Some discovery opportunities

ν_e, ν_μ, ν_τ not mass eigenstates
"MNS" matrix not fully measured
CP violation ?

Any rare, stable matter overlooked
→ electron-like
→ in earth
→ dark matter.

γ "charge" → beams through magnets, "Faraday" rotation of vacuum

strong: "color deconfinement" at LHC

Higgs:

coupling $\propto m_f$
connection with π^+ decay

Electron Discovery

Two things originated it:

(1) Sources of DC voltage
→ frictional
→ batteries } 100 V ??

(2) Vacuum Pumps
1709 Hauksbee → $\frac{1}{60}$ atm

$\simeq 12$ torr

LHC Vacuum ... $\simeq 10^{-9}$ Torr

Key Point: mean free path in gas...

assume:

← size ~ 10^{-8} cm

area ~ 10^{-16} cm^2

atmosphere: $\frac{6 \cdot 10^{23}}{22.4 \cdot 10^3 \text{ cm}^3}$

$n \simeq 3 \cdot 10^{19}$ 1/cm^3

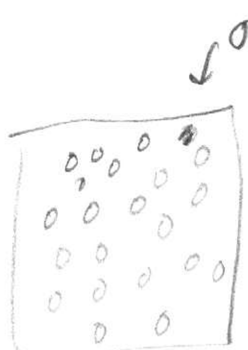
area density:

(aside... # nucleons $\propto$ mass)

$$\frac{\#\,\text{nucleons}}{cm^2} \propto \frac{\text{mass}}{cm^2} \sim \frac{gm}{cm^2}$$

$$s = \frac{\#}{cm^2} = \frac{N}{A} = n\ell' \leftarrow \text{area \# density.}$$

but each small dot has size...



$\leftarrow$ for small "coverage"

fraction of area covered.

$= n\ell'\sigma$ (dimensionless)

ℓ defined as when $\boxed{n\sigma\ell = 1}$ $\quad \ell$ = mean free path

$$\ell = \frac{1}{n\sigma}$$

$$= \frac{1}{3 \cdot 10^{19} \cdot 10^{-16}} \sim \frac{1}{3 \cdot 10^{3}}$$

$$\ell \sim \frac{1}{3} \cdot 10^{-3} \sim 3 \cdot 10^{-4}\ cm$$

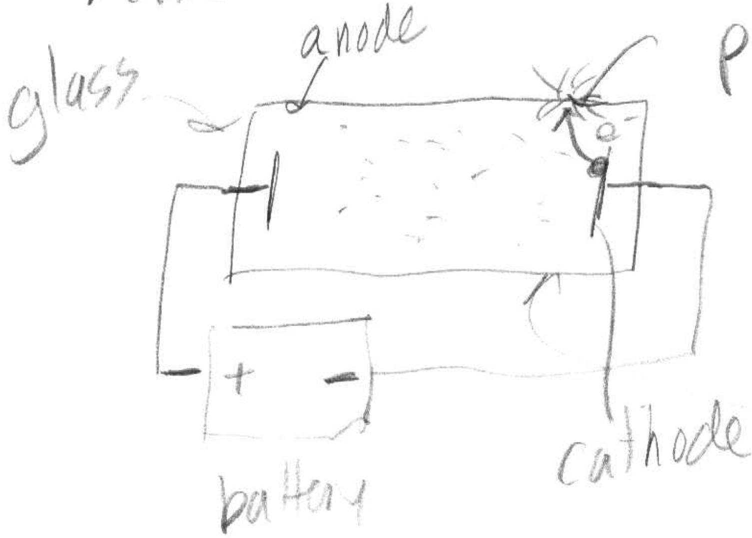
or $\boxed{\ell \sim 30\,\mu m}$ tiny.

$\frac{1}{60}$ atm... 60 times bigger... $\simeq$ 2 mm

Say ... 100 V over 2 mm ...

electron gains ~100 eV, more than enough to excite atom

Make a "discharge tube"



it GLOWS

Better Geissler, 1858, 10^{-4} atm

$\ell \sim 30\,\mu m \cdot 10^{4} \simeq \underline{3\,cm}$

"Cathode Rays" noticed (Plücker)

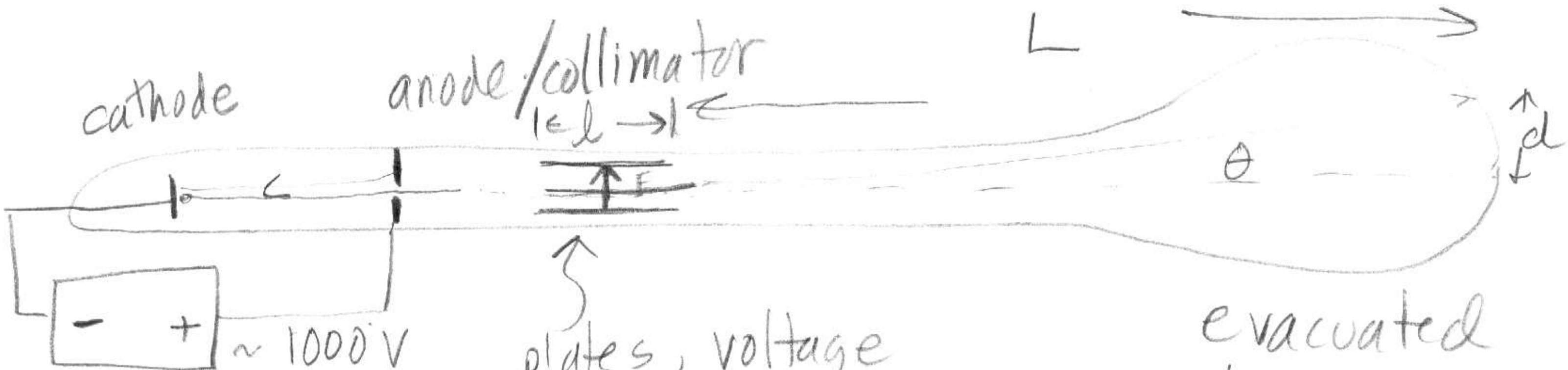
→ objects placed near cathode projected shadows

→ magnetic field influenced (unlike photons)

→ Had electric charge (negative) Perrin

Thomson's Experiment 1895-7

Prototype "Fixed Target" Experiment



Field line · inertia carries e^-

☆ Discuss "momentum kick"

→ CRT / Television Set (pre-LCD)

$$\frac{\Delta p_\perp}{\Delta t} = eE$$

$$\theta_e \sim \frac{\Delta p_\perp}{p} \simeq \frac{eE\,\Delta t}{p} \simeq \frac{eE\,l}{mv^2}$$

$$d_e \sim L\theta_e \sim \frac{eElL}{mv^2}$$

experimental

want to know

independent variable

don't know v...

Why not just "time" it?

→ estimate v

$T \simeq \frac{1}{2} m v^2 \simeq 1000$ eV (get it)

$\frac{1}{2} mc^2 \beta^2 \simeq 10^3$

$\frac{1}{2} \cdot 10^6$ eV

$\beta \simeq \sqrt{\frac{4 \cdot 10^3}{10^6}} = \sqrt{40 \cdot 10^{-4}}$

$\beta \simeq 6\ 10^{-2} = 0.06$ suprise!

NR

t to go one meter...

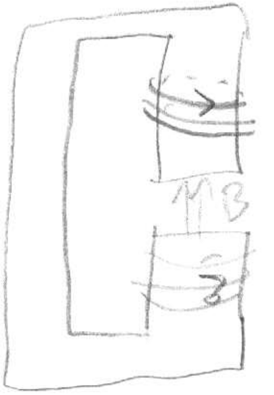
$v = \beta c = 6 \cdot 10^{-2} \cdot 3 \cdot 10^8 \cong 2 \cdot 10^7$ m/s

$t \sim \frac{1\text{ m}}{2 \cdot 10^7} \sim \frac{1}{20}$ μs

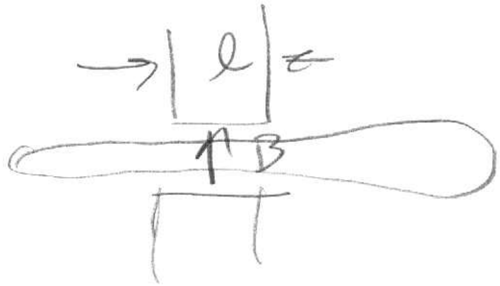
$t \sim 50$ ns   hard in 1897
today easy

⇒ need start time (today... what?)

1897: #2 Magnetic Deflection } LHC!
#3 Calorimetry



#2



now $F = evB$ ← extra power of v!

$$d_B \simeq \frac{e}{m}\frac{B l L}{v}$$

so, $$\frac{d_B}{d_E} = v\frac{B}{E}$$ can solve for B

Comment: (A) $E \simeq 10^4 \frac{\text{Volts}}{\text{meter}}$

$B \simeq 4 \cdot 10^{-4}$ Tesla] 4 Gauss

$vB \simeq 2 \cdot 10^7 (4 \cdot 10^{-4})$

$cB = 12 \cdot 10^4 > E$ $\simeq 8 \cdot 10^3 \sim E$

Today: $B \sim 4T$ (CMS)

10^4 times higher

E → very hard to do much better

(B) $d_B \propto \frac{1}{p}$ meaning: magnetic measurements get worse as $p \uparrow$

LHC: need huge B!

(#3)

"calorimeter"

→ measure heat deposited (just like today)

→ measure charge deposited new

$$\text{measure} \left\{ \frac{Q}{H} \right. = \frac{N_e \cdot e}{N_e \frac{1}{2} m v^2} \leftarrow$$

$= p$ the more the energy, easier to measure

$$\frac{p}{d_B} = \frac{\frac{2e}{mv^2}}{\frac{e}{m} \frac{BeL}{v}}$$

$$= \frac{2}{BeL\, v} \Big\} \text{ can solve for } v$$

Experimental Importance of Electrons

① β-decay ...

$$\text{Nucleus}(Z, N) \rightarrow \text{Nucleus}(Z+1, N-1) + e^- \bar{\nu}_e$$

(Z: # protons; N: # neutrons)

ⓐ e^- not "in" nucleus

ⓑ missing energy ... $\bar{\nu}_e$

② Other Decays ...

absence of $\pi^- \rightarrow e^- \bar{\nu}_e$ ("leptonic")

"Semileptonic"

$$K^- \rightarrow \pi^0 e^- \bar{\nu}_e$$

③ J/ψ

} Ting/BNL.