

# The Standard Model of Particle Physics

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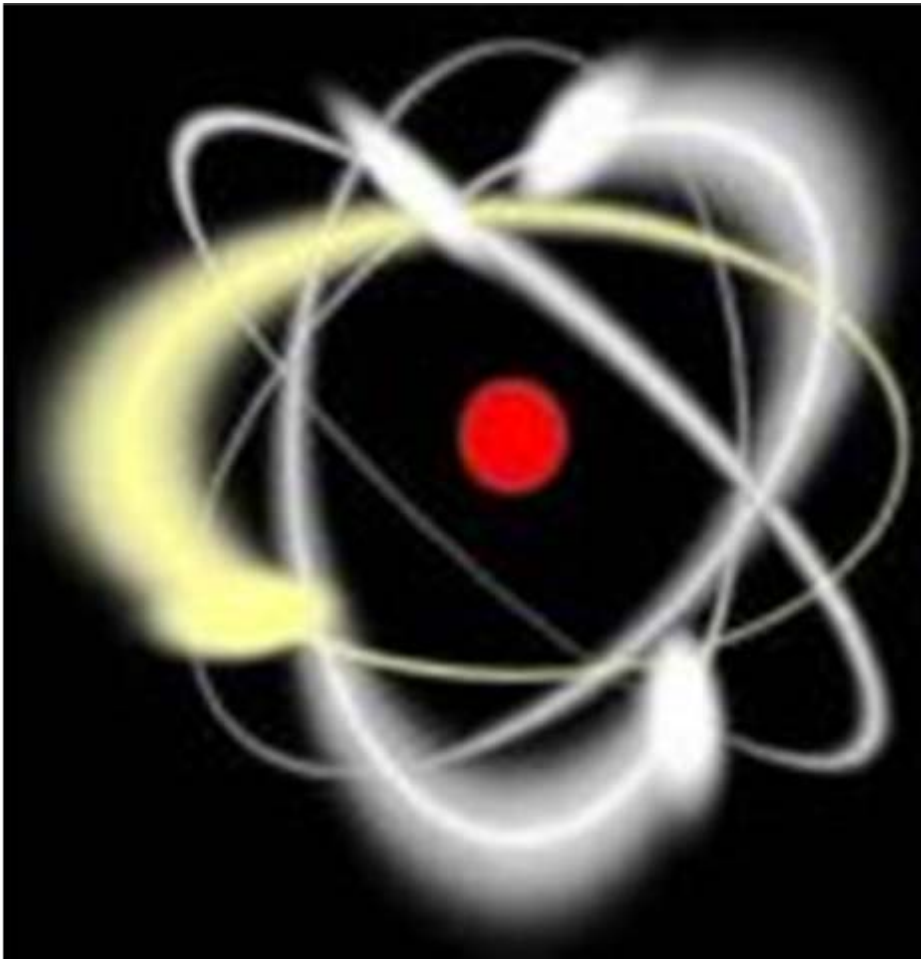
# Objective

- Find the most basic constituents of nature
- These will be the building blocks from which everything is made



# Starting off

Matter is made of atoms (Greek for indivisible)



A positively charged nucleus is surrounded by cloud of negatively charged electrons ( $e, -1$ )

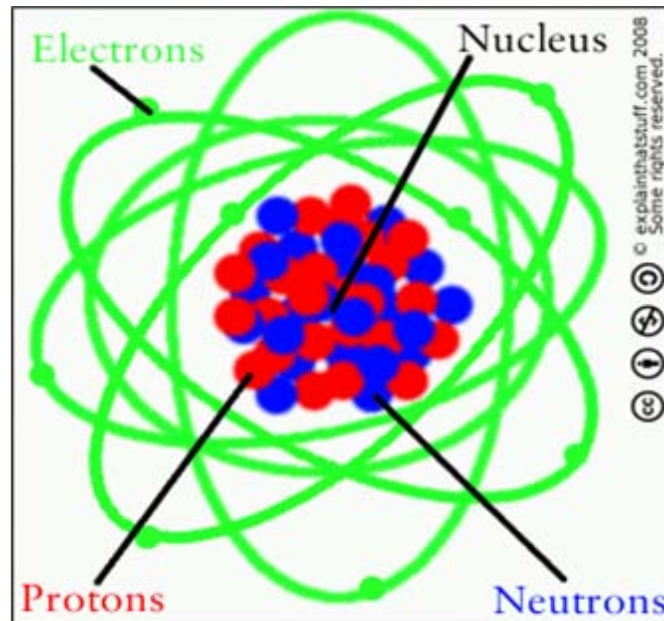
# Bingo!

- As far as we can detect, the electron does not have a substructure
- It is the first of our building blocks



# Examining the Nucleus

- Thousands of times more massive than an e
- Occupies a much smaller volume than e cloud
- Made of protons (p, +1) and neutrons (n, 0)
- Neutrons are slightly bigger



# A Step Further

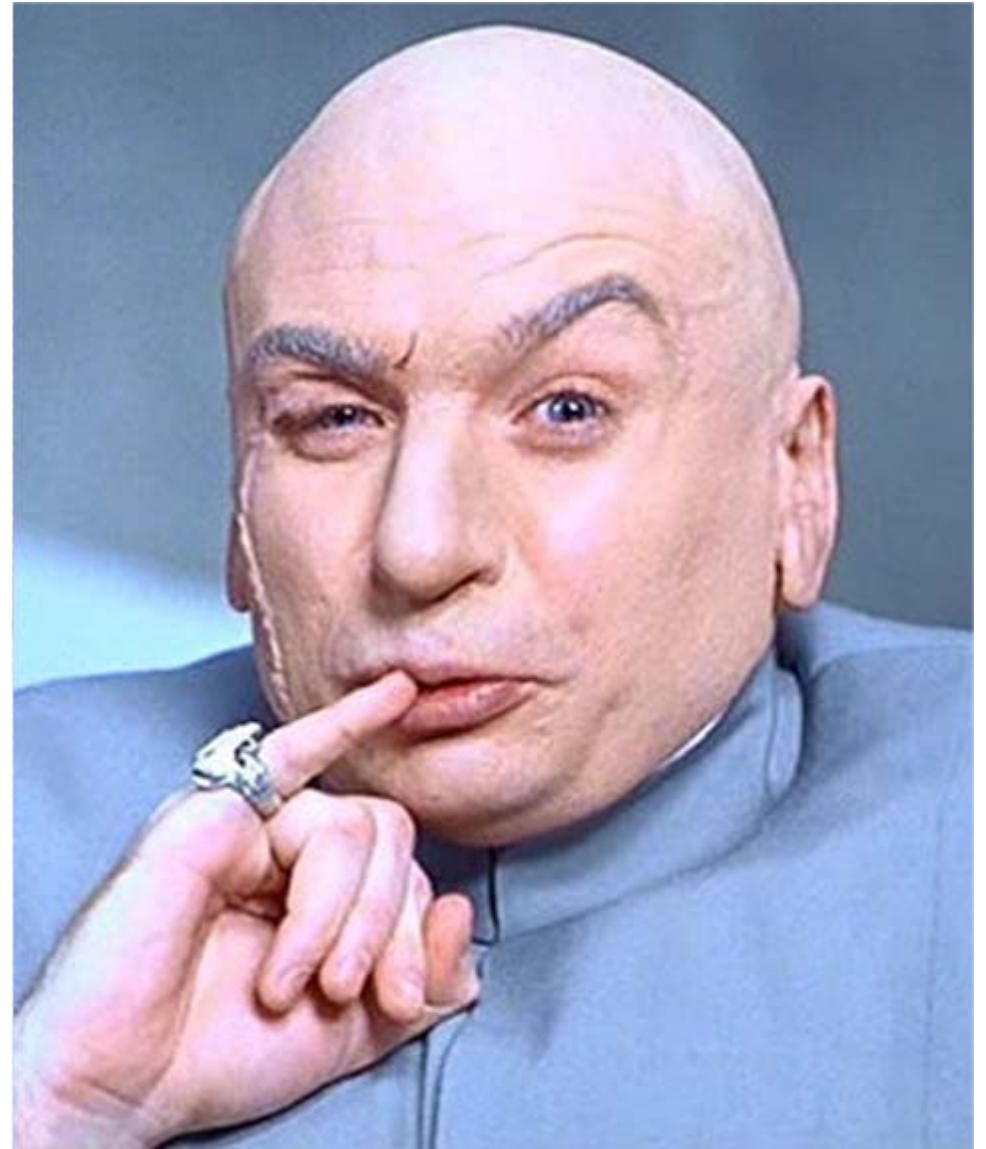
- Turns out protons and neutrons also have a substructure
- They are made of three quarks each



# Quarks

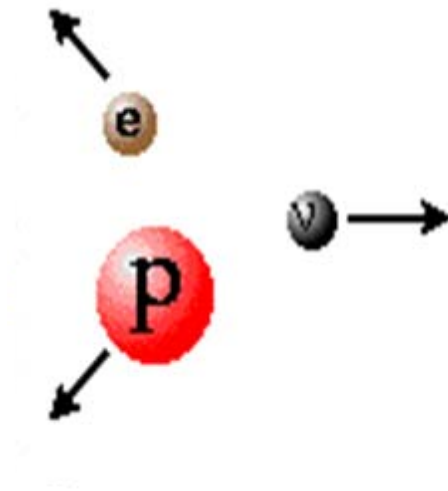
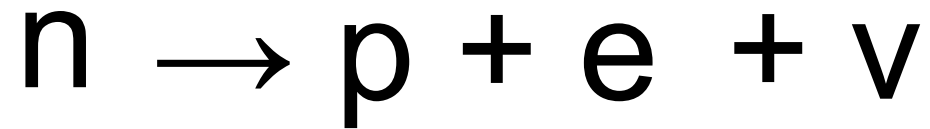
- Name comes from Joyce's Finnegans Wake
- Subject to *confinement*, which means that they are never alone
- Come in packs of two or three
- Matter is made of two varieties: Up (u,  $+2/3$ ) and Down (d,  $-1/3$ )
- Protons (uud) and neutrons (udd)
- Have a quantum number: Color

*One Million  
Dollars!*





# Taking a Jump: Beta Decay

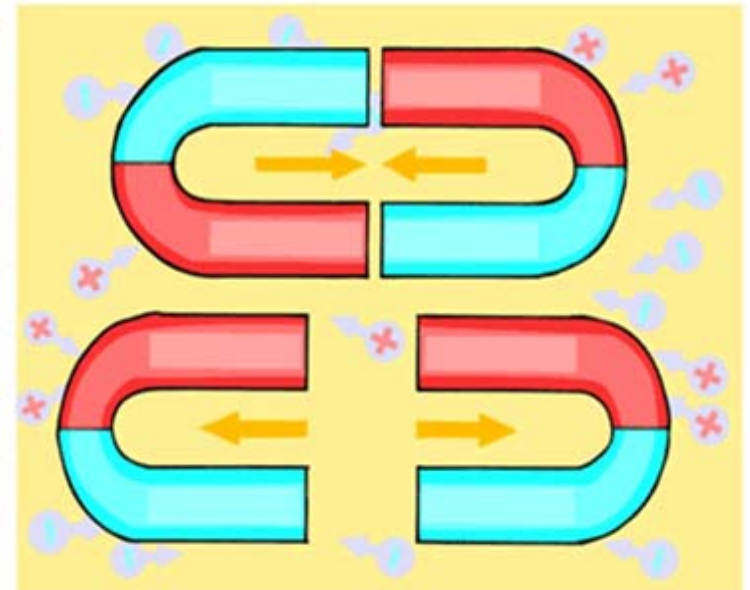
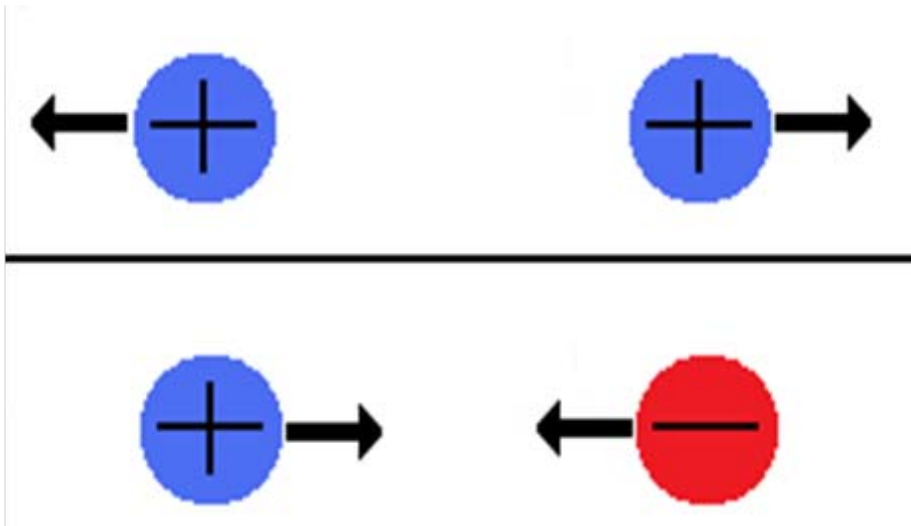


# $\nu$ ? That's Odd

- $\nu$  was introduced by Pauli to conserve energy and spin
- Named the neutrino (Italian pun: Thanks Fermi)
- Our last candidate for particles
- Carries no charge
- Tiny mass
- Until recently, many thought it was massless

# Exploring the Forces

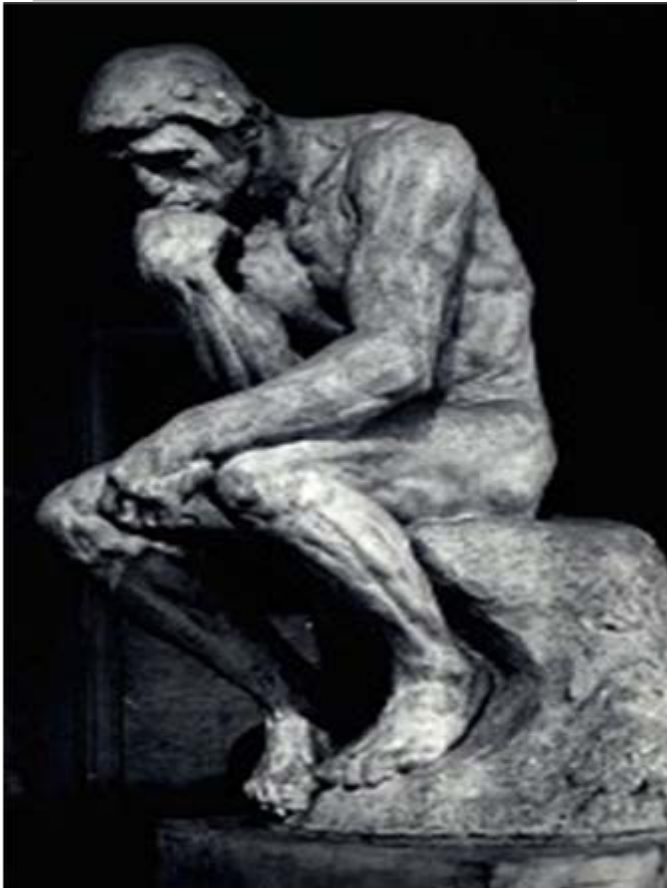
- Photon “mediates” the Electromagnetic Force
- Opposites attracting
- This covers the majority of the day to day forces we feel.





# Wait a second...

- Electromagnetic Force alone would blow apart the positively charged protons in the nucleus!
- There must be an even more powerful force holding them together!



# A Very Original Name...

- Strong Force
- Mediated by the gluon
- Holds quarks together
- Extremely strong at short ( $\sim 10^{-15}$  m) ranges
- Negligible at anything bigger

# Back to Betas

- Actually an example of a Weak Force interaction
- Mediated by the  $W^+$ ,  $W^-$ , and  $Z^0$  Bosons
- Way for heavy particles to decay into smaller ones (free neutron unstable)

# Something is Missing

- Gravity: the mystery force
- Counter intuitive, since it was the first force to be described classically



Mediated by the graviton?



Most Importantly...

Gravity is NOT  
part of the  
Standard Model



# Review

- 4 particles (u, d, e,  $\nu$ )
- 4 forces (Electromagnetic, Strong, Weak, and gravity)
- Mediators (photon, gluon, W/Z, graviton)

# I Am A Liar (sort of)

- These particles make up all of normal matter
- They are the “First Generation”
- Two more generations
- Each heavier than the last
- These make up weird stuff that you never see
- Each generation contains “cousins” of the first generation

# Second Generation

- Up (u)  $\rightarrow$  Charm (c)
- Down (d)  $\rightarrow$  Strange (s)
- Electron (e)  $\rightarrow$  Muon ( $\mu$ )
- Neutrino ( $\nu_e$ )  $\rightarrow$  Neutrino ( $\nu_\mu$ )

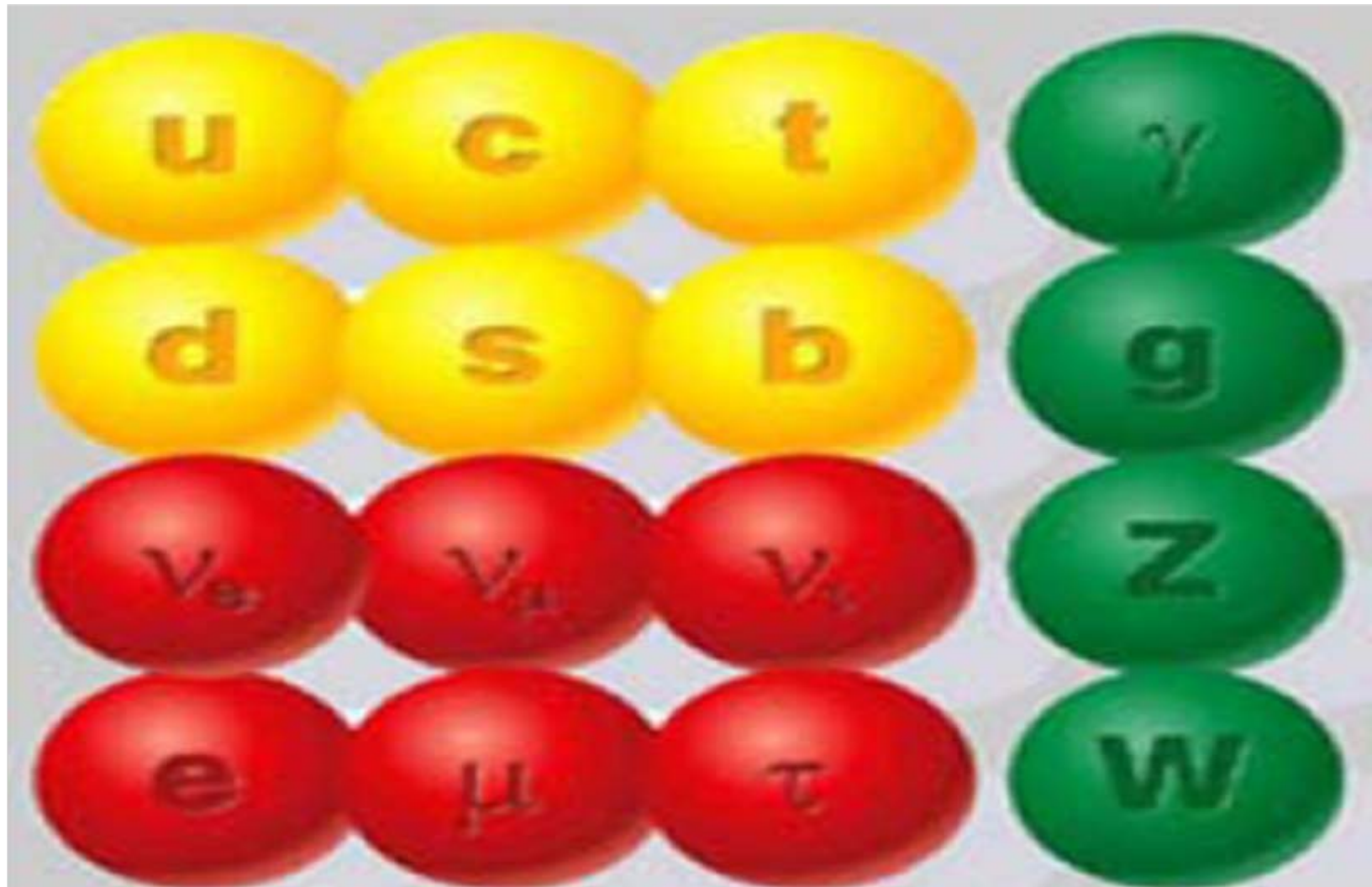
# Third Generation

- $u \rightarrow c \rightarrow \text{Top (t)}$
- $d \rightarrow s \rightarrow \text{Bottom (b)}$
- $e \rightarrow \mu \rightarrow \text{Tau (\tau)}$
- $\nu_e \rightarrow \nu_\mu \rightarrow \nu_\tau$

# Weird Names?

- Strange → new particles were... strange
- Charm → balance to strange
- Top/Truth and Bottom/Beauty
- Took a while to realize that neutrinos across generations were distinct

# At Last! The Standard Model!

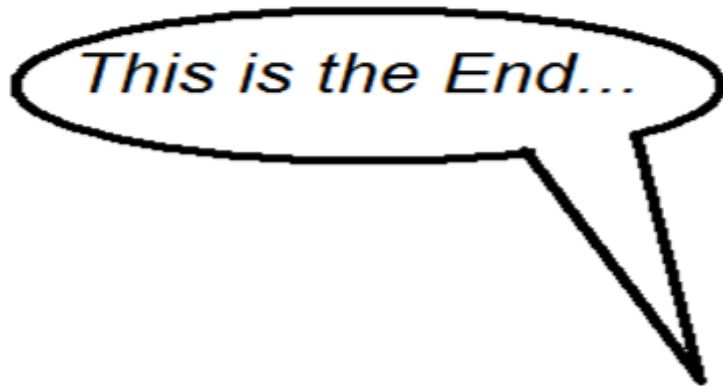


- Once again, I held out on you.
- Antimatter!
- All particles have an antimatter equivalent with equal mass but opposite properties (i.e. charge)
- When a particle collides with its antiparticle, they explode.



# WRONG!!!

- T  
M  
e  
description of  
the universe,  
but it is  
incomplete





# Gravity

- Gravity is NOT explained by the standard model
- Attempts have been made to reconcile it with the Standard Model
- This is why people are making a big deal about string theory



# Summary

- Despite being incomplete, it's the best we've got
- Provides a solid description of the Electromagnetic, Weak, and Strong Forces
- Wraps up the particles into a nice little table

