PH 438 E & M

BSC/ Physics
E.F. Deveney

Note Title 9/8/2004

Nothing = $|000000\rangle$

Fock # space
Hilbert

BIG BANG

$\Delta E \Delta t \geq \hbar$, Δt = huge ⇒'s
ΔE = small

~700,000 years

Inflation

how does particle + antiparticle fit into this energy scheme?

3000°K

e⁻'s condense onto p = H atom so particle density ↓ universe transparent CMBR

+ Energy + − Epotential = 0
E_K + Mass gravitational

OUR UNIVERSE 13.5 Billion years

nucleo-synthesis

'Particles' = Fermions $n(\frac{1}{2})$ spin

neutrino MBR 8 generations each → e⁻, ν, 2 quarks

leptons

'Force' = Bosons $n = 0, 1, \ldots$ spin

(1960's)
1.) E & M } QED
(1970) Electroweak γ, W^-, W^+, Z^0
2.) Weak nuc
(1980)
3.) strong nuc } QCD 8 gluons, g_{rb}
4.) gravity ?

GUT

TOE ⇑ Super strings

1.)	e^-, ν_e	u, d
2.)	μ, ν_μ	c, s
3.)	τ, ν_τ	t, b

quarks

18 quarks u_r, u_g, u_b one of each color charge!

now HADRONS

Baryons = 3 quark combo's

$p = (u_r u_g d)$ but colorless!

Note $\bar{u}_r$ has $\bar{r}$

or ....

$\Delta^{++} = (u_r u_g u_b)$ = colorless

* Note: because of this Baryon & Pauli exclusion, clear that addit quantum #, color, was needed

Mesons: = $q\bar{q}$ combo's (need to make colorless)

$\pi^+ (u\bar{d})$, $(u_g \bar{d}_{\bar{g}})$

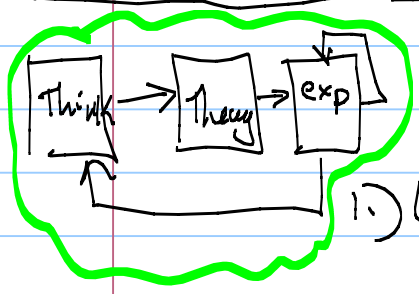
Jor ψ (psi) = $(c\bar{c})$ = November revolution!

2004: Penta quarks = 5 quark combos

Now

Classical
1.) Newtons Laws
2.) Maxi's Equations (E&M)
3.) Stat Mech Thermodynamics

1900



Quantum mechanics

1.) Light $\begin{cases} \text{wave} \\ \& \\ \text{particle} = \gamma \end{cases}$

2.) $e^- \begin{cases} \text{particle} = e^- \\ \text{wave?} \end{cases}$, Ψ = wavefunction

Solve Schrödingers equation

$$+i\hbar \frac{\partial \Psi(x,t)}{\partial t} = \hat{H}\, \Psi(x,t)$$

(1933 Nobel Prize)

But what is Ψ?

& $\Psi^* \Psi$ = probability density!

Schrödinger - Born
(Max... Olivia's Grand dad)
probabalistic interpretation of Q.M.
1954 Nobel Prize.

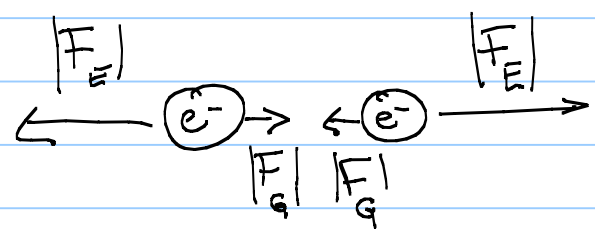
Tremendously successful! So apply Q.M. to Forces!

So Look @ 4 Forces.....

1.) E & M
2.) weak nuc
3.) strong nuc
4.) gravity

Obvious choice... gravity. BOT!

consider



$$\frac{|F_G|}{|F_E|} = \frac{G m_1 m_2 / r_{12}^2}{K q_1 q_2 / r_{12}^2} = \frac{G m_1 m_2}{K q_1 q_2}$$

$$m_e \cong 10^{-31}\ kg, \quad q_{e^-} = 1.6 \times 10^{-19}\ C$$

$$G = 6.67 \times 10^{-11}\ \frac{Nm^2}{kg^2}, \quad K = 10^{10}\ \frac{kg\,m^3}{s^2/C^2}$$

$$\left|\frac{F_g}{F_E}\right| \cong \frac{10^{-72}}{10^{-28}} \cong 10^{-44}$$

Relative Strengths & Ranges

1) strong	1	cm 10^{-13}
2) E&M	10^{-2}	∞
3) weak	10^{-13}	$\sim 10^{-15}$
4) grav	10^{-39}	∞

Clearly $F_E >> F_G$

what about

weak nuc, weak & short range $\sim 10^{-15}$ m

Strong nuc, strong BUT act $\sim 10^{-15}$ m of nuc

So, @ the size of

anything > atom

E & M Dominate!

So go about Describing E&M Force w/ Quantum Mechanics 1st

QED

Feynman
Schwinger
Tomonaga

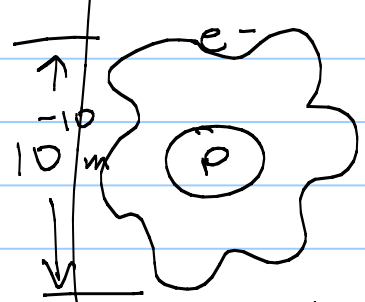
Nobel Prize 1965

e^-'s $\sim \Psi$ particle field } same setting!

Quantum Field Theory E&M $\sim$ Field

So

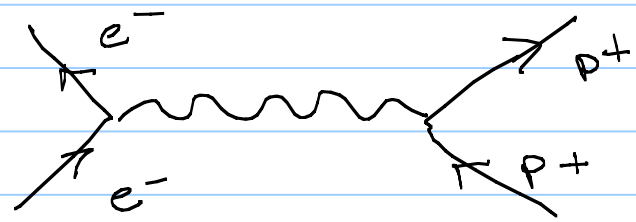
Size \ Speed	Slow →	Fast
BIG	Classical, <1900 1.) Newton 2.) Maxwell 3.) Stat mech - Thermal Baseballs o - - - - - →	Relativity ~1900 Albert Einstein $\frac{\lvert V\rvert}{c} >$, say 1% rocket ~ 20,000 mph ~ $2\times10^4 \frac{m}{s}$ so $\lvert V/c\rvert \sim 10^{-5}$ But μ's @ .94c atmosphere μ lifetime ~ 2 μ sec
	Quantum Mechanics 1900 - 1930 $m \sim 10^{-27}$ kg Hydrogen V_{atom} @ RT $\sim 10^6$ m/s $V_{e^-} \sim 10^6$ m/s so $\lvert \frac{V}{c} \rvert \sim 1\%$ relativistic effects	Quantum Field theory Q.M "needs" relativity to be "more" right ⇒'s 1.) particle - antiparticles &, it needs "consistent" treatment of Force Fields! so QFT Particles - Ψ fields Forces → E&M fields weak strong gravity
Small	1 mole = 12 grams (C) = 10^{23} atoms Fingernail ~ 10^{23} sec's in universe $\pi\times10^7 \frac{sec}{year} * 13.5\times10^9 y = 10^{17}$ sec	



atom = Q.M.
Extern field
= classical
= semiclassical

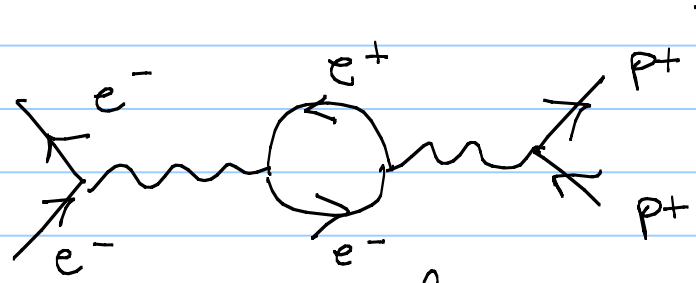
QED most successful, precise Theory ever!

H - atom



energy levels ~ 2 eV = orange light
Balmer series
$n \longrightarrow 2$

QED correction



virtual $e^- + e^+$ pair

Lamb Shift $\sim \frac{1}{10^6}$ eV

So experiment:

	2.000003
Theory (no Lamb)	2.000000
Theory (w/ Lamb)	2.000003

wow!

Great. But deeper? From nothing, can you show that you, the universe, needs to have

Ψ = particle fields

$\{$ 1 E&M
2 w nuc
3 s nuc
4 gravity

Force fields

?

Almost!

Guage Theories

Idea: Invariance Symmetries necessitate the Force Fields & maybe even the particle Fields

How: ? AJP, 1989, R. Mills "Guage Theory"

Based on Noether's Theorem
↳ Emily ... (mathematician)
student of Hilbert, she had hell of time getting prof job in Germany, forced to flee to US in 1933 and died 2 years later

Brief Sketch of guage Theory

Symmetry $\rightleftarrows$ Conservation; when you "enforce" this symmetry from global to Local, you have to add a gauge field for it to work (ie consistent mathemat)

ex:

Relativity:

Invariance of "Frames":

To Keep the physical Laws of motion

[Conserv of $\vec{p}$; cons of $\vec{L}$; cons of E
invariance of x_0) invariance of σ_0) invariance of t_0]

invariant to all frames, inertial & non inertial (accelerating)

need to include GRAVITY & IS you make it Lorentz Invariant Local,

Gravity = field that travels @ C

More abstract ....

in Q.M. $\Psi \to e^{i\theta}\Psi$ = Unitary Translation! from Q.M.

arbitrary phase

Then Schrö-Born prob interpret

$$\Psi^*\Psi = e^{-i\theta}\Psi^* e^{i\theta}\Psi = \Psi^*\Psi$$

So Q.M. wavefunct is invariant to $e^{i\theta}$

If $e^{i\theta(\vec{x},t)}$ = global, everywhere & sametime

presserves the "invariance" even w/ derivatives $\Psi^*\left(\frac{d}{dx}\right)\Psi$

But if demand it to be local

$$\Psi = e^{i\theta(\vec{x},t)}$$

Then

$$\Psi^*\left(\frac{d}{dx}\right)\Psi \neq e^{-i\theta(x,t)}\Psi^*\left(\frac{d}{dx}\right)e^{i\theta(x,t)}\Psi$$

So loose invariance! on "local" symmetry

Eisberg & Resnick does it well...

time dep Schrö

$$i\hbar \frac{\partial \Psi}{\partial t} = \hat{H}\Psi$$

if transform Ψ globally $\Psi' \to \Psi e^{i\sigma}$

if $\sigma \neq S(x,t)$ then this transformation leads to Schrö invariant.

But... if Local $\Psi \to e^{i\sigma(x,t)}\Psi$

Then

$$i\hbar \frac{\partial}{\partial t}\left(e^{i\sigma(x,t)}\Psi\right) = \left(-\frac{\hbar^2}{2m}\frac{\partial}{\partial x^2} + V(x)\right)e^{i\sigma(x,t)}\Psi$$

free particle

The temporal & spacial derivatives destroy the invariance of Schrö to local transformation!

However,

if $\Psi \to \left(e^{i\theta(\vec{x},t)} \Psi + F \right)$

Then $\Psi^* \left(\frac{d}{dx}\right) \Psi$ is Completely invariant! Locally!

if you investigate what $\vec{F}$ needs to be to make Ψ locally invariant,

SURPRISE exactly = E&M Field described by Max's Equations!

where are we?

Need

1.) Invariance of phase $\rightleftarrows$ cons of charge

γ = photons of E&M Force QED

Need

2.) " " Isospin

γ, Z^0, W^-, W^- } mass less

problem Not renormalizable! (crazy, ∞ity, answers)

But, add another field

H. ggs field that give mass to

Z^0, W^-, W^+ by spontaneous broken symmetry

The entire Theory becomes invariant AND renormalizable (Gerard 't Hooft in 1971

Nobel Prize in 2001?

Wow!

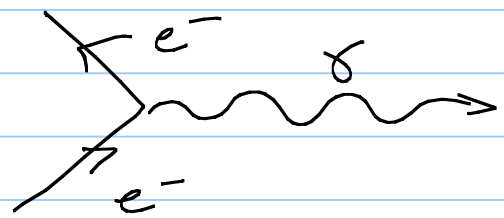
This is electroweak!

γ = photon = E&M

CERN in the 1980's

Z^0, W^-, W^+ } weak nuc, massive, short range neutral & charge currents } see

See



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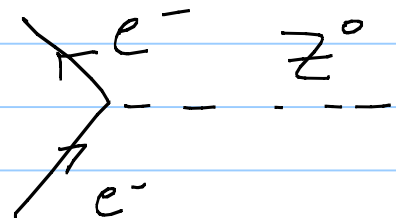

4.) "Color" charge conservation, invariance
quarks can come in (r, g, b)

$\Rightarrow$ is need "Gluon" $g_{\bar{g}b}$ field

8 of them

which explains { all know mesons, π, Kaon, & Baryons, p, n ....

1.) asymtotic freedom, why quarks seem "free" inside of p & n

2.) quark confinement ... yet never see individual quarks
(ant. screening cause gluons carry charge themselves)

seems like should get the

Quantum field for gravity! (graviton)

Then the Particles?

SuperSymmetry $\Leftrightarrow$ all the bosons should have
supersymmetric
Fermion 'super partner'

Bosons	Fermion
photon	tino
s	electron

Ex: Superstrings!