Abstract:

This is Bubble Chamber Film Analysis. One does not have to set up the equipments to produce the interactions and decays of particles, but has to scan through 500 frames of film which show the decays and interactions of particles. Numbers of beam tracks (K^-) are counted for every ten frames. The final results are:

(i) Branching Ratio of $K^- \to \pi^- + \pi^+ + \pi^-$ is $6.67 \pm 0.794\%$

(ii) Total Cross-Section $\sigma = 26.0 \pm 4.24$ mb

(iii) K^- lifetime $\tau = 1.33\times10^{-8} \pm 0.16\times10^{-8}$ sec

With

(a) Beam: K^- mesons with momemtum 1.5GeV/c

(b) 25'' Bubble Chamber

(c) Interactions: $K^- + p$.

why so many figures? Not useful.

Introduction:

The following pages are written in the attempt of giving a brief introduction to the essential concepts needed for the Bubble Chamber experiment. Of course, many important topics and details will be omitted due to the limitted length of this report and the lack of my knowledge on the subject.

Atom was once believed to be the smallest thing in the world. This idea was rejected when protons, neutrons, and electrons were discovered to be the constituents of the atom. And then , in the last few decades, the neucleons were found consisting of quarks. So, quarks, with the electrons, also known as leptons, now become the fundamental particles which we all believe that can not be divisible. The sizes of the constituents of matter are summarized in the following table.

Table 1:

Molecules		10^{-7} -10^{-8} cm
Atoms		about 10^{-8} cm
Nuclei		about 10^{-12} cm
Nucleons		about 10^{-13} cm
Quarks	Electrons	<10^{-15} -10^{-16} cm

All known particles can be divided into three groups: leptons, baryons, and mesons. Besides these three main groups; there is one other; the intermediate bosons. This group consists of particles, such as photon, that serve as carriers of interactions. The last two come from the combination of quarks.

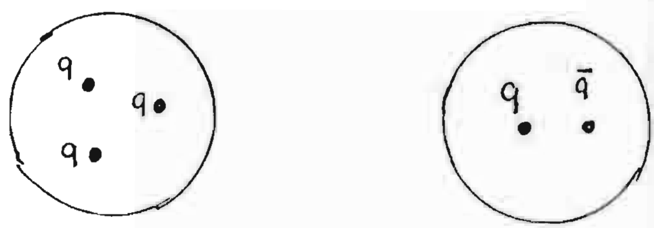
baryons + mesons?

So, a brief discussion of quarks is helpful. Quarks are point-like objects and carrying fractional electric charges of 2/3 and -1/3. They occur in several varieties, called flavors: u,d,s,c,b,t. Like the anti-property of the particles, each flavor has its own antiquark. They are $\bar{u}$, $\bar{d}$, $\bar{s}$, $\bar{c}$, $\bar{b}$, $\bar{t}$. With these six quarks and their corresponding antiquarks, all the known particles can be created.

Table 2:

Quarks			Antiquarks		
Charge	Spin	Flavour	Charge	Spin	Flavour
+2/3	1/2	Up (u), Charm (c), Top (t)	−2/3	1/2	$\bar{u}$, $\bar{c}$, $\bar{t}$
-1/3	1/2	Down (d), Strange (s), Beauty (b)	+1/3	1/2	$\bar{d}$, $\bar{s}$, $\bar{b}$

The baryons and mesons are collectively designated as hadrons, or strongly interacting particles, because they interact via strong force. The baryons are formed from any combination of three quarks and the mesons consist of a quark and antiquark pair.



Baryon Meson

Fig.1: Quark structure of hadrons (q stands for any quark flavor)

For example, a proton consists of a combination of u, u, and d quarks, giving total electric charge of (2/3+2/3-1/3)=1 unit of charge. On the other hand, a neutron consists of d, d, and u quarks with a total charge (-1/3-1/3+2/3)=0 unit of charge. Strangeness of some particles comes from the strange quark s. For example, K^+ is composed by u, $\bar{s}$; Λ^0 comes from d, u, s.

There are six different leptons. Table 3 lists these leptons, their masses, spins, electric charges, lifetimes, and decay modes. Of course, for each lepton, there is an anti-lepton.

Table 3:

LEPTONS (Spin $\frac{1}{2}$)

	Lepton	Charge	Mass	Lifetime	Principal decays
First generation	e	−1	0.511003	∞	—
	ν_e	0	0	∞	—
Second generation	μ	−1	105.659	2.197×10^{-6}	$e\nu_\mu\bar{\nu}_e$
	ν_μ	0	0	∞	—
Third generation	τ	−1	1784	3.3×10^{-13}	$\mu\nu_\tau\bar{\nu}_\mu$, $e\nu_\tau\bar{\nu}_e$, $\rho\nu_\tau$
	ν_τ	0	0	∞	—

MEDIATORS (Spin 1)

Mediator	Charge	Mass	Lifetime	Force
gluon	0	0	∞	strong
photon (γ)	0	0	∞	electromagnetic } electroweak
$W^\pm$	±1	81,800	unknown	(charged) weak } electroweak
Z^0	0	92,600	unknown	(neutral) weak } electroweak

BARYONS (Spin $\frac{1}{2}$)

Baryon	Quark content	Charge	Mass	Lifetime	Principal decays
N p	uud	+1	938.280	∞	—
N n	udd	0	939.573	900	$pe\bar{\nu}_e$
Λ	uds	0	1115.6	2.63×10^{-10}	$p\pi^-$, $n\pi^0$
Σ^+	uus	+1	1189.4	0.80×10^{-10}	$p\pi^0$, $n\pi^+$
Σ^0	uds	0	1192.5	6×10^{-20}	$\Lambda\gamma$
Σ^-	dds	−1	1197.3	1.48×10^{-10}	$n\pi^-$
Ξ^0	uss	0	1314.9	2.90×10^{-10}	$\Lambda\pi^0$
Ξ^-	dss	−1	1321.3	1.64×10^{-10}	$\Lambda\pi^-$
Λ_c^+	udc	+1	2281	2×10^{-13}	not established

BARYONS (Spin $\frac{3}{2}$)

Baryon	Quark content	Charge	Mass	Lifetime	Principal decays
Δ	uuu, uud, udd, ddd	+2, +1, 0, −1	1232	0.6×10^{-23}	$N\pi$
Σ^*	uus, uds, dds	+1, 0, −1	1385	2×10^{-23}	$\Lambda\pi$, $\Sigma\pi$
Ξ^*	uss, dss	0, −1	1533	7×10^{-23}	$\Xi\pi$
Ω^-	sss	−1	1672	0.82×10^{-10}	ΛK^-, $\Xi^0\pi^-$, $\Xi^-\pi^0$

PSEUDOSCALAR MESONS (Spin 0)

Meson	Quark content	Charge	Mass	Lifetime	Principal decays
$\pi^\pm$	$u\bar{d}$, $d\bar{u}$	+1, −1	139.569	2.60×10^{-8}	$\mu\nu_\mu$
π^0	$(u\bar{u} - d\bar{d})/\sqrt{2}$	0	134.964	8.7×10^{-17}	$\gamma\gamma$
$K^\pm$	$u\bar{s}$, $s\bar{u}$	+1, −1	493.67	1.24×10^{-8}	$\mu\nu_\mu$, $\pi^\pm\pi^0$, $\pi^\pm\pi^\pm\pi^\mp$
K^0, $\bar{K}^0$	$d\bar{s}$, $s\bar{d}$	0, 0	497.72	K_S^0 0.892×10^{-10} K_L^0 5.18×10^{-8}	$\pi^+\pi^-$, $\pi^0\pi^0$ $\pi e\nu_e$, $\pi\mu\nu_\mu$, $\pi\pi\pi$
η	$(u\bar{u} + d\bar{d} - 2s\bar{s})/\sqrt{6}$	0	548.8	7×10^{-19}	$\gamma\gamma$, $\pi^0\pi^0\pi^0$, $\pi^+\pi^-\pi^0$
η'	$(u\bar{u} + d\bar{d} + s\bar{s})/\sqrt{3}$	0	957.6	3×10^{-21}	$\eta\pi\pi$, $\rho^0\gamma$
$D^\pm$	$c\bar{d}$, $d\bar{c}$	+1, −1	1869	9×10^{-13}	$K\pi\pi$
D^0, $\bar{D}^0$	$c\bar{u}$, $u\bar{c}$	0, 0	1865	4×10^{-13}	$K\pi\pi$
$F^\pm$ (now $D_s^\pm$)	$c\bar{s}$, $s\bar{c}$	+1, −1	1971	3×10^{-13}	not established
$B^\pm$	$u\bar{b}$, $b\bar{u}$	+1, −1	5271	14×10^{-13} (for $B^\pm$ and B^0, $\bar{B}^0$)	$D + ?$ (for $B^\pm$ and B^0, $\bar{B}^0$)
B^0, $\bar{B}^0$	$d\bar{b}$, $b\bar{d}$	0, 0	5275		
η_c	$c\bar{c}$	0	2981	6×10^{-23}	$KK\pi$, $\eta\pi\pi$, $\eta'\pi\pi$

VECTOR MESONS (Spin 1)

Meson	Quark content	Charge	Mass	Lifetime	Principal decays
ρ	$u\bar{d}$, $d\bar{u}$, $(u\bar{u} - d\bar{d})/\sqrt{2}$	+1, −1, 0	770	0.4×10^{-23}	$\pi\pi$
K^*	$u\bar{s}$, $s\bar{u}$, $d\bar{s}$, $s\bar{d}$	+1, −1, 0, 0	892	1×10^{-23}	$K\pi$
ω	$(u\bar{u} + d\bar{d})/\sqrt{2}$	0	783	7×10^{-23}	$\pi^+\pi^-\pi^0$, $\pi^0\gamma$
ϕ	$s\bar{s}$	0	1020	20×10^{-23}	K^+K^-, $K^0\bar{K}^0$
J/ψ	$c\bar{c}$	0	3097	1×10^{-20}	e^+e^-, $\mu^+\mu^-$, 5π, 7π
D^*	$c\bar{d}$, $d\bar{c}$, $c\bar{u}$, $u\bar{c}$	+1, −1, 0, 0	2010	$>1 \times 10^{-22}$	$D\pi$, $D\gamma$
Υ	$b\bar{b}$	0	9460	2×10^{-20}	$\tau^+\tau^-$, $\mu^+\mu^-$, e^+e^-

Conservation laws:

Interactions among the particles are governed by some conservation laws. The conserved quantities are: energy, linear momentum, electric charge, baryon and lepton numbers, isospin, parity, and strangeness.

We are already familiar with the conservation laws of energy, linear and angular momentum in classical physics. We are also used to the idea of electric charge being conserved. These laws are universal. The rest of the laws will be discussed here.

1. Baryon conservation:

The family of the baryon is: proton, neutron, lambda (Λ), sigma (Σ), Xi (Ξ), Omega (Ω). The law holds for all interactions and decays: if a baryon appears on the left side of the interaction, one must appear on the right. A Baryon has a baryon number which is either +1 or -1. It is +1 for the particles listed above and -1 for their corresponding antiparticles: $\bar{p}$, $\bar{n}$, $\bar{\Lambda}$, $\bar{\Sigma}$, $\bar{\Xi}$, and $\bar{\Omega}$.

Example: $K^- + p \rightarrow \Lambda + \pi^0 + \pi^0 + \pi^0$

Baryon: 0 1 = 1 0 0 0 .

2. Lepton conservation:

Like the baryons, the leptons must be conserved in nuclear interactions. They have lepton number +1 and their anti-particles, u^+, e^+, $\bar{\nu}$, have lepton number -1.

Example: $K^- \rightarrow \mu^- + \pi^0 + \bar{\nu}$

Lepton: 0 = 1 0 -1

3. Strangeness conservation:

Some particles have the strangeness property, others do not.

The particles with strangeness numbers are: K^-(-1), K^+ (+1), K^0 (+1), $\bar{K}^0$(-1), Λ (-1), Σ^-(-1), Σ^0(-1), Ξ^-(-2), Ξ^0(-2), Ω^-(-3). Each of these particles has an anti-particle with the same strangeness number but with opposite sign.

Example: $K^- + p \rightarrow \Omega^- + K^0 + K^+ + \pi^0$

Strangeness: $-1 + 0 = -3 + 1 + 1 + 0$

4. Parity Conservation:

Parity conservation law holds only for strong and electromagnetic interactions. This law can be explained by the following example. Consider the reaction $p+p \rightarrow p + n + \pi^+$, in which π^+ is created. In such a case; it is necessary to assign an intrinsic parity to the pion in order to ensure the same parity in initial and final states.

5. Isospin:

The nuleons are seen as an analogue of the two possible spin states of a spin 1/2 fermion. We can talk about a spin quantum number. I=1/2 with isospin up (I_z=1/2) or isospin down (I_z =-1/2). The charges of the two states of the nuleons are $Q=1/2+I_z$. In general, for particles which are found to exist in three charged states (-1,0, or +1 on the charge of the electron) we have the formula: $Q=B/2+I_z$. B is the baryon number which equals 1 for the nucleons and 0 for mesons. This law only holds for the strong interaction.

The decays and interacations among the particles are produced in the bubble chamber. What we do in this experiment is to scan through the film which pictured the tracks and events, and to analyze 500 frames . The film we used came from the 25'' bubble chamber at the Bevatron. Other data needed to know in the experiment are:

- Beam: K^- mesons with momentum 1.5GeV/c
- Magnetic Field: 1.667 Tesla
- Chamber liquid: liquid hydrogen of density approximately 0.06 gm/cm^3.

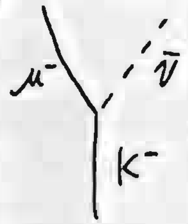
The creation of K^- mesons can be summarized as follow. Some gas hydrogen is passed through an arc chamber which ionizes the gas, leaving protons, which in turn are accelerated and directed to a target. Numerous particles of different energies result as products, from which K^-s of 1.5 Gev/c are selected and focused, and then fired into the cylindrical bubble chamber. The bubble chamber is immersed in a magnetic field and filled up with liquid hydrogen above its normal boiling point but under sufficient pressure to prevent boiling. There is a big piston inside the chamber and it is activated to expand the volume of bubble chamber suddenly, creating superheated hydrogen, liquid hydrogen does not boil right away. During this brief interval before boiling occurs, K^-'s enter the chamber; charged particles ionize liquid hydrogen and $H_2(liq) \rightarrow H_2(gas)$ thus form a string of bubbles. The chamber is illuminated through glass window and photograph is taken of the tracks.

EXPERIMENT

1. Scan 500 frames of film, from 0 to 500- Roll 5450.

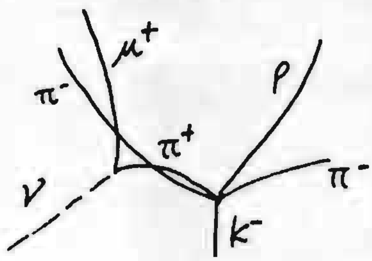
2. Ten typical different events found are:

(i) $K^- \rightarrow \mu^- + \bar{\nu}$



Frame 1

(ii) $\pi^+ \rightarrow u^+ + \nu$

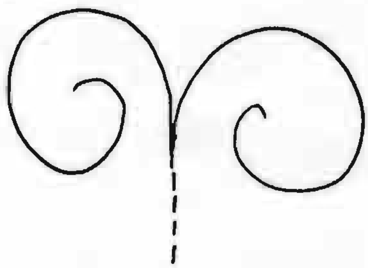


$K^- + p \rightarrow \pi^+ + \pi^- + \pi^- + p$

$\pi^+ \rightarrow \mu^+ + \nu$

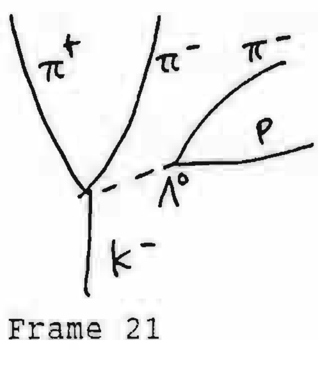
Frame 396

(iii) $\gamma \rightarrow e^+ + e^-$



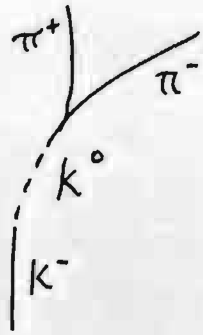
Frame 35

(iv) $K^- + p \rightarrow \pi^+ + \pi^- + \Lambda^0$; $\Lambda^0 \rightarrow p + \pi^-$



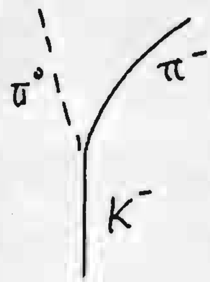
Frame 21

(v) $K^- + p \rightarrow n + K^0$; $K^0 \rightarrow \pi^+ + \pi^-$



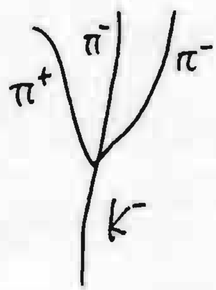
Frame 224

(vi) $K^- \rightarrow \pi^- + \pi^0$



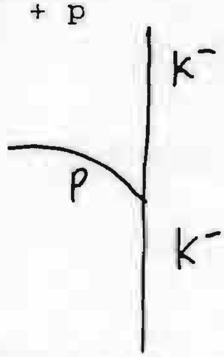
Frame 318

(vii) $K^- \rightarrow \pi^+ + \pi^- + \pi^-$



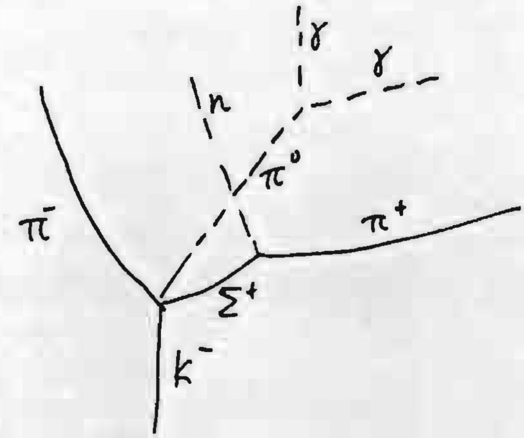
Frame 2

(viii) $K^- + p \rightarrow K^- + p$



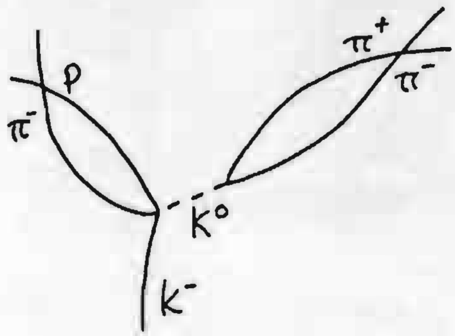
Frame 7

(ix) $K^- + p \to \Sigma^+ + \pi^- + (\pi^0)$; $\Sigma^+ \Rightarrow \pi^+ + n$; $\pi^0 \Rightarrow \gamma + \gamma$



Frame 46

(x) $K^- + p \to p + \pi^- + K^0$, $K^0 \to \pi^+ + \pi^-$



Frame 94

3. Branching Ratio of $K^- \to \pi^+ + \pi^- + \pi^-$:

- Number of decays in $K^- \to \pi^+ + \pi^- + \pi^-$ is 4
- Number of decays in "others" is 63

$$BR = \frac{\text{Rate}\ (K^- \to \pi^+ + \pi^- + \pi^-)}{\text{Rate}\ (K^- \to \text{all})} = (4/63)\times 100\% = 6.67\%$$

Note: Because of the difficulty of typing formulas and numbers, the rest of this report will be hand-written in ink. I am sorry for the inconvenience in reading. OK, Your writing is readable.

Calculation of The Uncertainty (T.A. Paul helped me this) ✓

Let $f = \frac{n_1}{n_2}$. $\sigma_f^2 = \sum_i \left(\frac{\partial f}{\partial n_i}\sigma_i\right)^2$, $\sigma_{n_1} = \frac{1}{\sqrt{n_1}}$, $\sigma_{n_2} = \frac{1}{\sqrt{n_2}}$.

$\frac{\partial f}{\partial n_1} = \frac{1}{n_2}$, $\frac{\partial f}{\partial n_2} = -\frac{n_1}{n_2^2}$.

$$\Rightarrow \sigma_f^2 = \left(\frac{\partial f}{\partial n_1}\sigma_1\right)^2 + \left(\frac{\partial f}{\partial n_2}\sigma_2\right)^2$$

$$= \frac{1}{n_2^2 n_1} + \frac{n_1^2}{n_2^4}\frac{1}{n_2} = \frac{n_2^3 + n_1^3}{n_1 n_2^5}$$

We have $n_1 = 4$, $n_2 = 63$.

$$\Rightarrow \sigma_f^2 = 6.3 \times 10^{-5} \Rightarrow \sigma_f = 7.9375 \times 10^{-3}$$

$$\Rightarrow \boxed{BR = 6.67 \pm 0.794\ \%}$$ ✓

This agrees with the published value ($\sim 6\%$).

4. Suppose we have N_0 K^-'s incident beam tracks within a cross-sectional area and length dx. In this region, we have $N_0 - N$ K^-'s either interact with protons or decay. Then,

$$\frac{N_0 - N}{N_0} = \text{probability of interactions and decays.}$$

Let ρ = density of protons
N_A = Avogadro's number
σ = ~~Atomic ...~~ Total Cross Section
A = Atomic number for Hydrogen

$$\Rightarrow \frac{N_0 - N}{N_0} = \frac{N_A \rho \sigma}{A} dx + P_{decay}$$

For P_{decay}; let τ = lifetime of K^- at rest

v = velocity of K^- observed in Lab Frame

Then $\frac{\tau}{\sqrt{1-(\frac{v}{c})^2}} = \gamma\tau$ = life time of K^- in Lab Frame.

where $\gamma = \frac{1}{\sqrt{1-(\frac{v}{c})^2}}$; c = speed of light. ✓

$$\Rightarrow P_{decay} = \frac{dx}{\gamma\tau v} = \frac{dx}{\gamma\tau\beta c} \quad \text{where } \beta = \frac{v}{c}$$

$$\Rightarrow \frac{N_0 - N}{N_0} = \frac{dx}{\gamma\tau\beta c} + \frac{N_A \rho \sigma}{A} dx$$

or $$-\frac{dN}{N_0} = \frac{dx}{\gamma\tau\beta c} + \frac{N_A \rho \sigma dx}{A}$$ ✓

$$\Rightarrow \boxed{N = N_0 e^{-\frac{x}{\gamma\beta c\tau}} e^{-x N_A \sigma \rho / A}}$$

5. Determine (a) total cross section σ for the interaction of 1.5 GeV/c K^- with protons. (b) K^- lifetime τ.

Let ΔN_I = total number of interactions

ΔN_D = Total number of decays ✓

$$\Rightarrow N = N_0 e^{-\frac{\Delta N_D}{N_0}} e^{-\frac{\Delta N_I}{N_0}} = N_0 e^{-(\Delta N_D + \Delta N_I)/N_0}$$

With Taylor expansion and $N_0 \gg N_D, N_I$, we have

$$N \simeq N_0 - \frac{1}{2}(\Delta N_I + \Delta N_D).$$ ✓

So,

$$\frac{\Delta N_I}{N} = \frac{x N_A \sigma \rho}{A}, \quad \frac{\Delta N_D}{N} = \frac{x}{\gamma\beta c \tau}$$

$$\Rightarrow \boxed{\sigma = \frac{A}{x N_A \rho}\left(\frac{\Delta N_I}{N}\right) \quad \text{and} \quad \tau = \frac{x}{\gamma\beta c}\left(\frac{N}{\Delta N_D}\right)}$$

Note: $\Delta N_D = 67$, $\Delta N_I = 125$, $x \sim 12$ inches.

For every 10 frames, I counted the number of tracks. In 500 frames, the number of counted tracks is 455.

$$\Rightarrow N_0 = 455 \times 10 = 4550.$$

$$\Rightarrow N \approx N_0 - \frac{1}{2}(\Delta N_I + \Delta N_D) = 4454 \simeq N.$$

We also have: $\rho = 0.06\ gm/cm^3$, $E = 1.5\ GeV/c$, $A = 1$, $x \simeq 30\ cm$

$$\Rightarrow \sigma = \frac{1}{30(6\times10^{23})(0.06)}\left(\frac{125}{4454}\right) = 2.60\times10^{-26}\ cm^2 = 2.6\times10^{-2}\ barn.$$

Statistical error: $n_1 = \Delta N_I$, $n_2 \simeq N$ (n_2 does not equal N, but N is a good approximation)

Then, $\left[\frac{n_1 n_2}{(n_1+n_2)^2}\right]^{1/2} = 0.1629 \Rightarrow$ Error $= 4.24$ mb

$$\Rightarrow \boxed{\sigma = 26.0 \pm 4.24\ mb}$$

Should simply be 26 ± 4 mb.

This agrees with the published value (~ 31 mb).

and $$\tau = \frac{30\ cm}{1.5\times10^{11}\ \frac{cm}{s}}\left(\frac{4454}{67}\right) = 1.33\times10^{-8}\ sec.$$

Statistical Error: $\left[\frac{n_1 n_2}{(n_1+n_2)^2}\right]^{1/2} = 0.12 \Rightarrow$ Error $= 0.16\times10^{-8}$ sec

$$\Rightarrow \boxed{\tau = 1.33\times10^{-8} \pm 0.16\times10^{-8}\ sec}$$

This agrees with the published value. (1.24×10^{-8} sec)

Since I didn't have any partner to scan the film with, I have to skip the "Scanning Effeciency" part. I apologize for this.

I don't understand this - need to explain.

Analysis and Questions:

1. (a) It is not feasible to measure the K^- lifetime at rest because the rest mass of K^- is only 493.7 MeV, so by uncertainty principle, the uncertainty in its lifetime, if measured at rest, would be large.

(b) This reinforces the Special Theory of Relativity which states that all laws of Physics are the same in all inertial reference frame. Not clear how the exp. shows this. What about time dilation?

(c) Particles and their corresponding anti-particles are alike in many ways except for their charges. If a particle decays into other particles, then the anti-particle also decays into the same particle with opposite charges. ✓

2. (a) We would obtain an "effective radius" R_{eff} if we used a classical model of interaction. ✓

$$R_{eff} = \left(\frac{2.60 \times 10^{-26}}{\pi}\right)^{1/2} = 9.1 \times 10^{-14} \text{ cm}.$$

(b) By Mass-Energy Conservation and Linear momentum Conservation, we can write

$$\bar{P}_k + \bar{P}_p = \bar{P}_R$$

$$\Rightarrow P_R^2 = P_k^2 + P_p^2 + 2\bar{P}_k \cdot \bar{P}_p$$

and, $m_R^2 = m_k^2 + m_p^2 + 2E_k m_p$? Seems to me this contradicts the previous equation

$\Rightarrow$ $m_R = \sqrt{m_k^2 + m_p^2 + 2E_k m_p}$, $E_k = 1.5$ GeV/c

$m_k \approx 500$ MeV $= 0.5$ GeV
$m_p = 838$ MeV $= 0.938$ GeV

$\Rightarrow$ $\boxed{m_R \simeq 2.1 \text{ GeV}}$

(c) $B=1$, $L_e = L_\mu = 0$, $Y(\equiv \text{hypercharge}) = 2$, S ($\equiv$ Strangeness) $= -1$

Spin $= \frac{1}{2}, \frac{3}{2}, \frac{5}{2}, \ldots$, $p = \pm 1$, isospin $= 0, 1$.

Conclusion:

This is the best experience I ever had in experimental Physics. Scanning through the film is not an interesting job, but by spending several days on reading materials needed for the analysis, I was fasinated to the structure of the particles. Quarks should be written about much longer and deeper but the limited lengths of this report doesn't allow me to do so. To be more effecient with the recognition of the decays and interactions, one should look and read carefully the Alvarez Scanning Group memo before coming to the lab room.

Acknowledgement :

1. Particle Properties Data Booklet
2. Modern Physics by Ohanian
3. Introduction to High-Energy Physics by Perskin
4. Alvarez Group Scanning Training Memo.

Raw Data ✓

Data 25" Bubble Chamber, Roll # 5450

Frame #: # of beam tracks

1) $K^- \to \mu^- + \bar{\nu}$, 13 tracks

2. $K^- \to \pi^- + \pi^+ + \pi^-$

3. N (No events)

4. N
5. N
6. N
7. $K^- + p \to K^- + p$

8. N
9. $K^- + p \to p + \pi^+ + \pi^- + \pi^-$

10. N 5 tracks

11. N
12. N
13. N

14. $K^- + p \to \pi^+ + \pi^- + \Lambda^0$

15. N
16. N

17. $K^- \to \pi^- + \pi^0$
18. $K^- \to \pi^- + \pi^0$

19. N

20. N 7 tracks

21. $K^- + p \rightarrow \pi^+ + \pi^- + \Lambda^0$

$\hookrightarrow p + \pi^-$

22. $K^- + p \rightarrow \Sigma^+ + \pi^- + \pi^0$, $\Sigma^+ \rightarrow \pi^+ + n$.

23. N

24.

25. N

26. N

27. N

28. N

29. N

30. N 14 tracks

31. $K^- + p \rightarrow \pi^+ + \pi^- + \Lambda^0$

32. N

33. N

34. N

35. $\gamma \rightarrow e^+ + e^-$

36. $K^- \rightarrow \pi^+ + \pi^0$

37. N

38. N

39. $K^- + p \rightarrow p + K^-$

40. N 13 tracks

41. N

42. N

43. N

44. N

45. $K^- + p \rightarrow K^- + p$

46. $K^- + p \rightarrow \Sigma^+ + \pi^- + \pi^0$, $\Sigma^+ \rightarrow \pi^+ + n$

47. N

48. $K^- + p \rightarrow \pi^+ + \pi^- + \Lambda^0$

49. N

50. N 11 tracks

51. $K^- \rightarrow \mu^- + \bar{\nu}$

52. $\gamma \rightarrow e^+ + e^-$

53. $K^- \rightarrow \mu^- + \bar{\nu}$

54. N

55. N

56. $K^- + p \rightarrow \pi^+ + \pi^- + \Lambda^0$

57. N

58 $K^- \rightarrow \pi^- + \pi^0$

59. N

60. $K^- + p \rightarrow p + K^-$ 13 tracks

61. N

62. N

63. N

64. N

65. N

66.

67. N

68. $K^- \Rightarrow \mu^- + \bar{\nu}$

69. $\gamma \Rightarrow e^+ + e^-$

70 $K^- + p \Rightarrow \pi^+ + \pi^- + \Lambda^0$ 8 tracks

71.

72. N

73. N

74. $K^- + p \Rightarrow p + \pi^- + K^0$, $K^0 \Rightarrow \pi^+ + \pi^-$

75. $K^- \Rightarrow \mu^- + \bar{\nu}$

76. N

77. N

78. $K^- + p \Rightarrow \pi^+ + \pi^- + \Lambda^0$.

79. $K^- \Rightarrow \mu^- + \bar{\nu}$.

80. N 17 tracks

81. N

82. N

83. $K^- + p \Rightarrow \pi^+ + \pi^- + \Lambda^0$

84. $K^- \Rightarrow \mu^- + \bar{\nu}$

85. N

86. $K^- + p \Rightarrow \pi^+ + \pi^- + \Lambda^0$

87. $K^- + p \Rightarrow \pi^+ + \pi^- + \Lambda^0$

88. $K^- \Rightarrow \pi^- + \pi^0$.

89. N

90. N 13 tracks

91. $K^- + p \to p + \pi^+ + \pi^- + \pi^-$,

$p + p \to p + \nu$, $p + p$

92. $K^- + p \to K^- + p$

93. N

94. $K^- + p \to \pi^+ + \pi^- + \Lambda^0$, $\Lambda^0 \to p + \pi^-$.

95. N

96. N

97. N

98. $K^- + p \to \pi^+ + \pi^- + \Lambda^0$, $\Lambda^0 \to p + \pi^-$.

99. N

100. $K^- + p \to \Sigma^+ + \pi^- + \pi^0$, $\Sigma^+ \to \pi^+ + n$, 14 tracks.

101. N

102. $K^- + p \to K^- + p$

103. N

104. N

105. N

106. $K^- + p \to K^- + p$

107. $K^- + p \to K^- + p$

108. N

109 N

110 $K^- + p \Rightarrow K^- + p$ 11 tracks

111. N

112. $K^- + p \Rightarrow \pi^+ + \pi^- + \Lambda^0$

113. $\gamma \Rightarrow e^+ + e^-$

114. $K^- + p \Rightarrow \pi^+ + \pi^- + \Lambda^0$, $\Lambda^0 \rightarrow p + \pi^-$

115. N

116. N

117. $K^- + p \Rightarrow K^- + p$

118. N

119. N

120. N 12 tracks

121. N

122. $\gamma \rightarrow e^+ + e^-$

123. N

124. N

125.

126. N

127. N

128. N

129. N

130. N 7 tracks

131. N
132. N
133. $K^- + p \rightarrow K^- + p$

134. N
135. N
136. N
137. N
138. N
139. N
140. N 11 tracks

141. N
142. $K^- + p \rightarrow K^- + p$

143. N
144. N
145. $\gamma \rightarrow e^+ + e^-$

146. N

147. $K^- + p \rightarrow p + K^-$, $K^- + p \rightarrow \pi^+ + \pi^- + \Lambda^0$.

148. N

149. $K^- + p \rightarrow \pi^+ + \pi^- + \pi^0$, $K^- \rightarrow \pi^- + \pi^0$.

150. $K^- \rightarrow \pi^- + \pi^+ + \pi^-$ 14 tracks

151. N
152. N
153. $K^- + p \rightarrow n + K^0$, $K^0 \rightarrow \pi^+ + \pi^-$

154.

155. N

156.

157. $K^- + p \rightarrow \pi^+ + \pi^- + \Lambda^0$

158. N

159. N

160. N 13 tracks

161. N

162. $K^- + p \rightarrow K^- + p$

163. $K^- + p \rightarrow K^- + p$

164. $K^- + p \rightarrow \pi^+ + \Sigma^- + \pi^0$, $\Sigma^- \rightarrow \pi^- + n$.

165. N

166. N

167. N

168. N

169. N

170. N 13 tracks

171 N

172. N

173. N

174. N

175 N

176 N

177 N

178 N

179 N

180 $K^- \rightarrow \pi^{+-} + \pi^0$, $K^- + p \rightarrow \pi^+ + \pi^- + \Lambda^0$. 13 tracks

181. N
182 N
183 N
184 N
185 N
186 N
187 N
189 N
190 N — 14 tracks
191 N
192. $K^- \to \pi^- + \pi^0$
193. N
194. N
195 N
196 $K^- + p \to K^- + p$
197. $K^- + p \to \pi^+ + \pi^- + \Lambda^0$

198. N
199 $\gamma \to e^+ + e^-$, $K^- \to \mu^- + \bar{\nu}$

200. N — 15 tracks

201. $K^- + p \Rightarrow p + \pi^+ + \pi^+ + \pi^-$

202. N
203. N
204. $K^- \rightarrow \pi^- + \pi^0$
205. $K^- \rightarrow \pi^- + \pi^0$
206. N
207 N
208

209. N
210. N 14 tracks
211. N
212 N
213. NE
214 N
215 N
216 N
217 N
218. $\gamma \rightarrow e^+ + e^-$
219. N
220. $K^- + p \Rightarrow K^- + p$ 12 tracks
221 N
222. $K^- \rightarrow \pi^+ + \pi^- + \pi^-$
223. $K^- + p \Rightarrow K^- + p$

224. $K^- + p \rightarrow n + K^0$, $K^0 \rightarrow \pi^+ + \pi^-$

225. N
226. N
227. N
228.

229. ~~$K^- + p \rightarrow \pi^+ + \pi^- + \ldots^0$~~

$K^- + p \rightarrow \Sigma^- + \pi^+ + \pi^0$, $\Sigma^- \rightarrow \pi^- + n$.

230. $K^- \rightarrow \mu^- + \bar{\nu}$ 13 tracks

231. $K^- + p \rightarrow \pi^+ + \pi^- + \Lambda^0$

232. N

233. N

234. $K^- + p \rightarrow p + K^-$

235. N

236. N

237. N

238. N

239. N

240. N 13 tracks

241. N

242. $K^- + p \rightarrow K^- + p$.

243. $K^- + p \rightarrow K^- + p$.

244. N

245. N

246. $K^- \rightarrow \pi^- + \pi^0$

247. N

248. N

249. N

250. $K^- \rightarrow \mu^- + \bar{\nu}$ a tracks

251. $K^- \rightarrow \pi^- + \pi^0$

252. N

253. N

254. $K^- + p \rightarrow p + K^-$

255. N
256. N
257. $K^- + p \rightarrow \pi^+ + \pi^- + \Lambda^0$, $\Lambda^0 \rightarrow p + \pi^-$

258. N
259. N
260. N 12 tracks
261. N
262. N
263 $K^- + p \rightarrow K^- + p$

264. $K^- + p \rightarrow p + \pi^- + K^0$, $K^0 \rightarrow \pi^+ + \pi^-$

265. $K^- + p \rightarrow K^- + p$

266. $K^- \rightarrow \pi^- + \pi^0$

267. N
268. N
269. $K^- + p \rightarrow K^- + p$

270. N 13 tracks
271. $K^- + p \rightarrow K^- + p$
28
272. $K^- + p \rightarrow K^- + p$

273. N
274. N
275 $K^- + p \rightarrow K^- + p$
276. N
277. N
278. N
279. $K^- + p \rightarrow K^- + p$

280. $K^- + p \rightarrow \Sigma^+ + \pi + \pi^0$, $\Sigma^+ \rightarrow \pi^+ + n$, 12 tracks

281. N
282. N
283. $K^- + p \rightarrow K^- + p$.
284. N
285. N
286. $K^- + p \rightarrow K^- + p$.
287. N
288 N
289 N
290. N 7 tracks

291. $K^- + p \rightarrow \pi^- + \pi^+ + \Lambda^0$

292. N
293. $K^- + p \rightarrow K^- + p$

294. N
295. N
296. N
297. N
298. N
299 N
300. $K^- + p \rightarrow n + K^0$, $K^0 \rightarrow \pi^+ + \pi^-$, 6 tracks

301. $K^- + p \rightarrow \pi^+ + \pi^- + \Lambda^0$
302. N
303. N
304. N
305. $K^- + p \rightarrow \pi^+ + \pi^- + \Lambda^0$
306. N
307. $K^- \rightarrow \pi^- + \pi^0$

308. N

309 $K^- + p \rightarrow p + \pi^- + K^0$, $K^0 \rightarrow \pi^+ + \pi^-$.

310. $K^- + p \rightarrow \pi^+ + \pi^- + \Lambda^0$, 10 tracks

311 $\gamma \rightarrow e^+ + e^-$

312. N

313. N

314. $K^- + p \rightarrow \pi^+ + \pi^- + \Lambda^0$, $\Lambda^0 \rightarrow p + \pi^-$

315. N

316. N

317. N

318. $K^- \rightarrow \pi^- + \pi^0$

319. N

320. $K^- + p \rightarrow K^- + p$ 14 tracks

321. N

322. N

323. $K^- + p \rightarrow \pi^+ + \pi^- + \pi^-$

324. N

325. N

326. N

327. N

328. $K^- + p \rightarrow \pi^+ + \pi^- + \Lambda^0$

329. $K^- + p \rightarrow K^- + p$

330. N 13 tracks

331. N

332. N

333. N
334. N
335. $K^- + p \Rightarrow \pi^+ + \pi^- + \Lambda^0$
336. N
337. N
338. N
339. N
340. N 14 tracks
341. N
342. $K^- + p \Rightarrow \pi^+ + \pi^- + \Lambda^0$
343. $K^- + p \Rightarrow \pi^+ + \pi^- + \Lambda^0$, $\Lambda^0 \Rightarrow p^+ + \pi^-$.

344. $K^- \Rightarrow \pi^- + \pi^0$

345. $K^- + p \Rightarrow K^- + p$

346. $K^- + p \Rightarrow K^- + p$
347. N
348. N
349 N
350 $K^- + p \Rightarrow n + K^0$, $K^0 \Rightarrow \pi^+ + \pi^-$, 11 tracks

351. $K^- + p \Rightarrow \pi^+ + \pi^- + \Lambda^0$

352. N
353. $K^- + p \Rightarrow \pi^+ + \pi^- + \Lambda^0$

354. N
355. $K^- + p \Rightarrow \Sigma^+ + \pi^- + \pi^0$, $\Sigma^+ \Rightarrow \pi^+ + n$
256. N
257 N
258. N
259 N

360. 12 tracks

361 n
362 N
363 N
364 N
365. N
366. N
367. N
368. N
369 N
370 $K^- + p \to \pi^+ + \pi^- + \Lambda^\circ$, $\Lambda^\circ \to p + \pi^-$, 13 tracks

371. N
372 N
373 N
374 N
375 $k^- + p \Rightarrow K^- + p$
376. N
377 $K^- + p \Rightarrow \pi^+ + \pi^- + \Lambda^\circ$
378. N
379. N
380. N [illegible] tracks
381 N
382. $K^- + p \to n + K^\circ$, $K^\circ \to \pi^+ + \pi^-$

383. $K^- + p \to K^- + p$
384. N
385. $K^- + p \Rightarrow \pi^+ + \pi^- + \pi^- + p$

386. N
387. N

388. $K^- + p \rightarrow n + K^0$, $K^0 \rightarrow \pi^+ + \pi^-$

389. N

390. $K^{\mp} + p \rightarrow p + K^-$ 12 tracks

391. $K^{\mp} + p \rightarrow \pi^+ + \pi^- + \Lambda^0$

392. N

393. N

394. N

395. N

396. $K^+ + p \rightarrow p + \pi^- + \pi^- + \pi^+$, $\pi^+ \rightarrow \mu^+ + \nu$

397. N

398. N

399. $K^+ + p \rightarrow n + K^0$, $K^0 \rightarrow \pi^+ + \pi^-$

400. N 9 tracks

401. $K^- \rightarrow \mu^- + \bar{\nu}$

402. N

403. N

404. N

405. N

406. N

407. N

408. $K^- \rightarrow \mu^- + \bar{\nu}$

409. N

410. $K^{\mp} \rightarrow \pi^+ + \pi^- + \pi^-$ 13 tracks

411. $K^- + p \rightarrow \pi^+ + \pi^- + \pi^- + p$

412. N

413. N

414. N

415. $K^{\mp} + p \rightarrow K^- + p$

416. N

417. N

418. N

419. $K^- \rightarrow \pi^- + \pi^0$

420. N 6 tracks

421. N

422. N

423. $\to K^- \to \pi^- + \pi^0$

424. N

425. $K^- + p \Rightarrow \pi^+ + \pi^- + \Lambda^0$

426. N

427. $K^- + p \Rightarrow \pi^+ + \pi^- + \Lambda^0$

428. N

429. N

430. $K^- + p \Rightarrow p + \pi^+ + \pi^- + \pi^-$ 8 tracks

431. N

432. $K^- + p \Rightarrow p + K^-$

433. $K^- \Rightarrow \mu^- + \bar{\nu}$

434. N

435. N

436. $K^- + p \Rightarrow \pi^- + \pi^+ + \Lambda^0$

437. N

438. N

439. $K^- \to \mu^- + \bar{\nu}$ 4 tracks

440. N

441. N

442. $K^- \Rightarrow \pi^- + \pi^0$

443. $K^- + p \Rightarrow \pi^+ + \pi^- + \pi^- + p$

444. $K^- + p \Rightarrow \pi^+ + \pi^- + \Lambda^0$

445. $K^- + p \Rightarrow p + \pi^- + K^0$, $K^0 \Rightarrow \pi^+ + \pi^-$

446. $K^- + p \Rightarrow K^- + p$

447. N

448. N

449. N

450. $K^- + p \Rightarrow \pi^+ + \pi^- + \Lambda^\circ$ 6 tracks
451. $K^- \rightarrow \mu^- + \bar{\nu}$
452. $K^- + p \Rightarrow \pi^+ + \pi^- + \Lambda^\circ$, $\Lambda^\circ \rightarrow p + \pi^-$
453. N
454. N
455. $K^- + p \Rightarrow \pi^+ + \pi^- + \Lambda^\circ$, $\gamma \Rightarrow e^+ + e^-$
456. N
457. $K^- + p \Rightarrow K^- + p$
458. N
459. N
460. N 14 tracks
461. N
462. $K^- + p \Rightarrow \pi^+ + \pi^- + \Lambda^\circ$
463. N
464. N
465. N
466. N
467. N
468. N
469. N
470. $K^- \Rightarrow \mu^- + \bar{\nu}$ 10 tracks
471. N
472. N
473. N
474. N
475. N
476. N
477. N
478. $K^- + p \Rightarrow \pi^+ + \pi^- + \Lambda^\circ$
479. N
480. $K^- + p \Rightarrow \Sigma^+ + \pi^- + \pi^0$, $\Sigma^+ \rightarrow$ 7 tracks

481.

482. N
483. N
484. N
485. N
486. N
487. $K^- + p \rightarrow \pi^+ + \pi^- + \Lambda^0$, $\gamma \rightarrow e^+ + e^-$
488. N
489 N
490 N 8 tracks
491. N
492 N
493 N
494 $K^- \rightarrow \pi^- + \pi^0$
495 N
496 N
497 N
498 N
499 N
~~495~~
500 N 11 tracks.