Lecture # 10

Particle Physics

Curie demonstrated that radioactivity had nothing to do with chemistry and was awarded Nobel prizes in 1903 and 1911.

Radioactivity was studied by observing the ionization of air using electrometers.

Null measurement would be an electrometer that did not discharge when no radioactive material was present.

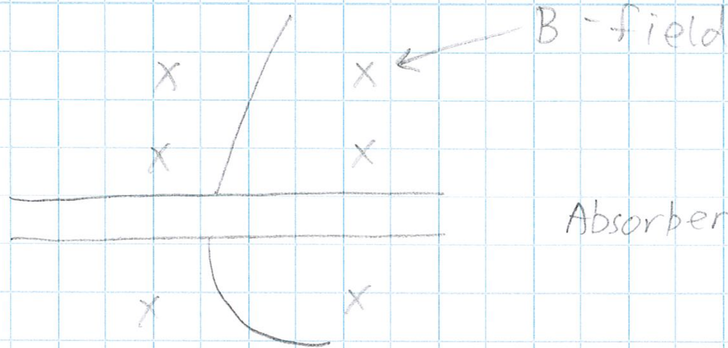
But even the best built electrometers would discharge. The rate was approximately independent of location.

Reasoning that the source of ionization was from the earth, Hess ascended in a baloon expecting the rate to decrease. But it increased and he reasoned that the source of ionization were "rays of great penetrating power".

At 5300 m the rate was 4x that at ground level.

Compton found that the rate varied with latitude (hence the Earth's magnetic field) so they must be charged particles - not photons.

In 1933 Wilson observed a positive electron



Less energy below the absorber implied that the particle was traveling down, not up.

As we learned, the amount of ionization determines the velocity. Curvature in a magnetic field determines momentum.

$$p = \gamma \beta m = \frac{\beta m}{\sqrt{1-\beta^2}}$$

$$m = \frac{\beta}{p\sqrt{1-\beta^2}}$$

Meanwhile...
Yukawa had proposed a particle of intermediate mass as being responsible for nuclear forces.

$$\phi(r) \sim \frac{e^{-r/\lambda}}{r}$$

$m \sim 1/\lambda$ $\quad$ $\lambda \sim 1\text{ fm} \Rightarrow m \sim 197\text{ MeV}$

$(\hbar c = 197.327\text{ MeV}\cdot\text{fm})$

Anderson & Neddermayer observed a particle of intermediate mass. But it was not the carrier of the nuclear force.

Bohr radius of a particle of mass m:

$$a_0 = \frac{\hbar^2}{m e^2}$$

$$e^2 = \frac{\hbar c}{137} \qquad a_0 = \frac{\hbar \cdot 137}{m c} = \frac{\hbar c \cdot 137}{m c^2}$$

$$= \frac{(197.327 \text{ MeV} \cdot \text{fm})(137)}{m c^2}$$

For $m = 0.511 \text{ MeV}/c^2$,

$$a_0 = 0.054 \text{ nm}$$

For $m = 200$ MeV

$$a_0 = 135 \text{ fm}$$

But $a = \frac{a_0}{Z}$

so for moderately heavy nuclei, $a \sim r$.

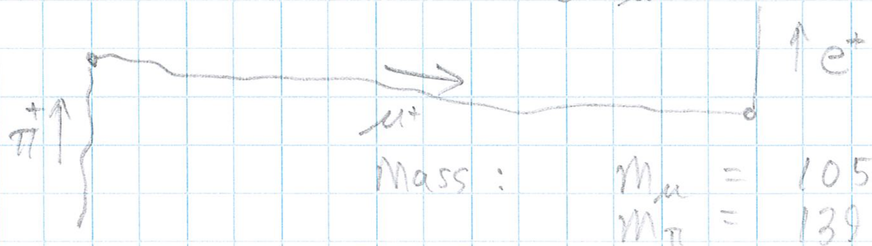
eg, Au has $Z = 79$ $a = 1.71$ fm
but $r = (1.25 \text{ fm}) \sqrt[3]{197} = 7.27$ fm.

Such a particle would orbit inside the nucleus.

They had observed muons $\mu^- \to e^- \bar{\nu}_e \nu_\mu$.

Later, pions were observed in photographic emulsions.

$$\pi^+ \rightarrow \mu^+ \nu_\mu$$
$$\hookrightarrow e^+ \nu_e \bar{\nu}_\mu$$



Mass: $m_\mu = 105.66 \text{ MeV}/c^2$
$m_\pi = 139.57 \text{ MeV}/c^2$

Lifetime: $\tau_\mu = 2.20 \times 10^{-6} \text{ s}$

$\tau_\pi = 26 \times 10^{-9} \text{ s}$

Decay distance:

$$d = \gamma\beta c t \quad \text{(time dialation / lorentz contraction)}$$

$$= \frac{pt}{m} \qquad E = \gamma m c^2, \quad p = \gamma\beta m c$$

If $p = 100 \text{ MeV}/c$ then for a muon

$$d = \frac{(100 \text{ MeV}/c)(2.2 \times 10^{-6} \text{ s})}{(105.66 \text{ MeV}/c^2)}$$

$$= (2.08 \times 10^{-6} \text{ s})(2.998 \times 10^{10} \text{cm/s})$$

$$= 624 \text{ m}.$$

For a pion, $d = 7.37$ m.

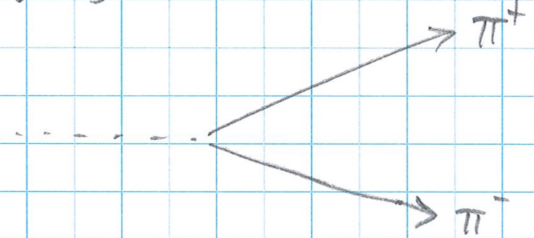
There are three types of pions

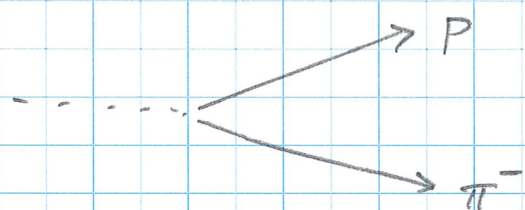
$\pi^{\pm}$ decays to $\mu^{\pm}$ and neutrinos
π^0 decays immediately to $\gamma\gamma$.

$m_{\pi^0} = 134.977 \text{ MeV}/c^2$.

Other particles were observed in cosmic rays

V^0's





In accelerators, a new type of particle was observed. Easily produced in pairs but with a long lifetime.

ΛK^+, K^+K^-, $K^0\bar{K}^0$ ΛK^0

$\Lambda \rightarrow p\pi^-$ 63.9%
$\quad\;\; n\pi^0$ 35.8%

$m_\Lambda = 1115.683 \text{ MeV}/c^2$

$\tau_\Lambda = 0.263 \times 10^{-9}$ s

$K^+ \to \mu^+ \nu_\mu$ 63.6 %
$\pi^+ \pi^0$ 20.7 %

$m_{K^+} = 493.677 \text{ MeV}/c^2$

$\tau_{K^+} = 12.38 \times 10^{-9}$ s

Neutral kaons seem to come in two types.

Long-lived $K^0_L \to \pi^+ e^- \bar{\nu}_e$ 40%
$\pi^+ \mu^- \bar{\nu}_\mu$ 27%
$3\pi^0$ 20%
$\pi^+ \pi^- \pi^0$ 13%

$m_{K^0} = 497.611 \text{ MeV}/c^2$

$\tau_{K^0_L} = 51.16 \times 10^{-9}$ s

Short-lived $K^0_S \to \pi^+ \pi^-$ 69%
$\pi^0 \pi^0$ 31%

$m_{K^0} = 497.611 \text{ MeV}/c^2$

$\tau_{K^0_S} = 0.0896 \times 10^{-9}$ s

Kaons and Λ's must carry a quantum number (charge) that is conserved in strong interactions but not in weak interactions.

It was called "strangeness".