Note Book

PHYSICS. I.

Sept. 1948 ~ (~~Oct.~~ Nov.) 1948

Berkeley ~ Princeton

Lectures and Speeches
in
United States
1948 ~ 1949

also
Summary of Papers
relevant to our Research

and

Seminars

H. Yukawa, Bemerkungen über die Natur des Mesotrons
(ZS. f. Phys. 119 (1942), 201)

~~Stoppe~~
not realized

13, Monday

Postponed to Sept. 13.

Short Talk on the Nature of the ~~Mesotron~~ Meson and as to the whole theory of elementary particle

Sept. 9, Thursday, 1948

at the Colloquium of Radiation Laboratory, Univ. of Calif. Phys. Dep.

Yesterday Dr. Serber asked me, if I could talk something on the occasion of this colloquium. As I am little prepared for making a systematic speech, the only thing which is possible for me now is to ~~discuss various~~ ~~po~~ ~~pick up a few points which seem to be of importance~~ express my feeling as to the nature of meson, nuclear forces ~~of importance in the meson theory, which are probably interesting also for you those who are making experiments concerning the nature of the mesons~~.

As you all know very well, there are many points which are not yet settled down ~~both as to~~ in connection with the intrinsic properties of ~~the~~ mesons as well as with their interaction with ~~other elementary particles~~ each other and with. ~~On purely theoretical ground, there are so many possibilities~~ As for intrinsic properties, we can enumerate

i) ~~spin and statistics~~ masses

ii) ~~spin and statistics~~ charge

iii) ~~charge~~ spin (statistics).

As for ~~their~~ interaction ~~with~~ we can divide it ~~take up among other things~~ in two parts, namely

i) the interaction with the nucleon, which is closely related with the nature of ~~the~~ nuclear forces and which has been the central problem of the meson

~~the~~ theory from the beginning.

(V) The interaction with the lepton (i.e. the name ~~light particles by~~ ~~Rosen~~ Møller and Rosenfeld according to summarizing the electron and the neutrino), ~~and~~ and the photon, ~~and the interaction~~ including the interaction with various kinds of mesons with each other, which is also very important in connection with the life-time of mesons.

Now on purely theoretical ground, there are so many ~~possibilities as~~ possible answers ~~as~~ to these questions, that we had better wait for ~~the further development~~ accumulation ~~of the experimental data~~ a while, especial at this very time when ~~important~~ experiments are being performed one after another here in this laboratory ~~as the~~ by using artificially produced mesons ~~as~~ directly or by using high energy nucleons. ~~Thus~~ It is a very ~~happy~~ lucky chance for me to be able to spend several days in the middle of this busy and exciting atmosphere of this laboratory, before I ~~shall~~ go over to Princeton.

Nevertheless ~~it may be a duty for~~ always a theoretical ~~physicists to give~~ it is ~~still~~ a duty for theoretical physicist to make mutual connection between various phenomena discovered by ~~the~~ experimenter as clear as possible and as precise.

i.e. π and μ mesons

In order to do this, we have to construct a one model or other for the mesons interacting with other sort of particles. One point which is ~~very~~ cleared up today is the existence of, at least two sorts of ~~un~~ charged mesons with different masses, owing to the admirable experiments by Bristol physicists including Mr. Lattes.

The next points are

a) masses and spins of them

b) existence ~~of~~ neutral mesons and if they exist, ~~spins of the~~ masses and spins of them.

As to the spins of charged mesons, there are at least four alternatives, as already discussed by Marshak and Bethe:

π	μ	
0	0	Tanikawa
0	1/2	Sakata-Inoue
1/2	0	
1/2	1/2	

Lattes - Gardner - Serber:

π-μ-decay, ~~mass~~ mass ratio ~~as~~ m_π/m_μ as function of kinetic energy of μ-meson E, when the mass of the neutral partner is zero.

$$m_\pi c^2 = \frac{m_\mu c^2}{\sqrt{1-\frac{v_\mu^2}{c^2}}} + p_\nu c$$

$$p_\nu = \frac{m_\mu v_\mu}{\sqrt{1-\frac{v_\mu^2}{c^2}}}$$

$$m_\pi c^2 = \frac{m_\mu c^2\left(1+\frac{v_\mu}{c}\right)}{\sqrt{1-\frac{v_\mu^2}{c^2}}} = m_\mu c^2\sqrt{\frac{1+v_\mu/c}{1-v_\mu/c}}$$

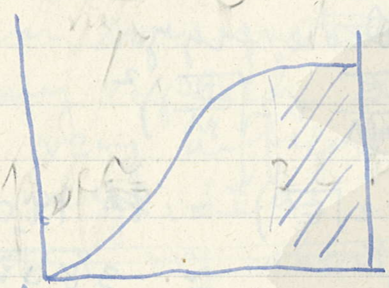
$$\frac{m_\pi}{m_\mu} = \sqrt{\frac{1+v_\mu/c}{1-v_\mu/c}} = 1.31$$

$$\left(\frac{1}{1+\frac{E}{m_\mu c^2}}\right)^2 = 1-\frac{v_\mu^2}{c^2}$$

$$\frac{v_\mu}{c} = \left\{1-\left(\frac{1}{1+E/m_\mu c^2}\right)^2\right\}^{1/2} = \frac{\sqrt{E/m_\mu c^2\,(2+E/m_\mu c^2)}}{1+E/m_\mu c^2}$$

~~$$\frac{m_\pi}{m_\mu} = \sqrt{\frac{1+\sqrt{}}{1-\sqrt{1-\frac{E}{m_\mu c^2}}}}$$~~

Serber: μ-β-decay, energy distribution of electrons, when two neutrinos are simultaneously emitted



Models of π-μ-decay

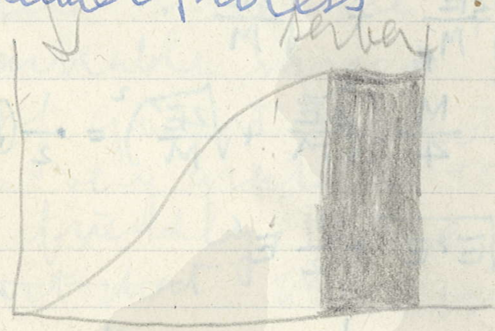
i) $\pi(0) \rightarrow \mu(1/2) + \nu(1/2)$

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

$P \rightarrow N + \pi$

$P \rightarrow N + e + \nu$

Oppenheimer Process



Anderson Process

$\pi(0) \rightarrow \mu(1/2) + \mu^0(1/2)$

ii) $\pi(1/2) \rightarrow \mu(1/2) + \gamma$

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

$P \rightarrow N + \pi + \nu$

$P \rightarrow N + e + \nu$

shower

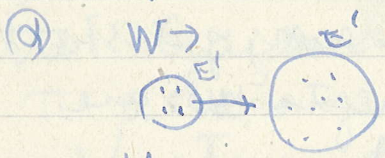
$\pi \rightarrow \mu + \mu^0$

div. dif. is more serious

Anderson process

$\pi(1/2) \rightarrow \mu(1/2) + \mu^0(0)$

Meson-Production by High Energy α-Particles



relative max. velocity

$$\sqrt{\frac{2E}{4M}} + 2\sqrt{\frac{2E'}{M}}$$

(n) $E = \frac{W}{4} \rightarrow$

max. rel. energy

$$\frac{M}{4}\left(\sqrt{\frac{2E}{4M}} + 2\sqrt{\frac{2E'}{M}}\right)^2$$

W = 380
E = 95
E′ = 25 →

$$= \frac{1}{2}\left(\sqrt{E} + 2\sqrt{E'}\right)^2 = ~~93~~ \; 190 \text{ MeV.}$$

$$\cong 380 \, m_e$$

Talk with Mr. Smith
Jan. 2, 1949 at Mr. Bourgin's House

Meson-Production by High Energy Protons
Berkeley Cyclotron 350 MeV ~ 700 m_e

rel. max. vel:

$$\sqrt{\frac{2E}{M}} + \sqrt{\frac{2E'}{M}}.$$

max. rel. energy:

$$\frac{M}{4}\left(\sqrt{\frac{2E}{M}} + \sqrt{\frac{2E'}{M}}\right)^2 = \frac{1}{2}\left(\sqrt{E} + \sqrt{E'}\right)^2$$

$$= \frac{1}{2}E + \sqrt{E \cdot E'} + \frac{1}{2}E'$$

E = 350
E′ = 25

$$= \frac{1}{2}\, 375 + \frac{1}{2}\, 190$$

$$= \frac{565}{2} = 282. \text{ MeV}$$

19
19
171
19
361

$$\cong 565 \text{ MeV.}$$

S.I

I. Short talk on the Nature of Mesons and Nuclear Forces

Sept. 13, 1948
Phys. Dep., Univ. Calif., Berkeley

I am sorry ~~that~~ I am little prepared for my speech and moreover ~~I find it~~ it is very difficult for me at present to put ~~get~~ my ideas in order, because, ~~after during my short stay to here in this university~~ I ~~was informed~~ have learned so many new things at once during my short stay here in this university. Nevertheless I am very fortunate to ~~be~~ in that I arrived here just the moment when important discoveries have been made one after another since the ~~splendid success~~ remarkable success of producing mesons ~~as~~ by giant cyclotron early in this year. I am very grateful to you ~~all~~ who are all very friendly to ~~me~~ us Japanese in spite of ~~fact that~~ the serious mistake of Japan to your country.

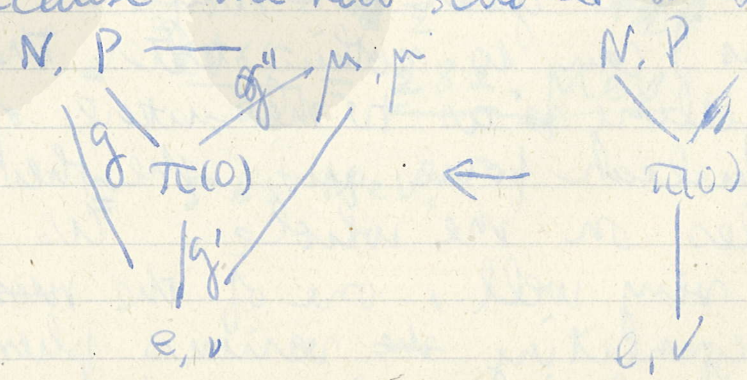
Thus I can do nothing better than to express my feeling ~~as~~ as to the nature of the meson, the nuclear force and the theory of elementary particles on the whole. As you all know very well, one of the ~~most~~ simplest way of connecting ~~the~~ various phenomena found in the field of nuclear physics and cosmic rays, are to as already discussed by many physicists including Marshak and Bethe assume the existence of ~~only~~ two kinds of mesons, i.e. π- and μ-mesons. ~~We~~ apparently we ~~have~~ ~~make~~ ~~choice~~ can choose one from the following possibilities:

i) π(0): integ. spin μ(0) integ. spin
ii) π(0) μ(1/2)
iii) π(1/2) μ(0)
iv) π(1/2) μ(1/2)

~~But~~ Very recent experiments concerning the energy of the electrons created by the decay of μ-mesons see to show that the ~~decay~~ mechanism of decay is such that

$$\mu \rightarrow e + 2\nu,$$

although there ~~are~~ still remains the controversy as to whether the energy is unique or continuous. If so, only the cases ii) and iv) are permitted. If we take the case ii), which was already considered by Sakata and others several years ago, the departure from the origin form of the meson theory is not so large, because the new scheme is nothing



but slight ~~re~~generalization of the original scheme of the theory. The difficulties which remain in this theory are

i) if we ~~take~~ adjust the ~~mass of the μ-meson~~ coupling constants g'' so small that the capture of negative mesons ~~through the indirect~~ due to the indirect interaction between μ-meson and the nucleon is very rare, then the life-time of μ-meson due to β-decay ~~very~~ becomes very long. ~~As emphasized by Dr. Serber, the~~

ii) ~~The observed~~ the life-time of π-meson ~~seems~~ observed in Rad. Lab. ~~seem~~ as about 5.7 × 10⁻⁹ sec. and seems to be too long to reconcile with the β-decay of ~~the~~ nucleon through the π-meson.

Of course we can introduce the direct interactions ~~between~~ of nucleons, μ-meson and light particles with one another and adjust the ~~constants~~ interaction constants. ~~On the other hand As for the other possibility~~ although ~~but~~ these sorts of assumptions ~~argument~~ spoils the simplicity of the original meson theory.

As for the other possibility that ~~the~~ both π- and μ-mesons are particles with spin 1/2, we can say little, because the nuclear forces due to the ~~so called~~ generalized meson pair theory have ~~too~~ so strong a singularity that any quantitative result can hardly be obtained at present. ~~Anyhow~~

~~In any ca~~ In this connection, it seems very interesting that the ~~very recent~~ newest value for the ratio of masses of π- and μ-mesons are so small that it can be reconciled with the assumption that the neutral partner of the π-μ-decay is a particle with the rest mass zero. If so, it will be a crucial test for ~~the as~~ the meson theory to verify whether this partner is a neutrino (ii) or a photon (iV). ~~Thus the~~

A point which seems to be a another serious drawback of the meson-neutrino theory of the nuclear forces ~~are~~ is ~~that~~ ~~how to~~ that the ranges of the forces between neutron-proton and those between proton-proton are approximate the same so far as the experiments hitherto ~~obtained~~ is concerned. In this connection, we ~~expect that~~ the ~~result~~ high energy proton-proton experiments which are been undertaken ~~starting~~ in Rad. Lab. will supply us a very valuable information.

At any rate, any one of the present meson theory is incomplete in ~~that~~ it can not explain all the phenomena at once. So we are very much embarassed to find the nature is much more complicated ~~as~~ than we expected. ~~Nevertheless~~ Of course we hope that this apparent complication is due to the lack of insight on the part of ~~we~~ us physicists rather than nature itself. ~~but~~ I do not know what is really the ~~then~~ point that is missing, but ~~I feel that~~ Although ~~I am~~ we are quite sure now that the nuclear forces are intimately connected ~~with the mesons at least~~ with some kind of mesons, which may have been already observed or may have not, we feel that the connection is a more subtle one than we hitherto expected. ~~I mean, that the nuclear forces and the meson that for example,~~

One ~~may~~ can imagine that the two alternatives ~~be~~ above mentioned are not contradictory with each other in the future theory. ~~In~~ As to the details of ~~this~~ such a sort of theory, I can say little at present. I want rather think over the whole matter after I ~~have~~ settle down in Princeton.

44 I want to add a few words concerning the general feature of the field theory. I wonder that the theoretical works made independently ~~with each other~~ in this country and in Japan coincide with each other more than once in the specific meson-theory ~~and~~ as well as in more abstract formulation of the field theory. ~~Especi As to the latter case~~ Theories of Schwinger and Tomonaga belong to the latter case. We can think that these theories are something like the marks indicating the ~~boundary of the region~~ extreme limit whe~~re~~ we can reach by accepting both the special theory of ~~the~~ relativity and the quantum mechanics in the present form. What lies out this limit, we don't know.

D

Mesons and Nucleons

By Prof. O. Klein
Institut för Mechanik och Matematisk Fysik, Stockholms Högskolas

(Nature, June 5, 1948, 161, 897)

(1) μ-meson and neutral counterpart with spin 1/2. charge meson decays into neutral meson, electron and neutrino.
(2) These particles interact by means of Yukawa field corresp. to charged particles of integral spin. (electro-photons) (no neutral one) some σ-mesons may be of this kind
(3) π-meson and possibly others of still higher mass[1], are supposed to be metastable compound system of mesons, held together by means of the interaction mentioned above. As a working hypothesis, assume nucleons to be stable compound systems of mesons.

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1. Leprince-Ringuet and L'Héritier, J. Phys. 7 (1946), 66, 69; Rochester and Butler, Nature 160 (1947), 855.

○ Meson Scattering with Nuclear Excitation
H. J. Bhabha, R. R. Daniel
Tata Institute of Fundamental Research
Bombay
(Nature June 5, 1948, 161, 884)

○ A Doubly Charged Cosmic Ray Particle
A. B. Sahiar (ibid)
(ibid. May 22, 1948, 161, 810)

D Capture of Negative Mesons by Nuclei

(A.S. Lodge Nature 161, (1948), 809)
(Clarendon Laboratory, Oxford)

A: $\pi \rightarrow \mu + \rho$ (f) ρ: neutral meson
A': $\mu \rightarrow \pi + \rho$
B: $N \rightarrow P + \pi^-$ (g)

C: $P + \pi^- + \rho$

$P + \mu^-$ ↗ ↘ $N + \rho$

$N + \pi^+ + \mu^-$

X $P + \mu^- \rightarrow N$ (10^{-16} sec)

from A: (1) $\frac{1}{\tau_\pi} = \frac{1}{8\pi} \frac{f^2 \hbar^3}{m_\pi^2 c} \frac{m_\mu c^2}{\hbar} \frac{v_\mu}{c}$

v_μ: vel. of μ-meson

for nuclear capture of μ-meson from K-orbit through C.

(2) $\frac{1}{\tau_c} \sim \frac{1}{4\pi^2} \frac{f^2 \hbar^3}{m_\pi^2 c} \frac{g^2}{\hbar c} \left(\frac{e^2}{\hbar c}\right)^3 Z^4 \left(\frac{m_\mu}{m_\pi}\right)^2 \frac{m_\rho c^2}{\hbar} \frac{p_\rho}{m_\rho c}$

$Z = 13$, $\tau_c = 10^{-6}$ sec; $\frac{e^2}{\hbar c} = 1/137$, $\frac{g^2}{\hbar c} = 0.1$

$\frac{m_\pi}{m_\mu} = 1.64 \pm 0.11$ $\frac{m_\mu}{m_e} = 205 \pm 20$ [10]

[10] Powell Priv. Comm.

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A: $\pi \to \mu + \rho$ (f) ρ: neutral meson
A': $\mu \to \pi + \rho$
B: $N \to P + \pi^-$ (g)

C: $P + \mu^- \searrow N + \pi^+ + \mu^- \nearrow N + \rho$, $\nearrow P + \pi^- + \rho \searrow$

X $P + \mu^- \to N$ (10^{-16} sec)

from A: (1) $\frac{1}{\tau_\pi} = \frac{1}{8\pi} \frac{f^2 \hbar^3}{m_\pi^2 c} \frac{m_\mu c^2}{\hbar} \frac{v_\mu}{c}$

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for nuclear capture of μ-meson from K-orbit through C.

(2) $\frac{1}{\tau_C} \sim \frac{1}{4\pi^2} \frac{f^2 \hbar^3}{m_\pi^2 c} \frac{g^2}{\hbar c} \left(\frac{e^2}{\hbar c}\right)^3 Z^4 \left(\frac{m_\mu}{m_\pi}\right)^2 \frac{m_p c^2}{\hbar} \cdot \frac{p_p}{m_p c}$

$Z = 13$, $\tau_C = 10^{-6}$ sec; $\frac{e^2}{\hbar c} = 1/137$, $\frac{g^2}{\hbar c} = 0.1$

$\frac{m_\pi}{m_\mu} = 1.64 \pm 0.11$ $\quad \frac{m_\mu}{m_e} = 205 \pm 20$ [10]

---

[10] Powell Priv. Commun.

$v_p/m_p c = 1$, $v_\mu/m_\mu = 1/2$ $v_\mu/c = 1/3$

~~七分~~

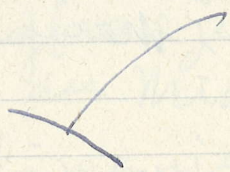
$\therefore$ $\frac{f^2 \hbar^3}{m_\pi^2 c} \sim 10^{-14}$

$\therefore$ $\tau_{\pi \to \mu} \sim 4 \times 10^{-8}$ sec.

(Greisen: P.R. 73 (1948), 521
$\tau_{\pi \to \mu} = 6 \times 10^{-8}$ sec)

○ Scattering of 100-MeV. Neutrons by Protons
F. C. Barker
(Nature 161, May 8, 161, 726)

hammer tracks ; $Li^8 \rightarrow He^4 + He^4 + e^-$
(0.88 sec)



($Li^8 \rightarrow Be^8 + e^-$
$Be^8 \rightarrow He^4 + He^4$)
$n \rightarrow C^{12} \rightarrow Li^8 + \cdots$?

○ A New Method for the Determination of the Mass of Mesons
Powell and Rosenblum
(Nature 161, March 27, 1948, 473)

Jungfraujoch High-Altitude Research Station

mass, sign of charge
emulsion の中の track を直接 mg. field で
曲げようとすると 10^6 gauss 位が必要
そこで 二枚の emulsion を向い合わせ、3 mm の
gap に垂直に 8,600 Gauss の field をかける。 two plate の geometrical relation
をきめるために X-ray の fine pencil を
development の前にあてる。(in a form of
geometrical grid)

○ The Artificial Production of Mesons
Dr. G. P. S. Occhialini
and
Dr. C. F. Powell
(Nature April 10, 1948, 161, 551)
Lattes, Gardner: Science, March 12, 1948.
313 ± 16 me
Goldschmidt
King, Muirhead and Ritson (Bristol)
(270 ± 40) me for both π- and σ-mesons.

$m_\pi / m_\mu = 1.65 \pm 0.15$

$m_\mu = 200\, m_e \quad m_\pi = 330 \pm 30\, m_e$

~~τ_μ~~ $\tau_\pi > 0.4 \times 10^{-10}$ sec.

Production Mech.
McMillan and Teller, P.R. 72, 1 (1947)
Horning and Weinstein, ibid. 251 (1947)

① Observations on the Production of Mesons by Cosmic Radiation

By Occhialini and Powell (H.H. Wills Lab.)

(Nature July 31, 1948, 162, 168)

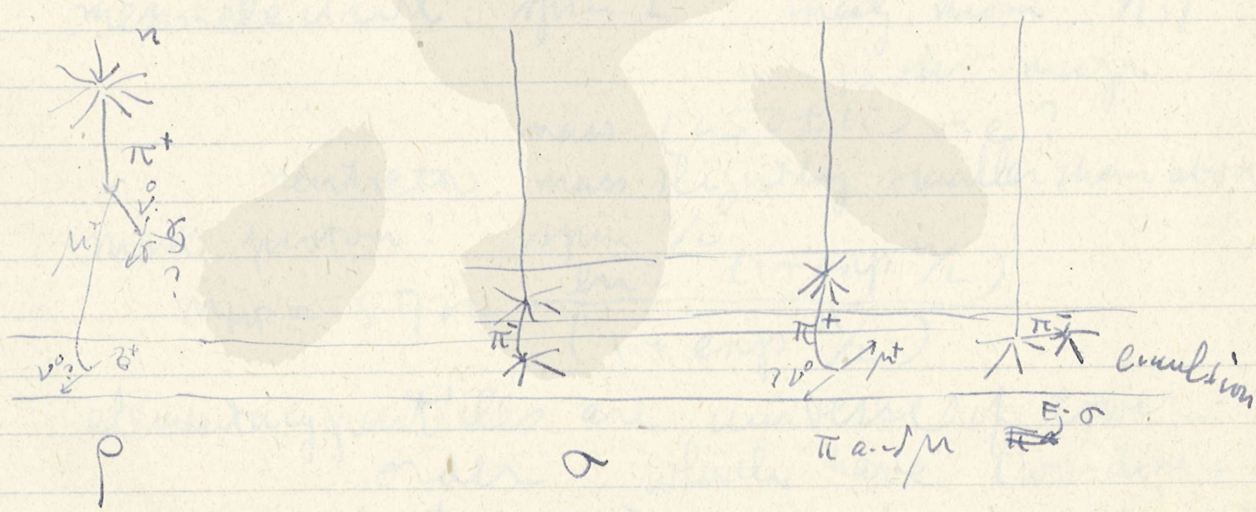
Jungfraujoch
Pic du Midi) 10,000 ft ht.

Kilimanjaro
Chacaltaya) 18,000 ft ht.

twenty nuclear exclusions accompanying the emission of slow mesons.

σ : disintegrates nucleus
π : decays into μ
μ : decay product
ρ : give rise no observed secondary.

$N_\sigma / N_\pi = 1.05 \pm 0.25$



○ Observations on Slow Mesons of the Cosmic Radiation
By U. Camerini, H. Muirhead
C. F. Powell and D. M. Ritson
(Nature 162 (1948), 433 Sept. 28)

1) absence of heavy charged particles emitted in the process of capture of ~~meso~~ negative μ-mesons by nuclei:

$H^{+} + \mu^{-1} \to n^{0} + \nu^{0}$

ν^{0}: neutretto.

(Sard, Ittner, Conforto, Crouch; P.R. 74 97 (1948))

(Groetzinger and McClure; P.R. 74 (1948), 341)

2) $\tau_{\pi} \sim 6 \times 10^{-9}$ sec. $(6 \pm 3 \times 10^{-9}$ sec)

ρ-ηの値は π-decay product が assumeした.

○ Radiation Damping and Velocity of light
Ferretti and Peierls, Nature 160, 531, 1947
Heitler, 161, 628, May 1, 1948.

○ Mesons of Different Masses
J. Barnóthy
Inst. f. Experimental Physics
University of Budapest
(Nature 161, 681, May 1, 1948)

Papers of Terrestrial Magnetism Hungary, No. 2 (1947)

Review: Nature 160 (1947), 847

meso-electron: spin 1, mag. mom. 1/137 Bohr magn.
mass $(250 \pm 10)\, m_e$?
neutretto. mass slightly smaller than above
meso-proton: spin 1/2

$$m_{MP} = 5720 \frac{\ln 2 \cdot (1 + \exp \pi/2)}{(1 + \exp \pi/2)}$$

elementary particles are universes of lower order, which have two-dim. intersections with our universe.

Phys. Rev.

◎ Cloud Chamber Track of
a Decaying ~~Elect~~ Mesotron
Schutt, DeBenedetti and Johnson
Bartol Research Fundation
of Franklin Justitute,
Swarthmore, Pennsylvania,
(Phys. Rev. 62 (1942), 552)

mass 40 ~ 400 m_e
energy of decay el. : > 3×10^7 eV

Journ. de Phys. Rad.

○ Existence Probable d'une Particule des Masse (990 ± 12 pour 100) m_e dans le Rayonnement Cosmique
Par L. Leprince-Ringuet et M. L'Héritier

(J. Phys. Radium 7 (1946), 66)

method of elastic scattering

1. $\mu_{moy} \cong 300$ $\mu_{max} < 700$
2. $200 < \mu < 450$
3. $\mu_0 = 990 \pm 12$ pour 100.

(Compt. Rend. 219 (1944), 618.)

○ Recherches sur les Protons de grande Énergie et sur les Mésotrons dans la Partie Pénétrante du Rayonnement Cosmique
(ibid. p. 69)

Phys. Rev.

○ The γ-Instability of Mesons

R. J. Finkelstein

Univ. Calif. → Cal. Tech

(Phys. Rev. 72 (1947), 415)

(A) $M_0 \to \gamma_1 + \gamma_2$ $\tau_A = 1 \times 10^{-16}$ sec.

(B) $M_1 \to \gamma_1 + \gamma_2 + \gamma_3$ $\tau_B = 2 \times 10^{-11}$ sec.

(C) $M_1 \to M_0 + \gamma$ $\tau_C = 1 \times 10^{-18}$ sec

(D) $M_1^{\pm} \to M_0^{\pm} + \gamma$ $\tau_D = 4 \times 10^{-18}$ sec

0 : pseudoscalar ± : charged

1 : vector

(D) $M_1^+ \to P^+ + (N)$ $P^+ \to P_i^+ + \gamma_i$

$P_i^+ + (N) \to M_0^+$

$$\tau_D = 4\,\tau_C$$

$M_i^+ \to M_1^+ + \gamma$ の如き type の transition は

∴ この process は forbidden.

Schwinger Mixture

Jauch and Hu, P. R. 65 (1944), 289.

$\mu_1/\mu_0 = 1.6$ $\mu_0 = 177$

$f_0^2/\hbar c = 0.05$ $f_0/\mu_0 = f_1/\mu_1$

○ Quantum Mechanics of Fields.

I. Pure Fields.

Max Born and H. W. Peng
University of Edinburgh

(Proc. Roy. Soc. Edinburgh A
LXII (1943–1944) 40)
(March 7, 1944)

Introduction

Bohr theory → matrix mechanics
field の Fourier expansion → single term
を matrix とみる.

1. Scalar Field: Classical Treatment

$$\phi_\alpha = \frac{\partial \phi}{\partial x_\alpha} \qquad \phi_\alpha^* = \frac{\partial \phi^*}{\partial x_\alpha} \qquad (1.1)$$

$\Lambda(\phi, \phi^*; \phi_1, \phi_1^*; \phi_2, \phi_2^*; \ldots)$
→ Lagrangian density: real

$$\left.\begin{aligned} \Phi^* &= \frac{\partial \Lambda}{\partial \phi} & \Phi &= \frac{\partial \Lambda}{\partial \phi^*} \\ \Phi_\alpha^* &= \frac{\partial \Lambda}{\partial \phi_\alpha} & \Phi_\alpha &= \frac{\partial \Lambda}{\partial \phi_\alpha^*} \end{aligned}\right\} \quad (1.2)$$

field eq:

$$\left.\begin{aligned} \sum_\alpha \frac{\partial \Phi_\alpha}{\partial x_\alpha} &= \Phi \\ \sum_\alpha \frac{\partial \Phi_\alpha^*}{\partial x_\alpha} &= \Phi^* \end{aligned}\right\} \quad (1.3)$$

Conservation laws:

$$\left.\begin{aligned} \sum_\beta \frac{\partial T_{\alpha\beta}}{\partial x_\beta} &= 0 \\ T_{\alpha\beta} &= \phi_\alpha \Phi_\beta^* + \Phi_\beta \phi_\alpha^* - \Lambda \delta_{\alpha\beta} \end{aligned}\right\} \quad (1.4)$$

$$\left(\because \quad \sum_\beta \frac{\partial T_{\alpha\beta}}{\partial x_\beta} = \phi_\alpha \sum_\beta \frac{\partial \Phi_\beta^*}{\partial x_\beta} + \sum_\beta \frac{\partial \phi_\alpha}{\partial x_\beta} \frac{\partial \Lambda}{\partial \phi_\beta^*} \right.$$

$$+ \sum_\beta \frac{\partial \Lambda}{\partial \phi_\beta^*} \frac{\partial \phi_\alpha^*}{\partial x_\beta} + \sum_\beta \frac{\partial \Phi_\beta}{\partial x_\beta} \phi_\alpha^*$$

$$- \frac{\partial \Lambda}{\partial x_\alpha}$$

$$= \phi_\alpha \Phi^* + \sum_\beta \frac{\partial \phi_\alpha}{\partial x_\beta} \frac{\partial \Lambda}{\partial \phi_\beta^*} + \sum \frac{\partial \Lambda}{\partial \phi_\beta^*} \frac{\partial \phi_\alpha^*}{\partial x_\beta}$$

$$+ \Phi \phi_\alpha^* - \frac{\partial \Lambda}{\partial \phi} \phi_\alpha \frac{\partial \Lambda}{\partial \phi}$$

$$- \frac{\partial \Lambda}{\partial \phi^*} \phi_\alpha^* - \sum_\beta \frac{\partial \Lambda}{\partial \phi_\beta^*} \frac{\partial \phi_\beta^*}{\partial x_\alpha} - \sum_\beta \frac{\partial \Lambda}{\partial \phi_\beta} \frac{\partial \phi_\beta}{\partial x_\alpha}$$

$$\left. = 0 \right)$$

Lorentz Transformation

$$\phi_\alpha' = \phi_\alpha + \varepsilon \sum_\beta f_{\alpha\beta} \phi_\beta \qquad (1.5)$$

$$f_{\alpha\beta} = - f_{\beta\alpha}$$

$$\Lambda' = \Lambda + \varepsilon \sum_{\alpha,\beta} \left(f_{\alpha\beta} \phi_\beta \frac{\partial \Lambda}{\partial \phi_\alpha} + \frac{\partial \Lambda}{\partial \phi_\alpha^*} f_{\alpha\beta} \phi_\beta^* \right)$$

$$\Lambda' - \Lambda = \varepsilon \sum_{\alpha,\beta} f_{\alpha\beta} (\phi_\beta \Phi_\alpha^* + \Phi_\alpha \phi_\beta^*) \quad (1.6)$$

$\therefore$ if Λ: Lorentz invariant, (1.6) should vanish, so that

$$\phi_\beta \Phi_\alpha^* + \Phi_\alpha \phi_\beta^*$$

or $T_{\alpha\beta}$ itself should be symmetrical, or vice versa.

If Λ is gauge-invariant with respect to the transformation $\phi \to \phi e^{i\gamma}$ with γ arbitrary real constant,

$$i\left(\phi \frac{\partial \Lambda}{\partial \phi} + \sum_\alpha \phi_\alpha \frac{\partial \Lambda}{\partial \phi_\alpha^*} - \frac{\partial \Lambda}{\partial \phi^*}\phi^* - \sum_\alpha \frac{\partial \Lambda}{\partial \phi_\alpha^*}\phi_\alpha^*\right) = 0$$

or

$$i\left(\phi \Phi^* + \sum_\alpha \phi_\alpha \Phi_\alpha^* - \Phi\phi^* - \sum_\alpha \Phi_\alpha^* \phi_\alpha^*\right) = 0 \quad (1.7)$$

~~which eq. is~~ We have thus the law of conservation of charge or **load**; ~~i.e.~~

$$\sum_\alpha \frac{\partial s_\alpha}{\partial x_\alpha} = 0 \qquad s_\alpha = i(\phi \Phi_\alpha^* - \Phi_\alpha \phi^*)$$

(:

Born and Peng, Quantum Mechanics of Fields II. Statistics of Pure Fields (Proc. Roy. Soc. Edinburgh LXII (1943~1944), 92)

apeiron(s) : ἄπειρον (Anaximander of Miletos (about 550 B.C.) means the boundless and shapeless primordial matter which is the first product (arché, ἀρχή) of the creation and develops into the specific types of ordinary matter.

$$H = \frac{1}{2}(p_1^2 + \nu_1^2 q_1^2) + \frac{1}{2}(p_2^2 + \nu_2^2 q_2^2)$$

equivalent to reducible representation of

$$E = \frac{1}{2}(p^2 + \nu^2 q^2) \quad \text{with} \quad \nu = \begin{pmatrix} \nu_1 & 0 \\ 0 & \nu_2 \end{pmatrix}$$

Born and Peng, III. Electromagnetic Field and Electron Field in Interaction (ibid. LXII (1944~1946), 127)

○ M. Markow

Über das vierdimensional-ausgedehnte Elektron in dem relativistischen Quantengebiet

Journal of Physics 2 (1940), 453.

Louis de Broglie

Étude de la Théorie générale des Particules à spin par la Méthode de Fusion

(Solvay Report
(avril) Sept ~ Oct, 1948)

1. La Mécanique ondulatoire du photon
2. Théorie générale de particules à spin par la method de fusion
3. Remarque sur le Sens de la méthode de fusion

Broglie, Théorie générale des particules à spin. Paris, Gautier-Villars 1943
Mécanique ondulatoire du photon sous presse

Frenkel, Rel. Q. T. (J. Phys. U.S.S.R. 9 (1945), ~~1943.~~ 465.

(J. de Phys. 9 (1948), 147)

Sur la Désintégration du méson

Par C. Marty (Collège de France) et J. Prentki (Institut Henri-Poincaré)

Sommaire: $\pi(0,1) \to \mu(1/2) + \mu^0(1/2)$

$\tau_\pi \sim 10^{-8} \sim 10^{-9}$ sec,

les constantes de couplage sont celles de p désintégration.

(J. de Phys. 9 (1948), 137)

L'Hypothèse d'une Particule [illegible]ntermédiaire Légère (méson λ) dans les Grandes gerbes Cosmiques de l'Air (Gerbes d'Auger)

Étude à la Chambre de Wilson

Fretter, P.R. 73 (1948), 41.

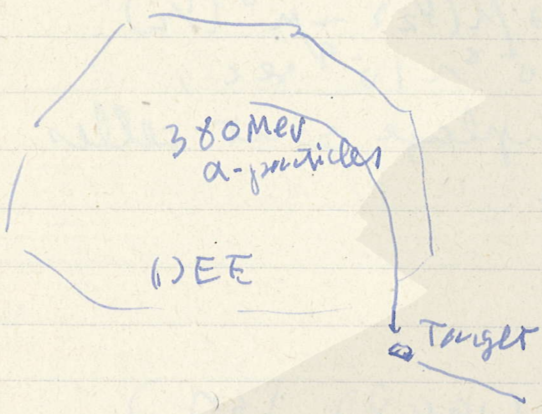
penetrating shower と electron の 3 [illegible] の mass の λ-meson に [illegible]

Science

(1) Production of Mesons by the 184-inch Berkeley Cyclotron

by Eugene Gardner and ~~C. G. L.~~ C. M. G. Lattes

(Science, 107 (1948), March 12, p. 270)



negative meson;
→ 313 ± 16 me

(from Hρ - range)

carbon target
(C, Be, U)

50-meson tracks
mean mass of

McMillan, Teller P.R. 72, 1
Herring, Weinstein 72 251

$\frac{1}{2}(\sqrt{95}+\sqrt{25}+\sqrt{25})^2 \sim 195$ MeV

star に伴うものはうちあたものがあるが、どうも
mass の値疑問、

Short Talk III

Postponed ~~to Nov.~~
to Jan. 1949
A.P.S. meeting

On the Nature of Mesons and Nuclear Forces

Sept. 29 1948
Dep. Phys., Columbia University

I am too little prepared to speak in a very systematic way and the only thing which is possible for me now is to express my feeling as to the present situation of the theory of elementary particles. Fourteen years ago, we knew nothing about mesons. Protons, neutrons, electrons, ~~and~~ neutrinos and photons were ~~the on~~ considered as the only constituents of our ~~uni~~ world. Something was lacking, however, in order to account for the remarkable stability of atomic nuclei. Mesons were discovered and they seemed just the things to fill the gap. But, now the situation is ~~so~~ completely changed. We are embarassed by the existence of so many kinds of mesons. ~~A few days ago, Prof. Rabi said to me "What are the use at all of mesons~~ At least there are two kinds of mesons, π-mesons and μ-mesons and there is a certain evidence for the existence of mesons with the mass 1000 times as large as that of the electrons. Moreover we have some reason to believe the existence of neutral mesons in addition to the charged mesons. Prof Rabi asked me some days before "What is the use at all of ~~the~~ μ-mesons?" I could not give a satisfactory answer to him.

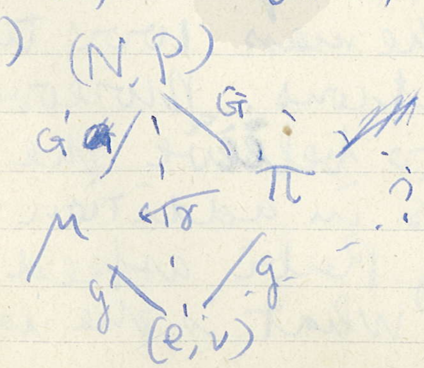
It is certain, however, that these mesons ~~to~~ are not things which are ~~and~~ entirely independent with each other, but they interact with one another as well as with the particles such as protons, neutrons, electrons, neutrinos and photons. And it is an important task for us to determine the nature and magnitude of these interactions. Of course, there are so many possibilities that we cannot take up all cases at once. We believe that ~~the nature~~ there are some very simple laws in nature, so we ~~may~~ had better to take up various cases in the order of simplicity. First of all, if we assume the existence of only two sorts of mesons, π and μ, there remain four cases

i) π (0,1) μ (0,1)

ii) π (0,1) μ (1/2)

iii) π (1/2) μ (0,1)

iv) π (1/2) μ (1/2)

i) 

(π-μ decay is about 4×10^{-18} sec, if we assume both responsible for nuclear force
Finkelstein, P.R. 72)

~~π~~ If we assume $G'^2/\hbar c$ to be smaller than $G^2/\hbar c$ by a factor of the order of 10^{-9}, the lifetime of π due to the process

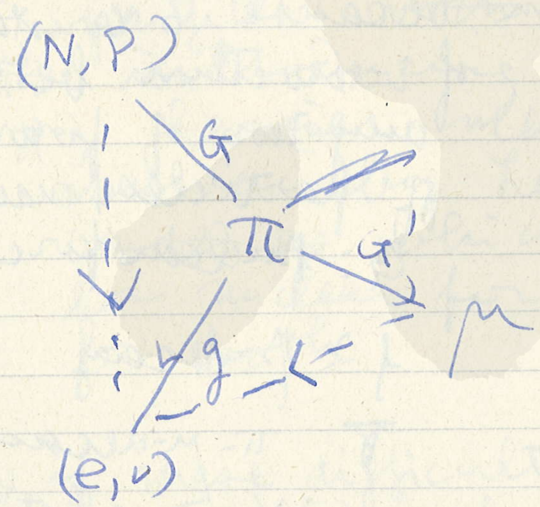
$$\pi \to \mu + \gamma$$

becomes about 4×10^{-9} sec, which is in accord with the recent experiment in Berkeley. But it is still difficult to account for ordinary β-decay, because ~~if we take the mass of π-m~~ the mass of π-mesons are about 286, which reduces the life-time of π-β-decay to ~~the order of magnitude~~ less than 10^{-8} sec, if we assume the ordinary decay to be caused by the double process, ~~for example~~ such as

$$N \to P + \pi^- \qquad \pi^- \to e^- + \nu,$$

as pointed out by Schiff and Serber.

ii)

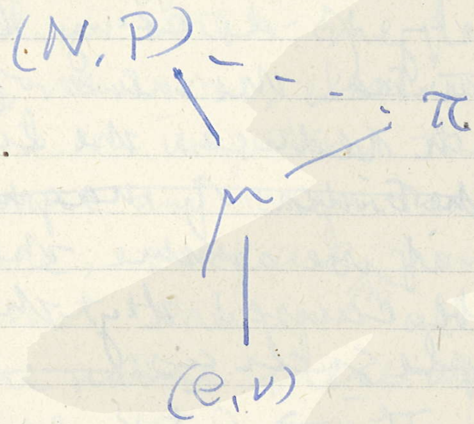


In this case also, we meet with the difficulty of the ~~lif~~ π-mesons with respect to direct β-decay compared with that with respect to π-μ-decay. Furthermore, the life-time of μ-mesons with respect to ~~the~~ β-decay become extremely long in contradiction with the observed lifetime

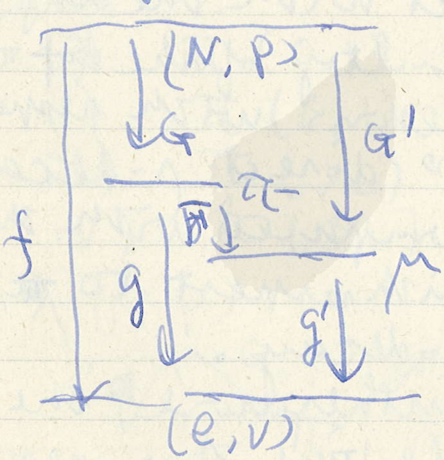
† In this case it is most urgent needed to determine the properties of the neutral partner accompanying the π-μ-decay as well as the μ-β-decay.

10^{-6} sec., if we assume only the interaction ~~with~~ between Fermi particles and Bose particles according to the ~~original~~ general idea of the field theory.

iii) This case is of little ~~least~~ interest, because we cannot construct any simple interaction scheme suitable for interpreting both ~~the~~ nuclear forces and cosmic ray phenomena.



iv) In this last case, we have the largest degree of freedom, because 6 constants of interaction between any two of four sorts of particles, namely



G: nuclear force

f: β-decay

g: π-μ-decay (~~interaction between π-μ and photon or neutral particle~~ with integer spin)

$$\frac{4\cdot 3}{1\cdot 2} = 6.$$

~~The choice among the four cases is~~
For the time being it is difficult to choose the best one among these case, especially because of the lack of the information as to the nature of neutral mesons.

F should not be large, because the π-μ-decay is certainly a two particle process instead of three particles process such as

$$\pi \to \mu + \mu^{(0)} + \gamma$$

~~for example~~ Instead of F, we should ~~take the~~ interaction have some mechanism such as

$$\pi \to \mu + \gamma$$

or

$$\pi \to \mu + \mu^{(0)}$$

where $\mu^{(0)}$ is a neutral particle with small mass and integer spin.

In any of these four case, there remain some serious difficulties, which can only be eliminated by assuming
i) extra coupling between Fermi particles ~~with~~
or ii) ~~introducing~~
ii) heavier mesons, such as observed by Leprince-Ringuet ~~?~~ ~~order as~~ which is responsible for nuclear forces or β-decay or both.

Even if these difficulties are ~~as~~ eliminated, there ~~are~~ still another kind of difficulties. That is the divergence difficulty, as ~~we~~ you all know, which is common to all sorts of field theory including the electrodynamics and various kinds of meson theory.

In order to get rid of this kind of difficulty, various attempts ~~were~~ have been made. Among them, ~~we~~ the following two are noteworthy. One is the socalled ~~m~~ "method of mutual compensation" developed by Pais. Similar attempt was made also by Sakata and his collaborators independently. ~~The idea is that~~ It is the extension of the mixed field theory first proposed by Møller and Rosenfeld. The idea is that the singularities appearing in the expressions for the interaction potential as well as the ~~dif~~ ~~de~~ infinities appearing in those for self-energy compensate with each other if we consider two or more kinds of fields simultaneously and adjust the constants of interaction in a suitable way. In this way one can not only get a reasonable finite value for the self-energy of the electron, ~~and~~ but also one can explain the mass difference between the neutron and the proton. Unfortunately, we can hardly expect ~~this~~ that sort of mutual compensation is effective ~~in all cases, because~~ in the case of Bose particle such as photons and mesons with integer spin, ~~the~~ as already shown by Pais and also by Sakata.

The second is ~~the so-calle~~ the method developed by Schwinger and by Tomonaga independently. I wonder why new ideas appear ~~at~~ so often almost simultaneously in the different parts of the world. ~~Anyhow~~, Schwinger calls his ~~theory~~ method, "theory of identification" and Tomonaga calls his method, "method of self-consistent-subtraction". I heard that Schwinger hated ~~to~~ the name "subtraction", but at any rate, the two theories ~~are~~ should be essentially the same, although I don't know the detail of Schwinger's theory, because he has not yet published detailed papers. Anyhow the idea is that certain terms which appear in the current theory of electromagnetic field and which are found to be infinite should be considered ~~as~~ as

i) either a part of observed mass of the charged particle, such as the electron.

ii) ~~or~~ ~~due~~ ascribed to the situation that the ~~cha~~ observed electric charge include already ~~the~~ ~~infinitey~~ extra charge due to ~~vac~~ polarization of vacuum.

It is remarkable that the remaining

finite terms give the correct ~~value~~ results for results which agree with the experimental value hydrogen level shift ~~obtain by ingenious~~ ~~as~~ discovered by Dr. Lamb as well as the anomalous magnetic moment of the electron discovered by ~~Rabi Dr. Rabi~~ Foley and Kusch*. However this method also can not be regarded as a final solution of the whole problem, because ~~the we do not know~~ it does not gives us the true way of getting rid of ~~of~~ the infinities.

Thus the present situation of the theory of elementary particles is still ~~very~~ quite embarasing, although there ~~has been~~ was a great progress in these two or three years. I can not tell you anything definit as to the future of the theory, but I feel that ~~the~~ an essential change of the concept of the "field" itself seems to be necessary, which may ~~lead to~~ well lead to ~~the~~ the unified stand point ~~for~~ in contrast to the ~~com~~ present complicated scheme, in which various sorts of particles with different masses and spins, and probably ~~we~~ we shall ~~may~~ be able to give a correct answer to Prof. Rabi's question "what is the use of mesons?".

---

* Foley and Kusch (Columbia), P.R. 73 (1947), 412

$$g_s = 2.00244 \pm 0.00006$$

Schwinger, ibid. 416 $\quad \delta\mu/\mu = (\frac{1}{2\pi}) e^2/\hbar c = 0.001162$

On the Self Energy of Mesons

by A. Pais
Institut for theoretical Physics,
University, Utrecht

Physica XII (1946), 81.

~~Summary~~:

The self-energy of mesons is composed of contributions due to their interaction with the electromagnetic, ~~field~~ the electron-neutrino and the nucleon field. Furthermore, if it is supposed that a particle creating an electromagnetic field also creates a short range neutral scalar field[1)], the latter also contributes to the self-energy. The various first order self-energies are computed. For no kind of meson mutual compensations of the divergences by means of convergence relations is possible.

~~Meson の~~ Self-energy of the meson consists of the following 4-parts:

1) electromagnetic self-energy
2) "electron-neutrino" 〃
3) "nucleic" 〃
4) f-self-energy

~~の四つの部分からなる．~~

1.) A. Pais, On the theory of elementary particles Chap. III, Phys. Rev. 68 (1945), 227.

~~Each of them~~ They diverge ~~according~~ in the following ~~according to~~ manner;

W_e : quadratic, logarithmic

W_{em} : quadratic, linear logarithmic

W_{nucl} : quadratic, linear, logarithmic

W_f : quadratic, linear, logarithmic

In order to obtain a finite value for the total sum of these four types of self-energies, we need three conditions for the compensation. It is, however, impossible as can be inferred easily from the fact that the interaction constants ~~have~~ differ very much;

$$\left.\begin{array}{l} \frac{f^2}{4\pi\hbar c} = \frac{2e^2}{4\pi\hbar c} \sim 10^{-2} \\ \frac{\hat{f}^2 \text{ or } \hat{g}^2}{4\pi\hbar c} \sim 10^{-17} \\ \frac{f^2 \text{ or } g^2}{4\pi\hbar c} \sim 10^{-1} \end{array}\right\}$$

It seems that the mesons could be reduced to some compound of ~~two~~ particles with spin 1/2. ~~especially which~~ may well have some connection with the fact that the meson decays into an electron and a neutrino with a life-time ~~which~~ is which ~~is~~ transforms like the inverse of W_{em} by Lorentz transf.

○ ~~Th~~ On the Theory of Elementary Particles
By
A. Pais, Utrecht

Verhandelingen der Koninklike Akademie van Wetenschappen, AFD, Natuurkunde
EERSTE SECTIE, DEEL XIX, N°. 1. 1947
(p. 1 ~ 91)

(Kon. Ned. Akad. v. Wet., Verh. Dl. XIX, No. 1, 1, 1947)

Chapter I. On the self-energy of particles with spin 1/2
Chapter II. On the theory of the electron
Chapter III. On the self-energy of nucleons and the theory of nuclear forces.
Chapter IV. On some further consequences of the f-field hypothesis.

① Stefan Rozental
On the Theory of β-Decay
(Det Kgl. Danske Videnskabernes Selskab. Math.-fys. Medd. XVIII, 7. 1941)
Møller-Rosenfeld mixture or more general mixture of pseudoscalar and vector fields. Shape of β-ray spectra was discussed.

S, II

Nature of Mesons and Nuclear Forces

addressing the colloquium of physics at the University of Pennsylvania, Philadelphia

Oct. 6, Wed. 4.15 pm ~

I am very much delighted to have the opportunity of ~~speaking~~ visiting this university and speaking to you. I have been working in the field of ~~theoretical physics, especially~~ theory of elementary particles.▽ Fourteen years ago, we knew nothing about mesons. Protons, neutrons, electrons, neutrinos and photons were considered as the only constituents of our world. Something was lacking, however, in order to account for the remarkable stability of atomic nuclei. Meanwhile ~~the~~ the mesons were discovered and they seemed just the things to fill up the gap. But now, the situation ~~changed~~ have been changing completely. We are embarrassed not by the lack of mesons, but by the existence or the possibility of existence of so many kinds of mesons. At least there are two kinds of mesons, socalled π- and μ-mesons,* which were discriminated by the wellknown experiments of Bristol group, ~~and~~ There ~~are~~ is ~~a~~ a certain evidence for the existence of another kind of mesons with the mass about 1000 times of the electron mass.† Moreover we have some reason to believe the

* ~~which~~ with the masses about 300 and 200 times of the electron mass respectively.

† according to the experiments by Leprince Ringuet, Rochester and Butler.

▽ especially of mesons.

existence of neutral mesons in addition to the charged mesons.** / Although there are still many uncertainties about the nature of these mesons, ~~but~~ it is certain that they are not things which are entirely independent~~ly~~ of ~~each~~ one another, but they interact with ~~each~~ one another ~~and with~~ as well as with the particles such as protons, neutrons, electrons, neutrinos and photons. It is naturally an important task for us to determine the nature of mesons themselves as well as ~~their~~ interaction of them with other particles. Unfortunately there are too many possibilities ~~as to the to select one~~ and the present ~~theory and exper~~ state of the theory and the experiment is not so favorable as to decide which one is the correct solution of the whole problem. Nevertheless we physicists always believe that in nature there ~~is~~ are some very simple fundamental laws, so that we usually take~~n~~ up various possibilities one by one in order of simplicity, unless there is some evident reason to discard any one of them. Thus, we assume for the time being the existence of only two sorts of mesons, π and μ.†† There

** It seems necessary to account for the non-exchange forces between the neutron and the proton as well as for the forces between ~~the~~ two protons or two neutrons,

†† and if we consider at first only charged mesons,

(~~already~~ a few years before the discovery by Bristol group of π and μ mesons, ~~or~~ theoretically by Sakata, Tanikawa and others)

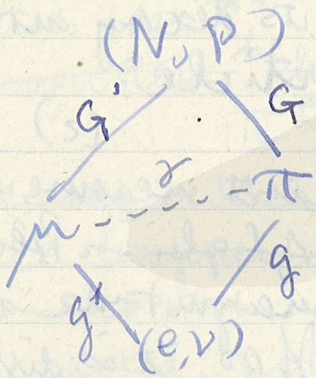
remain four cases ~~**~~ ***

	π	μ
i)	(0, 1)	(0, 1)
ii)	(0, 1)	(1/2)
iii)	(1/2)	(0, 1)
iv)	(1/2)	(1/2)

The case iii) was discussed recently by Bethe and Marshak ~~theoretically~~

Among these, the cases i) and ii) had been considered

Now in the case i), it is natural to assume the following scheme (I), in which the interaction constant G is so adjusted as to reproduce the nuclear forces ~~by the aid of~~ as good as possible the intermediary action of π-meson, which assumed to be pseudoscalar.



(I)

Of course we may need, in addition to the charged pseudoscalar meson, the neutral ps. meson as well as the charged and neutral vector mesons with the larger mass and with shorter life-time, but we ignor the details of nuclear field theory for the time being. The constant g can be so adjusted as to ~~give the β-d~~ account for the β-decay as caused also by the inter-

~~** We consider at first only charged mesons.~~

*** (As to the spin (0, 1) in the case of integer spin, we prefer 0 both for π and μ, ~~according to the~~ which is necessary to account for the nuclear forces and the burst produced by the hard component.

essentially

mediating action of the π-meson. ~~That~~ ~~Namely~~ Thus, the life-time of the π-meson is given by the expression of the form

$$\frac{1}{\tau_\pi} = \frac{\pi}{16}\left(\frac{\mu_\pi}{m}\right)^5 \left(\frac{\hbar c}{g^2}\right) \cdot \frac{1}{\tau_\beta} \qquad (1)$$

which has a value smaller than 10^{-8} sec. for $m_\pi \sim 300\,m$.* On the other hand, the mean life-time of the π-meson due to its decay into a μ-meson and a neutral particle

$$\pi^\pm \rightarrow \mu^\pm + \mu^{(0)} \qquad (2)$$

is 5.7×10^{-9} sec. according to recent measurement by Lattes and Gardner of ~~Univ. of Cal.~~ in Berkeley, which is, at least, the same order of magnitude as that of due to π-β-decay. If so, it is difficult to account for the fact that we have no positive ~~direct~~ evidence so far for the π-β-decay, which should occur side by side with π-μ-decay. In this connection, it should be noticed that there is some ~~controversy~~ uncertainty as to the nature of the neutral particle accompanying the π-μ-decay. ~~Thus~~ According to the ~~experiment~~ observation by Powell, Occhialini and others, the mass of ~~the~~ $\mu^{(0)}$ is about 100 times

---

* In the case of the pseudoscalar meson, $\frac{1}{\tau_\pi}$ takes the form

$$\frac{1}{\tau_\pi} = \frac{m_\pi c^2}{2\hbar} \left\{\frac{f_1'}{\sqrt{\hbar c}} - \frac{f_2'}{\sqrt{\hbar c}}\left(\frac{m}{m_\pi}\right)\right\}^2$$

in contrast to

$$\frac{1}{\tau_\pi} = \frac{m_\pi c^2}{2\hbar}\left\{\frac{2}{3}\frac{g_1'^2}{\hbar c} + \frac{1}{3}\frac{g_2'^2}{\hbar c}\right\}$$

for vector π-meson.

as that of the electron, the mass ratio m_π/m_μ being found to be about 1.65. Thus in the scheme (I), we ~~to~~ may add the neutral meson with integer spin. According to more recent ~~obs~~ experiments by Lattes and Gardner, the mass ratio is about 1.36, which is consistent with the ~~assumption~~ value 1.31 deduced from the assumption that the neutral particle has the mass zero.** If we accept this result, (2) ~~can~~ ~~be written~~ ~~changed into~~ ~~the~~ there may be process

$$\pi^\pm \to \mu^\pm + \gamma, \qquad (2.1.)$$

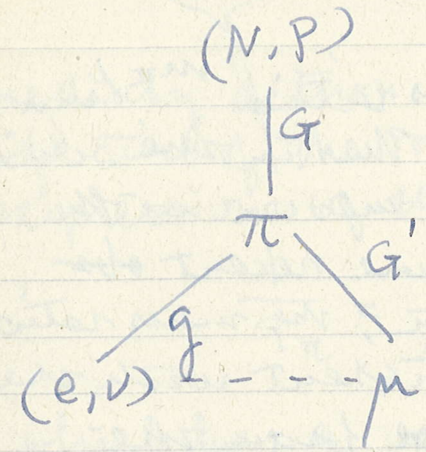
~~because~~ instead of (2). This sort of process may well happen, if both ~~the~~ π-mesons and ~~the~~ μ-mesons interact with the nucleon, as already pointed out by Finkelstein, (Phys. Rev. 72 (1947), 415), if π and μ has different values ~~$M_1^\pm \to M_0^\pm + \gamma$~~ of spins, for example 1 and 0 respectively, according to the scheme

$$M_1^\pm \to M_0^\pm + \gamma,$$

but if they both have the same spin value, this process is prohibited.

Next in the case ii), the scheme (I) should be replaced by (II);

** They measured the mass of ~~the~~ negative π-mesons produced by cyclotron and ~~four~~ estimated it 286 m_e, whereas they took the mass of μ-mesons 212 m_e, which ~~was~~ obtained by Brode and Fretter ~~to~~ is the value for ordinary cosmic ray mesons.



The nuclear forces are again caused by π-mesons with spin 0, ~~at~~ and the interpretation of β-decay is the same as in case i). The mechanism of the π-μ-decay, ~~however changes as follows~~ ~~however,~~ ~~$\pi^\pm \to \mu^\pm +$~~ changes in is also the same as 2), but this time the neutral particle $\mu^{(0)}$ should have ~~the~~ spin 1/2 instead of 0 or 1. If we accept the ~~result~~ experimental result that ~~the neut~~ $\mu^{(0)}$ has the mass zero, then it ~~should be~~ can be identified with the neutrino ν and ~~the~~ (3.1) should be replaced by

$$\pi^\pm \to \mu^\pm + \nu \qquad (3.2)$$

Thus it is very important to decide ~~the~~ experimentally the nature of neutral particle accompanying ~~the~~ the π-μ-decay.

Another point which is equally important for ~~so far~~ the choice between the cases i) and ii), ~~is difficult~~ is the mechanism of μ-β-decay. In the case i), it takes the form

$$\mu^\pm \to e^\pm + \nu, \qquad (4.1)$$

so that the decay electrons should have the unique energy ~~about 25.5 Mev~~ half Mev. In the case ii), ~~it takes~~ (4.1) should be replaced

by
$$\mu^{\pm} \rightarrow e^{\pm} + 2\nu \qquad (4.2)$$
because the process
$$\mu^{\pm} \rightarrow e^{\pm} + \gamma \qquad (4.2)'$$
seems to be in contradiction with experiment.* If we accept (4.2), the energy spectrum of decay electrons should extend from 0 to half Mev. The experimental informations available at present are more or less at variance with one another, so that we cannot prefer one out of two possibilities.†

As to the ~~nuclear force~~ interpretation of ~~In the cases iii) and iv), the interpretation of~~ nuclear forces, these two cases are similar with each other. ~~changes completely and we have to turn to a sort of meson-pair theory.~~ In this connection, Two points should be taken into account: ~~Now~~ one is that recent experiments in Berkeley indicated ~~definitely~~ on the one hand the large contribution of exchange forces to the scattering of high energy neutrons by protons, but on the other hand these results can be explained quantitatively only if we assume the coexistence of ordinary forces of about equal amount. ~~Thus the fundamental~~ general idea of the

*

† In ~~both~~ case ii), there is a drawback that life-time of μ-meson is too long, if we assume that it decays into electron and neutrinos through the virtual emission of a π-meson, so that we have ~~further~~ to assume further the direct interaction of μ-mesons with electrons and neutrinos.

meson theory of interpreting nuclear forces by the intermediary action of both charged and neutral mesons of the mass about 300 times the ~~electron~~ electron mass seems ~~thus~~ to be, not only consistent with these results, but also the range of forces between the neutrons and the protons deduced from the theory is good accord with ~~the experiment~~ these experiments, although there are still many uncertainties and controversies.

In the cases of iii) and iv), the ~~situation~~ way of interpreting nuclear forces changes completely and we have to turn to ~~the meson~~ a sort of meson-pair theory. In order to account for the facts just mentioned, ~~the spin~~ the interaction between a neutron and a proton should be of the form

$$\left.\begin{aligned} N &\rightarrow P + \pi^- + \nu \\ P &\rightarrow N + \pi^+ + \nu \end{aligned}\right\} \quad (5,34)$$

in contrast to
~~instead of~~

$$\left.\begin{aligned} N &\rightarrow P + \pi^- \\ P &\rightarrow N + \pi^+ , \end{aligned}\right\} \quad (5,12)$$

and further

$$\left.\begin{aligned} N &\rightarrow N + \pi^+ + \pi^- \\ P &\rightarrow P + \pi^+ + \pi^- \end{aligned}\right\} \quad (6.34)$$

in contrast to

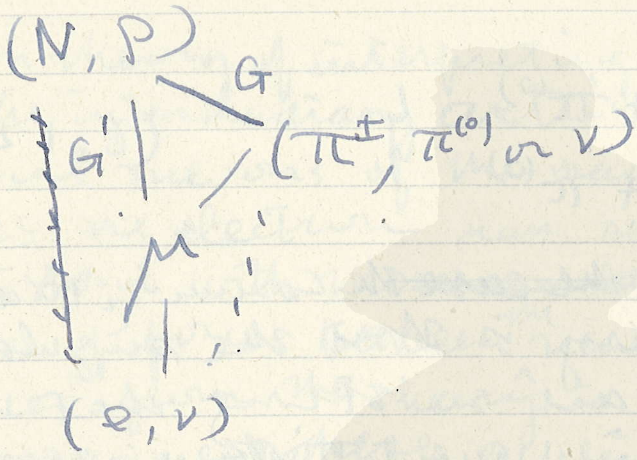
$$\left.\begin{array}{l} N \to N + \pi^{(0)} \\ P \to P + \pi^{(0)} \end{array}\right\} \qquad (6.12)$$

The drawback of ~~the case~~ th common to all sorts of pair-theory is that the singularity of nuclear forces are so strong that we ~~to~~ can hard obtain quantitative consequence, unless we look to ~~a new~~ some device of cutting-off for help.

~~As I~~ In this connection, I have been interested in the idea of de Broglie *

As to the π-μ-decay and μ-β-decay, the cases iii) and iv) differ from each other. Thus for the case iii), the scheme III also again necessitates direct interaction between nucleons and electron-neutrino, and the π-μ-decay takes

*



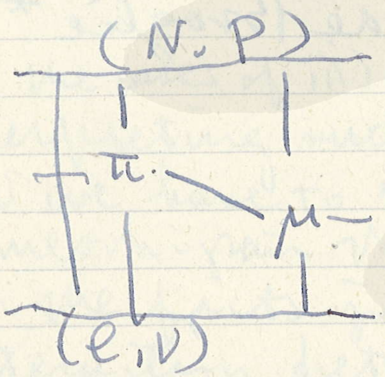
III

the form ~~wh~~

$\pi(1/2) \rightarrow \mu(0) + \mu^{(0)}(1/2)$

~~and~~
which is the same as in the case ii), so that $\mu^{(0)}(1/2)$ ~~may~~ might be a neutrino.

In the case iv), we may assume any amount of interactions of any suitable magnitude ~~amount~~ between any two ~~of sorts~~ of four kinds of particles, so that we have 6 independent ~~interaction~~ constants in all to ~~But~~ be adjusted ~~by~~ so as to fit with experiment.



IV.

Thus in any of these four cases, ~~there~~ we need, ~~some~~ either to introduce some,

i) extra coupling between Fermi particles such as nucleon and electron-neutrino

ii) or to take into account still heavier mesons.

* Very recently Araki succeeded also to ~~it~~ make the anomalous magnetic moment of the nucleon finite by mixing the ~~ps~~ pseudovector meson field with the pseudoscalar field. Even if ~~these~~ the meson theory is ~~amended~~ improved in this way, there is still another kind of difficulty. That is the well known difficulty common to all sorts of field theory including electro~~mag~~dynamics and various kind of meson theory.

In order to get rid of this kind of fundamental difficulty, various attempts have been made. Among them, the following two are noteworthy. One is the socalled "method of mutual compensation" developed by Pais. Similar attempts was made also by Sakata and his collaborators of ~~the~~ Nagoya University independently. It is ~~on the one hand~~ an extension of the mixed field theory first proposed by Møller and Rosenfeld in the case of the meson on the one hand and at the same time ~~an extension~~ a modification of Bopp's theory in the case of the electromagnetic field. The idea is that the singularities appearing in the expressions for ~~the singular~~ the interaction potentials as well as the infinities appearing in those for self-energies compensate with each other, if we consider two or more kinds of fields simultaneously around an elementary particle and ~~a~~ adjust the constants of interaction in a suitable way.*

* of various elementary particles

In this way one can not only get a reasonable finite value for the self-energy of the electron, but also one can explain the mass difference between the neutron and the proton. Unfortunately, we can hardly expect that this ~~sort of~~ method of mutual compensation is ~~very powerful~~ effective by ~~it~~self in the case of Bose particle ~~such as with integ~~ such as photons and also mesons with integer spins as already shown by Pais and Sakata.

The second is the method developed by Schwinger and by Tomonaga independently. I wonder why new ideas appear so often almost simultaneously in different parts of the world! I heard that Schwinger called this method "~~theory of~~ method of Identification", whereas Tomonaga calles it "method of Self-Consistent Subtraction". I don't know the detail of Schwinger's theory, because ~~his complete work~~ I could only see his ~~a~~ short letter. At any rate these two methods seems to be essentially the same. The idea is that certain terms which appear in the current theory of electromagnetic field and which are found to be infinite should be ~~considered as~~

i) either considered as a part of observed mass of the charged particle such as the electron

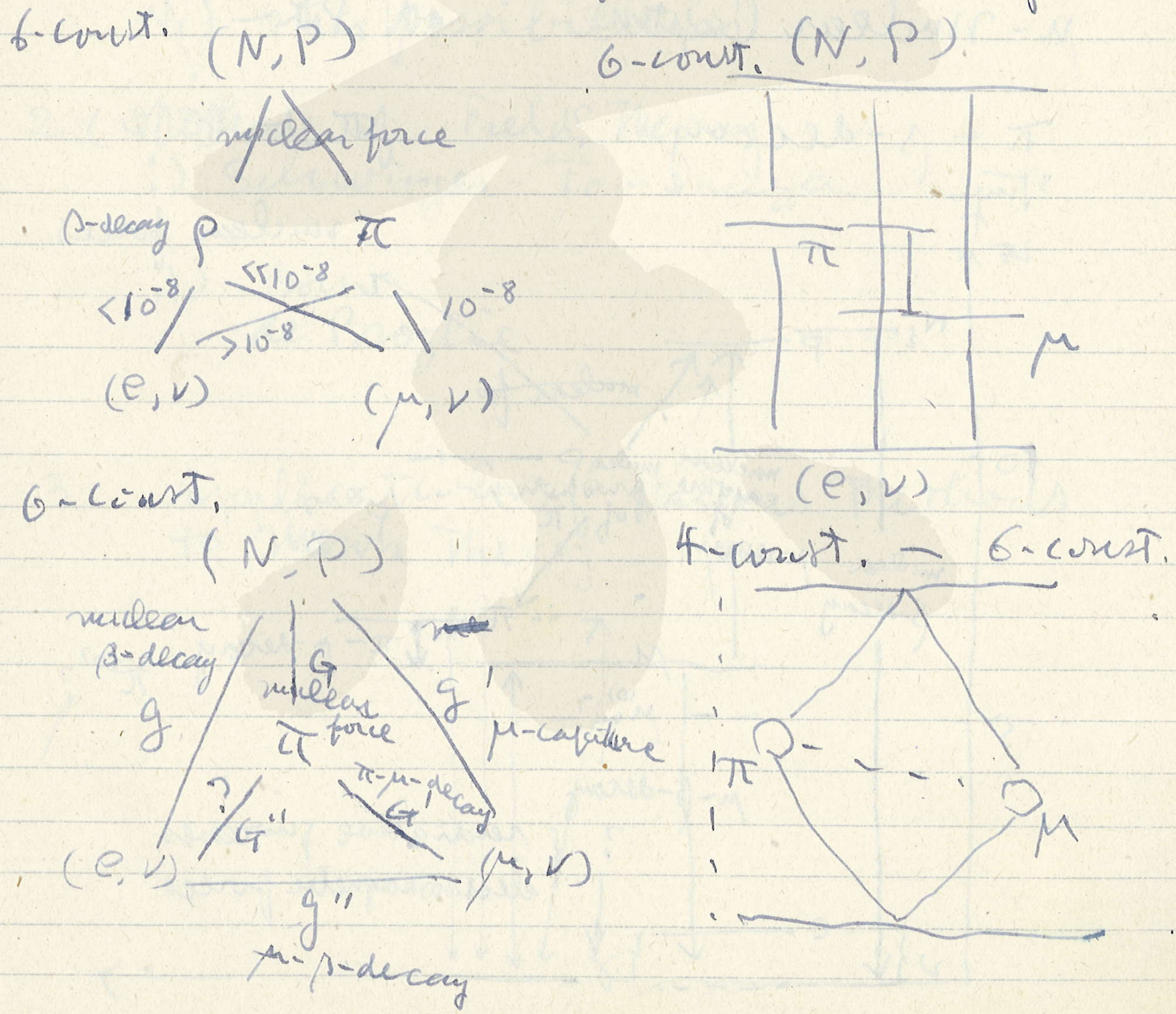
ii) or ascribed to the situation that the observed electric charge already include the extra charge due to the polarization of vacuum.

It is remarkable that the remaining finite terms give the results which agree with the experimental value for hydrogen level shift, ~~discovered~~ discovered by Lamb and Retherford and ~~confirmed~~ dealt ~~as well as~~ theoretically first by Bethe, as well as the anomalous magnetic moment of the electron. Nevertheless this method too cannot be regarded as a final solution of the whole problem, because it does not give us the whole scheme of the theory which is devoid of the infinity from the beginning.

Thus the present situation of the theory of elementary particles is still quite embarrassing in spite of ~~the~~ rapid progress in ~~this field~~ these few years. I ~~cannot~~ can hardly tell anything definite as to the future development of the theory, but I feel that an essential change or generalization of the concept of the "field" itself seems to be necessary, which may well lead us to the unified standpoint in contrast to the present complicated scheme in which various sorts of particles with different masses and spins are taken into account one after another. Among various attempts in this direction, I want to mention only two. One is ~~that~~ the socalled "method of fusion" according to de Broglie, which is an extension of his neutrino theory of photons. The idea is to reduce reduce all sorts of fields to some ~~superpost~~ combination of fields accompanied by Fermi particles.

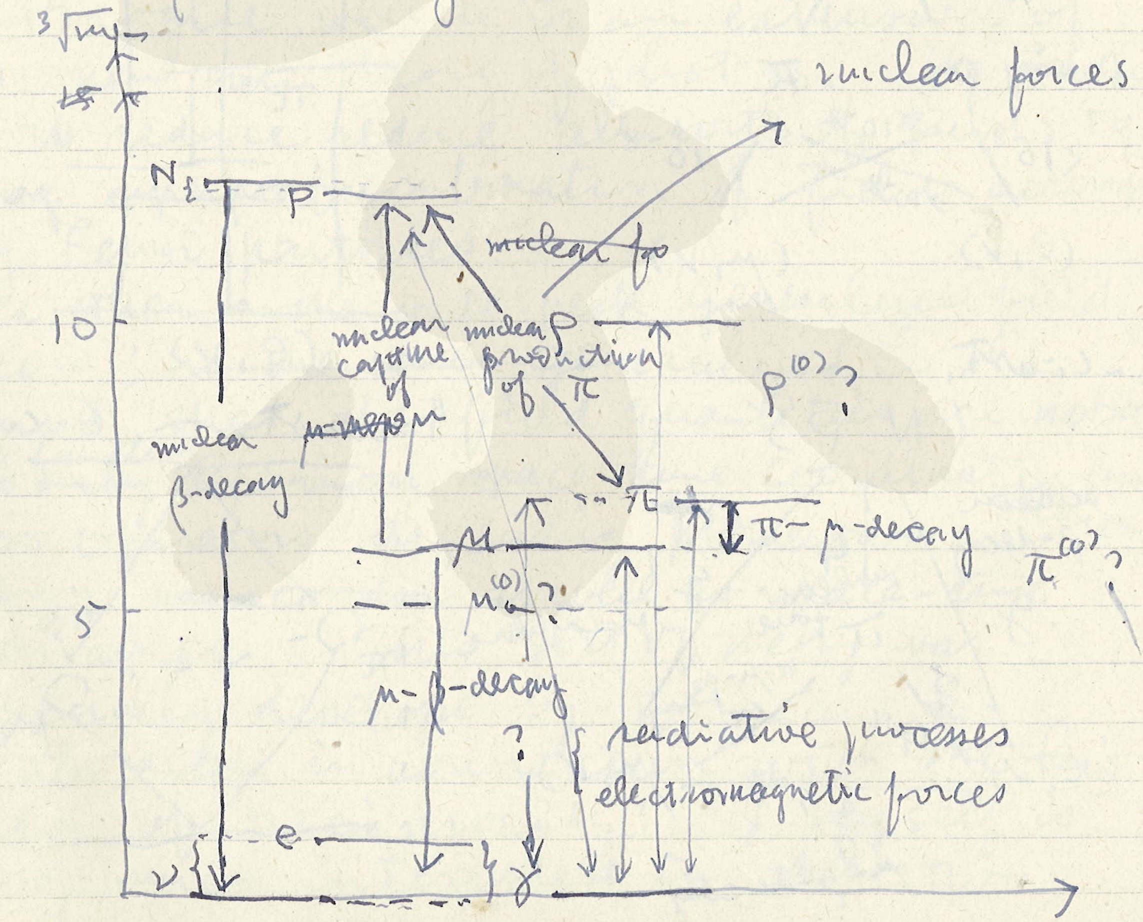
The other is the so to speak "generalized field theory", ~~in the sense~~ generalized in the sense that the field quantities are not more ~~not only~~ function depending on space-time coordinates alone but ~~also~~ operators depending momentum-energy ~~vari coordin~~ as well as space-time variables. This sort of theory was especially developed by Born and his colaborator, in connection with ~~the~~ his idea of "reciprocity". I myself is very much interested in these two methods, and I feel that ~~they~~ these two theories are not so much different with each other, as they ~~for~~ appear at first sight, and it might well be that these two theories are in some way united to a scheme. ~~of~~

Possible Scheme of Meson Theory



Exp. Implication

Nuclear Forces (π-meson production)	(N, P) — π
Nuclear β-decay	(N. P) — (e, ν)
π-μ-decay	π — μ
μ-β-decay	μ — (e, ν)
μ-nuclear Capture	(N, P) — μ
π-β-decay ?	π — (e, ν)



~~Seminary~~

~~Institute for Advanced Study~~

~~Oct. 7, 1948~~

Programme

1. Meson Models
   i) Two Meson Theory
   Types of
   ii) other possibilities

2. Methods of Field Theory
   i) Schwinger-Tomonaga
   ii) Born
   de Broglie

3. Application of Various Methods to Meson Theory

Seminar I. Oct. 1.

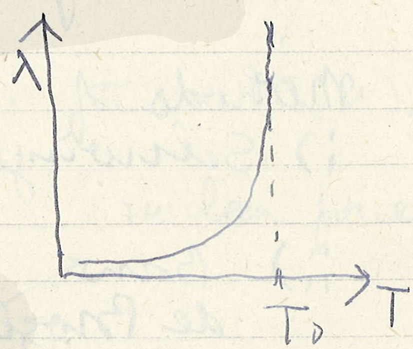
Prof. von Laue: Superconductivity 1.

London Theory

$$J = J^0 + J^l \qquad \frac{\partial \rho^{0,l}}{\partial t} + \mathrm{div}\, J^{0,l} = 0$$

$$J^0 = \sigma E \qquad \boxed{\frac{\partial(\lambda J^l)}{\partial t} = E}$$

$$\frac{|J^0|}{|J^l|} = \nu\sigma\lambda \qquad |\nu\lambda J^l| = |E|$$

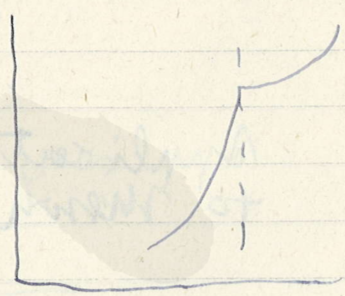


McLennan

$$\boxed{\mathrm{rot}(\lambda J^l) = -\frac{1}{c} H}$$

$$\frac{1}{2}\frac{\partial}{\partial t}\left(\varepsilon E^2 + \mu H^2 + \lambda J^{l2}\right)$$

$$+ \sigma E^2 + \mathrm{div}\, c[E H] = 0$$



Hexagonal Crystal

$$\lambda_{\alpha\beta} = \lambda_{\beta\alpha}$$

S.3

~~Meson~~ Models for Mesons
(Seminar 2, Fuld Hall,
Oct. 12, Tuesday 4.15 pm)

~~My turn came too early to speak ~~spe~~ something~~ worthwhile.
Anyhow ~~fear~~
~~I wonder have to speak about physics, but I beg you allow me to say a few words about language before entering into physics, according to a precedent~~
follow.

Today
I have to speak something. I am always worrying about language as much as about physics. In this respect I perfectly agree with Prof. von Laue. I beg you ~~will~~ would forgive me to speak so slowly that I shall not make too many mistakes in English in addition to possible mistakes in physics. I suppose I have to speak something about mesons. Unfortunately ~~everything~~ are still very uncertain ~~and~~ about mesons and I am afraid that no definite conclusion comes out after a long discussion. Certainly we have no consistent theory of elementary particles. When a physical theory ~~claim to~~ is said to be consistent, it should naturally be consistent in two ways;

i) It should be mathematically consistent
logically or

From logical or formal standpoint

ii) ~~It~~ and it should also be empirically or physically consistent. [first of all]

In other words there should be no self-contradiction in the ~~the~~ formalism itself, and further it should find a proper place in the whole domain of our ~~experien world of exp~~ experience.

~~Now~~ ~~No~~ we can have a physically consistent theory only if ~~we~~ it is mathematically consistent, but from empirical or historical standpoint this order is ~~of~~ very often reversed. For example, we had a n.. classical quantum theory of Planck-Bohr which cannot ~~be~~ said to be mathematically consistent, before we have a rational quantum mechanics. ~~In other words,~~ ~~Thus~~ historically we have very often

i) first a qualitatively ~~correct~~ consistent theory, or a sort of model

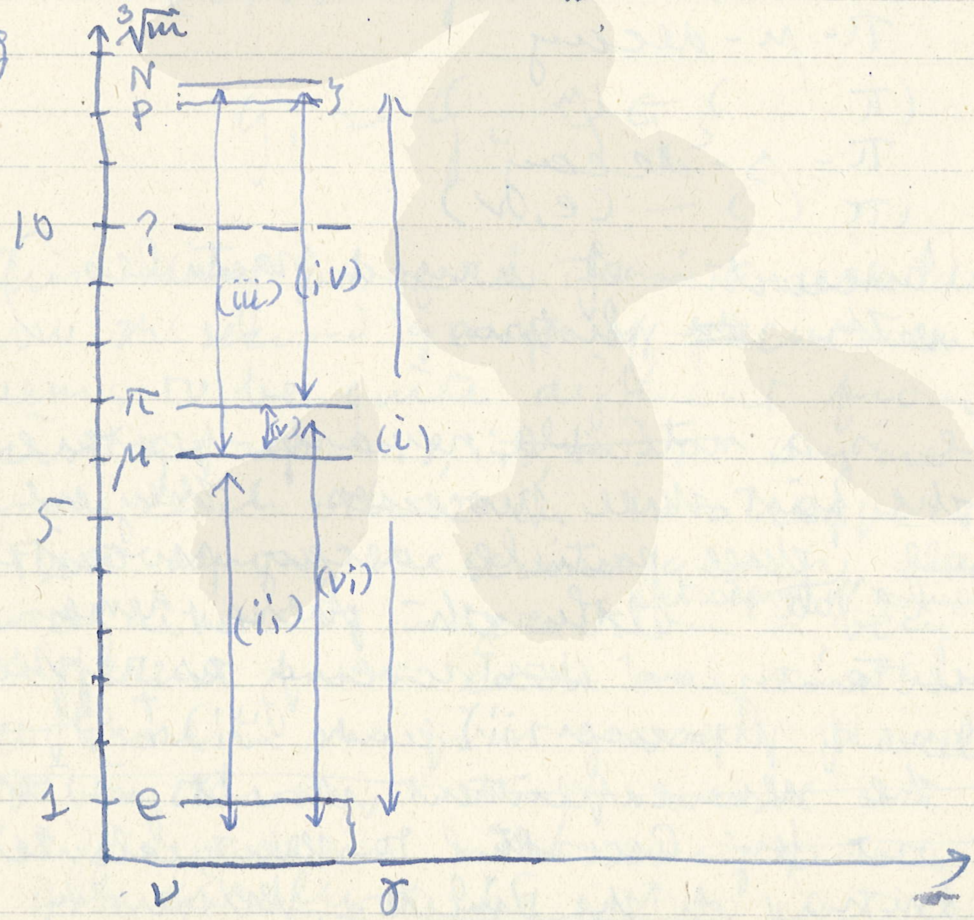
ii) then ~~a quanti~~ it ~~can~~ developes into a quantitively consistent theory, or a theory in the narrow sense.

Now we have certainly no ~~consi~~ mathematically consistent theory of elementary particles as yet. ~~The question is that We cannot get rid of the divergence difficulties~~ still

We have no ~~satis~~ theory which is ~~free~~ completely free from the divergence difficulties. Then the question arises:

Have we already a model for the system of elementary particles, which can at least qualitatively (if not quantitatively) account for all phenomena ~~in the field of~~ concerning atomic, nuclear and cosmic rays?

Today ~~we~~ I should like to confine our attention to answering this question. I want ~~How do we avoid~~ to approach this question from more or less empirical side: First of We ~~can~~ arrange the known kinds of elementary particles in order of their masses. We ~~take~~ as coordinate the cube root of the mass in units of electron mass only for conveni-ence sake.



$\sqrt[3]{200} \cong 6$ (216)

$\sqrt[3]{300} \lesssim 7$

$\sqrt[3]{1800} \gtrsim 12$

Next we can estimate the ~~magnitude of interactions~~ properties and magnitude of interactions between two ~~kinds of particles~~ two groups of kinds of particles from ~~fundamental facts~~: processes ~~know~~:

First group
i) nuclear β-decay $N \to P + e^- + \nu$
(N, P) — (e, ν)
ii) μ-β-decay $\mu \to e + \nu + (\nu)$?
(μ ~~(μ)~~) — (e, ν)
iii) nuclear ~~scatter~~ capture of μ-mesons
(μ) — (N, P) $\mu^- + P \to N + (\nu)$

Second group
iv): ~~creation~~ production and absorption of π-mesons by nuclear collision
(π) — (N, P)
v) π-μ-decay
(π) — (μ)
vi) π-β-decay
(π ( ) — (e, ν)
(vii) Interaction of charged particles with ~~the~~ photons)

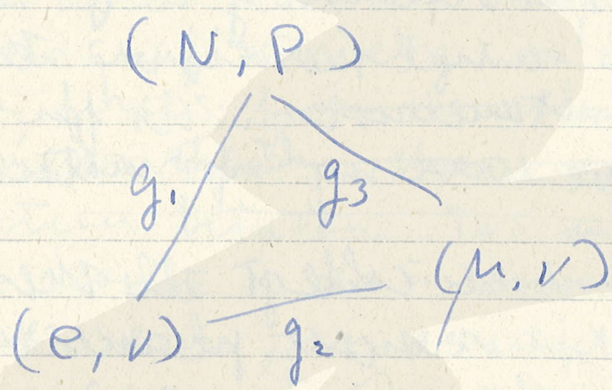
~~viii~~

Now there is a ~~noticeable~~ remark feature in ~~com~~ the first three processes. They are very ~~namely all~~ (three particle decay processes, likely to be all) although there remain still uncertainty and controversy as to the mechanism of processes ii) and iii)! ~~If we accept the new experiment results in Berkeley As point out by~~ According to recent calculation by Tiomno of the Princeton University,
+ and moreover they ~~interaction~~ are all very slow processes indicating that the interactions are

as many of you have heard last wednesday, magnitudes of interactions of between these three kinds of particles

(N, P) ; (μ (ν)) ; (e, ν)

~~seems to be~~ are about the same ~~of magnitude~~ order.



$$g_1 \sim g_2 \sim g_3$$

This may be more than an accident.
Now the second group of phenomena iv), v), vi) seems to be quite different from the first group i), ii), iii), they are different from each other in two respects.
First among the second group, order of magnitude of interaction between of π-mesons with other particles is very much different from ~~each~~ one another, in contrast to those in the first group. Namely π-(N,P) is very strong, π-μ weak and π-(e,ν) still weaker. In the second place, they are all likely to be a two particle decay

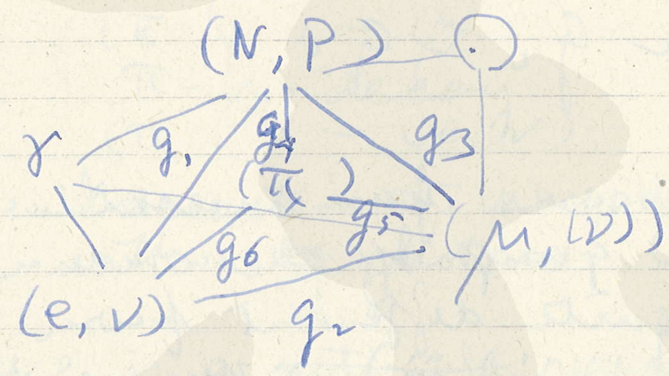
g,

-all quite small.)

instead of three particle decay. In the case of π-μ-decay, there is no doubt. In the case of π-(N,P)-interaction, the fact that the total mass energy of the π-meson is likely ~~seems~~ to change into the kinetic energy of nucleons after explosion produced by a π-meson, indicate that no neutral meson or neutrino are emitted simultaneously. As for the π-β-decay, we have no information available as yet.

If we ~~collect these~~ collect all these facts together, it is most plausible to construct a scheme:

(I)



$$g_1 \sim g_2 \sim g_3$$

$$g_1 \gg g_5 > g_6$$

Among ~~four~~ five kinds of particles, (N, P), (μ, (ν)), (e, ν) have spin 1/2
π, γ have spin 0 or 1.

~~The ms~~ ~~thus~~ This scheme so far seems to be ~~consistent~~ consistent at least qualitatively.
There remains, however, the ~~impor~~ most important point of the whole scheme still untouched, that is, of course, ~~the interaction~~ problem between nucleons, the central problem of the meson theory.
At least qualitatively, we can deduce the nuclear forces, ~~from the assumption characteristic to the meson theory that the in as that the interaction between two nucleons is~~ as the result of the interaction of the nucleon and the meson, an assumption characteristic to the meson.† ~~Quantitively~~ We are not yet certain whether we can account for quantitatively ~~the~~ various nuclear ~~forces~~ phenomena by assuming only one kind of ~~m~~ mesons responsible for the nuclear forces. It may well be that the heavier mesons with the mass 1000 times the electron mass ~~are~~ also contribute to the nuclear forces.
~~In this wa~~
At any rate ~~Thus~~ we have to ~~abandon~~ discard the ~~restriction~~ original assumption of the meson theory that there exist only interactions
i) between Fermi particle and Bose particle
and ~~it~~ have to add ~~the~~ assumption is that the range of forces

† An important point, which is in favour of this

ii) the direct interaction between Fermi particles
and moreover
iii) the interaction between Bose particles
is also necessary as in the case of interaction between charged π-mesons with the photon.

Now the introduction of direct interaction between Fermi particles give rise in turn to the appearance of stronger singularity of forces between like particles due to the intermediary action of other kind of Fermi particles, but this is no more a problem of a crude model, but the construction of a math. consistent theory, which is outside the scope of speech today.

I think the above model is most plausible for the time being, I do not, of course, insist that this is the only model, but on the contrary there are several other possibilities. I should like to mention only one of them, which seems to be simple as well as attractive; this to assume that

i) The elementary particle in the true sense is only restricted to Fermi particles with the spin $1/2$.

ii) The ~~particle~~ Bose particle with the spin 0 or 1 is regarded as some combination of a pair of Fermi particles.

This idea is the extension of neutrino theory of light ~~developed by~~ proposed many years ago by de Broglie. de Broglie called this the method of fusion and tried in fact to extend to other kind of particles, but so far with no success. If we apply this ~~idea to~~ method successfully [kind] to the meson theory, we ~~may be~~ might be able to obtain a sort of modifyed meson pair theory.

In order that the range of nuclear forces agree with the experiment, we have to assume

~~to~~ i) ~~either~~ that ~~interac~~ processes such as

$$N \to P + \pi^- + \nu$$

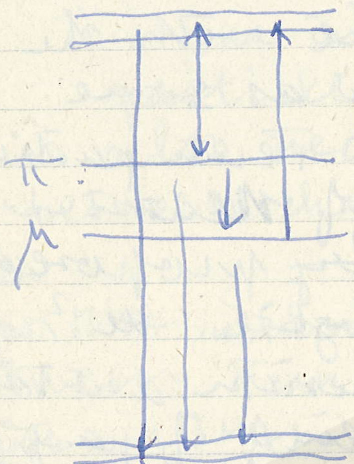
is responsible for the nuclear forces

ii) or ~~tha~~ to introduce ~~to~~ ~~the~~ universal length λ which is ~~equal at least~~ equal to $\lambda = \hbar/m_\pi c$.

The latter assumption seems to be rather arbitrary and the former assumption seems to be more plausible in the light of new experimental results ~~on~~

obtained in Berkeley.

The ~~main~~ scheme in this case is very simple and we can ~~take~~ adjust six constants quite easily so as to be in accord with the experiment. As for the phenomena of first group the ~~thing~~ situation is quite the same as in the case of the model mentioned before.



(II)

~~many~~ as for the ~~the difference~~ the situation is very much different. ~~a~~ phenomena of the second group

Namely iV), π-meson should be in process always accompanied by a neutrino, and in V) the mechanism of π-~~μ~~-decay should be

$$\pi \to \mu + \gamma \qquad (5.2)$$

$$\text{or } (\mu + \mu^{(0)})$$

in which $\mu^{(0)}$ is a neutral Bose particle of small mass. In the latter case, it may have some connection with the f-field introduced by Pais and by Sakata independently etc.

The difficulty is that if this process

has some connection with the el. mg. prop. of the charged mesons, the life-time of π-meson may well be very short compared ~~by~~ with the observed life-time 5.7×10^{-9} sec. Of course, it is not necessary to connect this process with the charge e directly, and we are able to introduce some smaller constant in place of e.

~~The~~ Thus ~~π~~ ~~μ-decay~~ it is the most crucial test for or against these theory to determine the nature of the neutral partner accompanying the π-μ decay process. Another point of importance is to determine the ranges of forces between ~~Anyhow it is most ne neutron-neu~~ proton-proton as well as proton-neutron ~~from~~ by comparing with scattering experiments. The reason is that in the model II, the forces between ~~two~~ two proton should be a result of intermediate action of ~~two~~ a pair of charge π-mesons, so that the range should only one half of the range of forces between neutron-proton, while in the ordinary theory and I, the range of force between two proton depends on the mass of a neutral π-meson and may be the same as that between ~~prob~~ possibly neutron and proton.

Thus there ~~are many~~ seems to be qu ~~di~~ essential diff. in two models, but I think that they may not be so different, but the future correct model be something which retain the advantages of both ~~the~~ models. Of course I am not yet quite sure as to this point.

○ Electromagnetic Shift
of Energy levels
by
H. A. Bethe
(Inst. International de Physique Solvay
Huitième Conseil 29/9 ~ 2/10, 1948)

1. Nonrelativistic theory

$$W = -\frac{e^2}{\pi\hbar c}\frac{1}{m^2c^2}\int_0^K k\,dk \sum_{\bar{e}}\sum_n \frac{|(\bar{p}\cdot\bar{e})_{on}|^2}{E_n + k - E_0}$$

for free electron:

$$W_0 = -\frac{2e^2}{3\pi\hbar c}\left(\frac{p}{mc}\right)^2 K.$$

for bound electron (− free electron):

$$W' = W - W_0 = \frac{e^2}{3\pi\hbar c}\frac{1}{m^2c^2}\int_0^K dk \sum_n \frac{(p_{on})^2(E_n - E_0)}{E_n - E_0 + k}$$

which diverges logarithmically

$$W' = \frac{8}{3\pi}\left(\frac{e^2}{\hbar c}\right)^3 Ry\,\frac{Z^4}{n^3}\ln\frac{mc^2}{16.721\,Ry\,Z^2}$$

for 2S state of hydrogen:

$$W' = 1.040 \text{ megacycles}$$

2. Relativistic Theory
Subtraction Procedure → Lamb

Schwinger's Contact Transformation, which eliminates all processes of absorption and emission of quanta by free electrons:

$$H = H_{part} + H_{field} + H_{rad} = H_0 + H_{rad}$$

$$H_{part} = c\bar{\alpha}\,\bar{p} + \beta m_0 c^2$$

$$H_{field} = \sum_\lambda k_\lambda q_\lambda^* q_\lambda$$

$$H_{rad} = \beta \sum_\lambda k_\lambda^{-1/2} \bar{e}_\lambda \bar{\alpha} (q_\lambda e^{i \bar{k}_\lambda \bar{r}} + q_\lambda^* e^{-i \bar{k}_\lambda \bar{r}})$$

with $\beta = \sqrt{\frac{4\pi}{\Omega}}$ etc

$$\psi' = e^{iS}\psi, \quad H' = e^{iS} H e^{-iS}$$

S is so chosen that H' does not contain any coupling terms between electron and radiation, which are of first order in e.

$$H' = e^{iS} H_0 e^{-iS} + e^{iS} H_{rad} e^{-iS}$$

$$= H_0 + i[S, H_0] + \dots$$

$$+ H_{rad} + i[S, H_{rad}] + \dots$$

$$i[S, H_0] = -H_{rad}$$

$$H' = H_0 + i[S, H_{rad}] - \frac{1}{2}[S,[S, H_0]]$$

$$= H_0 + \frac{1}{2} i[S, H_{rad}]$$

$$(\bar{p}_2 \bar{k} | S | \bar{p}_1, 0) = -i\beta k^{-1/2} \delta(\bar{p}_2, \bar{p}_1 - \bar{k}) \frac{(u_2^* \bar{\alpha} \bar{e}\, u_1)}{E_2 + k - E_1}$$

H' contains terms of the following type:

(1) self energy terms for free electron

$$(\bar{p}\, 0 | H' - H_0 | \bar{p}\, 0) = \beta^2 \sum_\lambda k^{-1} \frac{|u^*(\bar{p}+\bar{k}) \bar{\alpha} \bar{e}\, u(\bar{p})|}{E(\bar{p}+\bar{k}) + k - E(\bar{p})}$$

(2) which diverge linearly ~~—~~ and if combined

with the hole theory, divergen. log.

(2) Terms in which a quantum is emitted by one electron and absorbed by another, which give Møller interaction between electrons.

(3) Terms in which two quanta are emitted, which have no effect on the level shift.

(4) Terms in which one quantum is absorbed and another emitted, corresponding to Compton effect.

(5) If the Dirac hole theory is used, there are also terms, in which a quantum is absorbed by producing a virtual electron pair, and this pair is then annihilated, re-emitting the quantum. This would give rise to infinite self-energy of light quantum.

(6) In hole theory, there will be terms corresp. to the annihil. of electron pair with emission of two quanta, and to the creation of a pair by absorption of two quanta.

The same transformation must be applied to any external potential V;

$$V' = V + i[S,V] - \frac{1}{2}[S,[SV]]$$

$[S,V]$ gives rise to absorption and emission of radiation in a potential. $[S,[SV]]$ gives the electromagnetic shift of energy levels.

Schwinger's theory is superior to the more elementary subtraction theory in four respects:

1) mass terms and the ~~rela~~ reactive effects of radiation are clearly separated from the beginning
2) The theory works with the observed mass of the electron rather than mech. mass.
3) convergent integrals without further manipulation
4) Constant potential give no effect.

When hole theory is taken into account, it is necessary to apply a second contact transf. to deal with the polarization of the vacuum. According to Schwinger, the polarization gives rise to terms in the Dirac equation terms proportional to

$$\varphi - \bar{\alpha}\bar{A}$$

with $\varphi, \bar{A}$ of the external field, ~~and other~~ can be combined with or terms of the same type by redefining the charge of the electron

$$e = e_0 + e_1,$$

where e is the observed charge, e_0 the originally assumed in the Dirac equation and e_1 the (infinite) additional charge due to the polarization of vacuum.

In order to remedy the lack of relativistic invariance, Schwinger developed a second theory using Tomonaga's many time theory and applying again the contact transf. To the equation

$$mc^2 \psi^+ \psi = \psi^+(x) \sum_\mu \gamma_\mu (p_\mu - eA_\mu(x)) \psi(x)$$

should be added the radiative term

$$R = \iint d\xi' d\xi'' \psi^+(x+\xi') \sum_\mu eA_\mu \sum_\nu \gamma_\nu$$

$$\times \{ S_1(\xi') \gamma_\mu |S|(\xi') \gamma_\nu |D|(\xi'+\xi'')$$
$$+ |S|(\xi') \gamma_\mu S_1(\xi'') \gamma_\nu |D|(\xi'+\xi'')$$
$$+ |S|(\xi') \gamma_\mu |S|(\xi'') \gamma_\nu D_1(\xi'+\xi'') \} \psi(x-\xi'')$$

where

$$S_1(\xi) = \sum_\alpha \left(\gamma_\alpha \frac{\partial}{\partial x_\alpha} - \frac{mc}{\hbar}\right) \Delta_1(x)$$

$$|S|(x) = \sum_\alpha \left(\gamma_\alpha \frac{\partial}{\partial x_\alpha} - \frac{mc}{\hbar}\right) |\Delta|(x)$$

vh → dinary

$$\Delta_1(x) = \frac{c}{(2\pi)^3} \int \frac{d\bar{k}}{\omega} e^{i\bar{k}\bar{r}} \cos \omega t$$

$$|\Delta|(x) = \frac{c}{(2\pi)^3} \int \frac{d\bar{k}}{\omega} e^{i\bar{k}\bar{r}} \sin \omega |t|$$

with

$$\omega = c\sqrt{k^2 + (mc/\hbar)^2}$$

whereas D_1 and D are the same expressions with

$$\omega = ck$$

For two plane waves ψ_μ and $\psi^\dagger$, R becomes still infinite, but infinite part is proportional to $\sum_\mu \gamma_\mu A_\mu$, so that it can be interpreted as a change of the charge of the electron due to the polarization of the vacuum. Thus

$$R = \int \psi^\dagger(x) \sum_\mu \gamma_\mu A_\mu(q) f(q) \psi(x) d\tau$$

$A_\mu(q)$ being the Fourier component of the potential A, corresponding to the momentum transfer q. To take the charge renormalization into account, we need only subtract from (50e) its value for zero momentum change. This gives for the true effect

$$R = \int \psi^\dagger \sum \gamma_\mu A_\mu(q) [f(q) - f(0)] \psi(x) d\tau \qquad (50f)$$

and this result is finite.

3. Feynman's Theory

classical electrodynamical interaction:

$$V_{ab} = e_a e_b \, \delta(S_{ab}^2)$$

$$S_{ab}^2 = c^2(t_a - t_b)^2 - (\bar{r}_a - \bar{r}_b)^2$$

Feynman's proposal:

$$\delta(S_{ab}^2) \to f(S_{ab}^2)$$

$$f = 0 \quad \text{for} \quad S_{ab}^2 < 0$$

$$\int f(S_{ab}^2)\, dS_{ab}^2 = 1$$

f is continuous and falls off rapidly with increasing S_{ab}^2, so that classical electrodynamics leads to a finite well-defined self-energy.

In quantum theory, the self-energy is also finite and covariant; for a free electron of momentum p it is

$$W = \frac{e^2}{\pi c} \int g(\lambda)\, d\lambda \int \frac{c^3 d\bar{k}}{\omega} [W_+(\bar{p}, \bar{k}, \lambda) - W_-(\bar{p}, \bar{k}, \lambda)]$$

$$W_+ = \frac{|u^*(\bar{p}+\bar{k}, +)u(\bar{p})|^2 - |u^*(\bar{p}+\bar{k}, +)\bar{\alpha}\, u(\bar{p})|^2}{E(\bar{p}+\bar{k}) - E(\bar{p}) + \omega}$$

$$W_- = \frac{|u^*(\bar{p}+\bar{k}, -)u(\bar{p})|^2 - |u^*(\bar{p}+\bar{k}, -)\bar{\alpha}\, u(\bar{p})|^2}{E(\bar{p}+\bar{k}) + E(\bar{p}) + \omega}$$

$$\omega = c\sqrt{k^2 + \lambda^2 c^2} \qquad E(p) = c\sqrt{p^2 + m^2c^2}$$

$g(\lambda)$: Fourier transform of the interaction 函数 f

$$g(\lambda) = \delta(\lambda) + \text{term of high } \lambda$$

$$\int g(\lambda)\, d\lambda = 0 \quad \dagger$$

simple choice:

$$g(\lambda) = \delta(\lambda) - \delta(\lambda - \lambda_0)$$

Bopp と同様に vector massive quanta を assume することになる. pair の発生を通って relat. invariant しかし 現の代り negative energy の問題は起きてない. 理由が更に後の如, massive quanta に関する consequence を eliminate できると期待される. 従って λ-term は単に convergence のための artifice と考えられる.

self-energy の値は 前の K の代りに λc^2 を入れたものになる.

更に transverse, longitudinal el. mag. field を同様に取扱い得る.

Feynman theory の result の式は (50 f) と同じだが, charge renormalization は不必要である.

$\dagger$

$$\int g(\lambda) e^{i\lambda x}\, d\lambda = f(x)$$

$$f(x) = \delta(x) \rightarrow \quad g(\lambda) = \text{const.}$$

4. Results of Schwinger and Feynman theory

$Ry \ll k_1 \ll mc^2$

の範囲の quanta について

$$H_1 = \frac{e^2}{3\pi\hbar c}\left(\frac{\hbar}{\mu c}\right)^2 \Box^2 e(\varphi - \bar{\alpha}\bar{A})$$

$$\left(\ln \frac{mc^2}{k_1} + a - \ln 2\right)$$

$$- \frac{e^2}{2\pi\hbar c}\,\frac{e\hbar}{2mc}\,\beta(\bar{\sigma}\bar{B} - i\bar{\alpha}\bar{E})$$

$$\begin{cases} a = 5/8 & \text{(Feynman)} \\ a = 3/8 & \text{(Schwinger)} \end{cases}$$

anomalous magnetic moment of the electron: $\mu_0 f$

$$f = 1 + \alpha/2\pi \qquad \mu_0 = \frac{e\hbar}{2mc}$$

level shift in Coulomb field

$$W = \frac{8}{3\pi}\left(\frac{e^2}{\hbar c}\right)^3 Ry \frac{Z^4}{n^3}\left(\ln \frac{mc^2}{16.721\, Ry\, Z^2} + a - \ln 2\right) \quad \text{for } l = 0$$

$$W = \frac{8}{3\pi}\left(\frac{e^2}{\hbar c}\right)^3 Ry \frac{Z^4}{n^3}\left(\frac{3}{8l(l+1)(2l+1)}\,\bar{l}\,\bar{\sigma} + N\right) \quad \text{for } l \neq 0$$

Table 1.

Theory.	a	2s	2s − 2p
Schwinger	3/8	1003.13	1016.11
Feyman + polarization	5/8 − 1/5	1009.91	1022.89
Feyman without polariz.	5/8	1037.03	1050.01
Lamb	3/4 − 1/5	1026.86	1039.84
Weisskopf and French	5/6 − 1/5	1038.15	1051.13
Lamb without polariz.	3/4	1053.98	1066.96

Experiment Lamb 1046 ± 40

Radiative Effects on Scattering
~~Lewis~~
Lewis, Oppenheimer, Wouthuysen

Seminar 4, Tuesday Oct. 19, 1948

Oppenheimer

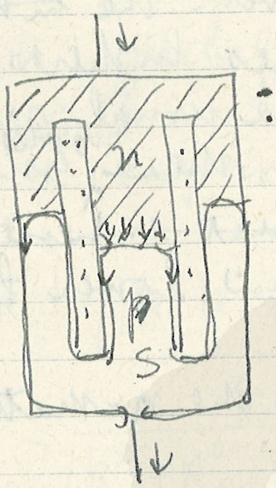
Questions
Oriz
Dysonage
Morette
Case

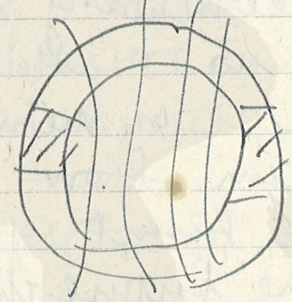
$s=0$: Uhlenbeck - Pais

Seminar 5, Saturday Oct. 23, 1948

Laue 3rd lecture

Superconductivity





1924 Kamerlingh Onnes

Meissner effect

① Die beobachtbaren Größen in der Theorie der Elementarteilchen. III. *

von W. Heisenberg

(ZS. f. Phys. 123 (1944), 93)

In order to ~~give~~ determine upper and lower limits to the ~~alter~~ change of the present theory, previous works were completed ~~by~~ in two directions. In part 1, it is shown that the η-matrix allow us to determine not only the probability of collision processes, but also the position of stationary states, so that η-matrix contains all the necessary informations about observable quantities. In part 2, we start from as in traditional theory from Hamilton function and wave equation and show that even the ~~hither~~ interactions of elementary particles hitherto well-known compell us to extend the usual scheme of wave equation. On the whole, these two-sided considerations answer the question ~~how to what extent~~ of determining the ~~limit~~ upper and lower ~~to~~ boundaries of the future theory.

I. Consequences from the η-matrix

a) η-Matrix as analytic function.

$$S = e^{i\eta} \qquad (1)$$

を Kramers 等は $(k_i'|S|k_i'')$ 等の matrix element が k_i', k_i'' の analytic fn と見做し complex value に許すことから stationary state を求め得ると考えた.

* I: 120 (1943), 513; II: 120 (1943), 673.

即ち S は incoming wave と outgoing wave とを結びつけるものであるが、system の total energy が小さくなれば、k が imaginary となり、wave は exponential に外へ大きくなるか小さくなるかする。若しも k_0 k の或 imaginary な値に対して exponential に減ずる wave が消失するなら、それが stationary state に対応すると考えられる。故に k-pl. の imaginary axis 上の ~~pole~~ η の ~~plo~~ pole が stationary state に対応することになる。

f) η-matrix によって elementary particle の model ができる。例えば
1. 一種類の particle だけがあり
2. spinor 0 で Bose-Einstein statistics に従い
3. charge をもつ
4. particle の数は保存されない、

此等の間に force が働き、二つ以上の particle が一つの compound particle を作り得る ~~場~~ 場合を考える。

$$(k_1' k_2' | \eta | k_1'' k_2'') = \frac{1}{\pi} (k_1^{0\prime} k_2^{0\prime} k_1^{0\prime\prime} k_2^{0\prime\prime})^{-\frac{1}{2}} \times$$

$$\times \left[1 - \frac{4\kappa^2}{(k_1^{0\prime} + k_2^{0\prime})^2 - (k_1' + k_2')^2} \right]^{-\frac{1}{2}} \operatorname{arctg} \left(\alpha \sqrt{1 - \frac{4\kappa^2}{(k_1^{0\prime} + k_2^{0\prime})^2 - (k_1' + k_2')^2}} \right)$$

$$\times \delta(k_1' + k_2' - k_1'' - k_2'') \, \delta(k_1^{0\prime} + k_2^{0\prime} - k_1^{0\prime\prime} - k_2^{0\prime\prime}) \quad \cdots (2)$$

$$\left. \begin{aligned} \eta_{00} &= 2 \operatorname{arctg} \left(\alpha \sqrt{1 - \frac{4\kappa^2}{(k_1^{0\prime} + k_2^{0\prime})^2 - (k_1' + k_2')^2}} \right) \\ &= 2 \operatorname{arctg} (\alpha v) \\ \eta_{nm} &= 0 \quad \text{für alle anderen } n, m \end{aligned} \right\} \quad (3)$$

collision cross-section in centre of mass system

$$Q = \frac{4\pi}{k^2}\frac{(\alpha v)^2}{1+(\alpha v)^2} = \frac{4\pi\alpha^2}{k^{0\,2}+\alpha^2 k^2}$$

in original coord. system in which $k_2' = 0$

$$Q = \frac{4\pi\alpha^2}{\varkappa^2 + (1+\alpha^2)\frac{\varkappa}{2}(k_1^{0\prime}-\varkappa)}$$

$k^0 = k_p^{0\prime} + k_2^{0\prime}$ が余り小さくないと、k は imaginary になる。

η は outgoing wave e^{ikr} と incoming wave e^{-ikr} の phase difference を表はす故、~~k が~~ 例へば
$k = -i|k|$
とすると incoming wave は $e^{-|k|r}$、outgoing は $e^{|k|r}$ となる。

$\eta = i\infty$

に於いて、$e^{|k|r}$ (outgoing wave) が消えてしまう (3) によると

そうなるのは

$\alpha v = i$

なり、従って

$$-i\alpha\left|\frac{k}{k^0}\right| = i$$

で、これが成立するのは $\alpha < 0$ の場合だけで

$$-\frac{1}{\alpha^2} = 1 - \frac{4\varkappa}{(k_1^{0\prime}+k_2^{0\prime})^2 - (k_1'+k_2')^2}$$

or $K^{0\,2} - K^2 = 4\pi^2\frac{\alpha^2}{1+\alpha^2}$

従って二つの elementary particle からなる

nucleus の rest energy は

$$\kappa_2 = 2\kappa \frac{-\alpha}{\sqrt{1+\alpha^2}} < 2\kappa$$

となる。

$|\alpha| \gg 1$ ならば、mass defect は小さく $\frac{\kappa}{\alpha^2}$ の order になる。

この model は deuteron の場合とよく似ている。即ち stationary state が一つしかない。

~~この~~ 三つの particle の場合も同様にして取扱へる。

実際の model はもっと複雑であろうが、問題は現象の多様性の正しい把握にあり、精緻の問題にはない。

II、Extension of canonical scheme of wave ~~eq~~ quantization

Photon-electron の interaction の場合、electron pair の creation-annihilation を通じて photon 同士が indirect に作用するため Maxwell eq. が nonlinear integrodifferential equation に変化する1)。従って通常の Maxwell 式は或る近似と考えられる。同様なことが全ての elementary particle にも成立するであろう。

そこで Divergence difficulty を導き出す Nahewirkung をやめて Lorentz-invariancy を保つ Fernwirkung に相当する integrodifferential equation に移るのがよさそうである

1) R. Serber, 48 (1935), 49; Uehling, 48 (1935), 55.

これに対しては、(一方ではくとも) classical field theory の範囲内で electron の有限の self-energy を与える理論としては Born-Infeld, Wentzel-Dirac-Bopp-Stückelberg[2)] 等がある。

しかし、Serber-Uehling, Heisenberg-Euler[3)] の positron theory から見ても nonlinear integral equation が必要であるらしく思われる。例えば

$$\int dx' A(x-x')\varphi(x') + \int dx'dx'' B(x-x', x-x'')\varphi(x')\varphi(x'') + \cdots = 0$$

$$\left.\begin{aligned} \varphi(x) &= \int e^{ik_\mu x_\mu}\varphi(k)dk \\ A(x) &= \int e^{ik_\mu x_\mu} A(k)dk \end{aligned}\right\}$$

$$A(k)\varphi(k) + \int dk' B(k', k-k')\varphi(k')\varphi(k-k') + \cdots = 0 \qquad (27)$$

線型の場合、$A(k) = \sum_\nu k_\nu^2 + \kappa^2$ で non-linear terms はない。

そこで (27) のような equation から quantization をすれば先ず

1. energy-momentum tensor を作ることである。Bopp に従えば

$$T_{\mu\nu}(k) = \int dk' A(k')\varphi(k')\varphi(k-k')\frac{k'_\mu k'_\nu}{k'_\lambda k'_\lambda} + \cdots$$

---

2) Stückelberg, Nature 144 (1939), 118; Helv. Phys. 14 (1941), 51; 17 (1944), 3; Bopp Ann. d. Phys. 38 (1940), 345, 42 (1943), 573

3) H. und E., Z. f. Phys. 98 (1936) 714.

$$+\int dk'dk''B(k'k'')\varphi(k'')\varphi(k'-k'')\varphi(k-k')$$
$$\times\left\{\frac{k''_\mu k''_\nu}{k''_\lambda k''_\lambda}+\frac{(k'_\mu-k''_\mu)(k'_\nu-k''_\nu)}{(k'_\lambda-k''_\lambda)k_\lambda}\right\}+\cdots$$

は意味、

$$\sum_\nu T_{\mu\nu}k_\nu=0$$

を満足する。

symmetric で divergence が 0 であるような $T_{\mu\nu}$ は上の expression と divergence 形の term だけ違っていて、total energy, momentum は unique にきまってしまう。

一般に $T_{\mu\nu}$ なる tensor は δ-fn を含んでいるので それ自身としては indeterminate である場合が多い、例えば $B=C=0$ なら

$$\varphi(k)=\delta(k_\nu^2+\kappa^2)\chi(k)$$

であるから、$T_{\mu\nu}$ の値は kの或る値に於いて $0\cdot\infty$ の形となり、limiting case として その値をきめねばならぬ。

total energy momentum vector は

$$J_\mu=i\int T_{\mu4}(x)\,dx_1dx_2dx_3$$
$$=i\int e^{ik_4x_4}T_{\mu4}(0\,0\,0\,k_4)\,dk_4$$
$$=i\int T_{\mu4}(0\,0\,0\,k_4)\,dk_4$$

然し

2、この形の理論を quantize するにはどうすればよいか；［quantize する φ に対する canonical conjugate がないから

$$[\varphi(x), \varphi(x')] = \varphi(x)\varphi(x') - \varphi(x')\varphi(x)$$

のような bracket symbol は ~~複雑な~~ integral equation から複雑な操作で初めて決定される。

しかし

$$J_\mu \varphi(x) - \varphi(x) J_\mu = i\hbar \frac{\partial \varphi}{\partial x_\mu}$$

or $$J_\mu \varphi(k) - \varphi(k) J_\mu = -k_\mu \varphi(k) \qquad (35)$$

は直接關係がなって、theory の mathematical scheme はきまってしまう。

從って J_μ を diagonal にする representation を考えて

$$(J'_\mu - J''_\mu + k_\mu)(J'|\varphi(k)|J'') = 0$$

(37) $$\begin{cases} (J'|\varphi(k)|J'') = \delta(J' - J'' + k)(J'|\varphi|J'') \\ (J'|\varphi(x)|J'') = (J'|\varphi|J'')\, e^{i(J''_\mu - J'_\mu)x_\mu} \end{cases}$$

$$\delta(k) = \delta(k_1)\delta(k_2)\delta(k_3)\delta(k_4)$$

(37) を wave equation (28) に入れると

$$A(J' - J'')(J'|\varphi|J'') + \int dJ''' B(J''' - J', J''' - J') \times (J'|\varphi|J''')(J'''|\varphi|J'') + \cdots = 0 \qquad (39)$$

更に $(J'|T_{\mu\nu}|J'')$ を作って積分すると

$$(J'|J_\mu|J'') = J_\mu \delta(J' - J'')$$
$$= \delta(J'_1 - J''_1)\delta(J'_2 - J''_2)\delta(J'_3 - J''_3) \times i(J'|T_{\mu 4}|J'') \qquad (41)$$

従って(39), (41)を満す matrix $(J'|\varphi|J'')$を求めれば quantum theoretical な problem が解かれたことになる。

~~然しながら~~ 実際 これ等を満す解が存在するか問題は　であれば、A, B, C は特別の形でなければならぬ點である。一番簡単な

$A = k_\nu^2 + \varkappa^2$, $B =$ ~~...~~ const　$C = 0$ ...

の場合でさえ divergency diff. で解かれない。

Stückelberg-Bopp:

$$A(k)\varphi(k) = 0$$

$$A(k) = k_\nu^2 (k_\nu^2 + \varkappa^2)$$

の場合も elementary particle の interaction が入っていない。

$B \neq 0$ の場合には、全く調べたが(39), (41)を満すものはない。

もし一般にこのようなものがないなら Wellengleich. による scheme はだめで、一段の飛躍が必要になる。もしあるとしても、どうしてこれを見つけるか、やはり難しい問題である。

いずれにしても 上の考察は、(39)の如き式を見ても、どんな種類の elementary particle が可能か最初からはわからぬ ~~點~~ ことを示す點で重要である。此の一つの sinnvoll な Frage は J_μ の discrete eigenvalue をもつかどうか、いいかえれば ~~(39)~~ J_1, J_2, J_3 を与えて (39), (41) を満す discrete な J_4 の値を求めることにある。~~然~~ $(J'|\varphi|J'')$ が $\delta(J_\nu'^2 + \varkappa^2)$ の如き factor を含めば、それが一つの closed system の

その沢山に於て

massをもつことになり，その若干が(elementary) particleと~~存~~なりうるものとなる．それらがelementaryかcompoundかを判定することはprincipallyにimpossibleである．future theoryではかくしてmassが多数粒子のenergyと関係してstationary stateの決定されるであろう．そこでは素粒子やelementaryとcompoundの差は~~殆~~，消失しているであろう．

Seminar 6. Oct. 26, Tuesday, 1948

Oppenheimer
Uhlenbeck
~~Sh~~ Schwinger.

1° definition of vacuum;

$$\mathcal{A}^{+} = 0$$

$$A^{+} = 0$$

2° polarization of vacuum:

a) justification of putting ε under $\frac{\partial}{\partial x_\mu}$

$$\Box g = R\ ?$$

$$\langle j_\mu \rangle = -\frac{8e^2}{\hbar c} \int g(\lambda)\, J_{\mu}(x')\, dx\, d\omega'$$

$$\lambda = -(x_\mu - x'_\mu)^2$$

b) Proof of $\Box g = R$.

3° a) What is $\mathcal{H}^{(2)}$

b) Derivation of Möller interaction

c) Self energy

d) systematic (and quick) deriv.

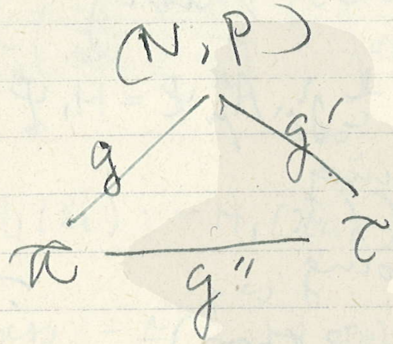
1) Pseudoscalar mesons do not give tensor forces in nonrelativistic approximation
(Nelson, Phys. Rev. 60 (1947), 173.
Dyson, 73 (1948), 929.)

2) ~~Every~~ The meson theory is always associated with ..δ- ~~function~~ type forces characterizing direct interaction between nucleons.
The mesonic force of type

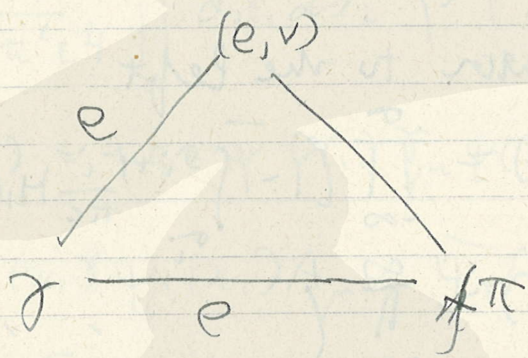
$$\kappa^2 \frac{e^{-\kappa r}}{r}$$

converges to δ-function for $\kappa \to \infty$, which gives infinite binding energy for the deuteron, because it corresponds to ~~$V_0 a^2$~~ the infinite value of $V_0 a^2$, V_0 being proportional to $1/a^3$. In other words, δ-range force is so adjusted ~~that~~ so as to give finite collision cross-section, it give infinite binding energy and on the contrary if it is adjusted so as to give finite binding energy, ~~the~~ collision cross-section will be 0.
Thus there may be forces of very short range, which contribute only to binding, but not to ~~scatt~~ collision.

3) self-Energy of Bose Particle



$g \sim g' \sim g''$



4

Pais, Physica 1946
Tomonaga, Phys. Rev. 1948
Hara . Prog. 3 (1948)

Seminar 7. Thursday, Oct. 28.

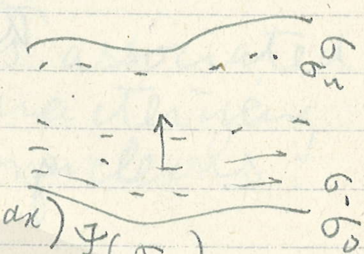
Dyson : Feynman's Theory

$$i\hbar c \frac{\partial \Psi}{\partial \sigma} = -\frac{1}{c} j_\mu A_\mu \Psi = H_1 \Psi$$

$\Psi(-\infty)$ incoming

$\Psi(+\infty)$ outgoing

$$\Psi(+\infty) = S\,\Psi(-\infty)$$



$$\Psi(\sigma) = \prod_0^n \left(1 - \int_{\sigma_i}^{\sigma_{i+1}} \frac{i}{\hbar c} H_1(x)\,dx\right) \Psi(\sigma_0)$$

Later operator to the left

$$\Psi(\sigma) = \prod_{-\infty}^{\sigma} \left(1 - \int_{\sigma_i}^{\sigma_{i+1}} \frac{i}{\hbar c} H_1(x)\,dx\right) \Psi(-\infty)$$

$$= S(\sigma)\,\Psi$$

$$\Psi(\infty) = \prod_{-\infty}^{\infty} \left(\quad , \quad , \quad \right) \Psi(-\infty)$$

$$= S(\infty)\,\Psi$$

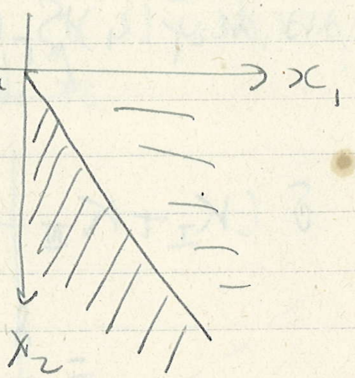
$P\,(F_1(x_1), F_2(x_2), \cdots)$

$$S(\sigma) = 1 - \frac{i}{\hbar c}\int_{-\infty}^{\sigma} H_1(x_1)\,dx_1 + \left(\frac{-i}{\hbar c}\right)^2 \int_{-\infty}^{\sigma} H_1(x_1)\,dx_1$$

$$\times \int_{-\infty}^{\sigma(x_1)} H_1(x_2)\,dx_2 + \cdots$$

$$+\left(\frac{-i}{\hbar c}\right)^2 \frac{1}{2} \int_{-\infty}^{\sigma}\int_{-\infty}^{\sigma} P(H_1(x_1), H_1(x_2))\,dx_1\,dx_2$$

$$S(\infty) = \sum_{n=0}^{\infty} \left(\frac{-i}{\hbar c} \right)^n \frac{1}{n!} \int_{-\infty}^{+\infty} \cdots \int dx_1 \cdots dx_n$$



$$\times P(H_1(x_1) \cdots H_1(x_n))$$

$$= P\left(\exp - \frac{i}{\hbar c} \int_{-\infty}^{\infty} H_1(x)\, dx\right)$$

$$S_2 = -\frac{1}{2\hbar^2 c^4} \iint dx_1 dx_2\, P\left(j_\mu^{(x_1)} A_\mu(x_1),\ j_\lambda^{(x_2)} A_\lambda^{(x_2)}\right)$$

$$j_\mu(x_1) = i\hbar c\, \bar{\psi}(x_1)\, \gamma_\mu \psi(x_1)$$

$$P\left(\bar{\psi}_\alpha(x_1)\psi_\beta(x_1)A_\mu,\ \bar{\psi}_\gamma(x_2)\psi_\delta(x_2)A_\lambda(x_2)\right)$$

$$\psi_\beta(x_1) = \sum a_n \phi_{n\beta}(x_1)$$

$$\bar{\psi}_\gamma(x_1) = \sum \bar{a}_n \phi_{n\beta}(x_1)$$

$$A = \sum_n (b_n A_n + \bar{b}_n A_n^*)$$

$$\bar{b}_{II} b_I \bar{a}_{II} a_I$$

$$\sum P(\bar{\psi}_\beta(x_1), \bar{\psi}_\gamma(x_2)) = S_{F\gamma\beta}(x_1 - x_2)$$

$$S_F(-x) = S_1(x) + i\,|S|(x)$$

$$= S_1(x) + i\left(\gamma_\mu \frac{\partial}{\partial x_\mu} - \kappa\right)\Delta(|x|)$$

$$\iint dx_1 dx_2 \bar{\psi}(x_1) \gamma_\mu S_F(x_2 - x_1) \gamma_\lambda \psi(x_2) A_\mu(x_1) A_\lambda(x_2)$$

$$\delta(K_I + K_{III} - K_{II} - K_{IV}) S_F(K_I - k_{III})$$

$$= \frac{\delta(\ )(q_\mu \gamma_\mu - \kappa_0)}{q^2 - k_0^2} +$$

Sen

Theoretical Seminar 1,
Oct. 29, Friday
(Oppenheimer, Bermingham and Solvay Reports

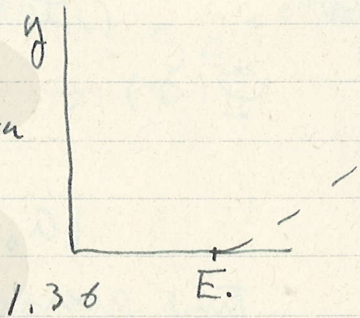
Serber, Berkeley experiments

$M_\pi = 294 \pm \frac{1}{2}$. m_e

integer spin

Probab. of meson production

fine matrix element



π-μ-decay

$M_\mu = 209 \pm 2 \, m_e$ $\quad \frac{M_\pi}{M_\mu} \simeq 1.36$

$M_0 = 0$?

$\pi \to \mu + "\nu"$ $\quad 10^{-8}$ sec.

$\pi^+ \to e^+ + \nu$

$\mu^+ \to e^+ + \nu + \nu$

$N \to e^- + P + \nu$

$P \to e^+ + \nu + \nu$?

$n - P_{-\nu}$, $p \; \nu e$

Electrodynamics

(N, -P)-scattering $\quad \frac{e^{-\mu r}}{r}$

Seminar 8. Oct. 30, Saturday
von Laue, continued.

Seminar 9, Tuesday Nov. 2,

Oppenheimer:

i) Renormalization of wave fn

Dyson: $\Psi(\infty) = S(\infty)\,\Psi(-\infty)$

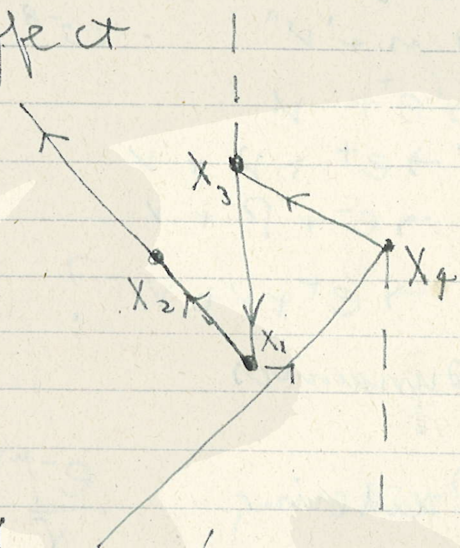
$$\Psi(\sigma) = a_0 \Psi_0 + \sum_i \Psi_i \frac{e^{(E_i - E_0)t/\hbar}}{E_i - E_0}$$

$$|a_0|^2 = 1 - |\quad|$$

time average:

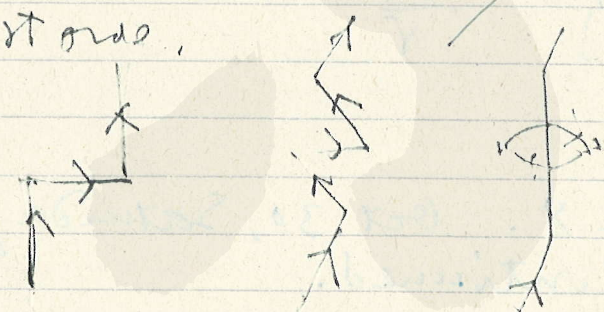
phase relation

Compton effect



1st order,

2nd order.



Theoretical Seminar ~~No.~~ 2. Friday Nov. 5

Weisskopf, Scattering and Absorption of High Energy Particles.

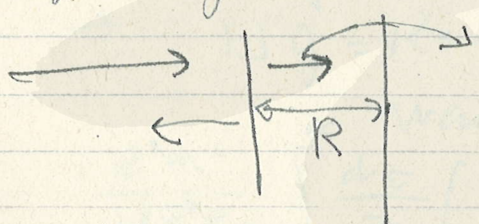
$$u(r) = r\varphi(r) = A\left(e^{-iK(r-R)} - S e^{+ik(r-R)}\right)$$

$$\sigma_{tot} = \sigma_{sc} + \sigma_a$$

$$f(R) = R\left(\frac{u'}{u}\right)_{r=R}$$

$$S = \frac{f+ix}{f-ix} \qquad x = kR$$

high energies: no resonances



$u \sim e^{-iKr}$

K: average wave number in the nucleus

$$f \sim -iKR$$

$$f = iX$$

$$\sigma_a = \pi\lambda^2(1-|S|^2)$$

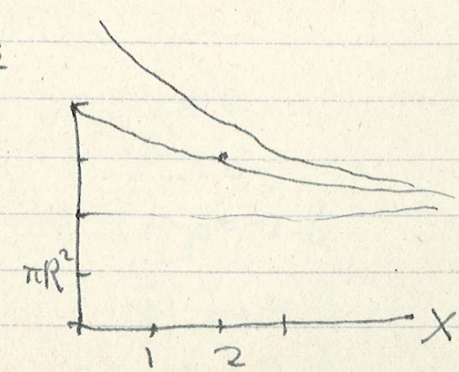
$$\sigma = \pi\lambda^2\left|(1-S)+(e^{2ix}-1)\right|^2$$

$$\sigma_a = \pi\lambda\Lambda\frac{X^2}{(X+x)^2}$$

$$\sigma_{tot} = \sigma_e + \sigma_{sc}.$$

$$\sigma_{tot} = 2\pi R^2$$

$$\sim 2\pi(R+\lambda)^2$$



Tyson

radiation :

Wigner :

Seminar 10. Saturday. Nov. 6, 1948

von Laue, Superconductivity

70 the birthday of Lise Meitner

Seminar 11.

Pais: Wentzel, P.R. 74 Nov. 15.
Peierls
Wentzel did not use
$\Box g = R.$
→ $\Box g = R + r$ $\quad r = \frac{dg}{d\lambda}$ ↙ ↖ $\frac{\partial j_{\mu\nu}}{\partial x_\mu} = 0$

Wentzel / Schwinger

F.D. $\frac{e^2 m^2}{16\pi^2 \hbar\nu} \int_0^\infty \frac{dz}{z}\left(\frac{\sin z}{z} - \cos z\right)$ $\quad 0$

B.E. $\frac{e^2 m^2}{16\pi^2 \hbar\nu} \int_0^\infty \frac{dz}{z} \frac{\sin z}{z}$ $\quad 0$

Tati, Tomonaga:

Case: magnetic moment
$H_0 + H_{Yuk} + H_{ext}$

	325	200
N	$\mu_n = 0$	$\mu_n = 0$
	$\mu_p = -2.8$	$\mu_p = -2.8$
Ch	$\mu_n = -8.0$	$\mu_n = -9.3$
	$\mu_p = 2.5$	$\mu_p = 3.6$

sym. $\mu_n = -8.0$ $\mu_p = -0.3$ $\mu_n = -9.3$ $\mu_p = 0.8$

sign mistake:
$\sqrt{4\pi} i g \psi^* \beta \gamma_5 \phi \psi$

neutral: $\mu_n = 0$
$\mu_p = -\frac{g^2}{\pi}\left[\frac{A_1}{8}\right]$

charge: $\mu_n = -\frac{g^2}{\pi}[A_2 + 2A_1]/8$
$\mu_p = \frac{g^2}{\pi}\left[\frac{A_2}{8}\right]$

325

N $\mu_n = 0$
$\mu_p = -0.7$

Ch $\mu_n = -2.4$
$\mu_p = +1.0$

S. $\mu_n = -2.4$
$\mu_p = +0.3$

Kuba - Takeda :

1) Schwinger - Hamiltonian
W. F. ; L. Kor.
2) Schwinger - Tomonaga - Feynman
Dancoff - Lewis
(2) Bethe
(2) Lewis (i)

(2) Schw. - Tom

Schw - Ham (i)

Weiss. Fr. (i)

L Kr

(2) Feynman

Radiative Correction
Scalar
Pseudoscalar
Vector

U	Lewis	
	Weisskopf - French	1052
	Lamb - Kroll	1052 + all that
S	(Schwinger I	1052
S	Schwinger II	1040?
	Feynman	

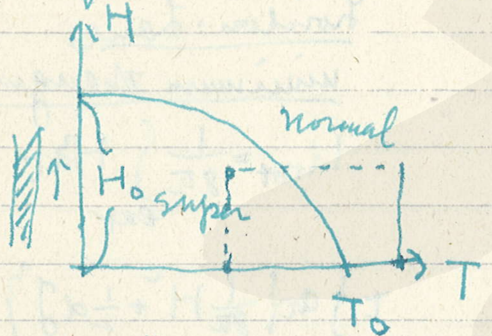
Seminar 12. Saturday
Nov. 13, 1948

Prof. Uhlenbeck

Facts

a. Zero resistance
permanent cur.
$R < 10^{-15} R_n$

b. Influence of mag. field



c. Meissner Effect
supercond = phase

d. $T > T_c$: spec. heat is normal
$C_n = \alpha T^3 + \beta T$
$T = T_c$: phase transition of second kind ($H=0$)

e. $H = H_0 \left(1 - \frac{T^2}{T_0^2}\right)$

$$\frac{C_s}{T} = \beta - \frac{H_0^2}{2\pi T_0^2} + \alpha T^2 + \frac{3 H_0^2 T^2}{2\pi T_0^4}$$

f. Kok rel.
$\beta = \frac{H_0^2}{2\pi T_0^2}$ $\alpha > \alpha_n$

Thermod. Theor. (Rutgers, Casimir - Gorter)

$$\zeta = U - TS - HM$$
$$d\zeta = -S\,dT - M\,dH$$
$$\left(\frac{\partial S}{\partial H}\right)_T = \left(\frac{\partial M}{\partial T}\right)_H$$

$T > T_c$ $\zeta = G_n(T)$

$T < T_c$ $B = H + 4\pi M = 0$
$M = -\frac{1}{4\pi} H$.

$$\zeta = -\int_0^T S\,dT + \frac{H^2}{8\pi}$$
$$= G_s(T) + \frac{H^2}{8\pi}$$

Equil. cond.:
$$G_n(T) = G_s(T) + \frac{1}{8\pi} H^2$$

$$\begin{cases} \frac{dG}{dT} = -S \\ \frac{dS}{dT} = \frac{C}{T} \end{cases}$$

$$S_n = S_s - \frac{1}{4\pi} H \frac{dH}{dT}$$

$$\frac{C_n - C_s}{T} = -\frac{1}{4\pi}\left(\frac{dH}{dT}\right)^2 - \frac{1}{4\pi} H \frac{d^2H}{dT^2}$$

Electrodyn. Th. (F. London)

$$m\frac{dv}{dt} = eE$$
$$J = nev$$
$$\frac{d\vec{J}}{dt} = \frac{ne^2}{m} E = \alpha \vec{E} + a\frac{d\vec{J}}{dt}$$

$$\frac{\partial}{\partial t} \operatorname{curl} J = \alpha\left(-\frac{1}{c}\frac{\partial H}{\partial t}\right)$$

$$\operatorname{curl} J = -\frac{\alpha}{c}(H - H_0)$$

~~curl H =~~

$$\Delta H = \frac{4\pi}{c^2}\alpha(H - H_0)$$

$H_0 = 0$
Meissner Effect

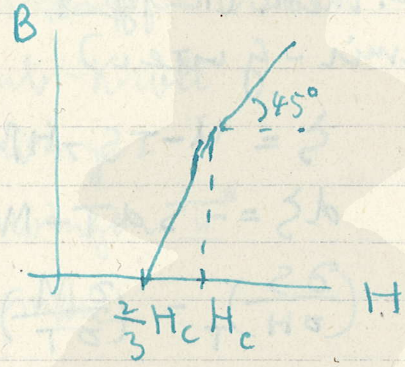
$$\operatorname{curl} J = -\frac{\alpha}{c} H$$

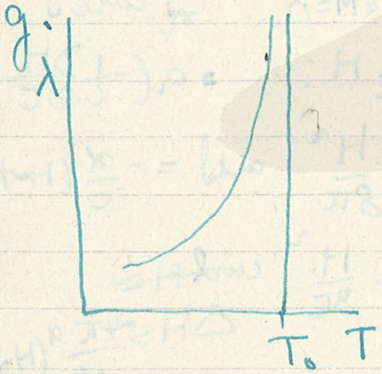
$$\frac{1}{\lambda^2} = \frac{4\pi n e^2}{m c^2}$$
$n = p n_0$
$$\lambda \sim \frac{10^{-6}}{\sqrt{p}} \text{ cm}$$

Transition state

sphere

$B = (-2H_c + 3H)\cos\theta$





Proof of existence of permanent currents.

London-Laue minimum theorem

$U_{tot} = \frac{1}{8\pi}\int_{ext} H^2 d\tau$

$+ \int_{S.C} d\tau \{\frac{1}{8\pi}H^2 + \frac{1}{2}\alpha J^2\}$

$\delta U_{tot} = 0$

London cond (boundary):

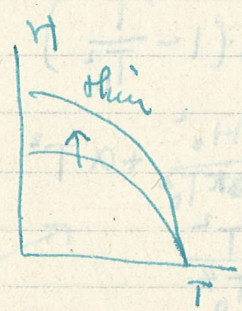
$G_n(T) = G_s(T) + \frac{1}{2\alpha}J^2$

for thick supercond

$\frac{1}{2\alpha}J^2 = \frac{1}{8\pi}H^2$

In general

$\frac{1}{2\alpha}J^2 \; ~~>~~ < \; \frac{1}{8\pi}H^2$



h. H_c is bigger for thin S.C. (Appleyard) surface energy

$\alpha_{ns} \rightarrow \Delta = \dfrac{8\pi\,\alpha_{ns}}{H_c^2}$

Landau

$\Delta > \lambda$

Theorem of Bloch → Bohm

Seminar 13

Nov. 17

Oppenheimer:

W. F]
L K] 1051
? – – S T T] –
– [– – – –
S T] 1023
F]

Bethe:

Dyson: S T = F

Symmetrical Treatment of Vector Potential

Identify mass terms

$p^+ + (E_m) \to (p-k) +$ (a)

$p^- - (V) \to p' +$ (d)

$(p-k) + (\text{Abs}) \to p-$

6 terms + + – – 4 + –

Renormalization of wave fn

$$\psi'(p) = \psi(p)\left(1 - \tfrac{1}{2}e^2 \sum_k (\ \ )^2\right) + e \sum_k \frac{(p-k|\alpha|p)}{E(p-k) - E(p) + \omega}$$

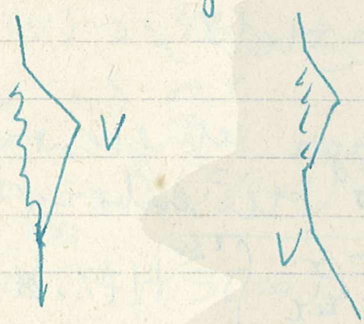
e^{-iEt}

$$\times\, \psi(p-k)\, X(k) \quad e^{-i(E(p-k)+\omega)t}$$

$p_1 \to p_2$

(Schwinger, Pocono mistake)
not change renormalization

Feynman diagram



Uhling Term

$\alpha^3 R_y$

higher order correction

$$\frac{E}{p} \ln \frac{E+p}{E-p}$$

Conventional	Feynman
10 day	20 min
half a ~~day~~ year	half a day

Seminar 14.   Nov. 18

external potential

$$-\frac{1}{c} j_\mu(x) A^e_\mu(x) = H_e(X)$$

$S(\infty)$ in Schrödinger representation
→ Heisenberg S-matrix

$$U(\infty) = \exp\left[-\frac{i}{\hbar c}\int_{-\infty}^{+\infty} H(X)\,dx\right.$$

$$H = H_1 + H_e$$

Born approximation:

$$U(\infty) \cong S(\infty) + \left(\frac{-i}{\hbar c}\right)\int_{-\infty}^{+\infty} \overbrace{R(\sigma(x))\, H_e(X)\, S(\sigma(x))}^{\boxed{H_F(x)}}\,dx$$

$$R(\sigma) = \exp\left[\int_\sigma^\infty\right]$$

$$= S(\infty)(S(\sigma))^{-1}$$

$$H_F(x) = \sum_{n=0}^{\infty} \frac{(-i/\hbar c)^n}{n!} \int\!\!\int\cdots\int_{-\infty}^{\infty} P\big(H_e(X), H_1(X_1)\cdots H_1(X_n)\big)\, dx_1\cdots dx_n$$

~~Schrödinger~~

Schwinger theory:

$$i\hbar c \frac{\partial \Psi}{\partial \sigma} = [H_1(x) + H_e(x)]\Psi$$

$$\Psi(\sigma) = S(\sigma) Q \Psi' = Y(\sigma)\Psi'$$

$$i\hbar c \frac{\partial \Psi'}{\partial \sigma} = Y^{-1} H_e Y \Psi' = H_s \Psi'$$

$$H_s = Q^{-1} S^{-1} H_e S Q = Q H_F Q$$

$$H_F = Q^{-2} S^{-1} H_e S$$

time reversal:

$$S(\sigma) \to S'(\sigma) = S(\sigma)\,(S(\infty))^{-1}$$

$$Q \to Q'$$

$$\$ Q = \$ (S(\infty))^{-1} Q'$$

$$Q^{2} = \sqrt{(S(\infty))^{-1}} \qquad Q' = Q^{-1}$$

	Schrö'd	Int	Sechir	Heisenberg
Phys. Sys. X	$H_0+H_1+H_e$	H_1+H_e	$H_S(H_S)$	0
	$\frac{\partial \Omega}{\partial t}=0$ →	H_0 →	$\frac{\partial \Omega}{\partial t}+H_0+H_1$	$H_0+H_1+H_e$
Phys. Sys. Y	H_0+H_S	H_S		
	0 ←	H_0		

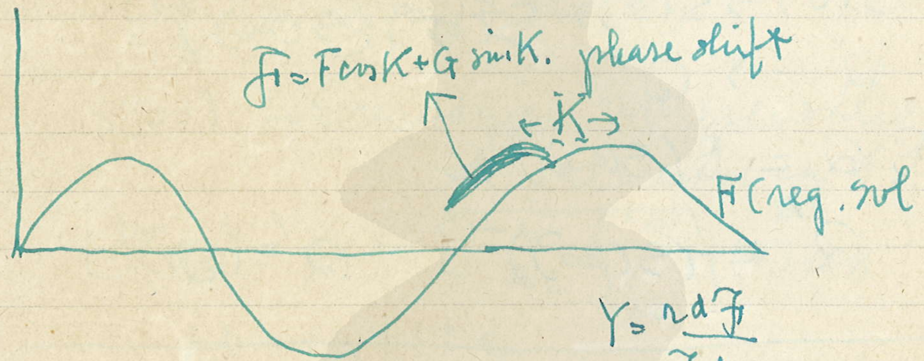
$$U_Y(\infty) = \Pi\left(1-\frac{i}{\hbar c}\int_C H_S\right)$$

$$U_X(\infty) = \sum_{n=0}^{\infty} \frac{(-i/\hbar c)^n}{n!} \int\!\!\int_n \overset{S_\infty S_1^{-1}}{R_1} H_e(x_1) S_1 S_2^{-1} H_e(x_2) S_2 S_3^{-1} \cdots dx_1 \cdots dx_n$$

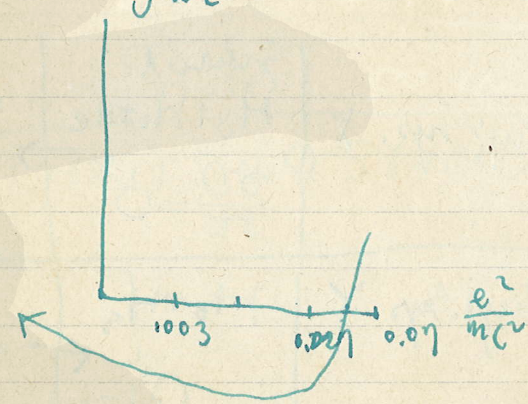
$$= Q^{-1} U_Y Q^{-1}$$

Theoretical Seminar 4, Nov. 19, 1948
Princeton University

Prof. Breit, Proton-Proton Scattering



$Y = \dfrac{r\,d\mathcal{F}}{\mathcal{F}\,dr}$



$b = e^2/mc^2$

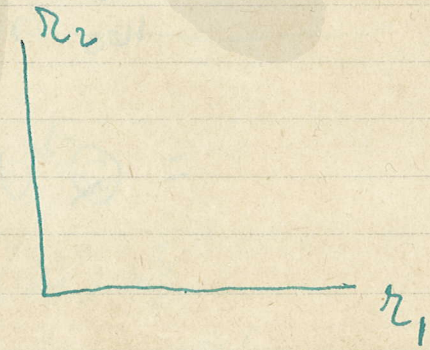
$D = 10.5$ MeV

$D = 10.6$ MeV

$b = e^2/2mc^2$
$D = 47.1$ MeV　definitely disagree

$$\left(\frac{\partial^2}{\partial x_1^2} + \cdots + \frac{\partial^2}{\partial x_n^2} + k^2\right)\psi = 0$$

increase of degree of freedom



$\dfrac{g^2}{r_0} = \mu c^2 \qquad r_0 = \dfrac{g^2}{\mu c^2}$

$r_0 = 10\left(\dfrac{m}{\mu}\right)\dfrac{e^2}{mc^2}$

Remark

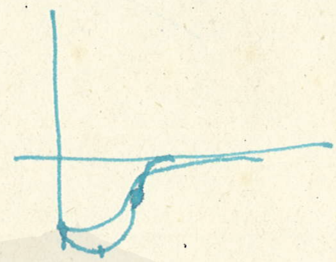
Bargman: [illegible] formula incorrect

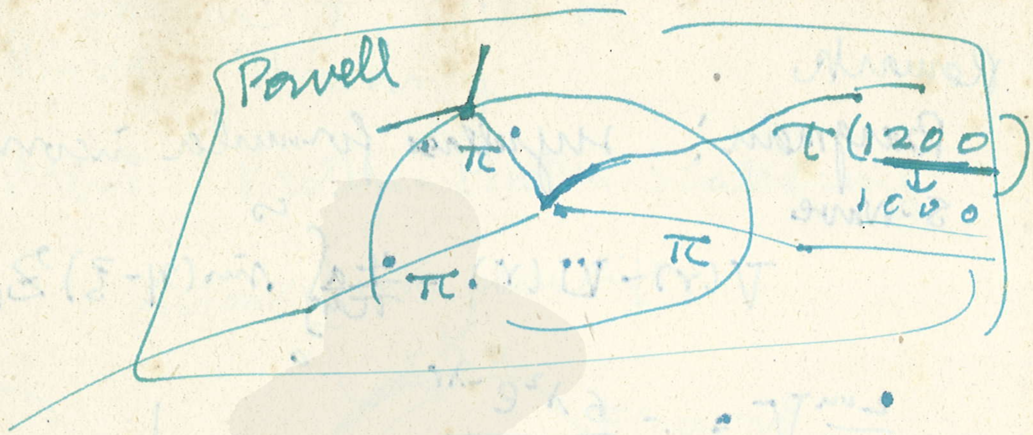
s-wave

$$V(r) - U(r) = \frac{4}{\pi}\frac{d}{dr}\int_0^\infty \sin(\eta - \zeta)\, Z_k(\cdot)\, dk$$

$$\frac{2m}{\hbar^2} V = -\frac{6\lambda^2 e^{-\lambda r}}{(1+e^{-\lambda r})^2}$$

$$\frac{2m}{\hbar^2} U = \frac{-24\lambda^2 e^{-2\lambda r}}{(1+3e^{-2\lambda r})^2}$$





1200
900
300 — 150 MeV

20 MeV

50 MeV