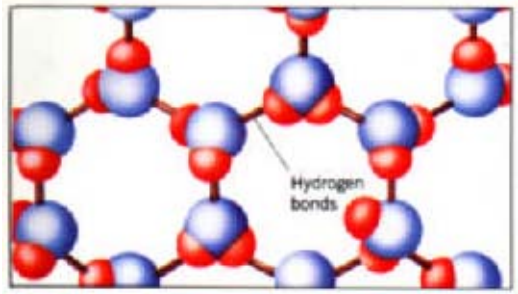
Steam



Hot !
Perfect
Symmetry



Ice



Cold !
Broken
Symmetry

Another example is iron, which below some critical temperature, becomes magnetic because the magnetic moments align. Above that temperature, spins not aligned, which is a state of greater symmetry.

What is a Particle?

Disturbance in an energy field

What is a Field?

- Temperature field (scalar field)
- Higgs is a scalar field
- Defined everywhere in space
- One number at every point

- Wind field (vector field)
- Magnetic field (vector field)

Spontaneous Symmetry Breaking(1)

- Ferromagnetism above the Curie temperature is spatially invariant and there is no magnetic field in space
- Below the Curie temperature the symmetry is spontaneously broken and there is a magnetic field created in space
- This is called a phase transition

Spontaneous Symmetry Breaking(2)

- In electroweak symmetry breaking there is a phase transition at the electroweak temperature
- The universe cooled below this temperature about a picosecond after the big bang
- Above this temperature, there was no Higgs field
- Below this temperature there was a Higgs field
- The electroweak symmetry breaks into electromagnetic and weak fields (same as rotational symmetry broken in ferromagnetism example)

- The W & Z (carriers of weak force) “eat” some of the Higgs field and gain mass (short range force)
- The photon (carrier of electromagnetic force) is massless (long range force)

Higgs Field

A scalar field that fills the entire universe

Particles traveling through the universe interact with this field & become massive

Importantly, the W and Z bosons receive mass but not the photon

Origin of Mass:

There might be something (new particle?!) in the universe that gives mass to particles

Nothing in the universe

Something in the universe

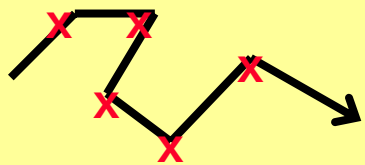
Higgs Particles:

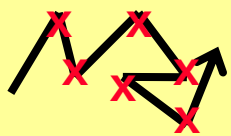
Coupling strength to Higgs is proportional to mass

Electron

Z,W Boson

Top Quark



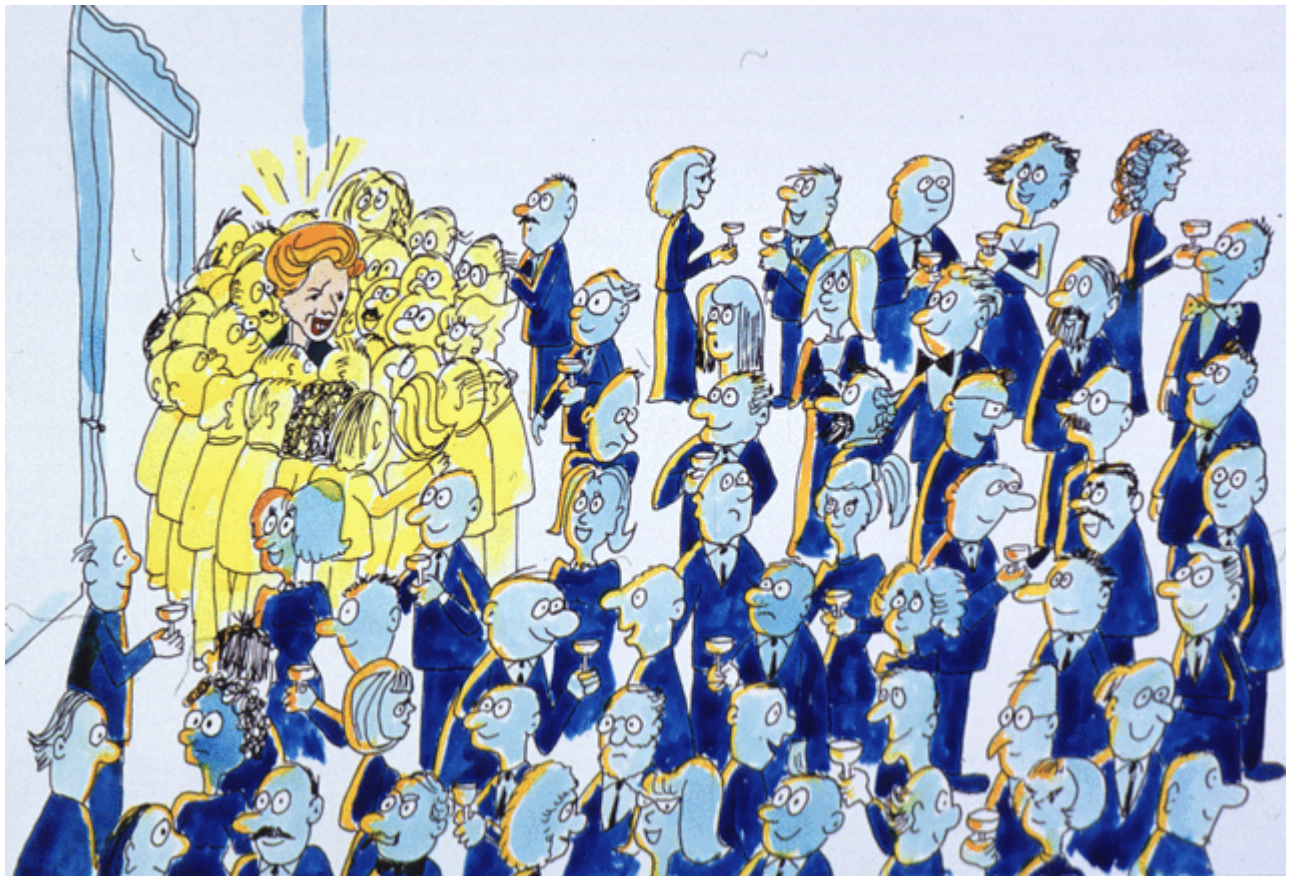


Higgs Mechanism (1)

Politicians (field points) at a party talking about politics

thanks to David Miller (University College London) and CERN

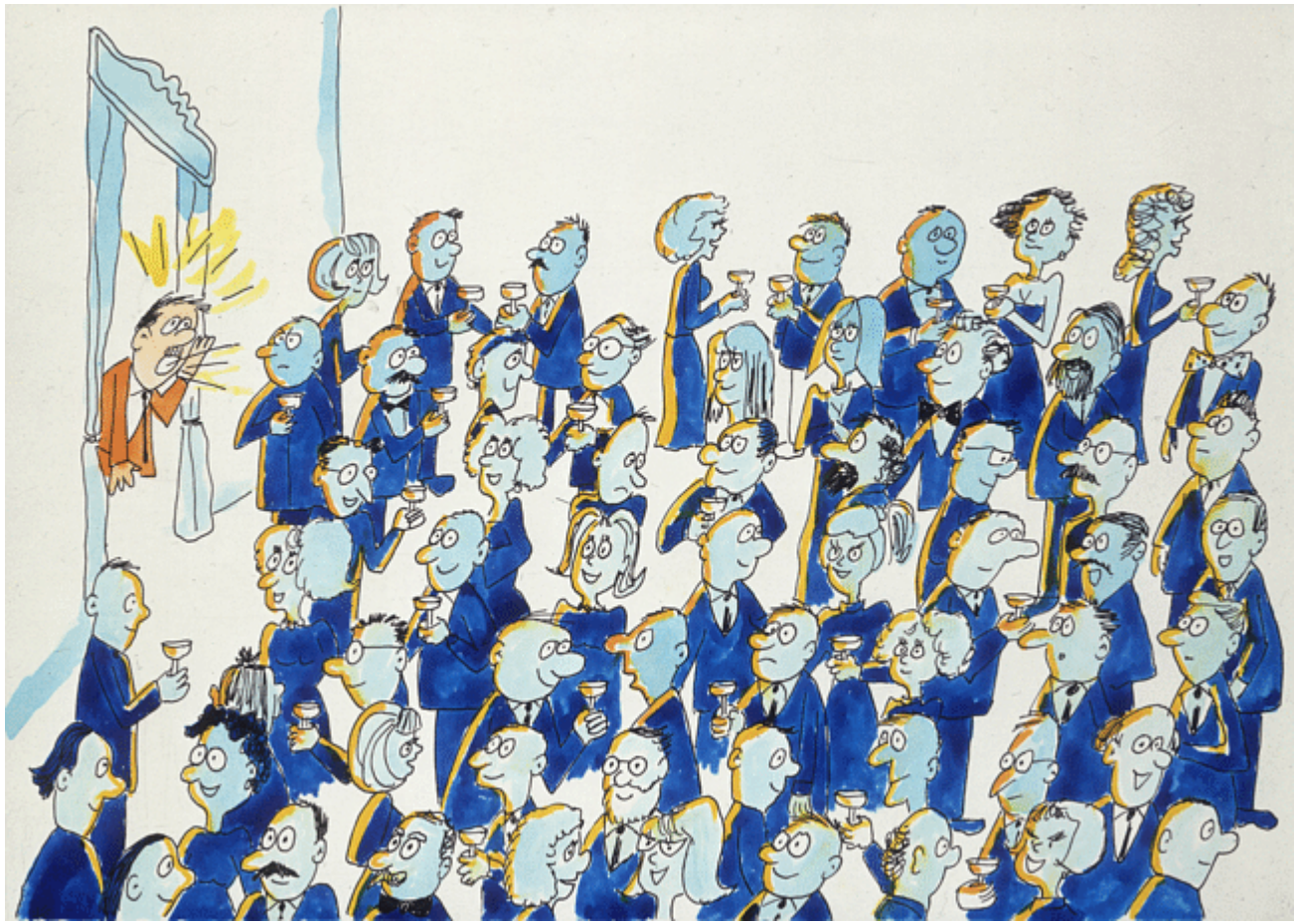
Higgs Mechanism (2)



Important politician enters the room and all cluster around her

and she “gains mass”

Higgs Boson (1)



Rumour whispered at one end of room of politicians

Higgs Boson (2)

As rumour moves through room, people cluster around ---- particle

The Higgs is Different!

All the matter particles are spin-1/2 fermions.
All the force carriers are spin-1 bosons

Higgs particles are spin-0 bosons.
The Higgs is neither matter nor force;
The Higgs is just different.
This would be the first fundamental scalar ever discovered.

The Higgs field is thought to fill the entire universe.
Could give a handle on dark energy(scalar field)?

If discovered, the Higgs is a very powerful probe of new physics.

ATLAS will discover the Higgs.
ILC will use the Higgs as a window viewing the unknown.

THE END