PH438 E&M

BSC/Physics
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Note Title

9/8/2004

Nothing = $|000000\rangle$

Fock # space

Hilbert

BIG BANG

$\Delta E \Delta t \geq \hbar$, $\Delta t = \text{huge} \Rightarrow$'s $\Delta E = \text{small}$

~700,000 years

Inflation

3000° K

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

+Energy + −$E_{\text{potential}}$ = 0

E_K + Mass

gravitational

how does ~~antipart~~ particle + antipart fit into this energy scheme?

OUR UNIVERSE

13.5 Billion years

nucleo-synthesis

neutrino MBR → we see ν's weakly

'Particles' = Fermions

3 generations

$n(\frac{1}{2})$ spin

each $\left\{ \begin{array}{l} \to e^- \\ \to \nu \\ 2 \text{ quarks} \end{array} \right.$

Leptons

1.) e^- ν_e

2.) μ ν_μ

3.) τ ν_τ

u, d

c, s

t, b

quarks

18 quarks

u_r, u_g, u_b

one of each color charge!

'Force' = Bosons

n = 0, 1, ... spin

1.) E&M } QED (1960's)

2.) Weak nuc } Electroweak (1970) $\gamma, W^-, W^+ Z^0$

GUT (1980)

3.) strong nuc } QCD

8 gluons, grb

4.) gravity ?

TOE

⇑

Super strings

now

HADRONS

Baryons = 3 quark combo's

$$p = \left(\begin{matrix} u_r \; u_g \\ d \end{matrix}\right)$$ but colorless!

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

or ....

$$\Delta^{++} = \left(\begin{matrix} u_r \; u_g \\ u_b \end{matrix}\right) = \text{colorless}$$

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

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

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

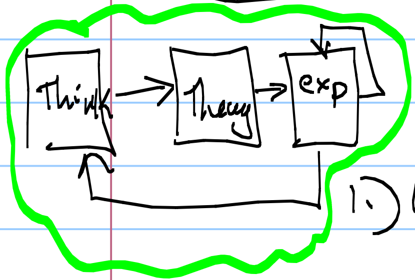
J or ψ (psi) = $(c\bar{c})$ = November revolution!

2004: Pentaquarks = 5 quark combos

Now

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

1900



Quantum mechanics

1.) Light $\left\{\begin{array}{l}\text{wave} \\ \& \\ \text{particle} = \gamma\end{array}\right.$

2.) e^- $\left\{\begin{array}{l}\to \text{particle} = e^- \\ \to \text{wave?}\end{array}\right.$, 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.

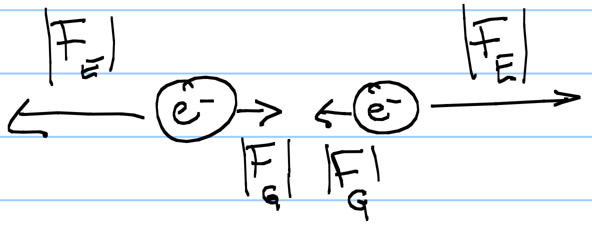
Tremendously successful! So apply Q.M. to Forces!

So Look @ 4 Forces.....

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

Obvious choice... gravity. BOT!

consider



$$\frac{|F_G|}{|F_E|} = \frac{Gm_1m_2/r_{12}^2}{Kq_1q_2/r_{12}^2} = \frac{Gm_1m_2}{Kq_1q_2}$$

$$m_e \cong 10^{-31}\ kg, \quad q_{e^-} = 1.6\times10^{-19}\ C$$

$$G = 6.67\times10^{-11}\ \frac{Nm^2}{kg^2}, \quad K = 10^{10}\ \frac{kg\,m^3}{s^2/C^2}$$

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

Relative Strengths & Ranges

		cm
1) strong	1	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 ~ Ψ particle field
E&M ~ Field
} same footing!

Quantum Field Theory

So

Speed

Size

Slow ⟶ Fast

BIG

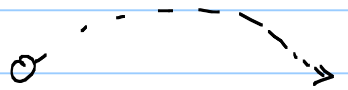
Classical, < 1900

1.) Newton

2.) Maxwell

3.) Stat mech - Thermal

Baseball's



Relativity ~1900

Albert Einstein

$\frac{|V|}{c} >$, say 1%

rocket ~ 20,000 mph ~ $2\times10^4 \frac{m}{s}$

so $|V/c| \sim 10^{-5}$

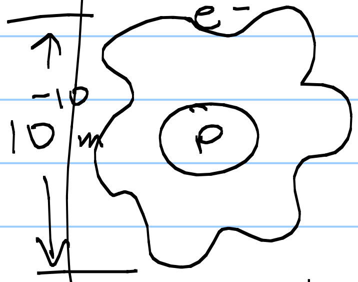
But

μ's @ .94c atmo-sphere μ ↓

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 $\left|\frac{V}{c}\right| \sim 1\%$ relativistic effects

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

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

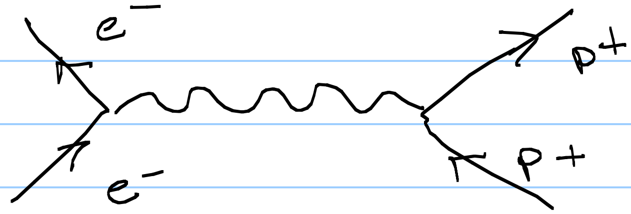
atom = Q.M.

Extern field = classical

= semiclassical

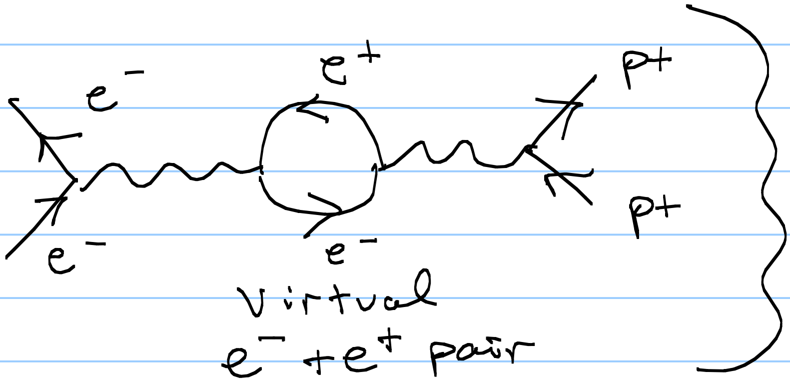
QED most successful, precise theory ever!

H-atom



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

QED correction



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 ?

$\left\{\begin{array}{ll} 1 & \text{E\&M} \\ 2 & \text{w nuc} \\ 3 & \text{s nuc} \\ 4 & \text{gravity} \end{array}\right.$ Force fields

Almost!

Guage Theories

Invariance ⇄

Idea: 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 θ_0) invariance of t_0]

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

need to include GRAVITY & if 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.

$\uparrow$

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 $e^{i\theta}$

IS $e^{i\theta(\neq f(\vec{x},t))}$ = global, everywhere @ same time

preserves the "invariance"

even w/ derivatives $\Psi^*(\frac{d}{dx})\Psi$

But is 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! or "Local" symmetry

Eisberg & Rosnick does it well....

time dep Schrö

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

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

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

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

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

free particle

The temporal & spacial derivatives destroy the invariance of schrö to Local transformation!

However,

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

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

is 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

$\left.\begin{matrix}\gamma \\ Z^0 \\ W^- \\ W^+\end{matrix}\right\}$ mass less

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

But, add another field

Higgs field that give mass to by spontaneous broken symmetry

Z^0

W^-

W^+

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

Nobel Prize in 2001?

Wow!

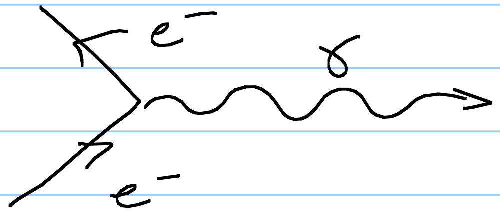
This is electroweak!

γ = photon = E&M

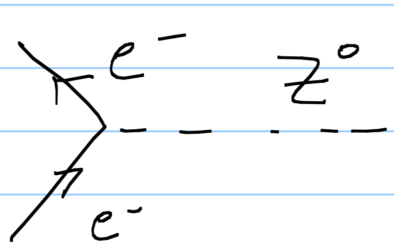
$\left.\begin{matrix}Z^0 \\ W^-, W^+\end{matrix}\right\}$ weak nuc, massive, short range, neutral & charge currents $\Big\}$ see

CERN in the 1980's

See



&



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

⇒ 's need "Gluon" $g_{\bar{g}b}$ field

8 of them

which explain { all know mesons, π, Kaon,
& Baryons, p, $\underset{\sim}{n}$ ....

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 them selves)

seems like should get the Quantum field for gravity! (graviton)

Then The Particles?

Super Symmetry ⟺ all the bosons should have supersymmetric Fermion 'super partner'

Bosons	Fermion
photon +ino	s+electron

Ex: Superstrings!