AD POLOSA — SAPIENZA UNIVERSITY OF ROME

PARTICLE PHYSICS

$$\hbar = 1.054 \times 10^{-27}\ \mathrm{erg \cdot sec}$$

$\hbar \simeq 0$ WRT ANY QUANTITY WITH DIMENSION OF ANGULAR MOMENTUM (ACTION) IN THE "CLASSICAL" WORLD

QUANTUM PARTICLES HAVE "SPINS"

$$0,\ \tfrac{1}{2}\hbar,\ \hbar,\ \tfrac{3}{2}\hbar,\ 2\hbar,\ \ldots$$

PARTICLES ARE IDENTICAL

$$\Psi(\xi_A, \xi_B) = \alpha \Psi(\xi_B, \xi_A)$$

└ a "phase factor".

$$\alpha \Psi(\xi_B, \xi_A) = \alpha^2 \Psi(\xi_A, \xi_B)$$

$$\alpha^2 = 1$$

FERMIONS

$\alpha = -1$ $\quad$ Spin $= \frac{\hbar}{2}, \frac{3}{2}\hbar, \frac{5}{2}\hbar \ldots$

$(e^-, p, \mu^-, \nu, \ldots)$

BOSONS

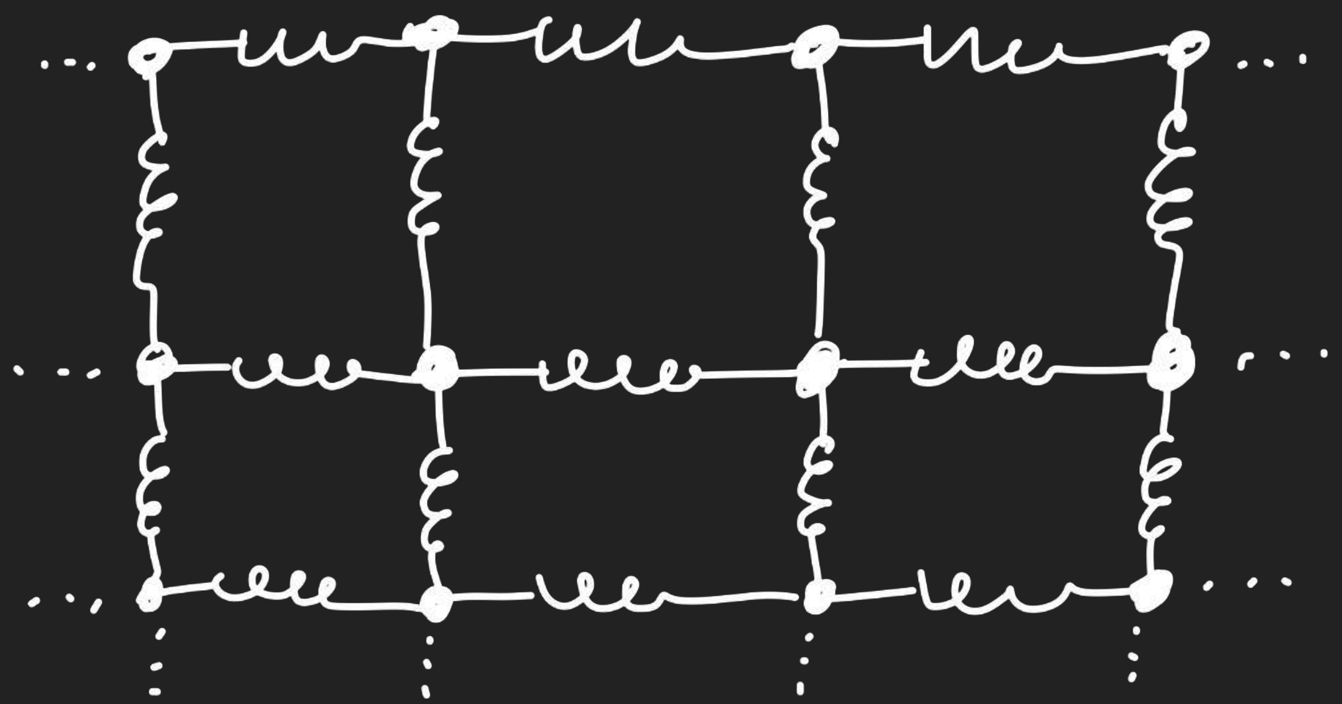
$\alpha = +1$ $\quad$ Spin $= 0, \hbar, 2\hbar, \ldots$

$(\pi, h, \gamma, Z, W^\pm, \ldots)$

PARTICLES CAN BE CREATED/DESTROYED

AS LOCAL EXCITATIONS OF THEIR FIELDS

FIELDS ARE PERMANENT



TAKE TWO (MASSIVE) LUMPS OF MATTER AT $\vec{x}_1$ AND $\vec{x}_2$ ON THE MATTRESS, AT REST WRT EACH OTHER.

WHAT DO THE VIBRATIONS IN THE MATTRESS DO TO THE TWO PARTICLES?

A "DISTURBANCE" ON THE FIELD IS SENT OUT FROM $\vec{x}_1$ AT TIME t_1.
THIS REACHES $\vec{x}_2$ AT TIME $t_2 > t_1$
CARRIED BY THE VIBRATION OF THE FIELD.

V = ENERGY DUE TO THE PRESENCE OF THE TWO LUMPS (PARTICLES) ACTING ON EACH OTHER THROUGH THE VIBRATIONS CARRIED BY THE FIELD

$$= -\frac{1}{r} e^{-mr}$$

$$r = |\vec{x}_1 - \vec{x}_2|$$

m = THE "DISTURBANCE" TRAVELING IN THE FIELD IS A PARTICLE w/ m.

THE TWO PARTICLES LOWER THEIR ENERGY BY GETTING CLOSER

ATTRACTION

WHAT ABOUT

REPULSION?

This is observed between particles with same electric charge

LIKE PARTICLES REPEL IN ELECTRICITY.

THE ELECTROMAGNETIC FIELD PROPAGATES "DISTURBANCES" CALLED PHOTONS W/ $m = 0$

$$F = -\frac{d}{dr}\left(-\frac{1}{r} e^{-0 \times r}\right)$$

$$= -\frac{1}{r^2}$$

Coulomb attraction between like charges ??

PHOTONS

Photons are Spin = 1 ($\hbar$) particles.

Spin can be represented by a vector oriented in the direction of motion of the photon, or opposite to it.

$$\vec{k} = \frac{\varepsilon}{c}\,\vec{n}$$

Looks the same in all frames

THERE IS NO WAY TO TELL THE POLARIZATION OF THE MESSANGER PHOTON_

IN SUCH CASES QUANTUM MECHANICS SAYS:

SUM ON ALL POSSIBLE ONES
(L, R)

THE RESULT OF THIS OPERATION BRINGS

$$F = + \frac{1}{r^2}$$

(between like charges)

THE EXCHANGE OF A SPIN Ø MEDIATOR BETWEEN TWO LIKE PARTICLES

$\Rightarrow$ ATTRACTION SPIN Ø

SPIN 1 MEDIATOR

$\Rightarrow$ REPULSION SPIN 1

SPIN 2 MEDIATOR

$\Rightarrow$ ATTRACTION SPIN 2

(the sum over polarizations of the graviton...)

FORCES

- ELECTROMAGNETIC FORCE

  SPIN = 1 "GAUGE" BOSON γ

- GRAVITY

  SPIN = 2 GRAVITON

- WEAK

  SPIN = 1 "GAUGE" BOSONS, $W^{\pm}$, Z^{0}

- STRONG

  SPIN 1 "GAUGE" BONS $g^{1}, \dots, g^{8}$

$$F = \frac{e_1 e_2}{r^2}$$

Require 1 dyne for two equal charges e at a distance of 1cm –

$$1\,\text{esu} = 1\,\text{cm}\sqrt{1\,\text{dyne}}$$

$$= \text{cm}\ \text{gr}^{1/2}\ \text{cm}^{1/2}\ \text{sec}^{-1}$$

$$= \text{cm}^{3/2}\ \text{gr}^{1/2}\ \text{sec}^{-1}$$

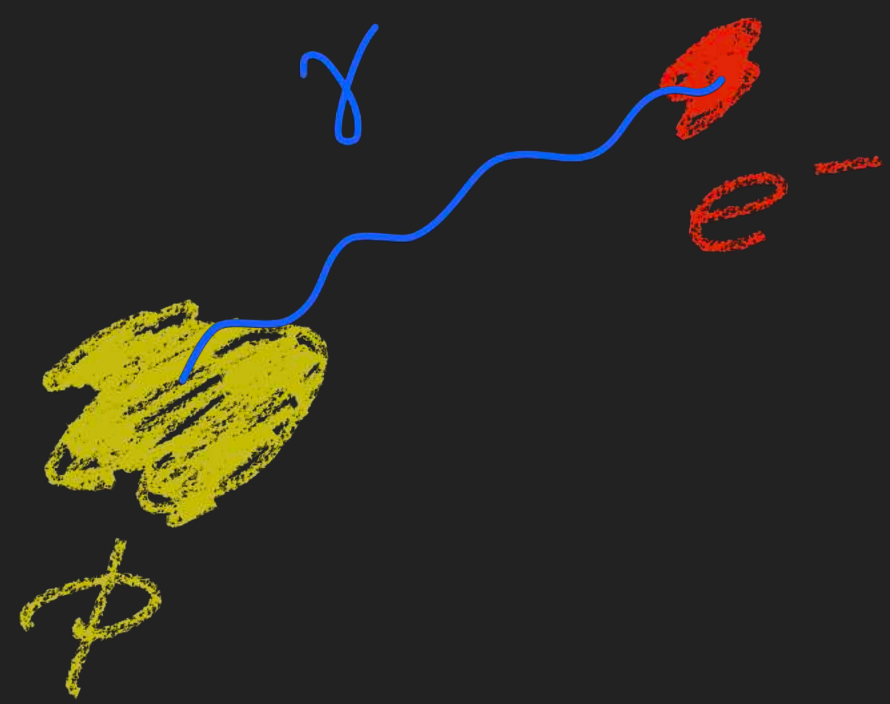
$$e\,(\text{electron}) = 4.8 \times 10^{-10}\,\text{esu}$$

$$\alpha = \frac{e^2}{\hbar c}$$

$$= \frac{(4.8 \times 10^{-10} \text{esu})^2}{(1.05 \times 10^{-27} \text{erg} \cdot \text{sec})(2.99 \times 10^{10} \text{cm/sec})}$$

$$= \frac{23 \times 10^{-20} \text{ cm}^2 \text{dyne}}{3.13 \times 10^{-17} \text{ erg} \cdot \text{cm}}$$

$$\simeq 7.32 \times 10^{-3} \simeq \frac{1}{137}$$



$$e,\ m_e(\simeq\mu),\ \hbar,\ c$$

MAKE A LENGTH OUT OF PREVIOUS CONSTANTS

$$a = \frac{\hbar^2}{m_e e^2} = 0.5 \times 10^{-8}\,\mathrm{cm}$$

$(.5\,\mathring{A})$

$$\frac{\mathrm{erg}^2\,\mathrm{sec}^2}{\mathrm{gr} \times \mathrm{cm}^2\,\mathrm{dyne}} = \frac{\cancel{\mathrm{dyne}^2}\,\mathrm{cm}^{\cancel{2}}}{\underbrace{\left(\mathrm{gr}\,\frac{\mathrm{cm}}{\mathrm{sec}^2}\right)}_{\cancel{\mathrm{dyne}}}\,\cancel{\mathrm{dyne}}\cdot\cancel{\mathrm{cm}}}$$

THE SIZE OF HYDROGEN.

$$W = F \cdot X$$
$$= eE \cdot X$$
$$= e \times \frac{1\,\text{Volt}}{\text{cm}} \times 1\,\text{cm}$$
$$= e \times 1\,\text{Volt} \equiv eV$$

work done on e^- in accelerating it through 1 Volt.

$$m_e c^2 = 0.5 \times 10^6\,\text{eV}$$

$$a = \frac{\hbar^2}{me^2} = \frac{\hbar^2}{mc^2 \frac{e^2}{\hbar c}\left(\frac{\hbar}{c}\right)}$$

$$= \frac{(\hbar c)}{(mc^2)\,\alpha}$$

$$\alpha = \frac{1}{137}, \quad mc^2 = 0.5\,\text{MeV}$$

$$\underline{\overline{\hbar c = 197\ \text{MeV}\cdot\text{fm}}}$$

Exercise

Compute a

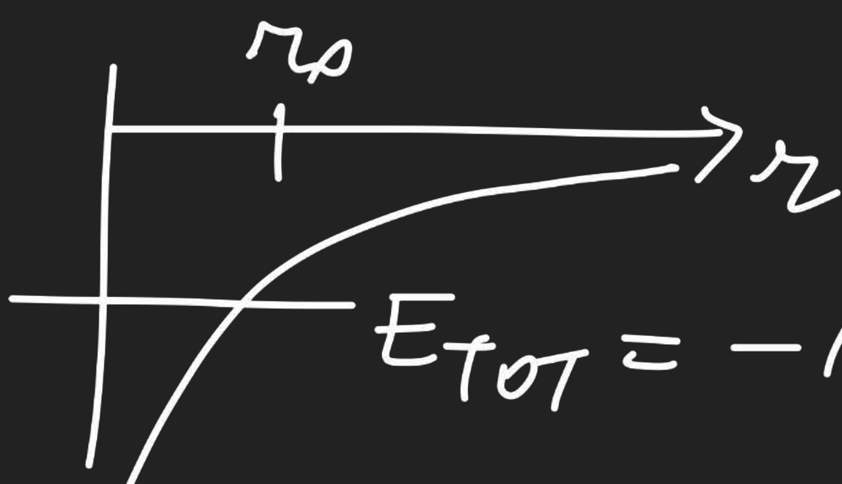
Make a velocity out of constants

$$v = \frac{e^2}{\hbar c} \cdot c \quad \left(= \frac{\hbar^2/me^2}{\hbar^3/me^4} \right)$$

$$= \alpha \cdot c$$

$$|E| = \frac{1}{2} m v^2 = \frac{1}{2}(mc^2)\alpha^2$$

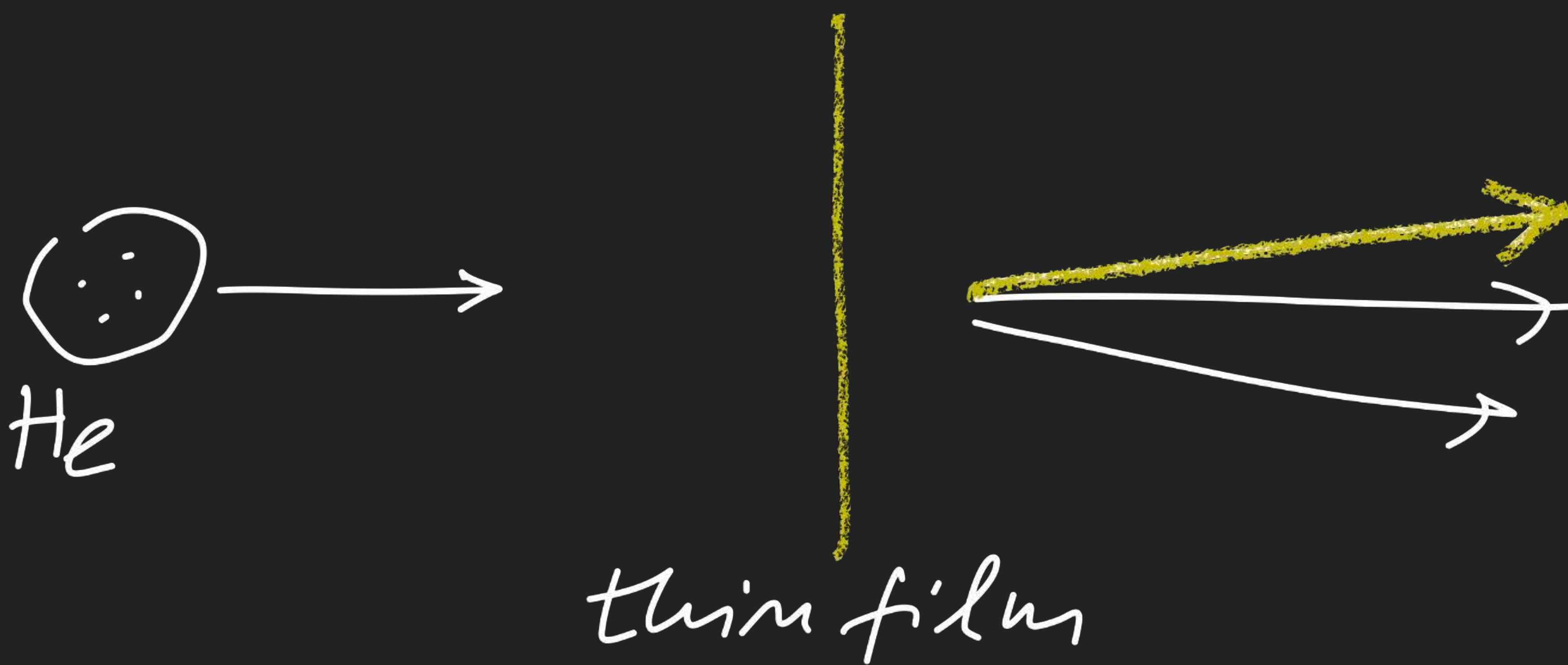
$$\cong 13\,eV$$

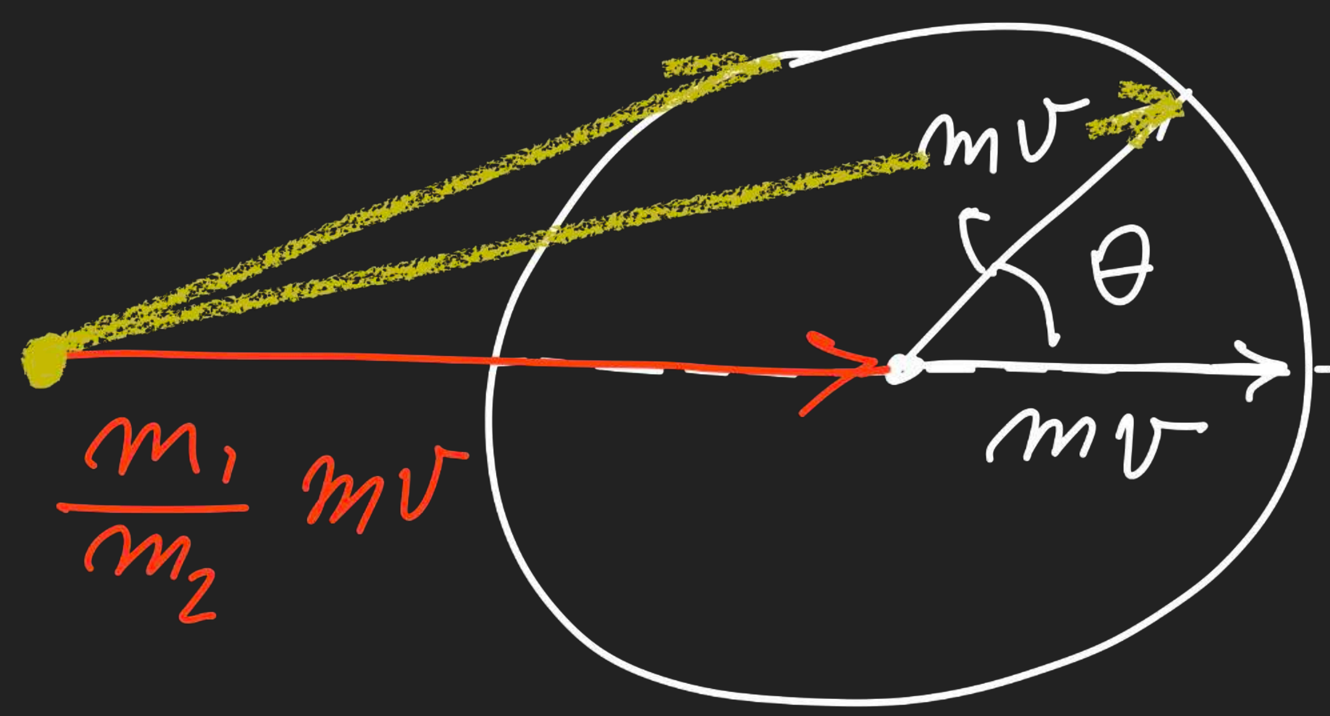


$$E_{TOT} = -13.6\,eV$$

If $\Delta r < r_0$,

$$\frac{\hbar^2}{2m\Delta r^2} - \frac{e^2}{r_0} > 0!$$





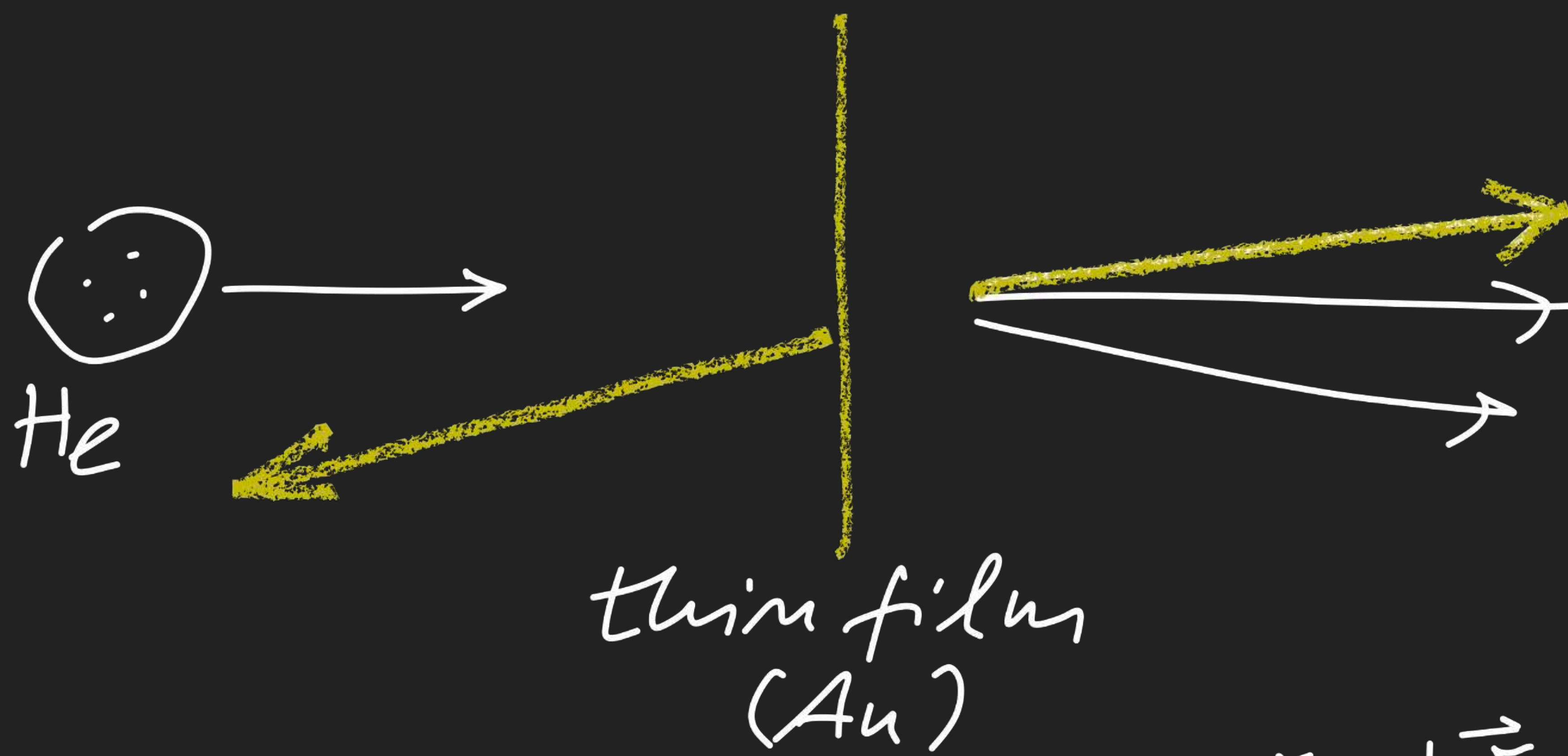
$m_1 \gg m_2$

$v = |\vec{v}_1 - \vec{v}_2|$

m = reduced mass

θ = scatt. ang. in COM

$\vec{v}_1{}' = \vec{v}_{10}{}' + \vec{V}$



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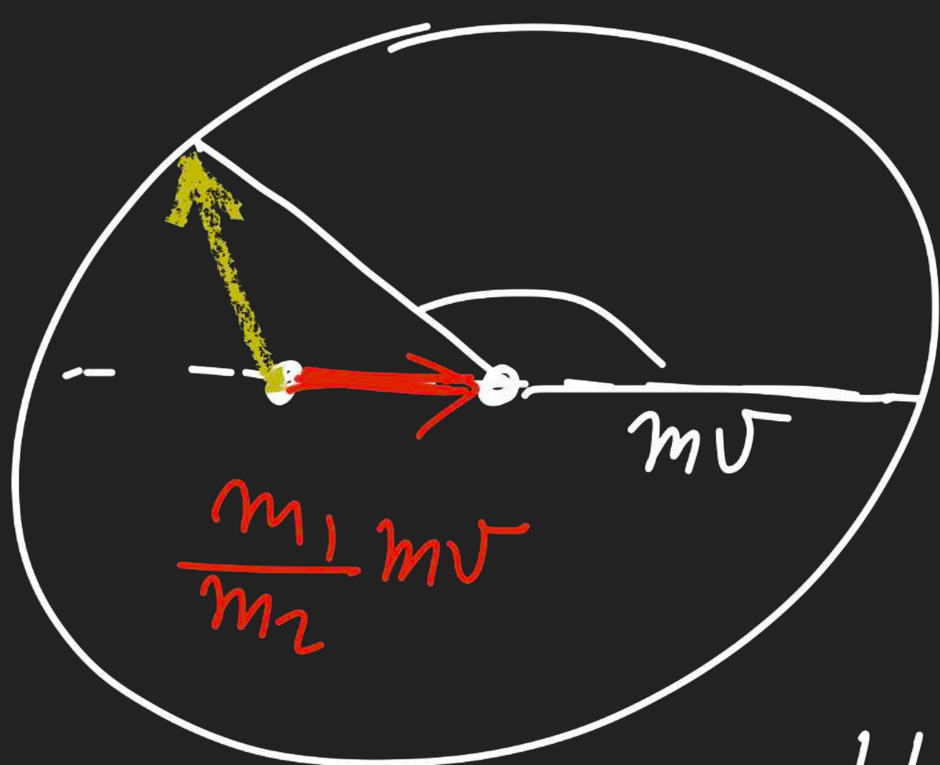


$m_1 \ll m_2$!!

TURNING POINT

$$\frac{1}{2} M_\alpha v^2 = \frac{(2e)(Ze)}{\underbrace{r}_{\approx \text{ size of nucleus}}}$$

$$r \simeq 3Z \times 10^{-14} \text{ cm}$$

with $v \approx 2 \times 10^9$ cm/sec

HEAVY & SMALL

ATOMS ARE ~ EMPTY

ELECTRON RADIUS

$$\underbrace{e \cdot \frac{e}{R}}_{\text{self-interaction}} \lesssim mc^2$$

$$R \gtrsim \frac{e^2}{\hbar c} \frac{\hbar c}{mc^2} = 2.8\,fm$$

as large as a nucleus with $A = 27$

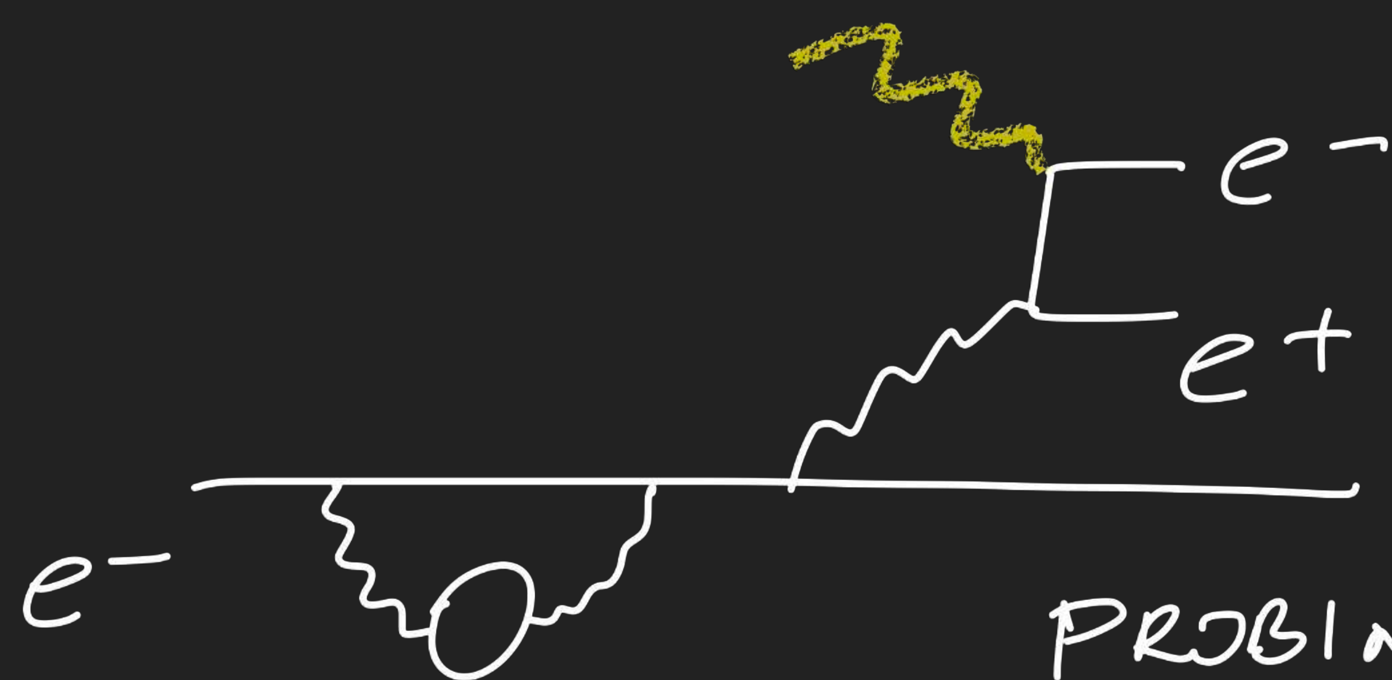
$$R_N \sim a_0 A^{1/3}$$

$$a_0 \approx 1\,fm = 10^{-13}\,cm.$$

COMPTON WAVELENGTH

$$E = h\nu = h\frac{c}{\lambda} = mc^2$$

$$\lambda_c = \frac{h}{mc} \sim 2 \times 10^{-10}\,\mathrm{cm}$$



PROBING AT 1 fm $\ll \lambda_c$. NEED e^+, e^-, γ

$$\frac{e^2}{r} \rightarrow \underbrace{\frac{e^2}{\hbar c} mc^2 \ln\left(\frac{\lambda\!\!\!^{-}_c}{r}\right)}$$

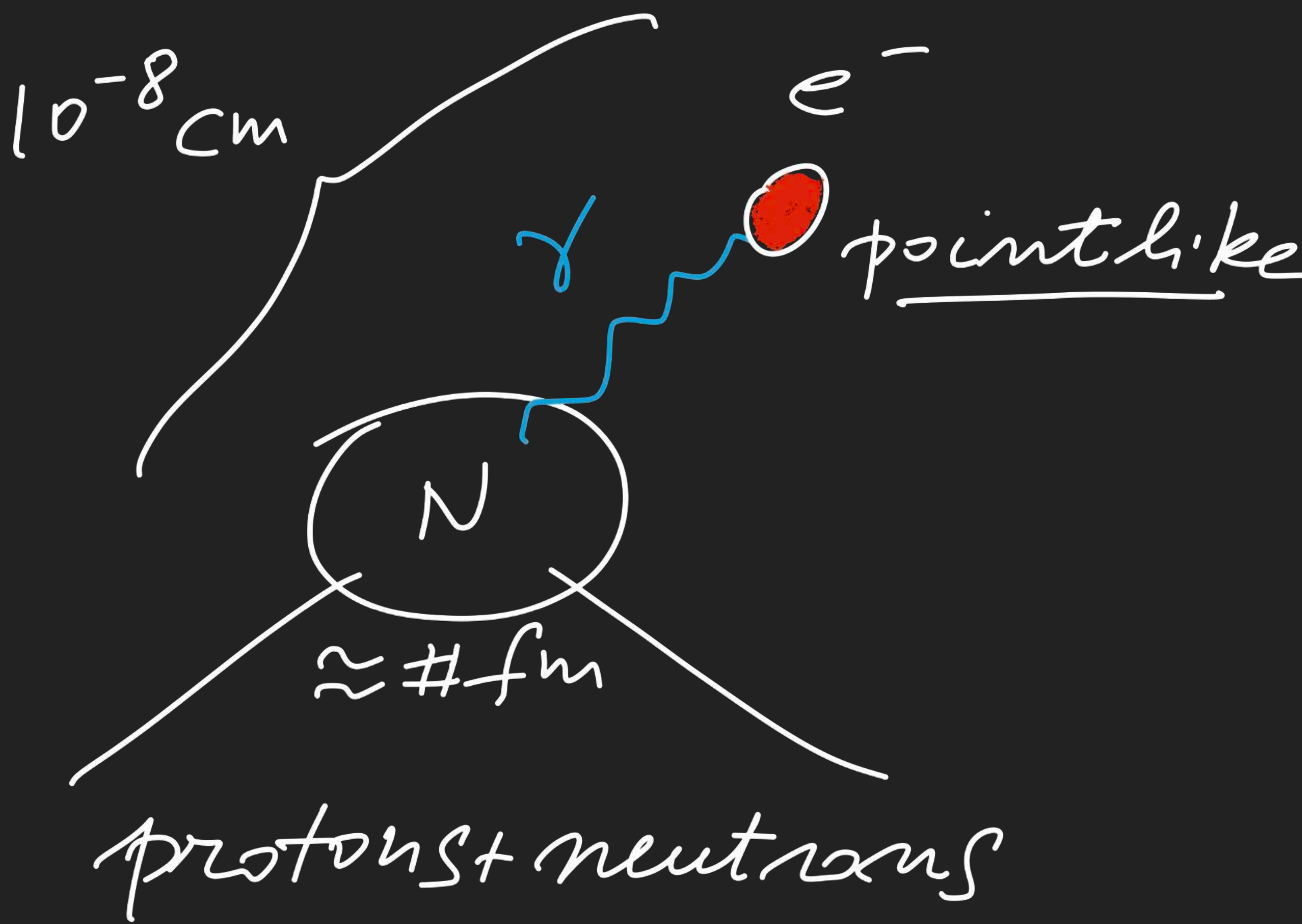
set this $= mc^2$

$$R \simeq \lambda\!\!\!^{-}_c \exp(-137)$$

THE ELECTRON IS POINTLIKE

ELEMENTARY

RECAP



MADE OF QUARKS

pointlike

MATTER

FERMIONS

LEPTONS

$e \quad \mu \quad \tau$

$\nu_e \quad \nu_\mu \quad \nu_\tau$

QUARKS

$u \quad c \quad t$

$d \quad s \quad b$

GAUGE FIELDS

BOSONS

EM.	γ
WEAK	$W^\pm, Z$
STRONG	$g^1, \dots, g^8$

NOT ELEMENTARY $p = uud$, $n = udd$,,,
(BARYONS)

(MESONS) $\pi = u\bar{d}$, $K = u\bar{s}$ ...

The theory predicted the existence of other massless vector bosons, other than the photons ('50)

NOT OBSERVED

- YM ~~WRONG~~
- VECTOR BOSONS HAVE MASSES
- "CANNOT" BE OBSERVED

$W^{\pm}$, Z have $M \simeq 90\,\mathrm{GeV}$!

GLUONS ARE MASSLESS BUT CANNOT BE SEEN.

WEAK VS GRAVITY

$$G_N = 6.67 \times 10^{-8}\, cm^3 gr^{-1} sec^{-2}$$

$$\simeq 6.7 \times 10^{-39}\, \hbar c \left(\frac{GeV}{c^2}\right)^{-2}$$

$$G_F \simeq 1.16 \times 10^{-5} (\hbar c)^3\, GeV^{-2}$$

$$\frac{G_N}{G_F} \frac{\hbar^2}{c^2} = 5.7 \times 10^{-34}$$

$$\frac{G_N m_e^2}{e^2} = 2.3 \times 10^{-43}$$

How W, Z get their mass?

Through the existence of a field, Higgs field (which has a Spin ϕ particle h^0)

IT INTERACTS WITH A STRENGTH PROP. TO THE MASS, OR ξ FOR VIRTUAL PARTICLES.

THE VACUUM IS FULL OF VIRTUAL PARTICLES ($\Delta E \Delta t \sim \hbar$)

$$\delta m_h^2 \sim k \Lambda^2$$

$$G_F \sim \frac{1}{m_h^2}$$

$$\Lambda \sim M_{Planck} = \sqrt{\frac{\hbar c}{G_N}} = 10^{20}\ \frac{GeV}{c^2}$$

So

$$K\Lambda^2 \sim G_F^{-1}$$

K FROM STANDARD MODEL $\frac{3G_F}{4\sqrt{2}\pi^2}\left(4m_t^2 - 2m_W^2 - m_Z^2 - m_\phi^2\right)$

K MUST BE SUPER SMALL.

But standard K is only $\approx 10^{-2}$ Must be the wrong one ABOVE 1TeV ...!