N 71

—NOTE BOOK—

Note of
Meetings and Discussions
during
the travel abroad

June ~ Sept. 1956

H. Yukawa

BOX 35

SPARTA NOTE

S 30

CHAPTER

CONTENTS

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①

CERN Symposium on High Energy Accelerators and Meson Physics

Geneva, June 1956

Second Week

June 18. Bubble Chamber
Glaser

June 19 Cerenkov Counter

Anti-proton: Segré, attenuation

Nucleon-Nucleon Scattering

June 20

② Lindau Meetings of Nobel Prize Winner (Lecturer) for Physics
June 25 ~ June 28 1956

June 25 Laue,
Cockcroft
Hertz

June 26 Heisenberg
Yukawa : Elementary Particles and Space-Time Structure

June 27 Dirac
Zernicke

June 28 Born
Raman
Blackett

July

③ London Harwell Cambridge
Cockcroft

Blackett

Mott
Dirac

July

④ Columbia University, N.Y.
Aug. 25, 1956
Kusch
Wu
van de Graf machine

⑤ Washington, D.C.
Aug. 30, 1956
AEC Strauss, Libby, Goodman
Pu
Training Reactor : Argonaut

(6) Brookhaven Talk

Aug. 6, 1956

Unified Theory of Elementary Particles

1. Schwinger theory and its failure
2. vacuum states. (parity)

(7) Talk at King Edward Hotel
Toronto, Canada, Aug. 10, 1956

(8) Cal. Tech., Pasadena
Aug. 17, 1956

C. Anderson

Bacher

(9) Rad. Lab., Univ. Calif.

~~July~~ Aug. 21 ~ Aug. 24, 1956

Alvarez: $\tilde{\theta}^0$ and Σ^0

$K^- + p \to n + \tilde{\theta}^0$

$\tilde{\theta}^0 \to \pi^+ + \pi^-$

$\Sigma^0 \to \Lambda^0 + \gamma$

Piccioni: anti-neutron

: ~~$\Sigma^+ - \Sigma^-$~~ $m_{\Sigma^+} \neq m_{\Sigma^-}$

Lepore:

⑩ Symposium on Reactor Problems
General Atomic, San Diego
Aug 27, 1956

E. Teller : Safe Reactors

decay: $\frac{1}{t^{1.2}}$ integral; $\frac{1}{t^{0.2}}$

$R = 0.01 \sqrt{kW}$

earthquake

homogeneous reactor (i) no accumulation
(ii) neg. temp. coef

water boiler

prison
fine
etc.

$\left(\frac{1}{\tau}\right)^{1.2}$ $\tau = l/\Delta k$ l: neutron regeneration time

v: rate of decrease of reactivity due to bubbles, vapor
void coefficient

$\left(\frac{1}{v}\right)^{0.5}$

l, v : twice Δk : twice

$\Delta k \approx v f(t, \tau)$

$\Delta k \approx v \frac{\cancel{(t/\tau)^n}}{\tau^n} = v t^n .$

$= v l^n/(\Delta k)^n$

$\Delta k = v^{\frac{1}{n+1}} l^{\frac{n}{n+1}}$

in particular $= v^{0.3} l^{0.7}$

or $v^{0.18} l^{0.82}$

swimming pool reactor
graphite between fuel elements

F. Dyson: Neutron Temperature Effect
Swimming pool reactor

instaneous response
large temp. coef.

Al-U	½ Fuel
NaH	¼ Internal
UH_3	H, Al
ZrH_2	¼ H_2O

Thermal exchange between neutrons and moderator.

$$\alpha = \frac{\langle E_{in} - E_{out} \rangle}{\langle E_{in} \sim E_{m} \rangle} \approx 0.04$$

$$\left(\alpha \doteq \frac{2A}{(A+1)^2} \sim \frac{2}{A}\right)$$

$$\delta k \simeq -\left[\frac{T_W - T_c}{2T_{Av}}\right]\left[\frac{p - A}{p}\right]$$

$$p = \int_{\text{whole}} \phi(r)\, Q(r)\, dr$$

origination

Importance fn

$$A = \int \Phi(r)\, A(r)\, dr$$

Absorption

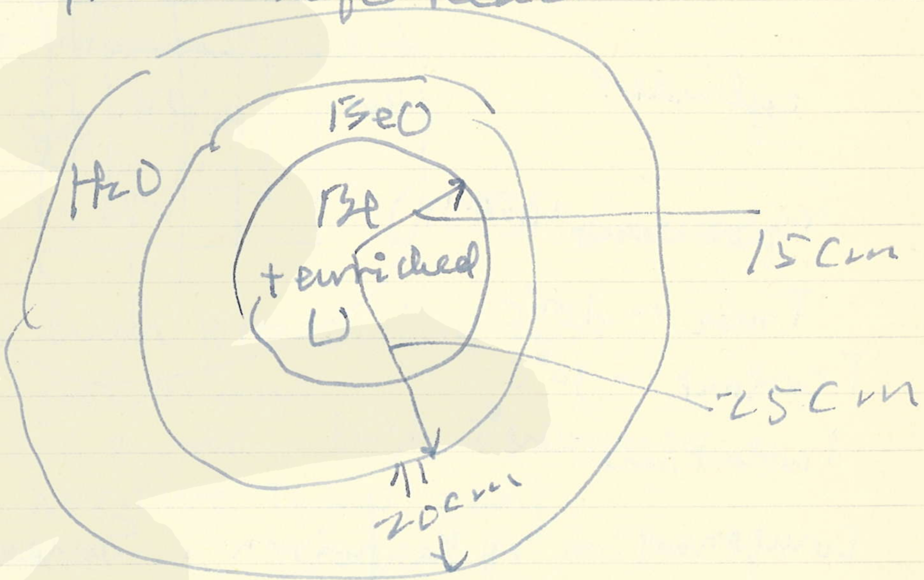
Hot

$$\delta k \simeq -\frac{T_F - T_c}{16T} \simeq -2\times10^{-4} \text{ per } {}^\circ C$$

$\Delta T = 500°C$　　$\delta k = 10\%$

Comments
Teller :

T. Taylor: A New Safe Reactor
(G. A.)



$m_{U_{235}} \sim 600g$

Enrichment ~ 20%

$Be/U_{235} \simeq 1300$ $Be/U_{238} \simeq 350$

atom

$10\,kW \sim 5\times10^{11}\ cm^{-2}/sec$

$1\,MW \sim 5\times10^{13}$ "

$(\Delta k)_{Xe} < .5\%$

$\left(\frac{\Delta k}{\Delta T}\right)_{Doppler} \simeq 5\times10^{-5}$

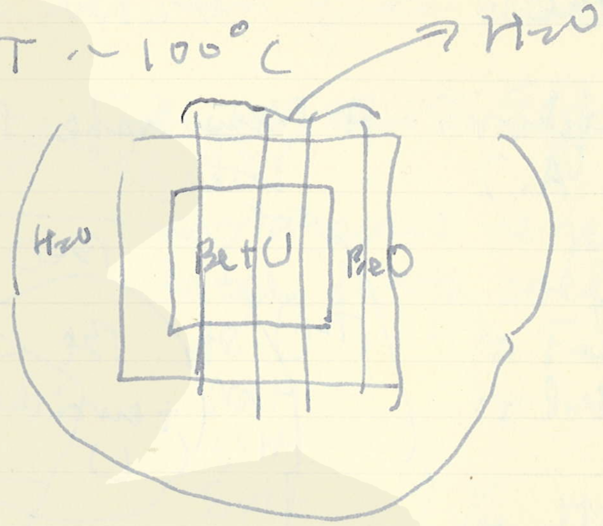
$\left(\frac{\Delta k}{\Delta T}\right)_{warm\ neutron} \simeq .4\times10^{-5}$

$\left(\frac{\Delta k}{\Delta T}\right) \sim 10^{-4}$

$('')_{exp} \simeq 2\times10^{-5}$

$(\Delta k_{excess})_{cold} \sim 1\%$

$\Delta T \sim 100°C$



cylinder

$r_{fuel\ element} \sim 1.5\ cm$

$T_{max} \sim 100°C$

$T_{coolant} \sim 30°C$

$T_{coolant\ issue} \sim 20°C$

Compensation of Xe poison : Samarium

600 g U_{235}	~ $9000
	$15,000
Be	~ $8,000
BeO	~ $8,000
	$30,000

4 ft concrete: $10,000 (100kW level)

Pu. positive temp. coeff.

Comparison with Argonaut.

Afternoon

Y. Fujioka: Japanese Reactor Program

Japan's own Tokai Village 1,000 acres
~~Experimental Power~~ Reactor

U 7 tons
D_2O 20 tons
10 MW (NRX, Canada)

Teller

Pu: (i) high processing cost
(ii) poisonous
(iii) 0.3 volt high resonance
positive temp. coef.

U^{233}: fast reactors, convertor
poisonous?

G. Holte: Swedish Reactors

R1
R2 1958
R 3 a 80~90MW power reactor for heating
R 3 b heat and electricity
R3a Nat. U + D_2O
(Al)
R3b U oxide UO_2

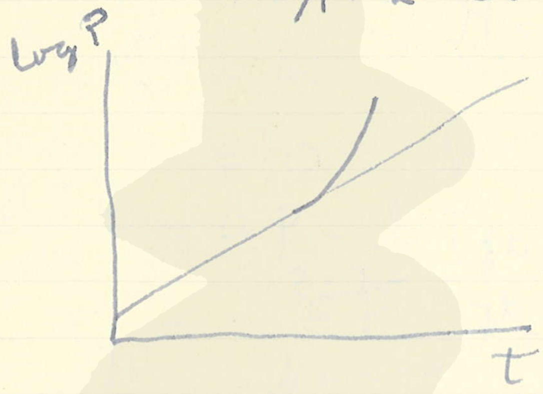
temp. coef.

J. Horowitz, { Be Oxyd $25/pound
{ ~~Temp. Coeff.~~
{ Graphite

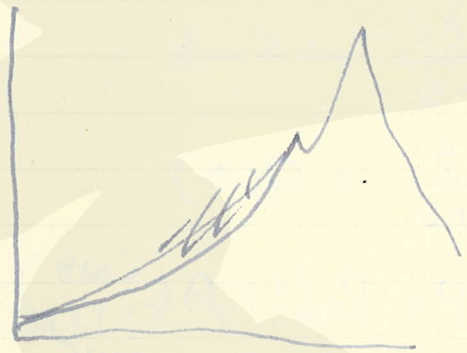
$\sigma(n, 2n) - \sigma(n, \alpha) \sim 30$ mb

Aug. 28

H. Bethe: Reactor Instabilities - I.
ANL 5577



positive temp. coef.



EBR I: Fast reactor
oscillation experiment
$\omega = .19/\text{sec}$ 95 gal/min
$.35/\text{sec}$ 195 gal/min

Kinchin

(positive temp. coef for
prompt neutron
negative temp.-coef for
delayed neutron

$$\left.\begin{aligned}\frac{dn}{dt} &= \frac{k_{ex}-\beta}{l} n + \sum c_i \lambda_i \\ \frac{dc_i}{dt} &= \beta \frac{n}{l}(1+\cancel{k_{ex}})a_i - c_i\lambda_i\end{aligned}\right\}$$

$l/p \sim 10^{-7}/10^{-2} = 10^{-5}$ sec.

$\frac{\beta n}{l} = P \qquad \frac{k_{ex}}{\beta} = R$

$$P = \frac{\sum c_i \lambda_i}{1-R}$$

$P \sim e^{st} \qquad \frac{dc_i}{dt} = c_i s$

$$c_i = \frac{P a_i}{\lambda_i + s}$$

$$1 - R = \sum \frac{a_i \lambda_i}{\lambda_i + s}$$

$$R = \sum \frac{a_i s}{\lambda_i + s} = Q(s)$$

$R = A e^{i\omega t} \qquad P = P_0(1 + B e^{i\omega t})$

$$c_i = c_i^0 + \Gamma_i e^{i\omega t}$$

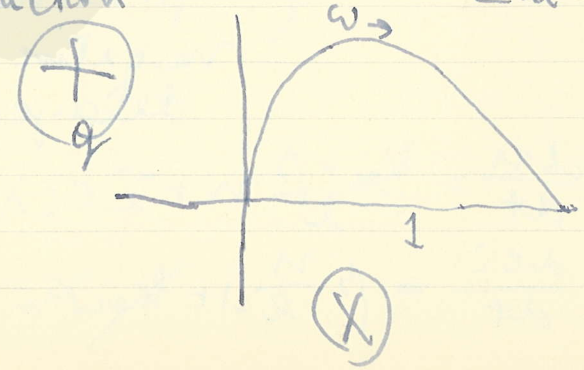
$$\left.\begin{array}{l} -A\cancel{e^{i\omega t}} P_0 + P_0 B \cancel{e^{i\omega t}} = \sum \lambda_i \Gamma_i \cancel{e^{i\omega t}} \\ (i\omega + \lambda_i)\Gamma_i = P_0 B a_i \end{array}\right\}$$

$$\Gamma_i = \frac{P_0 B a_i}{\lambda_i + i\omega}$$

$$\frac{A}{B} = Q(i\omega) = \sum \frac{a_i i\omega}{\lambda_i + i\omega}$$

reactor transfer function

$\sum a_i = 1$



power coef. X

$$A = A_0 + P_0 B X(\omega) = B Q(i\omega)$$

$$\frac{A_0}{B} = Q - P_0 X(\omega)$$

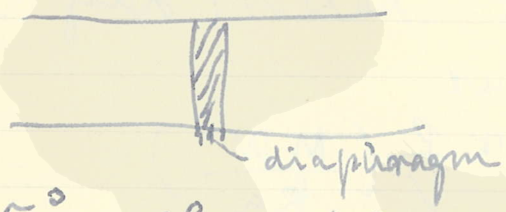
$$= 0$$ for resonance

$$\frac{dT_f}{dt} = aP - bT_f$$

$$T_f = \frac{aP}{b + i\omega} = \frac{cP}{1 + i\omega/\omega_f}$$

resonance
runaway } different phenomena

B. Rossi: Reactor Fuses. $\tau = 1$ ms



$T_0' < 55^\circ \simeq 26^\circ$ below

$$\rho = \frac{T_{fuel}}{T_{fuel}} = \frac{c_{fuel}}{c_{fuel}} \rightarrow \rho = 33 \rightarrow 30$$

R. Karplus, Materials Research Reactor.

Fuel Bearing
1. Fast neutrons
2. γ-rays
(slow neutrons)
3. Fission Fragments
Fission products
(nuclear properties)

Non-Fuel Bearing
1. Fast neutrons
2. γ-rays
(Slow neutron-capture)

mechanical
Thermal
corrosion (intersurface)

(fast)
fission neutron flux

$$\phi_f = 7\times10^{13}\frac{P}{V}\cdot\lambda \qquad \lambda \sim 10\,cm$$

γ-ray flux

$$\therefore \ \phi_f \simeq 7\times10^{14}$$

burn up (50%)

◎ $10^{15}/cm^2\,sec$ — 2 weeks
$10^{16}/cm^2\,sec$ — 1 day

slow neutron flux

$$\phi_s = \frac{1}{6}\times10^{18}\frac{P}{V}\left(\frac{MW}{kg}\right)$$

D₂O-moderator: up to 60

critical mass?

CP5

CP5 : $\phi_f = 7\times10^{13}\frac{f}{V}d$

d : thickness of fuel element

ctor
Bearing

Aug 29.
J. Schumar (A.N.L.): Fuel Element
Fabrication
Argonault U-Al UO_3
PWR
Th-U_{233}-circle
BORAX-4

U Nb, Zr. alloy Mo, Si
17 m thickness
Ziralloy
billet
cladding
canning

850°c Furnace

CP5 U-Al Al clad.

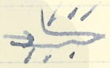
M. Simnad, Radiation Damage and Corrosion

1. Direct Chem. Attack
   $Fe + I \text{(methanol)} \rightarrow FeI_2$
   $\downarrow$
   $Fe_2O_3 + I_2$

2. " solution — liquid metal
3. Electrochemical { Aqueous solutions, Fused Salts
   Gas-metal — oxidation

↓

thermodynamics

1. General corrosion
2. pitting
3. Crevice 
4. Stress
5. Galvanic
6. Erosion

Associated with Metal { Impurity or Phase
Gr. Bound & Disloc.
Thermal Treatment

with surface { Roughness, edges
shape
Films

with Liquid { Concent. & pH
Aeration & Agitation
Heating - Thermogalvanic
Illum & Irrad.

Proton irrad. 260 MeV proton $10^{16}/cm^2$

1. Electrode Pot^l

W. Mo (Ni)

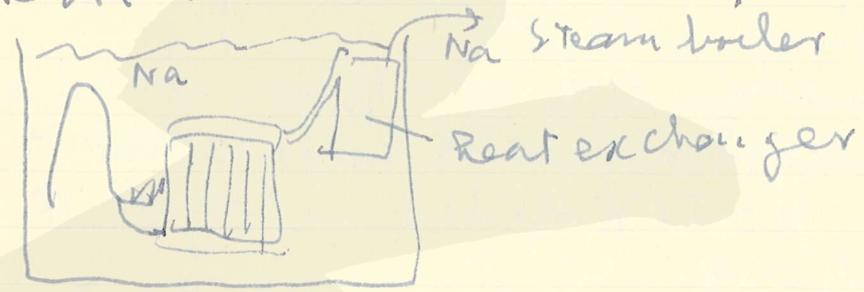
W 20 mV 84 mV

2 dissolution

graphite - CO_2

W. Pond: Liquid Sodium Heat Transfer Systems

EBR 2



M. Benedict: D_2O Production

99.75% D

CP5 5 tons

power reactor 1~2 lb/kw(elec)

200,000 lb

abundance

0.000149

$ 60~100/lb. $ 28/lb (AEC)

conv. power plant $150~200/kw

(D_2O $ 28~56/kw)

Distillation of water;

steam: $70/lb.

Kuhn: 1% → 99.75%
128 kW/lb. D_2O
$5.5/lb

Distillation of synthetic Gas
or H_2 (Separation ratio)

Clusius
Urey

France	2T/Y
Germany	7T/Y
Hydrocarbon Research Inc. Institute (U.S.A.)	40 T/Y

unit cost
plant $170/lb. D_2O/year
operation $16/lb. D_2O
$33

el. H_2 plant: → $25 ~ 30

Norsk Hydro	100 MW
Trail, B.C.	80 MW
Aswan	>1,000 MW
Nangal	160 MW

Distillation of H_2 & Exchange
>> $28/lb.

Electrolysis:

separ. ratio: 3 ~ 7

1 $/lb.

$70 / lb.

Norsk $60 ~ 100

Italy $42

+ exchange reaction

$H_2O + HD \rightleftarrows HDO + H_2$ (K = 2.8)

$ 35/lb. (USA)

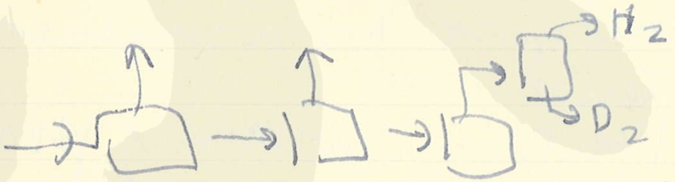
↓

$29/lb

Dual Temperature Process Water-H_2S exchange

$H_2O + HDS \rightarrow HDO + H_2S$

$28/lb (~~40~~ $23/lb ~ 43/lb)



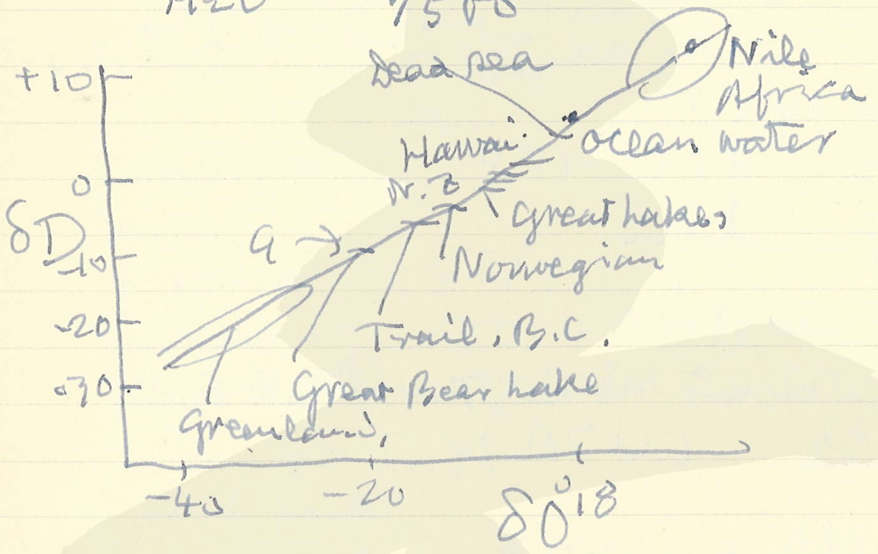
$20 ~ 25/lb.

Craig, Deuterium Abundance

H_2O 1

HDO 1/3230] 40% variation

H_2O^{18} 1/500



$$\delta = \left[\frac{R_{sample}}{R_{std}} - 1\right]$$

$R = D/H,\ O^{18}/O^{16}$

I. Dostrovsky (Israel)

A. E. enterprise for a small country
Raw material
Research Reactor – swimming pool
Power ?
Water – irrigation

nce

ination

M. Salesse

Fuel: U Nat. (<610°C)

Coolant: CO_2 140°~320°C

Can: Mg alloy 400°C → 500°C

Mod.: graphite

10 mills/kwh

5 mills/kwh

3 〃 〃

$C + CO_2 \rightleftarrows 2CO$

Mg → ~~Be~~

CO_2 → He , H_2

P. Fortescue: Boiling Reactors

Aug 30.

H. Yukawa: Elementary Particles

Schlork
Spurion

E. Teller: Nuclear structure

$$-a\psi\psi^*\varphi \quad + bD\psi D\psi^*\varphi$$

$$-\frac{\hbar^2}{2m} D\psi D\psi^*$$

$$M_{eff} = M/2$$

$$(\beta mc^2 - \beta\underset{\text{*attr.}}{\varphi_s})\psi$$

$$\frac{\hbar}{i}\dot{\psi} + \underset{\substack{\downarrow \\ \text{repulsion}}}{\varphi_0}\psi$$

spin-orbit coupling

Fermi-Yang.

ticles

M. Rosenbluth: Flat Flux Reactors

S. Gallone: Two Group Computations

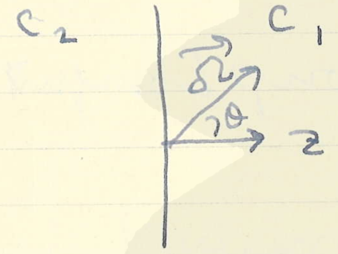
Aug. 31

Morning

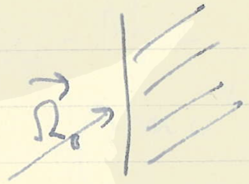
Afternoon

K. Case: Neutron Diffusion Theory

$c = \sigma_{scatt}/\sigma_{Total}$



$$\mu \frac{\partial \psi}{\partial z}(z, \vec{\Omega}) + \psi = \frac{c(z)}{4\pi} \int \psi(z, \Omega') d\Omega' + q(z, \vec{\Omega})$$



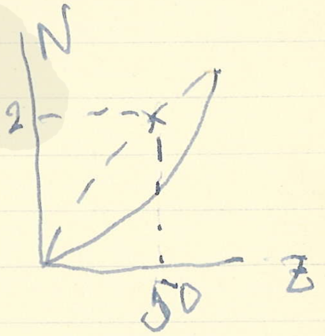
albedo

S. Gallone: Asymmetry of Fission

Liquid drop Model

(i) shape instability

(ii) hydrodynamical instability



R. Duffield: Asymmetry of Fission

magic number!!!

evening, Scripps, La Jolla

W. F. Libby: Tritium Hydrology

Miss River

Precastle
Postcastle

Ocean
3?, 6?, 6/8?
not much change

H. Craig: Mixing Rates in the Atmosphere and the Sea evaluated from C^{14} and H^3 studies

Ctr mixing time 200-2000 years

Sept. 1, 1956

B. Feld: Mesons and the Structure of Nucleons

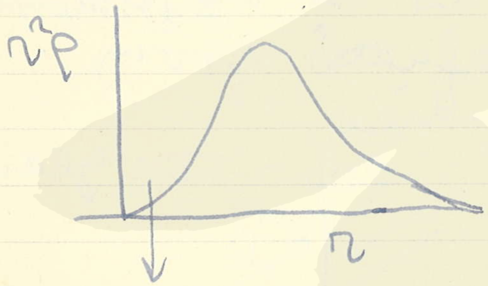
$$P \rightarrow -\sqrt{\tfrac{1}{3}}\, P\pi^0$$
$$\searrow \sqrt{\tfrac{2}{3}}\, N\pi^+$$

magnetic moment

$P_\mu \sim 2.8\,\mu_0$ }
$N_\mu \sim -2.8\,\mu_0$ }

radius of cloud:

hofstad (Stanford)



no nucleon core

$$N \rightleftarrows \sqrt{\tfrac{1}{3}}\, N\pi^0$$
$$-\sqrt{\tfrac{2}{3}}\, P\pi^-$$

no charge cloud

$M_N - M_p \cong 1.8\,\mathrm{MeV}$

$$n \leftrightarrows Y + K$$
$$P \rightleftarrows Y^0 + K^+$$
$$N \leftrightarrows Y^- + K^+$$

Schwinger: $\theta \rightleftarrows \tau + \pi$
$\tau \rightleftarrows \theta + \pi$

M. Goldhaber: Recent Progress in Meson Theory

G. Schmurer: Nuclear Maritime Propulsion

Tanker
400,000
length 700 ft
depth ↕ 50 ft
height

thermal eff. (high temp.)
(liquid metal cooled
gas cooled UO_2 Be
He CO_2 graphite
(high pressure storehouse)

gas turbine size

power < 100 MW

M. Rosenbluth: Controlled Thermonuclear Reactions

$$\frac{n_{reaction}}{cc\ sec} = N\overline{\sigma_v}$$

$$e^{-\frac{2\pi Z^2 e^2}{\hbar v}}\ e^{-\frac{mv^2}{kT}}$$

$$\downarrow$$

$$e^{-C/T^{1/3}}$$

kT = 10 keV

$\overline{\sigma_v}$	kT 10 keV	100 keV
DD	10^{-18}	3×10^{-17}
DT	10^{-16}	10^{-15} (max)

$NkT\tau \sim 10^8$

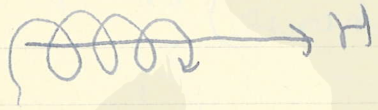
power: 10 kW/cc

magnetic field

100 atm

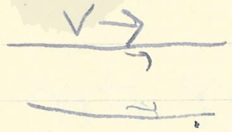
pressure: $\frac{H^2}{8\pi}$

$H \sim 10^5$ gauss



collision time ~ 1 sec.

collective effect: plasma oscillation



skin effect

Pinch colapse

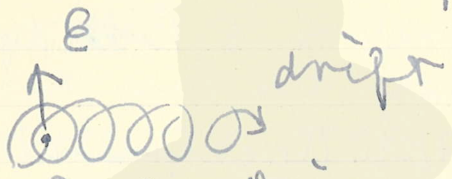
$$\dot{R} \sim \sqrt{\frac{Ec}{\sqrt{4\pi\rho}}}$$

$E \sim 10\ kV/cm$

hydromagn. instability

rmonuclear

$$\vec{\dot r}\,' = \vec{\dot r} + \frac{c\,\vec{E}_{ext}\times\vec{B}}{B^2}$$



polarization : dielectric const.

Λ_2 plasma

$$e\,\mathcal{E}_e\,y = M\,\mathcal{E}^2/B^2$$

$$\varepsilon = 4\pi NMc^2/B^2 + 1$$

gravitation

$$\Omega^2 = g/\cancel{x}$$

space charge:

$$\frac{d\sigma}{dt} = \frac{Nmg}{B}a$$

$$\dot D = 4\pi Nemg/\cancel{c}B\cdot a$$

$$\dot{\mathcal{E}} = aBg/\cancel{c}$$

$$\dot a = \frac{\mathcal{E}}{B}$$

$$\ddot a \sim \frac{g}{\lambda}a$$

Visit to Palomar Observatory
Dr. W. Baade : 200 inch Telescope
Age of stars < 5 ~~Billion~~ years
Gallaxy, ...
M 87 electron Accelerator
jet (injection mechanism)
Supernovae
Californium 52 days

Berkeley

Sept. 6　Research Progress Meeting
Yukawa, Systematization of Particles
ext. and int. degrees of freedom
strong and weak interactions

Sept. 7　Theoretical Physics Colloquium
Koba:
$E \gtrsim 10^3$ BeV　　Jet

1) Multiplicity
2) Composition
Bristol: 17~19 jet shower $(10^3 \sim 10^4)$

$$\frac{N_K}{N_\pi} \sim 0.5 \pm 0.2$$

Rochester:　$(10^3 \sim 10^4)$

$$\frac{N_K}{N_\pi} \sim 0.25$$

3) Inelasticity $= \frac{\text{energy of secondary}}{\text{total energy available}} \equiv \eta$

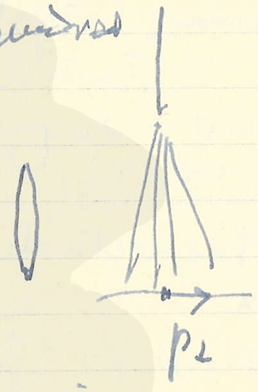
$\eta < 1$

Air shower:

$$\downarrow$$
$$\downarrow$$
$$\tfrac{1}{3} \quad \pi^0$$
$$\swarrow \searrow$$
$$\gamma \quad \gamma$$

$\eta \sim 0.4 \pm 0.2$

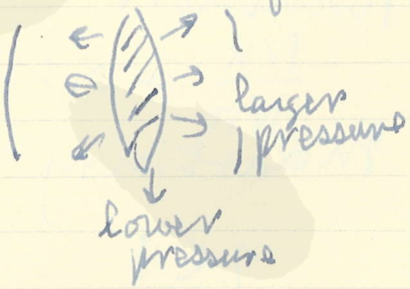
4) angular distribution
$p_\perp$ ~ several hundred MeV



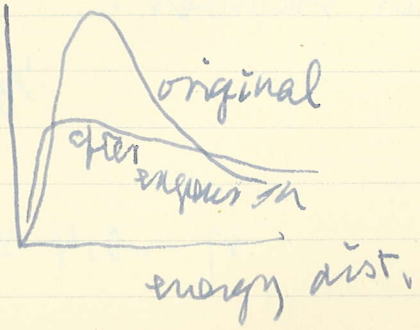
Fermi model
volume, energy
→ temperature
contradiction
with 2) ∵ K : spin 0 : $\frac{N_K}{N_\pi} \sim 1$
$10^3 \sim 10^4$ ← $\frac{N_K}{N_\pi} > 1.5$ T ~ 3.3
E ~ 10 ~ 100 BeV
and with 4) : $p_\perp$ ~ BeV.

Lower temperature is necessary

Landau model -
process of expansion
continuous medium → ideal fluid
number of degrees
of freedom
↳ finite, however



T_c,
no contradiction
with 2) and 4)
1) $E_0 \sim E_0^{1/4}$
3) "effective inelasticity"



Takagi-Kraushaar(-Matsumoto)

$\eta < 1$ $\quad p_t$ $\quad \pi : K_1 : N$

0.75 $\quad \mu$ $\quad 1 : 0.5 : 0.3$ ○ ○

η $\quad 0.5$ $\quad \mu$ $\quad 1 : 0.5 : 0.1$ excitation to

0.3 $\quad \mu$ $\quad 1 : 0.3 : 0.08$ metastable state

multiplicity: $f(\eta)$

Heisenberg model
classical non-linear wave eq.
Turbulence

$$N(p_0) \sim 1/p_0^2$$

2) composition: O.K.

3) ~~inelast~~ : $p_\perp$: O.K.

1) multiplicity: $N \propto E^*/\mu \propto E^{1/2}$ too large for large E.

[modification:

$$\eta \sim 0.01$$

long distance collision

criticism: $\Delta x \sim \frac{\sqrt{1-v^2}}{\mu}$ (thickness)

$$\Delta p \sim \frac{\mu}{\sqrt{1-v^2}}$$

quantum effect

for $\Delta p/p \leq \frac{\mu}{M}$

Landau : energy of π $\lesssim$ BeV
meson-meson interaction
(Heisenberg model, too)
Takagi : metastable state
of life-time $\gtrsim 10^{-23}$ sec.
(Lindenbaum : π production
$1 \sim 3$ BeV)

Lepore-Newman : anti-proton annihilation
multiplicity average ~ 6

Newman : $\gamma_1 \gamma_2 \gamma_3 \gamma_4$ ~~$= \sigma_1 \sigma_2 \sigma_3$~~
$\gamma_5\tau_1, \gamma_5\tau_2\ \gamma_5\tau_3\omega_1,\ \gamma_5\tau_3\omega_2\ \gamma_5\tau_3\omega_3$
9-dimensional space
16 x 16 matrix
$\rho_1\sigma_1, \rho_1\sigma_2, \rho_2\sigma_3, \rho_2, \rho_3\tau_1, \rho_3\tau_2,$ ~~$\rho_3\tau_3$~~
$\rho_3\tau_3\omega_1, \rho_3\tau_3\omega_2, \rho_3\tau_3\omega_3$

Yennie

$$j_\mu(p', p) = e\{\bar{u}_{p'}\gamma_\mu u_p F_1(q^2)$$
$$+ \frac{\kappa}{4}\bar{u}_{p'}\sigma_{\mu\nu}q_\nu u_p F_2(q^2)]$$

$$F_1^p(q^2) = 1 - \alpha_1 q^2 + \cdots \rightarrow \frac{r_{1p}^2}{6} q^2$$
$$F_2^p(q^2) = 1 - \alpha_2 q^2 + \cdots$$

$$f_1(r) = \int F_1(q^2)\, e^{iqr} d^3r$$

relat. effect : q^2/M^2 $\left(\sim \frac{v^2 \sin^2\theta}{c^2}\right)$

$$F^p_{\text{charge}}(q^2) \cong F_1 - \frac{q^2}{8M^2}[F_1 + 2\kappa F_2]$$

(two components theory)

Foldy term in ⟵ n-electron int.

$$\alpha_1 = \frac{1}{6}\int r^2 f_1 d\tau$$

$$r_{1p}^2 = \int r^2 \rho\, d\tau \cong [0.75 \times 10^{-13}]^2$$
> 0.6

$$F_1^n(q^2) = 0 - \frac{r_{1n}^2 q^2}{6} + \cdots$$

intrinsic electron-neutron interaction

$$F_1^p + F_1^n = F_1^{\text{core}}$$

$$F^p_{\text{charge}} + F^n_{\text{charge}} \cong F_1^p + F_1^n$$

$$\sqrt{r_c^2} \cong r_{1p}$$

1). large core
strong coupling ?

2) No charge symmetry.

X 3) $q_\mu j_\mu \neq 0$: does not help

4) Coulomb law breakdown

$$\frac{1}{q^2} \to \frac{C(q^2)}{q^2}$$

X field theory $C(q^2)$: increasing
(vacuum polarization)

X 5) finite electron size
radiative correction

6) more fundamental

I. C. T. P.

Monday, Sept 17, 1956, Univ. Wash.

9.30 am : Marley :

Wigner, Chairman

V. Bergmann, Relativity

a. Special theory of relativity
electrodynamics

active } Lorentz transf.
passive

Lorentz system S S′

phys. syst. F $\longleftrightarrow$ F′

(Robertson : 3 optical observations)
i) Michelson -
ii) Kennedy
iii) Ives transverse Doppler effect)

mass zero particle versus Hamiltonian formalism

b. general theory of relativity
local region
Fock

$g_{ik} \leftrightarrow$ gravit.) from special to general
geodesic

$L = [\sqrt{g}\, R - \lambda \sqrt{g}] + \dots$

covariance
conservation laws (variation principle

$G_{ik} = R_{ik} - \frac{1}{2} g_{ik} R$, $\mathfrak{G}_i{}^k{}_{,k} = 0$

instead of $T^{ik}{}_{;k} = 0$,

$$\frac{\partial}{\partial x^k} t^{ik} = 0$$

$$-\mathfrak{G}_i{}^k + u_i{}^k = \mathfrak{V}_i{}^{kl}{}_{,l}$$

$$\int \mathfrak{G}_i{}^k d^3x = \int \mathfrak{V}_i{}^{kl} n_i dS$$

test particle
Einstein - Infeld
Fock

$G_{ik} = -\kappa T_{ik}$	$\Delta \Phi = -4\pi\rho$

satelite

Hubble constant
Baade

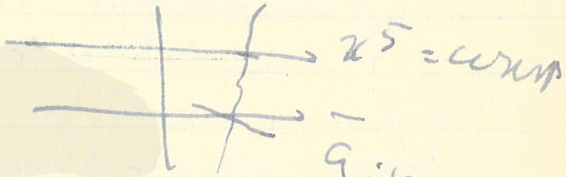
unified theory
5-dimension　　Kaluza, Klein.. etc.

(4) g_{ik} Φ_i
　　10　4

(5) 15 g_{ik}

$g_{ik}(x_1, x_2, x_3, x_4)$

$g_{55} = 1$



$\bar{g}_{ik}$
$= g_{ik} - g_{i5} g_{k5}$
g_{i5} : el. mag. pot.

Einstein
$\Gamma^i_{kl} \longleftrightarrow \Gamma'^i_{kl}$

Levi-Civita
g_{ik} : asymm.　　$\tilde{g}_{ik} = g_{ki}$

Quantization
Peter Bergmann
Gage group → Constraint
Rosenfeld
Consistence → 2nd constraint

Question : Garth

$\varphi_{i,k} - \varphi_{k,i} = f_{ik} \rightarrow f^{ik}$

metric?

$g^{iklm} \; f_{lm}$

Robertson

Kennedy-Thorndyke exp.

V. F. Weisskopf, Nuclear Physics

Nuclear Structure

size: 1.6×10^{-13} cm

proton: 0.7×10^{-13} cm

two body or many body

independent particle aspect

gas or superliquid

exclusion principle

high momenta of nucleons in nuclei

π- nuclear. reaction

$\gamma - 3\pi$

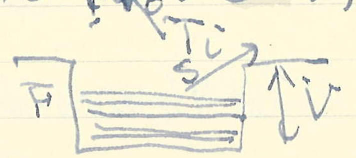
surface effect

Teller : no force inside

Brueckner

self-consistent scheme

$H \sim p^{(1)} + U(1)$ $\qquad U = -V.$



$P = -\frac{E}{A} = -\bar{T}_i + \bar{V}_{(1)}$ $\left(\frac{1}{2}\right)$

$S = -T_F + V_F$

$P \sim S$ (saturation)

$2P - S = -\frac{1}{5} T_F + (\bar{V} - V_F)$

~~δ~~ $\approx^{2} S$

$= 8$ MeV

$T_F \simeq 34$ MeV

$\bar{V} - V_F \neq 0$

$V = V_0 - \frac{k^2}{k_F^2} V_1$

$V_1 = 37$

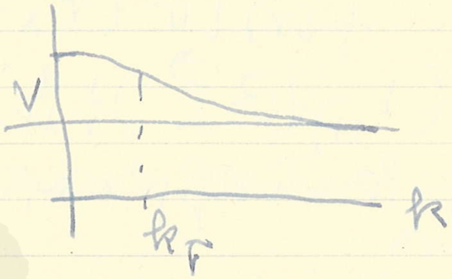
$V_0 = 29$

$H \simeq T^* = \frac{k^2}{2m^*}$

$m^* = 0,48M$

van Vleck 1935

exchange force → velocity dependent



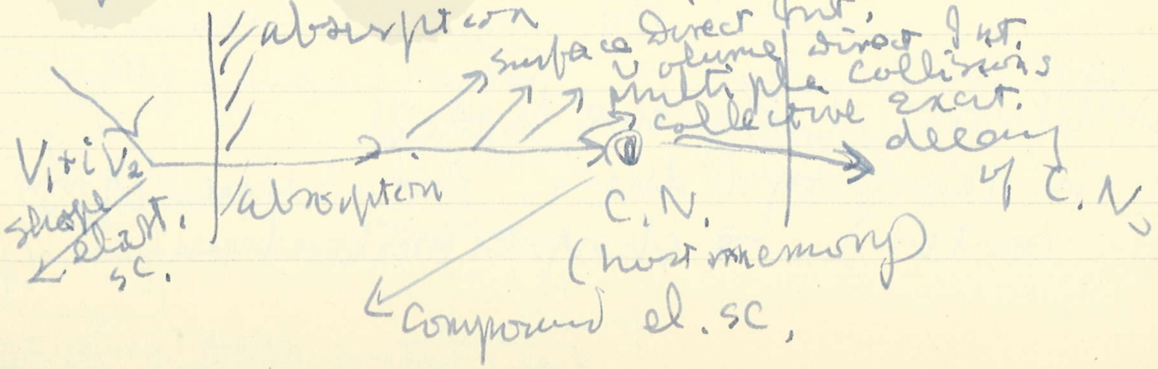
magnetic moment

g orbital is not twice

nuclear radius

nuclear potential radius

Deformation



Discussions:

Brueckner:

Two body force based on meson theory.

Three body forces are ~~un~~ unimportant.

Effective mass

Convergence

Eden:

Shell model

Afternoon

Jensen: Shell Model

$${}_{18}A_{21}^{39} \rightarrow {}_{19}K_{20}^{39}$$

$$f(r)(\vec{\sigma}[\vec{r} \times \vec{p}])$$

$$\left(1 \underset{(+)}{-} a(\vec{\sigma}\vec{\mathcal{L}})\frac{1}{r}\frac{d}{dr}\right)V(r) \Big| a = \left(\frac{\hbar}{2mc}\right)^2$$

Pauli approx.

Discussion

Eden: Velocity dependent potential

Brueckner: spin-orbit coupling

tensor force → average over closed shell → spin-orbit coupling

Wigner:

Mottelson: Collective Models

instability (due to the absence of center) → shape oscillation

heory.
mportant.

Feenberg. Velocity Dependence

Weisskopf:
Wigner:
Jensen:
Breit:

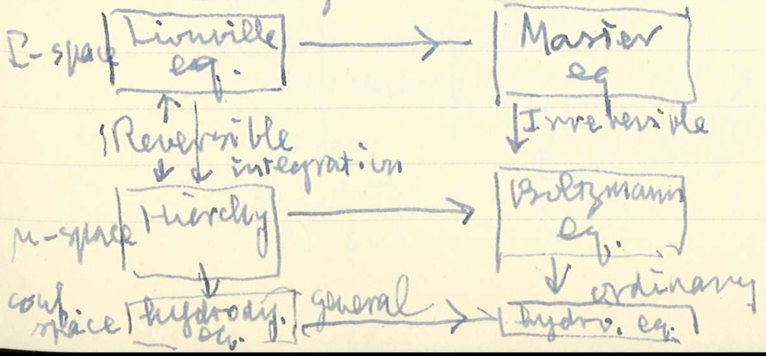
Wheeler: Damping

(Lane, Nuclear Reaction)

(Dinner Party)

Tuesday, Sept. 18:
(Van Hove, statistical Mechanics)

10:30 Panel Discussions on Statistical Mechanics
Uhlenbeck
Husimi: Condensation
Yamamoto - Matsuda: short range force
Ikeda: Cluster Integral
Boer: Phase Transition
Onsager: Irreversible Processes



relaxation time
Uhlenbeck
Prigogine

Discussion Group:
Two Nucleon Problem, Levy

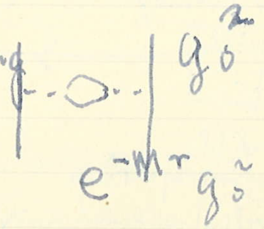
Brueckner: low energy
1. charge indep
2. tensor force
3. effective range ~ $\hbar/\mu c$

high energy
Christian-Hart: 40 ~ 90 MeV n-p

marshak -group
even triplet: tensor force is strong and longerrange (than central)
~~central~~ repulsive core of 5×10^{-14} cm $\pm 1 \times 10^{-14}$ cm
~~odd~~
even singlet: p-p scattering
d-scattering small
range is short
Jastrow: repulsive core of 5×10^{-14} cm $\pm 1 \times 10^{-14}$ cm

?
odd triplet: Christian-Noyces
p-p, non-central - singular
repulsion at low energy
Tensor
10 MeV: change sign
odd singlet: repulsive
odd triplet: central
+ non-static
$E > 100$ MeV
(spin-orbit)

B.W.
T.M.O.

Martirosyan:
Klein: $g_0^2 \left(\frac{\mu}{M}\right)^2 \ll 1$
excluding


correction is small

Klein; Pair of Nucleon

expansion: number of mesons

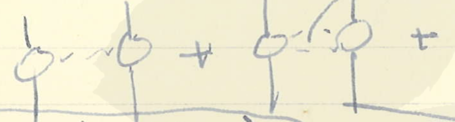
convergence: G_0^2

$r > \frac{1}{3}\frac{\hbar}{\mu c}$: one and two meson exchange

McCormick

Miyazawa

Sato



→ meson scattering off the energy shell (Low)

→ s-wave small

p-wave

renorm. coupl. const.

static limit

renormalized coupling const.

↓

tensor large

central force ~~small~~ large

‖

B. W. + scatt. corr.

Marshak

Klein : $\frac{f^2}{4\pi}\frac{e^{-\mu r}}{x^2} \to 2 \times 1$ for $r > 0.3$

pair term

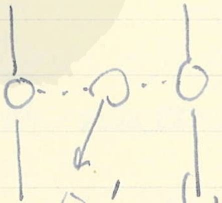
Fukuda;

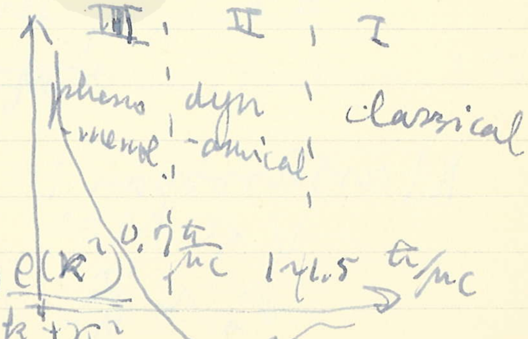
Machida;

I; one meson

II; two meson exchange. recoil

(dependent on cut-off)





$$\Delta_F' = \int d(\kappa^2)\frac{\rho(\kappa^2)}{k^2+\kappa^2}$$

$$\rho(k^2) = \delta(\kappa^2-\mu^2) + \sigma(\kappa^2)$$

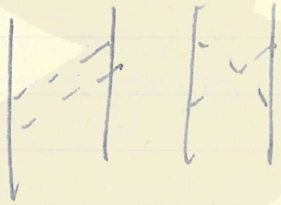
$\sigma(\kappa^2) = 0$ for $\kappa^2 \leq 3\mu$

Ambiguity in II:

B. W.: normalization wrong
imaginary part

F.S.T.:

x $\langle \delta v \rangle_m = \langle \psi_0, \delta v\, \psi_0 \rangle$



$\langle v \rangle \sim \langle \delta v \rangle$

triplet even state

$g^2 \cong 0.08$

[illegible] p-p-scattering

Feldman:

Marinsky: velocity dependence

$$V(r,p) = V_0(r) + V_{ij}(r) p_i p_j$$

$$p_i V_0(r) p_i$$

$$(p_1 - p_2) M_0^{-1} e^{-r^2/\beta^2} (p_1 - p_2)$$

○ energy levels: $p_1 p_2$

$\overline{M_0 \beta^2}$

Marthrosyan: Nucleon-$\overset{\text{anti-}}{\text{Nucleon}}$ Interaction

$V \ll Mc^2$

$\sigma_a \sim \frac{\pi}{M^2}$　　$\frac{\pi}{\mu^2}$　　$\sigma_{obs} \sim 50\,\sigma_a$

Takeda
1. Total cross-section　　twice geometrical

2. annihilation　　about as large

dark sphere　$\sim 0.5\, \hbar/\mu c$
absorp cross-section large
quantum effect. is large

Wednesday, Sept. 19
9.00 a.m.
Tomonaga: History
Dancoff 1939 — mass, charge renormalization
scattering — Tomonaga
outside → inside
inside → outside
optimist → dispersion
pessimist → Z　Lee　~~Lehmann~~ Landau, Källen
Lehmann

Wichmann: Q.E.D,
μ-mesic atom　radiative correction 1%
(vac. pol 0.5%)
electron-proton scatt.
positronium

$$\mu_e=\mu_0\{1+\frac{\alpha}{2\pi}-\underbrace{\frac{\cdot\cdot\,\alpha^3}{\pi}}_{10^{-5}}\}$$

Lamb shift　　H, D, He$^+$

1057.7..
±0.1

Hyperfine structure

$$R_{exp} - R_{th} = \frac{1}{8}\{1353) \times 10^{-4};\ H$$

$$\Delta W = \alpha^3 \cdots$$

Yennie: {Electron-proton-Scattering
Electron-neutron

1) e-n　$\int \rho_n r^2 d^3r \cong 0$

2) e-p　$\int \rho_p r^2 d^3r \cong (0.75)^2 \times (10^{-13})^2 \text{cm}^2$

$$\rho_n = \rho^{(n)}_{meson} + \rho^{(n)}_{core}$$

$$\rho_p = \underset{\overset{\pm}{\overline{\ 0\ }}}{\rho^{(p)}_{meson}} + \rho^{(p)}_{core}$$

$$\rho_{core} = \rho^{(p)}_{core} + \rho^{(n)}_{core}$$

$$\int \rho_{core} r^2 d^3r = (0.75)^2 \times (10^{-13})^2 \text{cm}^2$$

1) K-meson　insufficient
2) charge symmetry
3) charge conserv. → wrong direct
4) electron size due to radiative correction
→ none
5) other int. → neg. contrib.
short range vector interaction

6) Coulomb Law

$$\frac{1}{k^2} C(k^2)$$

vacuum : $C(k^2)$ increasing fn

Bogoliubov (Tamm)

strong int.

$$r_c \sim \hbar/\mu c$$

$$\begin{tikzcd}\pi \arrow[r] & N+AN \arrow[r] \arrow[d] & \pi \\ & N \arrow[r] & \pi\end{tikzcd}$$

core

[illegible]

$\nabla \psi = a \operatorname{div} N$?

Martirosyan (Landau)

$g_0 \ll 1$

$$\ln \Lambda^2/-k^2 = L - \xi \gg 1$$

$$\ln \frac{-k^2}{\mu^2} = \xi$$

$$f_0[x] + g_0^2 f_1(x) + (g_0^2)^2 f_2(x) + \cdots$$

$$x = g_0^2 (L - \xi) \sim 1$$

$$\left.\begin{aligned} G &\approx \rho^{-1} \beta \\ D &\approx x^{-2} d \\ \Gamma &\approx \gamma_5 a \end{aligned}\right\}$$

$$g^2 = \frac{g_0^2}{1 + A g_0^2 L}$$

$g_0(L)$

$g \to 0$

$A = 1/3\pi$ when?

$$d = \frac{1}{1 + A g_0^2 (L - \xi)} \sim (g_0^2 L)^{-1}$$

Thirring; Restricted Rel. Theory

$$\rho_a = \int dj\, M_{(j)} |a\rangle\langle a| M_{(j)}^{+}$$

(観測のwが<0
実際
↓
indefinite metric?

$\phi(X)$ $\phi(X + \Delta x)$

Lee model

$$g^2 = \frac{g_0^2}{1 + g_0^2 \ln L}$$

regularization
Edwards
Caianiello

Lorentz invariance

~~Lehmann:~~
Bogoliubov:

$$\int F(x) e^{i(E x_0 + \sqrt{E^2 - m^2}\, \vec{e}\vec{x})} dx$$

$F(x) = 0 \quad x \gtrsim 0 \quad (\text{or } E^2 < m^2)$

local theory

I) $\varphi(x)$

$S(\varphi)$

a^+, a $\qquad a^+ \cdots a^+ |0\rangle$

$\langle 0 | a \cdots a^+ \cdots |0\rangle + \cdots$

$$a(p) S - S a(p) = \sum a(p) \int e^{-ipx} \frac{\delta S}{\delta \varphi(x)} dx$$

$$S = T(e^{i\int L(x) dx})$$

compound particle

$$\frac{\delta}{\delta\varphi(y)} \left(\frac{\delta S}{\delta\varphi(x)} S^+ \right) = 0 \qquad x \gtrsim y \quad y \lesssim x$$

定理に基くの
実験

$$\frac{\delta^2 S}{\delta\varphi(x)\delta\varphi(y)} S^\dagger$$

$$T\{j(x)\, j(y)\} \qquad j(x) = \frac{\delta(S)}{\delta\varphi(x)} S^\dagger$$

Lehmann; Causality
Scattering Matrix
Dispersion ~~Relation~~ Formulae
Goldberger

nucleon m　　$M(\omega)$: forward scattering amplitude
meson μ

$$\mathrm{Re}[M(\omega)] - \mathrm{Re}[M(0)] = f^2 \frac{\mu^2}{m^2} \frac{(\omega^2-\mu^2)}{\omega^2-\nu^2}.$$

$$+ \frac{2(\quad)}{\pi} \int_{\mu}^{\infty} \frac{d\omega'\omega' \mathrm{Im}[M(\omega')]}{(\omega'^2-\omega^2)(\omega'^2-\mu^2)}$$

(Kramer. Kronig)

Assumptions;
1. exclude interactions other than n-μ.
2. Incoming, outgoing particles → free fields
3. Field operators: $\psi(x)$, $A(x)$ . . .
   $\lim_{t\to-\infty} A(x) = A_{in}(x)$ . . .
4. causality $[A(x), A(y)]$　$x-y$; space-like

Non-forward scattering
$r_n(x-x_1 \cdots x-x_n) =$ — — — —

Schwinger : Limitations and Extensions of Field Theory

Electromag. – Pion field analogy

(spin 1, 0 mass)

1. Intera: F.D. and B.E.

2. Dyn. def. of charge (0, ±1)

no charge itself

3. splitting mass → degeneracy (Reduces the dimension)

K-meson

1. F.D. (nucleon) $T=\frac{1}{2}$

2. nucleonic charge N (0, ±1)

hyper-charge $Y = 0, \pm 1$

$\boxed{\frac{N+Y}{2}}$ 3.

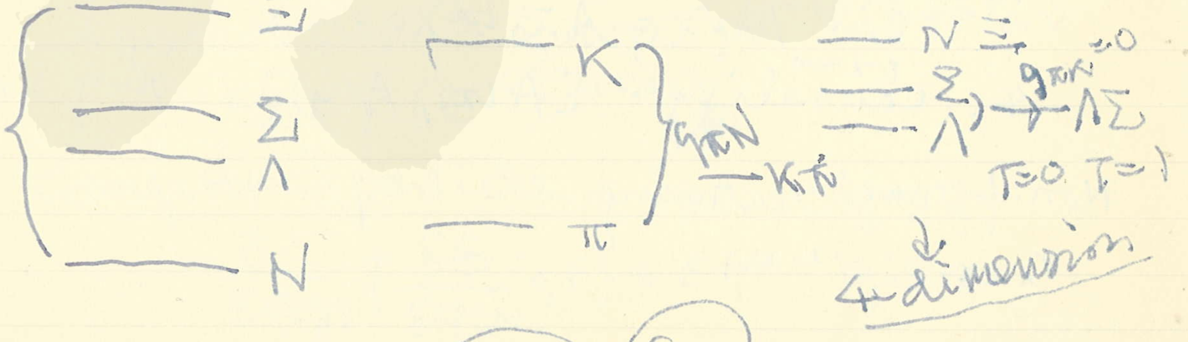
*

N	$T=\frac{1}{2}$	$Y=+1$
K	$T=\frac{1}{2}$	$Y=+1$
$\bar{K}$		$Y=-1$
Λ	$T=0$	$Y=0$
Σ	$T=1$	$Y=0$
Ξ	$T=\frac{1}{2}$	$Y=-1$

$S = Y - N$

π : $N=0$, $Y=0$

$g_{\pi N}=0$
$g_{\pi K}=0$



$g_{\pi N}$ g_K
$g_{\pi K}$ e

ctensions

analogy

K-meson

$\underbrace{\varphi_K \varphi_K}_{\begin{smallmatrix}0^+ \\ K\varepsilon \\ 0^-\end{smallmatrix}} \varphi_\pi$ → parity : dynamical
$K\!\!-\!0^-$

Inconsistency, because no universal length measurability

Thursday: Sept. 20 Pais
9.00 a.m. Yukawa: Introductory Remarks on Meson Theories
Oppenheimer
Low: Mesodynamics
1) Resonance, WK

2) shape

3) γ - π

4) Fine details

$$\frac{e^{i\delta}\sin\delta_{..}}{q^3 v^2(q)} = \frac{\lambda}{\omega} + \frac{1}{4\pi^2}\int_1^\infty \frac{d\omega_{..}}{p\,\omega\,p}\left[\frac{\sigma(\omega)}{\omega_{..}-\omega-i\varepsilon} + \sum \frac{A_{\alpha\beta}\overset{(\omega)}{\sigma_\beta}}{\omega_{..}+\omega}\right]$$

$$\lambda = \frac{2}{3} f^2 \begin{pmatrix} -4 \\ -1 \\ -1 \\ 2 \end{pmatrix}$$

(static approx.)

33 - resonance
Dispersion relation:

$$\frac{e^{i\delta_{33}}\sin\delta_{33}}{q^3} = \frac{4}{3}\frac{f^2}{\omega} + \frac{1}{4\pi^2}\int\frac{\sigma_{33}\,d\omega_p}{(\omega_p-\omega)}P + \text{h.e.c.} \searrow \boxed{\frac{f^2}{3}}$$

$$\boxed{\omega_r \approx \frac{1}{f^2\omega_m}}$$

narrow width $\sim f^2$

$$\frac{4}{3}f^2\frac{\cot\delta\cdot q^3}{\omega} \cong 1 - \frac{\omega}{\omega_r}$$

Watson-Lepore coupling constant

c. γ-π-production

d. Fine details : s-wave eq scattering

Goldberger : Isolated

$$\int_{\mu}^{\mu} + \int^{\mu}$$

$$\frac{e^{i\delta_{33}}\sin\delta_{33}}{q^3} = -\frac{2}{3}\frac{f^2}{\omega} + \frac{1}{4\pi^2}\frac{4}{3}\int\sigma_{33} \qquad \boxed{+\frac{f^2}{3}}$$

Thirring : sum Rules

$f^2 = 0.08$ (±15%) $\qquad f_0^2 = 0.22$ (±15%)

$$r_1 = \frac{\langle\sigma\rangle}{\sigma} = 0.36$$

$L = 4.7$ (cut-off momentum)

$E_0 = -10$ (self energy) $\qquad \bar{N} = 1$

$H^{int} = +8 \qquad M = 1.3$

$M = 1.3$

$\mu_p = 1.96 \qquad \mu_N = -1.2$

11.15 : Michel, Weak Interactions

Fermi 1934

$n \rightarrow p + e + \nu$

S
V) $\Delta I = 0$, no

T
A) $\Delta I = 1, 0$ $0 \leftrightarrow 0$ prohib. no
P no allowed transitions

$g_F = 6 \times 10^{-12}$ (natural unit)

$g_T, g_A \neq 0$; $g_S, g_V \neq 0$ (O^{14}, $0 \leftrightarrow 0$)

no interference no interference

g_T g_S

$(g_S/g_T)^2 < 1$

$g_V/g_S = 0.15 \rightarrow 0$

Morita, Fujita, Yamada (1953)

Forbidden transition

$g_S/g_T < 0$ still ambiguous

g_P?

even and odd coupling

$m_\nu = 0.0003\, m_e$ (odd)

$= 0.0010$ (even)

parity mixing

$\mu^- + p \rightarrow n + \nu$

$e + p \rightarrow n + \nu$

$\frac{|g_T|_\mu}{|g_T|_\varepsilon} = .94 \pm .26$

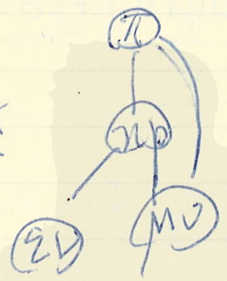
$\mu \rightarrow e + \nu + \nu$

$\rho = 0.64 \pm .10$ (Columbia)

g_P? $|g_S| = |g_T| = |g_P|$: no

Primakoff;
Michel;

~~Tensor~~



pv coupling

$\underrightarrow{10^{-5}}$

$\pi \to e + \nu + \gamma$ (Tensor)

Yang; New Particles

	N.	Q.	C.	S	$\vec{I}$	Cp
S	yes	yes	yes	yes	yes	yes
E	yes	yes	yes	yes	no	~~no~~ yes
W	yes	yes	yes	no	no	~~no~~ no ~~no~~

−2 Ξ^-

−1 $\overline{\Sigma^-}$ $\overline{\Sigma^0}$ $\overline{\Sigma^+}$

−1 $\overline{\Lambda^0}$

0 $\overline{N}$ $\overline{P}$

$\frac{-1}{K^-}$ $\frac{+1}{K^0}$ $\frac{+1}{K^+}$

$\frac{0}{\pi^-}$ $\overline{\pi^0}$ $\overline{\pi^+}$

1, $\left.\begin{array}{l} \theta^0 \to \pi^+ + \pi^- \\ \bar{\theta}^0 \to ? + ? + ? \end{array}\right\}$

2, spin

3, hyperfragment

4, K-particles ; $\tau^+ \to \pi^+ + \pi^+ + \pi^-$: $\boxed{0}$ 1^+ 2^- …

$\theta^+ \to \pi^0 + \pi^+$; 0^+ 1^- 2^+ …

① $\left\{\begin{array}{l} \theta^0 \rightleftarrows \pi^- + P + \bar{\Lambda}^0_1 \\ \tau^0 \rightleftarrows \pi^- + P + \bar{\Lambda}^0_2 \end{array}\right.$ parity conjugation Cp

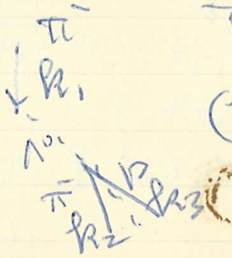
life-time identity cannot be explained

$K^- + P \to \Sigma^- + \pi^+$ $\Sigma^- \to n + \pi^-$

interference

② parity non-conservation

β-decay $(\sigma \cdot k)$



$(k_1 \times k_2) \cdot k_3$

$\underbrace{E, \vec{P}}$, J, P (T) C_e

③ Schwinger

Dalitz: Analysis

$\tau \neq \theta$

$\boxed{\tau \equiv \theta \; \boxed{2^+}}$

Bludman: π^0: weak coupling

Karplus: Parity Conjugation
forward-back symmetry

$2 < \Delta m_{\Sigma^-} - \Delta m_{\Sigma^0} < 23$

Marshak $m(\Sigma^-) - m(\Sigma^+) \approx 15 \pm 2\ m_e$

mag. moment. $\Delta m = \{a - b(\mu_+ - \mu_-)\}(\mu_+ + \mu_-)$

$\downarrow$ $4\frac{e\hbar}{2Mc}$

$e\,C(k)$ $\mu\,C(k)G(\varepsilon)$

$\Sigma^- \to \Sigma + \pi$ $\Sigma^- \to n + K$
$\Sigma \to n + K$ $\Sigma^+ \to p + \bar{K}^0$ $\}$ ps × $\boxed{\text{scalar}}$
$\to \Xi + K$

$\frac{1}{2}(\Sigma^- + \Sigma^+) - \Sigma^0 \gtrsim 1 \sim 2$ MeV $\mu^+ \sim \mu^-$
< 0 $\mu^+ > \mu^-$