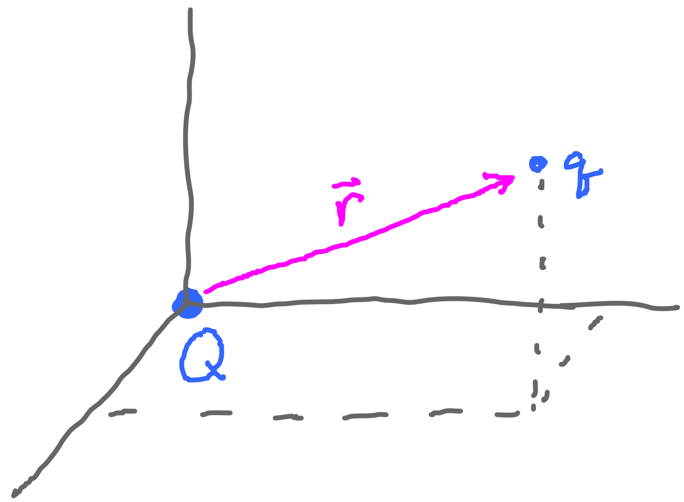
Physics 142 - September 4, 2014

- P.S. 1 is available ... Please enjoy
- Workshops begin Next week (Sept. 8)
- Any concerns / questions about syllabus and/or how class will run?

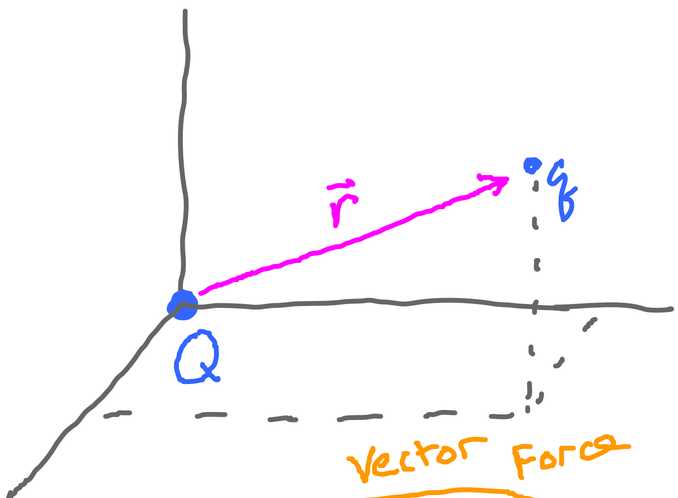
Last Time

Charles Augustin Coulomb (1736-1806)
France
Coulomb's Law ~1875



$$\vec{F}_{Q\,on\,q} = \frac{kQq}{r^2}\,\hat{r}$$

ElectroSTATICS

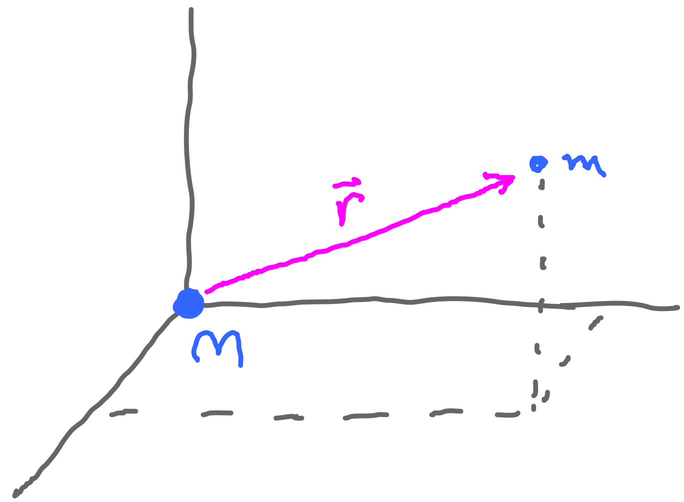


Vector Force

$$\vec{F}_{Q \text{ on } q} = \frac{kQq}{r^2}\,\hat{r}$$

Q, q each come as "+" or "−"

Gravitation



$$\vec{F}_{M \text{ on } m} = -\frac{GMm}{r^2}\,\hat{r}$$

M, m only +

- Electric charge is conserved

- Electric charge is quantized

unit is $|e| = 1.6 \times 10^{-19}$ "coulombs"

C ← MKS unit of electric charge

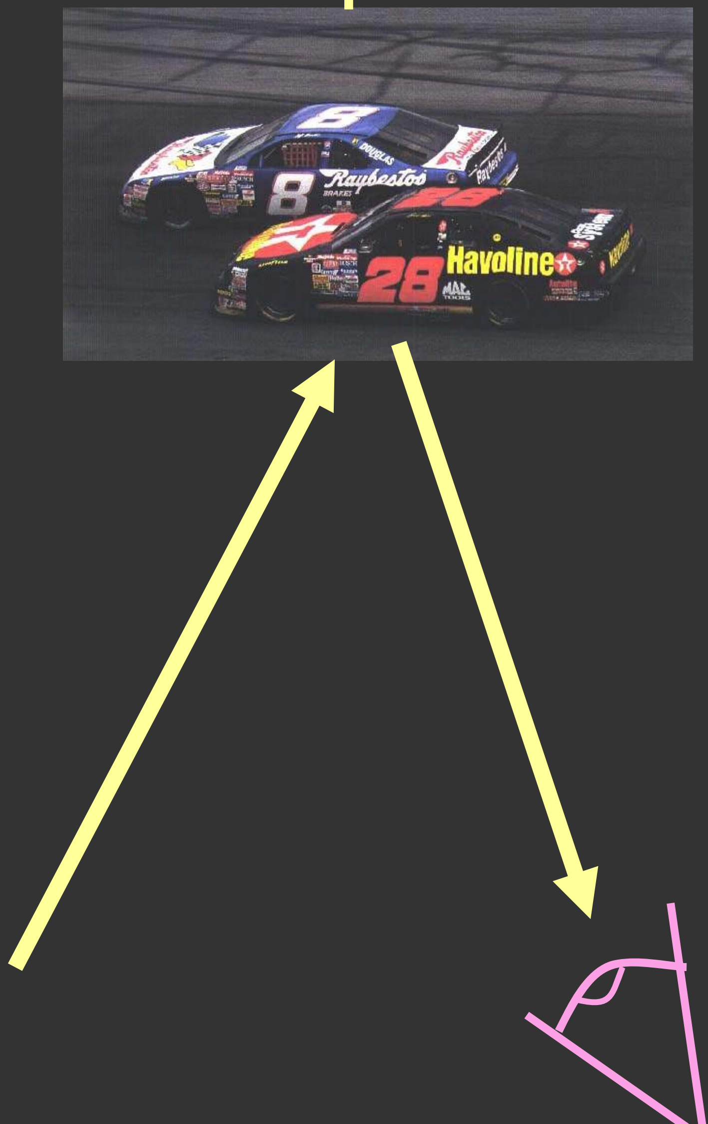
Return to tangent on quarks

Mini-Ph.D. – Quantum Mechanics 101

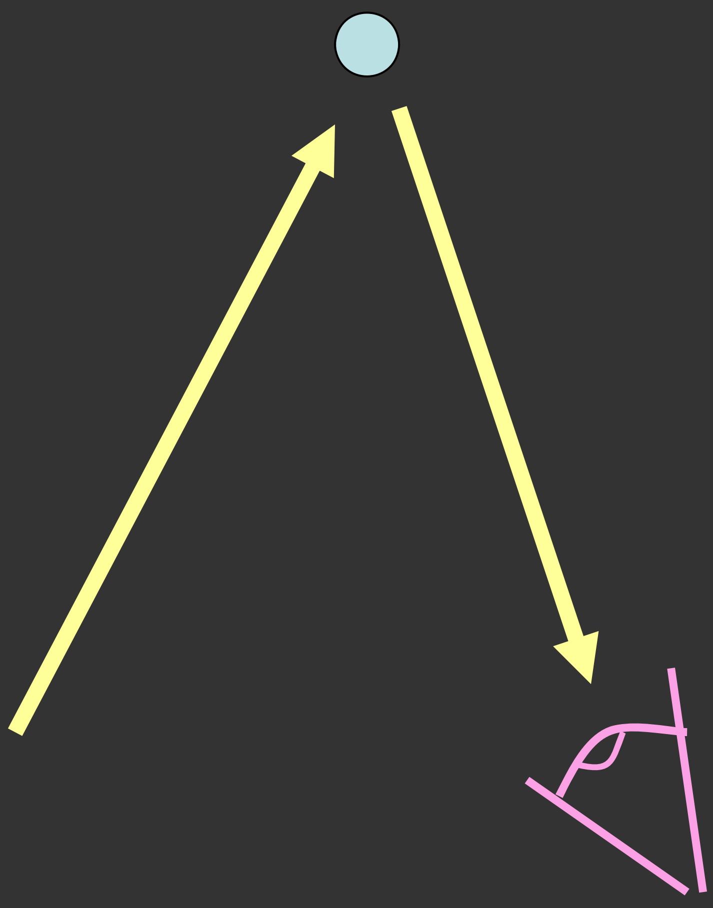
Lesson 1:

Size actually does matter.

Determine the postion and velocity of a car … no problem

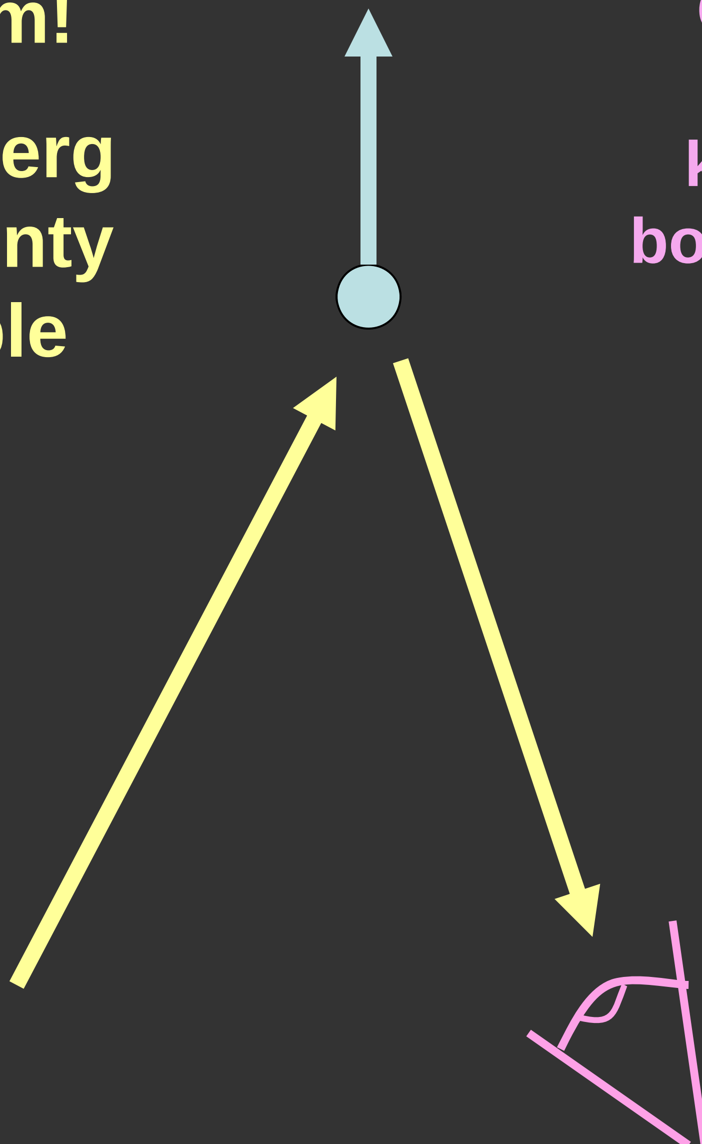


Determine the postion and velocity
of a small particle … no problem



Problem!

Heisenberg uncertainty principle



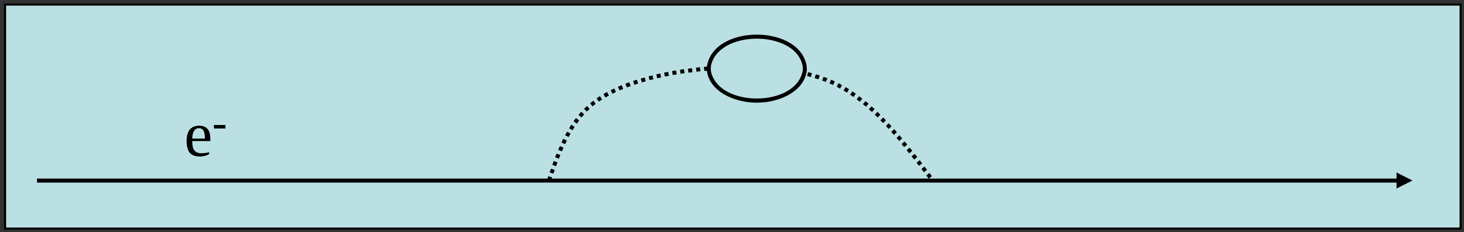
Cannot have perfect knowledge of both the position and velocity

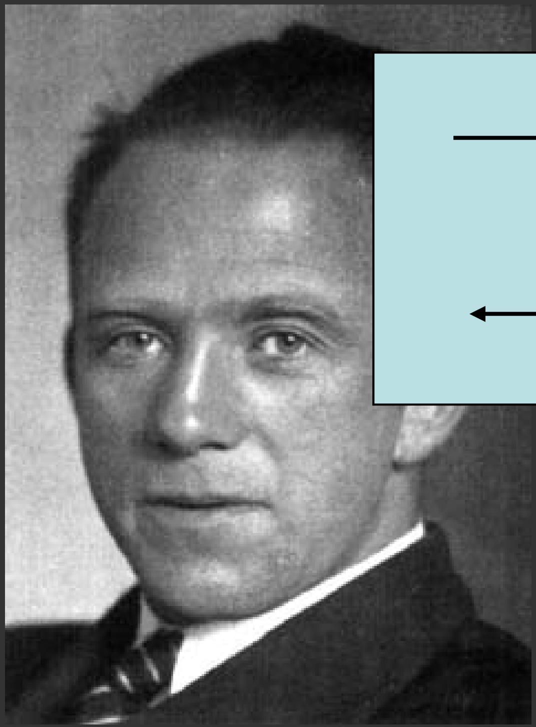
Heisenberg

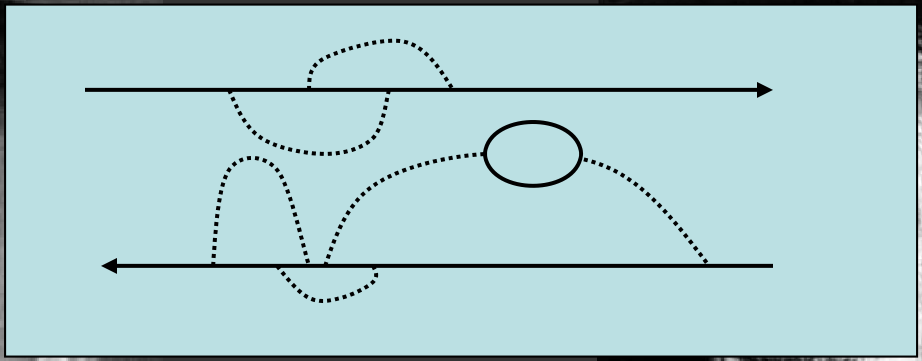
The fundamental nature of forces: virtual particles

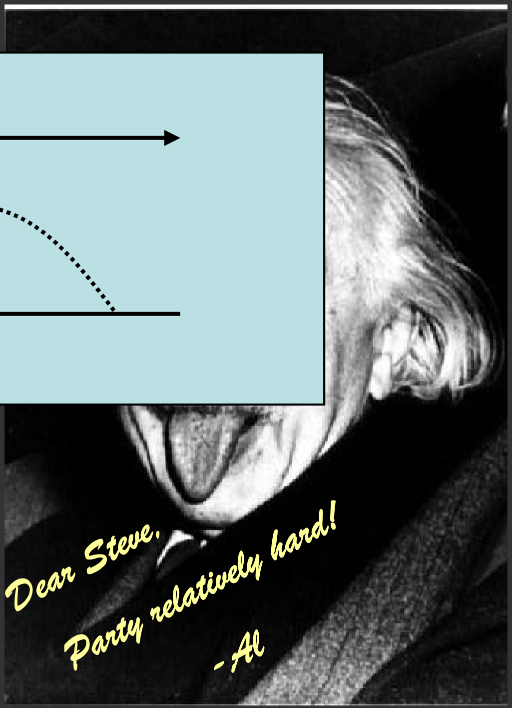
$\Delta E \Delta t \approx h$ Heisenberg

$E = mc^2$ Einstein



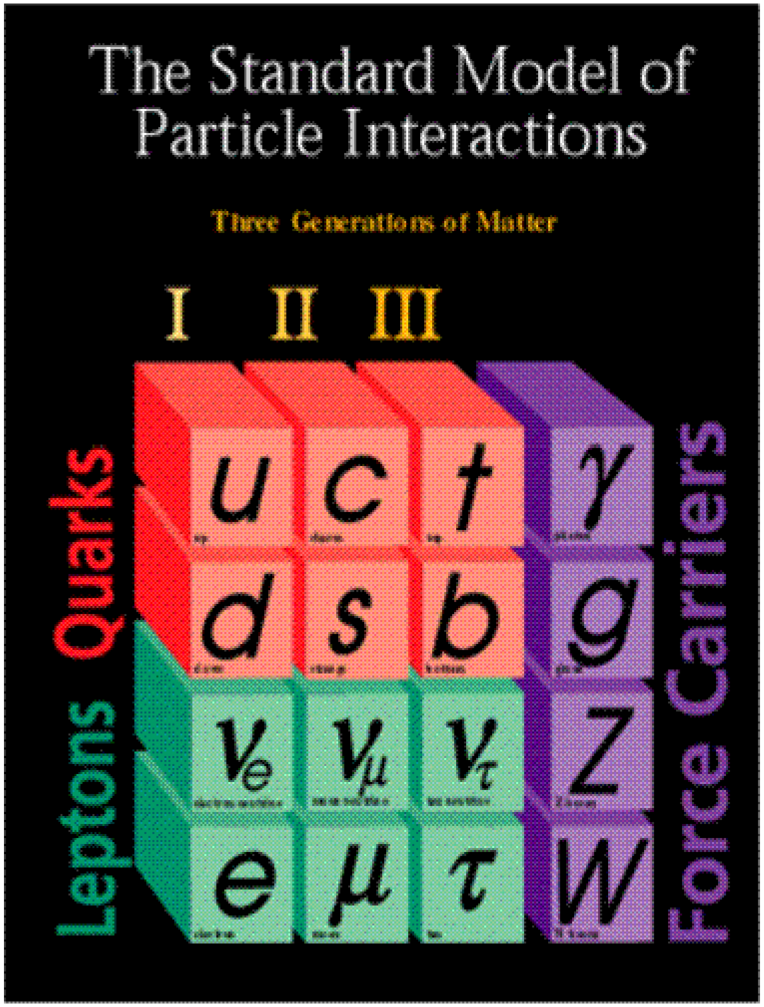






Quantum Field Theory → Exchange force

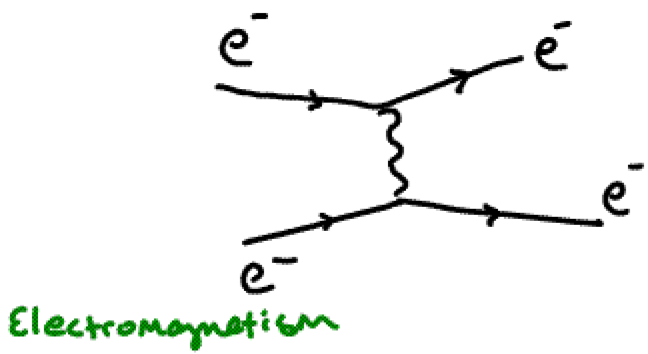

Frank and Ernest
YOU MADE IT ALL OUT OF QUARKS? -- GET OUTA HERE!
© 1989 by NEA, Inc.
11-17
THAVES

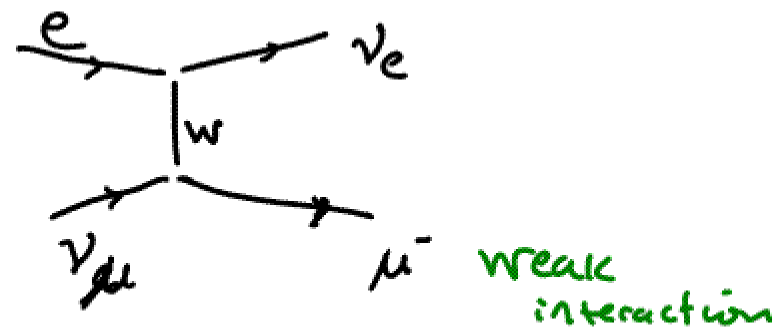

The Standard Model of Particle Interactions
Three Generations of Matter
I
II
III
u
c
t
d
s
b
ν_e
ν_μ
ν_τ
e
μ
τ
γ
g
Z
W
Quarks
Leptons
Force Carriers

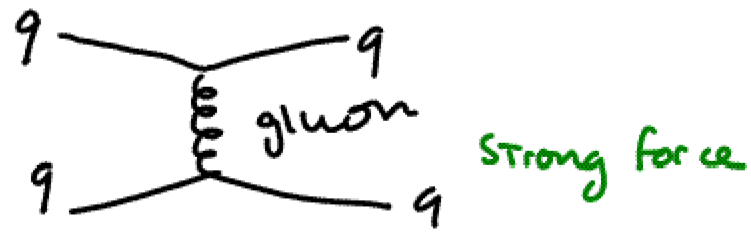
Antimatter Antimatter

Same mass - Opposite electric charge and magnetic moment

$\Delta E \, \Delta T \gtrsim h$







BOSONS

force carriers
spin = 0, 1, 2, …

Unified Electroweak spin = 1

Name	Mass GeV/c^2	Electric charge
γ photon	0	0
W^-	80.39	–1
W^+ W bosons	80.39	+1
Z^0 Z boson	91.188	0

Strong (color) spin =1

Name	Mass GeV/c^2	Electric charge
g gluon	0	0

Properties of the Interactions

The strengths of the interactions (forces) are shown relative to the strength of the electromagnetic force for two u quarks separated by the specified distances.

Property	Gravitational Interaction	Weak Interaction (Electroweak)	Electromagnetic Interaction	Strong Interaction
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge
Particles experiencing:	All	Quarks, Leptons	Electrically Charged	Quarks, Gluons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons
Strength at 10^{-18} m	10^{-41}	0.8	1	25
Strength at 3×10^{-17} m	10^{-41}	10^{-4}	1	60

The Vacuum

-R. Kolb

e^+e^- e^+e^- e^+e^- e^+e^- e^+e^-

$q\bar{q}$

Much ado about NOTHING:

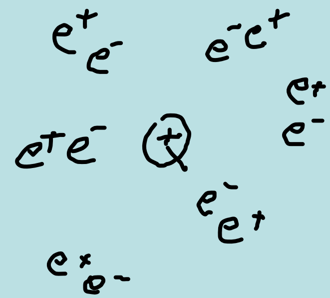
Nothing is something

Nothing has energy

Nothing interacts with something

$q\bar{q}$ $q\bar{q}$ e^+e^- $q\bar{q}$ $q\bar{q}$ $q\bar{q}$ $q\bar{q}$

Running coupling constants



Vacuum polarization causes EM force to drop as distance probed increases other particles

qqq

Baryons qqq and Antibaryons $\bar{q}\bar{q}\bar{q}$

Baryons are fermionic hadrons.
These are a few of the many types of baryons.

Symbol	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
p	proton	**uud**	1	0.938	1/2
$\bar{\mathrm{p}}$	antiproton	$\bar{u}\bar{u}\bar{d}$	–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

$q\bar{q}$

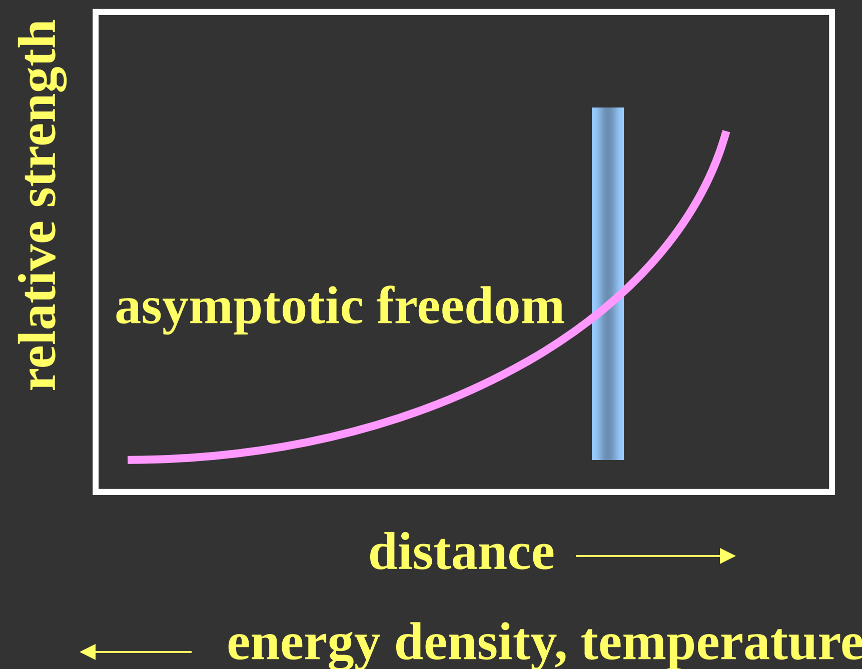
Mesons $q\bar{q}$

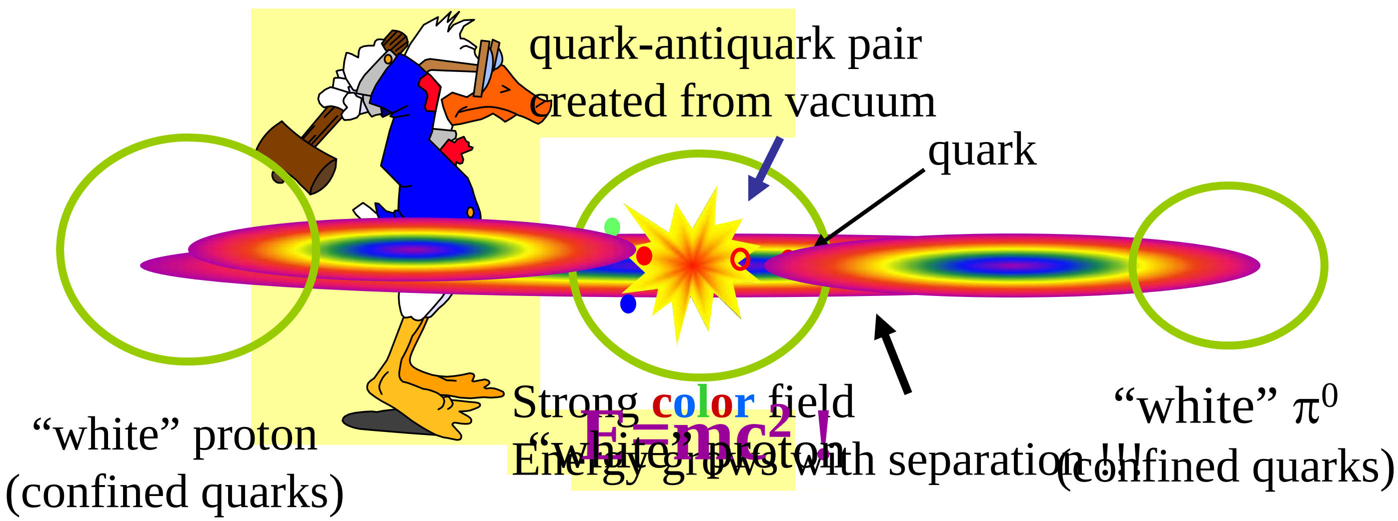
Mesons are bosonic hadrons
These are a few of the many types of mesons.

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	0.776	1
B^0	B-zero	$d\bar{b}$	0	5.279	0
η_c	eta-c	$c\bar{c}$	0	2.980	0

Quantum Chromodynamics
QCD

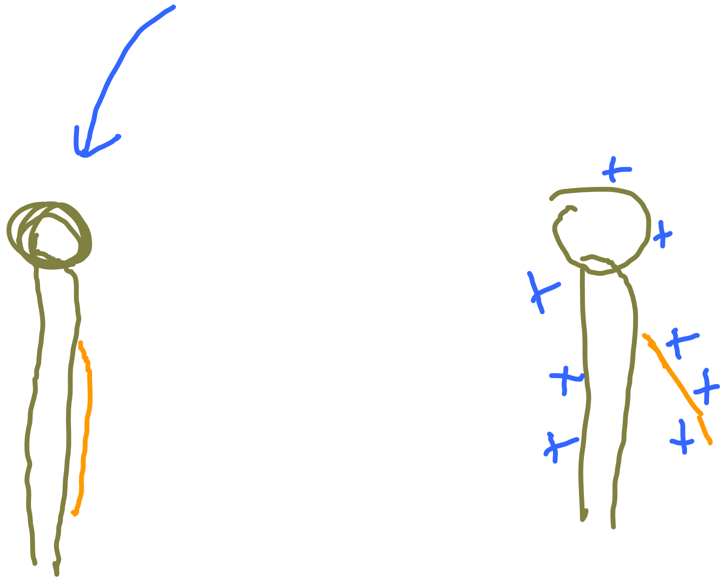
Why bare quarks have never been observed.



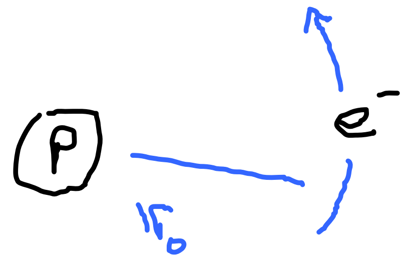


Thanks to Mike Lisa (OSU)
for parts of this animation

Electric charge and Electroscope



H atom



e⁻ orbits in circle

Bohr Atom

r_0 → Bohr radius $= 5.29\times10^{-11}\,m$

$Q_p = |Q_{e^-}| = 1.6\times10^{-19}\,C$

(a) how does em Force compare to grav. force bet. e⁻ + p

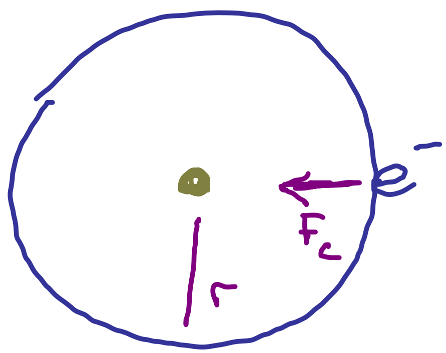
$$F_{em} = \frac{k q_1 q_2}{r_{12}^2} = \frac{8.99\times10^{-9}\,\frac{Nm}{c^2}\,(1.6\times10^{-19})^2 c^2}{(5.29\times10^{-11} m)^2}$$

$$F_{em} = 8.2 \times 10^{-8}\ N$$

$$F_{gr} = \frac{G M_e M_p}{r_0^2} = 3.6 \times 10^{-47}\ N$$

$$\frac{F_{em}}{F_{gr}} = 2.3 \times 10^{39}$$

(b) What is the speed of the e^-



$$F_c = \frac{m_e v^2}{r}$$

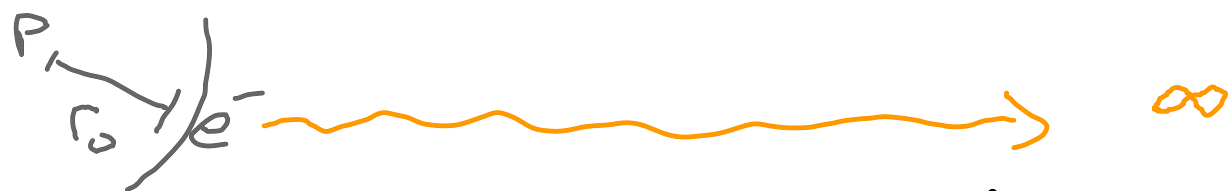
$$F_{em} = \frac{m_e v^2}{r_0}$$

$$v_e = 2.2 \times 10^6 \ m/s$$

$\sim 1\%$ of c

(C) How much Energy does it take to remove the e^- ionize the H· atom

$$\text{Energy} \approx \text{work} = \int_{r_0}^{\infty} \vec{F} \cdot d\vec{s}$$



$$W = \int_{r_0}^{\infty} \vec{F} \cdot d\vec{s} = \int_{r_0}^{\infty} \frac{k|e|^2}{r^2} dr = k|e|^2 \int_{r_0}^{\infty} \frac{1}{r^2} dr = k|e|^2 \left[-\frac{1}{r} \right]_{r_0}^{\infty}$$

$$W = k|e|^2\left[-\frac{1}{\infty} - \frac{-1}{r_0}\right] = \frac{k|e|^2}{r_0} = 4.3\times10^{-18}\ \text{Joules}$$

($\frac{1}{\infty} \to 0$)

$\to$ 26.9 eV

$1\ J = 6.2\times10^{18}\ eV$ electron volts

ionization energy of H is 13.6 eV

KE of moving e^- at r_0

$$\frac{1}{2}m_e v_e^2 = \frac{1}{2}(9.11\times10^{-31}\,kg)(2.2\times10^{6}\,m/s)^2 = 13.6\ eV$$

$$W - KE = 13.3\ eV$$

Electrostatics is a __Vector__ Force

"Think positive"

Test charge q

(+) q

Electric Field

$$\vec{E} = \vec{F}/q$$

Q